July 21, 2015

Tom Imeson, Chairman
Oregon Board of Forestry
Oregon Department of Forestry
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Dear Chairman Imeson and Oregon Board of Forestry Members:

The National Marine Fisheries Service’s Northwest Fisheries Science Center’s (NWFSC) mission is to conduct the science necessary to conserve marine and anadromous species and their habitats off the Washington, Oregon, and northern California coasts and in freshwater rivers of Washington, Oregon, and Idaho. Our research provides reliable, relevant, and credible information to help decision-makers and natural resource managers build sustainable fisheries, recover endangered and threatened species, maintain healthy ecosystems, and protect human health. I’d like to take this opportunity to build upon the testimony provided by my NWFSC colleague, Phil Roni, PhD on June 3, 2015 and provide additional perspective for your consideration on the action titled “Developing Riparian Rule Prescriptions”, which is scheduled for the Board of Forestry (Board) review on July 23, 2015.

Salmonids depend on many ecosystem functions for long-term survival and recovery, including riparian functions such as wood supply to the stream for habitat structure, shade to regulate stream temperature, retention of flood flows and sediment, and supply of leaf litter and nutrients that fuel the food web (citations). Many salmon species—including Chinook salmon, coho salmon, and steelhead—have an affinity for wood cover (e.g., Beechie et al. 2005), as well as for low velocity habitats such as pools that are created by wood (e.g., Bisson et al. 1998). Wood forms pools in a wide range of channel sizes, but is particularly effective in smaller streams where relatively small pieces of wood can form pools (Bilby and Ward 1989, Montgomery et al 1995, Beechie and Sibley 1997). As channel size increases, the size of wood required to form pools increases (Bilby and Ward 1989, Beechie and Sibley 1997, Abbe and Montgomery 2003). In larger rivers single wood pieces may not be large enough to create pools, and instead accumulations of wood anchored by large key pieces are a dominant pool-forming agent (Abbe...
and Montgomery 2003). In all channel sizes, low velocity habitats and wood cover are important habitat features for listed salmon species, including Chinook salmon, coho salmon, and steelhead (Bisson et al. 1988, Beechie et al. 2005).

In the past, logging of riparian forests has contributed to significant declines in habitat function via loss of wood recruitment (Grette 1985; Andrus et al. 1988; Carlson et al. 1990; Bilby and Ward 1991; Ralph et al. 1994). This in turn has contributed to decreased availability of low velocity habitats (pools) (Bilby and Ward 1991; Ralph et al. 1994, Montgomery et al. 1995, Beechie and Sibley 1997), and also to declines in the capacity of rivers and streams to support salmon populations (e.g., Beechie et al 1994). Today, wood recruitment to streams is recognized as an important function of riparian forests, and the practice of leaving forested buffers along streams to protect this function is now common in the western US. It is well known that as distance to the stream increases the probability of a tree providing wood to the stream decreases (Van Sickle and Gregory 1990, McDade et al. 1990). Therefore, the portion of a forested buffer nearest the stream tends to provide more wood than the portion of the buffer farther away from the stream. **Models and field data for western Oregon forests indicate that 90% of wood recruited to streams from conifer forests originates from within 90-131 feet of the stream** (McDade et al. 1990) (modeled for 131 foot tall trees - 107 feet; modeled for 164 foot tall trees - 131 feet; field data for mature conifer - 90 feet; field data for old-growth conifer - 123 feet). This suggests that most wood recruitment could be protected by leaving forested buffers 90 feet or greater in width.

Chinook salmon, coho salmon, and steelhead are cold-water fish species that require cool water during all life stages, including adult migration to spawning areas and the summer rearing life stages (Groot and Margolis 1991, Richter and Kolmes 2005). In a literature review of temperature thresholds for salmonids, Richter and Kolmes (2005) found that coho salmon spawning migrations tend to occur at temperatures <16°C, and that reduced egg viability or thermal barriers for Chinook, coho and steelhead occurred at 20-21°C. For juvenile rearing, coho salmon tended to select habitats <14.8°C, and optimal growth for Chinook salmon and steelhead occurred between 14°C and 15.6°C. Lethal temperatures for Chinook, coho, and steelhead range from 23-25.8°C. These data suggest that temperatures <16°C are likely to protect salmon and steelhead during both the adult spawning migration period and the juvenile summer rearing period.

Stream temperatures are significantly influenced by shading from streamside forests (e.g., Brown 1970, Brown and Krygier 1970, Brazier and Brown 1973). Recent field evidence in British Columbia showed that stream temperature was 3°C higher with a forested buffer 33 feet wide than in the forested control site, and 1.6°C higher with a 98 foot forested buffer (Kiffney et al. 2003). **By contrast, a recent modeling effort showed that, on average, a 90 foot forested buffer in Oregon forests was likely to keep the temperature increase less than 0.3°C** (upper 95% confidence interval 0.6°C, based on modeled stream temperature using Ripstream, Groom et al. 2011). **This suggests that stream temperatures may still not be protected in many reaches even with a 90 foot buffer.**
In summary, a long history of research on the influences of forested riparian buffers on stream habitats and Pacific salmon species suggests that forested buffer widths necessary to protect wood recruitment and stream shading functions in the Pacific Northwest will likely exceed 90 feet.

Respectfully,

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Cc: Peter Daugherty, Oregon Department of Forestry, Ex-officio Chief, Private Forests
Cc: F/NWC3 George Pess
Cc: F/NWC3 Rich Zabel

References cited
ATTACHMENT 2
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Modelling temperature change downstream of forest harvest using Newton’s law of cooling

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Abstract:
We adapted Newton’s law of cooling to model downstream water temperature change in response to stream-adjacent forest harvest on small and medium streams (average 327 ha in size) throughout the Oregon Coast Range, USA. The model requires measured stream gradient, width, depth and upstream control reach temperatures as inputs and contains two free parameters, which were determined by fitting the model to measured stream temperature data. This model reproduces the measured downstream temperature responses to within 0.4 °C for 15 of the 16 streams studied and provides insights into the physical sources of site-to-site variation among those responses. We also use the model to examine how the pre-harvest to post-harvest temperature change in daily maximum stream temperature depends on distance from the harvest reach. The model suggests that the pre-harvest to post-harvest temperature change approximately 300 m downstream of the harvest will be 56% of the temperature change that occurred within the harvest reach, depending primarily on the downstream width, depth and gradient. Using study-averaged values for these channel characteristics, the model suggests that for a stream representative of those in the study, the temperature change approximately 300 m downstream of the harvest will be 50% of the temperature change that occurred within the harvest reach. This adapted Newton’s law of cooling procedure represents a highly practical means for predicting stream temperature behaviour downstream of timber harvests relative to conventional heat budget approaches and is informative of the dominant processes affecting stream temperature. Copyright © 2015 John Wiley & Sons, Ltd.

KEY WORDS stream temperature; Newton’s law of cooling; downstream; timber harvest; temperature modelling

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INTRODUCTION
Stream temperature change due to forest harvest has been widely studied at both local scales (e.g. Gray and Edington, 1969; Brown and Krygier, 1970; Baillie et al., 2005; Gomi et al., 2013; Kibler et al., 2014) and downstream scales (Brown et al., 1971; Caldwell et al., 1991; Zwieniecki and Newton, 1999; Story et al., 2003; Rutherford et al., 2004; Cole and Newton, 2013; Garner et al., 2014; Johnson and Wilby, 2015). This abundance of studies reflects the concern over stream temperature impacts to aquatic ecosystems and has led to the evolution of stream protection rules for managed forests (e.g. Hairston-Strang et al., 2008). In the Pacific Northwest, studies have shown that contemporary forest practices (e.g. Groom et al., 2011a,b) produce less warming on fish-bearing streams relative to earlier practices (e.g. Brown and Krygier, 1970), yet there remains concern over downstream thermal impacts. In their review of timber harvest effects on stream temperature, Moore et al. (2005) found that only a few of the numerous studies they reviewed attempted to quantify the processes governing water temperature as it flows downstream (Brown et al., 1971; Story et al., 2003; Johnson, 2004). They go on further to say ‘Clearly, more research is required to clarify the mechanisms responsible for downstream cooling and how they respond to local conditions’.

Several studies examining downstream temperature response found general cooling trends as streams enter well-shaded reaches (e.g. Caldwell et al., 1991; Zwieniecki and Newton, 1999; Story et al., 2003), although both the direction and magnitude of temperature changes within individual streams are variable (e.g. Cole and Newton, 2013). Of the studies measuring downstream temperature, a few have attempted to quantify the mechanisms responsible for the observed variability in downstream responses. For example, some studies

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FUNDAMENTAL PHYSICS OF STREAM TEMPERATURE DYNAMICS

In order to provide a basis of understanding of the physical principles used in our model, we first review some key fundamentals. Equilibrium temperature, denoted by $T_{eq}$, is the temperature at which the sum of all thermal energy fluxes (net flux) into the stream is zero ($\sum q = 0$). The difference between the temperature of an object and its equilibrium temperature determines the direction and rate of heat flux to/from an object. Objects will have either positive (heating) or negative (cooling) heat flux such that the temperature will trend towards $T_{eq}$. Heat capacity, denoted as $C$, quantifies the resistance of the object to temperature change and is calculated as the mass of the object multiplied by the specific heat of the material comprising the object. The rate of temperature change of the object will then be $\sum q/C$. For the specific case of water flowing in a stream, the net heat flux and $T_{eq}$ depend on the stream and environmental temperatures in addition to the stream morphology, shade, stream bed material and all other factors influencing heat flux components in the area. Consequently, the temperatures of the stream water and the surrounding thermodynamic environment are not constant, resulting in a $T_{eq}$ that also is not constant. The commonly observed diurnal stream temperature oscillations are a result of the stream water continuously trending towards this diurnally oscillating $T_{eq}$.

The processes involved in thermal energy exchange in a stream have been thoroughly discussed elsewhere (Edinger et al., 1968; Adams and Sullivan, 1989; Bogan et al., 2003; Caisse, 2006), and we only briefly reintroduce them here for the purpose of establishing a basis of comparison with our model. The basic factors influencing the total rate of energy transfer ($q$) into or out of a stream can be expressed as follows:

$$\sum q = q_{\text{radiation}} + q_{\text{mixing}} + q_{\text{convection}} + q_{\text{conduction}}$$  \hspace{1cm} (1)

Here, $q_{\text{radiation}}$ includes the heat flux due to solar and blackbody radiation; $q_{\text{mixing}}$ includes both surface and groundwater inputs; $q_{\text{convection}}$ includes the heat flux due to conduction-convection and evaporation-convection; and $q_{\text{conduction}}$ includes bed conduction. When $q_{\text{radiation}}$ and $q_{\text{mixing}}$ are minimized because of high shading and few tributaries or groundwater sources, then the conduction and convection contributions to $\sum q$ dominate the total rate of energy transfer into or out of a stream. In this case, NLC may accurately describe the temperature behaviour of the system. NLC, described by Equation (2), is an empirical relationship, which states that the rate of temperature change of an object is proportional to the difference between the object temperature and the...
Considering this result, we hypothesized that for sections of the integrated form of NLC: equilibrium temperature, the solution to Equation (2) is described as:

\[ \frac{dT}{dt} = -\alpha(T_{eq} - T) \]  

(2)

The temperature decay coefficient (\(\alpha\)) in the preceding equation is given by \(\alpha = hA/C\), where \(A\) is the surface area across which heat is exchanged, \(C\) is the heat capacity of the object and \(h\) is the heat transfer coefficient, which describes the ease with which an object exchanges heat with its environment. For the specific case of a constant equilibrium temperature, the solution to Equation (2) is given by:

\[ T(t) = T_{eq} + (T_0 - T_{eq})e^{-\alpha t} \]  

(3)

A previous work has shown that \(Q_{radiation}\) may be so reduced within heavily shaded reaches that it no longer dominates the net heat flux (e.g. Garner et al., 2014). Considering this result, we hypothesized that for sections of streams that are sufficiently shaded and lacking tributaries, the \(Q_{radiation}\) and \(Q_{solar}\) contributions to \(\Sigma Q\) may be so reduced relative to \(Q_{convection}\) and \(Q_{conduction}\) that NLC becomes applicable. We tested this hypothesis by applying an NLC-based model to predict temperature changes in the heavily shaded downstream study reaches that did not have significant surface water inputs from tributaries. We assumed that any groundwater mixing would be relatively constant from before to after forest harvest.

Finally, an important concept in discussing downstream temperature behaviour is the measurement frame of reference. Stream temperature is typically measured in the Eulerian frame of reference, which is based on measuring the value of parameters in a spatially bounded location (Doyle and Ensign, 2009). In the Eulerian frame, a temperature sensor is stationary, and the stream flows past it. A time series of temperature at a specific location in the Eulerian frame is produced by measuring temperatures at successive instances in time, and thus, each temperature measurement is made on a different volume of water. The Lagrangian frame, in contrast, is a reference frame attached to a specific volume of water as it travels downstream. In the Lagrangian frame, the water parcel is continuously arriving in new environmental conditions, and stream temperature is measured always within the same parcel at different instances in time (and thus at different locations within the Eulerian frame).

The use of the terms heating and cooling without specification of the reference frame in which these changes in temperature are measured can be a source of confusion and misconception because the observed condition of heating or cooling as measured in one frame does not necessarily coincide with a temperature change in the same direction as observed in the other frame. For example, a parcel of water may travel through an upstream, low-shade reach, warming along the way, before passing into a high-shade reach. Within the downstream reach, the parcel may continue to warm, likely at a significantly decreased rate. A later measurement of the parcel temperature would indicate downstream heating in the Lagrangian frame, because parcel temperature monotonically increased with time. However, while this first parcel was in transit through the downstream reach, solar radiation may have increased during the diurnal cycle so that a second parcel passing through the low-shade upper reach might warm at such a high rate relative to the first parcel, currently in the shaded reach and largely unaffected by the increase in solar radiation, that the second parcel temperature becomes greater than that of the first parcel. At this instant in time, the temperature measured at the downstream location would be less than the temperature at the upstream location; thus, measurement in the Eulerian frame would indicate stream cooling. Here, we see the direct contradiction in temperature change as measured in the two different reference frames.

In order to avoid future confusion, we suggest specifying either Lagrangian or Eulerian heating and cooling when describing stream temperature changes (e.g. Rutherford et al., 2004). Within this paper, we will only use the terms heating and cooling in reference to the Lagrangian frame. The Lagrangian frame is more naturally suited to modelling cause-and-effect behaviour in stream temperature dynamics because it tracks how the temperature of fluid in motion changes over time as it encounters new thermodynamic environments. In contrast, the Eulerian frame compares the temperature of two different parcels of water at an instant in time, and those two parcels may have experienced completely different and causally detached thermodynamic environments up to that point. In order to compare predictions provided by a Lagrangian model to data taken in the Eulerian frame, the transit time for parcels of water between Eulerian locations must be measured or modelled. The transit time information allows for Eulerian frame temperature measurement at a specific time and location to be attributed to the temperature of a specific parcel of water arriving at that location at that time. The term advection is often introduced to describe this transport of thermal energy from one Eulerian location to another via stream flow. However, we see that the effects of advection are intrinsically included in a Lagrangian frame model. In fact, for continuous flow situations without significant pooling or
temperature with which the object is equilibrating \((T_{eq})\).

Despite the name, NLC also properly accounts for positive \(\frac{dT}{dt}\) (warming) when \((T < T_{eq})\) as can be seen from Equation (2) in the following:

\[
\frac{dT}{dt} = \alpha(T_{eq} - T)
\]

(2)

The temperature decay coefficient \((\alpha)\) in the preceding equation is given by \(\alpha = \frac{hA}{C}\), where \(A\) is the surface area across which heat is exchanged, \(C\) is the heat capacity of the object and \(h\) is the heat transfer coefficient, which describes the ease with which an object exchanges heat with its environment. For the specific case of a constant equilibrium temperature, the solution to Equation (2) is the integrated form of NLC:

\[
T(t) = T_{eq} + [T_0 - T_{eq}]e^{\alpha t}
\]

(3)

A previous work has shown that \(q_{rad}\) may be so reduced within heavily shaded reaches that it no longer dominates the net heat flux (e.g. Garner et al., 2014). Considering this result, we hypothesized that for sections of streams that are sufficiently shaded and lacking tributaries, the \(q_{rad}\) and \(q_{con}\) contributions to \(\Sigma q\) may be so reduced relative to \(q_{con}\) and \(q_{con}\) that NLC becomes applicable. We tested this hypothesis by applying an NLC-based model to predict temperature changes in the heavily shaded downstream study reaches that did not have significant surface water inputs from tributaries. We assumed that any groundwater mixing would be relatively constant from before to after forest harvest.

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However, we see that the effects of advection are intrinsically included in a Lagrangian frame model. In fact, for continuous flow situations without significant pooling or
recirculation, the values in a time series of temperatures measured in the Eulerian frame are the temperatures, tracked in the Lagrangian frame, of successive parcels of water arriving at that location.

DATA COLLECTION METHODS

The pertinent information on field data collection for this analysis is described later. A full description of data collection and field protocols can be found in Groom et al. (2011b); also see Dent et al. (2008) for a map of the study area and full description of site selection criteria and Groom et al. (2011a) for a summary of the forest harvest reach site characteristics including channel and riparian vegetation statistics pre-harvest and post-harvest. The criteria for stream selection included no beaver influence (dams with ponds or disturbed vegetation), average annual flow rates of 283 l/s or less and treatment reaches harvested according to state and private forest prescriptions for fish-bearing streams, which require varying amounts of overstory tree retention depending on ownership and stream size.

Programmable, waterproof data loggers (referred to as ‘probes’ in this paper; ‘W’ indicates water probes as opposed to air probes) were installed in control reaches upstream of forest harvest (Figure 1; reach between probes 1W and 2W). These control reaches were established to provide a measure of year-to-year and spatial variability in stream temperature that occurs independent of harvest. The treatment reach (Figure 1; reach between probes 2W and 3W) was established to quantify stream temperature changes due to forest harvest. The downstream reach (Figure 1; reach between probes 3W and 4W) was established to examine potential downstream temperature responses to any temperature changes occurring within the harvest unit (Figure 1). The downstream reach was approximately 180 to 345 m below the treatment reach and had to be relatively homogeneous with intact riparian vegetation and no major tributaries in order to minimize confounding variables including mixing. These criteria resulted in only 18 of the 33 study sites having a downstream reach. Hourly stream temperature was monitored for 2 years before timber harvest and 5 years after harvest between 1 June and 30 September. Other data collected for the study include maximum stream depth, bank full and wetted width, shade and stream gradient. These parameters were measured within each reach at 60-m intervals. Channel metrics were collected according to Kaufmann and Robison (1998). Hemispherical photographs were taken using a self-leveling fish-eye camera 1 m above the stream surface using the protocol according to Valverde and Silvertown (1997). Solar radiation indices based on latitude, longitude and elevation were derived from these photographs using HemiView® software version 2.1 (Delta-T Devices, Ltd, Cambridge, UK).

Shade was estimated by 1 – GSF, where GSF (global site factor) is the ratio of direct plus diffuse solar power below canopy to direct plus diffuse power above canopy. Further detail on the processing of these data is described in Groom et al. (2011a).

For this analysis, data from the summer immediately before and immediately after harvest were used. If data from only one of the immediate pre-harvest or post-harvest years were not available, then data from the next adjacent year were used for this analysis (e.g. 2 years pre-harvest or 2 years post-harvest). Sites with two consecutive years of unavailable data on either side of harvest were not used. As a result of these temporal data constraints, 16 of the 18 downstream sites were used in this analysis. The sites used in this analysis were an average of 5.0 m wide (range = 2.8–7.0 m) with a mean watershed area of 327 ha (range = 80–692 ha). The temperature metric analysed in this paper was the 40-day mean of maximum daily temperature computed from the daily maximum values from 15 July to 23 August. This metric was chosen because it aligns with a previous study using the same metric computed from these same data (Groom et al., 2011b). In contrast to Groom et al. (2011a,b), this work focuses on the downstream data. Specifically, this paper describes application of an NLC model to understand the dependence of downstream pre-
harvest to post-harvest change in maximum temperature on change in harvest reach maximum temperature, as well as measured downstream stream properties and distance downstream of the harvest reach.

**NLC MODEL DEVELOPMENT**

**Initial assumptions**

We first assume that a parcel of water moving downstream in a highly shaded reach will follow NLC, and thus, the rate of temperature change for the parcel will be proportional to the difference between the parcel temperature and its unknown, environmentally influenced, equilibrium temperature. The equilibrium temperature may be correlated with, but is not entirely represented by, the temperature of any particular entity in the stream environment. Rather, the equilibrium temperature is a weighted average of the temperatures of all environmental entities with which the stream exchanges energy, with the weights being the rate at which energy can be exchanged with each entity. Therefore, the equilibrium temperature is constantly changing on diurnal and seasonal time scales.

To apply NLC to streams, the conditions that $T_{eq}$ and $\alpha$ are constant require that the transit time, $\tau$, is small compared with the time over which the downstream $T_{eq}$ and $\alpha$ change appreciably. Thus, the reach length over which the NLC model is applied must be sufficiently short and/or fast flowing to meet the constant $T_{eq}$ and $\alpha$ conditions (Rutherford et al., 2004). When using NLC to model a parcel of flowing water, the value of $ht$ is anisotropic (dependent on direction) because the horizontal surface area is greater than the vertical surface area (e.g. the streams are wider than they are deep) and heat is exchanged with different materials by various different mechanisms in different directions, for example, conduction into the stream bed in the downward direction and convection with the air in the upward direction. To account for these complexities, we defined the effective decay coefficient, $\alpha' = \gamma C$, where $\gamma$ is the sum of the different $hA$ terms for each direction.

One of the primary goals of this study was to reduce the number of stream parameters required for a predictive model; thus, the stream data necessary to accurately calculate the values of $T_{eq}$ and $\gamma$ from first principles were not provided by this study. Instead, the pre-harvest to post-harvest change in $T_{eq}$ will be modelled using changes in control reach temperature, resulting in the first free parameter of the model, and $\gamma$ will be incorporated into the second of the two free parameters. The values of the two free parameters in our NLC model are determined by fitting the model to the measured changes in maximum downstream temperature. However, we will show that for the set of streams used in this study, the free parameters are not necessarily site specific, and the lack of a priori calculation of $T_{eq}$ and $\gamma$ does not prevent the NLC model from accurately describing changes in maximum downstream temperatures between pre-harvest and post-harvest summers.

**Applying the integrated NLC**

First, we apply Equation (3) to a parcel of water in transit through the un-harvested downstream reach, between temperature probes 3W and 4W, as indicated in Figure 1. Setting $\tau = 0$ when the parcel passes temperature probe 3W at the end of the harvest reach and $\tau$ equal to the transit time between temperature probes 3W and 4W allows conversion from the Lagrangian frame to the Eulerian (thermistor data) frame. The correspondence between terms in Equation (3) and terms in the stream temperature model becomes $T_{W3} \rightarrow T(t=0)$, $T_{W4} \rightarrow T(t=\tau)$ and $T_{eq} \rightarrow T_{4W_{eq}}$, where $T_{4W_{eq}}$ represents the equilibrium temperature in the downstream reach, and finally, $\alpha' \rightarrow \alpha'$ as discussed previously. Making these substitutions in Equation (3), we arrive at

$$T_{4W} = T_{4W_{eq}} + [T_{3W} - T_{4W_{eq}}]e^{-\alpha' \tau} \quad (4)$$

This model treats the temperature measured at a specific probe location in the Eulerian frame as equal to the temperature of the water parcel passing over the probe at that time, which is modelled in the Lagrangian frame. This model also treats $T_{eq}$ as constant in space across the downstream reach and constant over the transit time ($\tau$). As discussed previously, this assumption requires that $\tau$ is small compared with the time over which $T_{4W_{eq}}$ and $\alpha'$ change appreciably and that the length of the downstream reach is small compared with the distance over which $T_{4W_{eq}}$ and $\alpha'$ change appreciably (Rutherford et al., 2004). Consequently, application of the model is restricted to $\approx 300$ m downstream of the harvest reach. Within this distance, shade values do not vary significantly, and the transit time is on the order of only 1 h, as indicated by an average flow speed of 0.1 m/s computed from dye-based velocity measurements performed on a subset of representative streams.

**Deriving the across-harvest temperature change**

The measured change in downstream temperature across the harvest period ($\Delta T_{4W}$) is determined by subtracting $T_{4W}$ during the summer prior to harvest from $T_{4W}$ during the summer after harvest. This results in Equation (5).
\[ \Delta T_{4W} = T_{4W_{\text{post}}} - T_{4W_{\text{pre}}} \]  

(5)

With \( T4W \) modelled by Equation (4) and given that 

\[ T_{4W_{\text{eq}}} = \alpha \Delta T_{4W} \]  

(6)

\[ \Delta T_{4W} = T_{3W_{\text{eq}}} + [T_{3W_{\text{post}}} - T_{3W_{\text{eq}}}]e^{-\alpha \tau} - T_{4W_{\text{eq}}} + [T_{3W_{\text{pre}}} - T_{4W_{\text{eq}}}]e^{-\alpha \tau} \]  

(6)

With some algebraic simplification, the change in 

\[ \Delta T4W = \Delta T3W_{\text{eq}} + \Delta T4W_{\text{eq}} \left[ 1 - e^{-\alpha \tau} \right] \]  

(7)

Here, \( \Delta T3W \) and \( \Delta T4W_{\text{eq}} \) are the across-harvest-year changes in temperature at the 3W probe and in the 

downstream reach equilibrium temperature, respectively. 

Within this model, the stream properties serving as the 

primary drivers of the measured variations in \( \Delta T4W \) do so via their influence on \( \alpha^* \) and \( \tau \). Modelling the dependence 

of \( \alpha^* \) and \( \tau \) on the site-specific stream properties allows for 

prediction of the measured variation in \( \Delta T4W \) among the 

study streams.

**Downstream transit time.** The transit time of the downstream reach is modelled as 

\[ \tau = L/v, \]  

where \( L \) is the downstream reach length and \( v \) is the flow speed in the downstream reach. We do not have direct flow speed measurements for all streams in the downstream reach, so we modelled the flow speed using gradient measurements together with Manning’s formula (Subramanya, 2009), which states that 

\[ v \propto G^{1/2} \]  

resulting in Equation (8):

\[ \tau \propto \frac{L}{G^{1/2}} \]  

(8)

Here, \( G \) is the average gradient of the stream within the 

downstream reach, typically defined as length along the 

stream divided by change in elevation. The site-specific \( G \) 

values used in the model are an average of these gradient 

measurements for each downstream reach.

**Heat capacity of the stream.** The heat capacity (\( C \)) of 

the modelled parcel of water is proportional to the volume of 

the parcel and consequently the cross-sectional area of 

the stream. For streams approximated as triangular or 

trapezoidal, the volume is proportional to the maximum 

depth (\( D \)) multiplied by the wetted width (\( W \)). We use the 
average measurements \( W \) and \( D \) for each downstream 

reach (Equation (9)).

\[ C \propto W D \]  

(9)

**Downstream shade factor.** Shade and shelter provided 

by stream-side vegetation and local topography reduce 

solar heating during the day and radiative cooling at 

night and also reduce wind speed, and consequently 

conduction-convection and evaporation-convection. We 

hypothesize that through these processes, the level of 

downstream vegetation may influence the downstream 

temperature response to forest harvest. The site-specific 

downstream shade factor (\( S \)) was derived from the 

global site factor as discussed in the Section on 

Methods. However, uniformity in the un-harvested 

downstream canopy among the study streams produced 

a small range of \( S \) values (0.83 to 0.96), which was not 

sufficient to significantly affect the predictions of 

the model. This result suggests that a study incorpora-

ting a wider range of downstream canopy densities 

would be needed in order to provide the information 

required to evaluate and validate a downstream shade 

component in the model, as discussed further in the 

Section on Modelling Discussion.

**Integrating site specificity.** The dominant stream properties driving variation in 

\( \Delta T4W \) are incorporated into our model by combining 

Equations (8) and (9) to arrive at

\[ \alpha \& \tau \propto \frac{L}{WDG^{1/2}} \]  

(10)

Here, \( \varphi \) is a model parameter incorporating the 

proportionality constants associated with Equations (8) 

and (9). Given limited environmental and stream data, 

we initially assume that \( \varphi \) is approximately non-site specific 

for the streams in this study, which is supported by the 

success of the model when a general \( \varphi \) value is used.

**Downstream equilibrium temperature.** Finally, we 

model the yet-unknown changes in downstream equilib-

rium temperature (\( \Delta T4W_{\text{eq}} \)), which are not harvest related 

(e.g. climatic). Our model requires only the change in 

equilibrium temperature, so we are not forced to attempt a 

calculation of the absolute equilibrium temperature both 

pre-harvest and post-harvest. Instead, we use pre-harvest 

to post-harvest changes in the stream temperature 

measured at probes 1W and 2W, which lie upstream 

from harvest, to estimate \( \Delta T4W_{\text{eq}} \) directly. In the context 

of our NLC model, year-to-year changes in the local 

climate will influence actual stream temperature by 

changing \( T_{ew} \). From Equation (7), we see that the rate at 

which the change in downstream temperature varies as 

equilibrium temperature varies, 

\[ \frac{d\Delta T_{4W}}{dT_{ew}} = 1 - e^{-\alpha \tau}, \]  

is
indicated by comparing observed versus predicted values in Figure 2. The RMSEs for the linear model and the NLC model were 0.48 and 0.18, respectively. Similarly, AICc = 28.7 for the linear model and −1.6 for the NLC model, indicating substantially greater support for the NLC model (Burnham and Anderson, 2002). The LOOCV procedure results in an RMSE value of 0.21, and imputed results (Figure 2) indicate that no particular point is driving the fit of the model or disproportionally influencing the free parameter values.

We see that the two-parameter NLC model outperforms the linear regression model at predicting the measured ∆T4W values, despite having the same number of free parameters (two). In Table I, the differences between modelled and measured ∆T4W values are all <0.4°C in magnitude, with the exception of site 7353. At this site, ∆T4W, ∆T2W and ∆T3W (harvest reach) were all negative, and yet ∆T4W was positive. We therefore conclude that the increase in downstream temperature was not caused by harvest, but rather by some as-yet-unknown local effect occurring in the downstream reach. The model uses temperature data taken upstream of the harvest reach to account for the effects of non-harvest-related temperature fluctuations and thus cannot account for the behaviour of this site because of the localized nature of the downstream disturbance. Considering this result, site 7353 was not included in the fitting procedure used to determine φ and β; a model predicted value of ∆T4W for this site is not shown in Table I, and model data for this site are not shown in subsequent figures.

We quantify the relative rates at which the pre-harvest to post-harvest change in the temperature will diminish with distance travelled in the downstream reach at each site by removing the effect of the varying reach lengths. The exponent in the NLC model is normalized to the reach length L, and we calculate (α’t)/L = φ(WDG1/2). Relatively large values of (α’t)/L indicate that the magnitude of the temperature changes measured at a specific downstream locations will decrease in a shorter distance downstream compared with sites with small values of (α’t)/L. Table I provides the site-specific values of (α’t)/L. In order to further understand how the distance dependence of ∆T4W results in the observed values, the site-specific reach length, L, in Equation (12) is replaced with a general distance variable, x, to arrive at an expression for the distance dependence of a change in downstream temperature:

\[ \Delta T4W(x) = \Delta T3W e^{-\frac{x}{\alpha’ WD G}} + \beta \Delta T3W \left[ 1 - e^{-\frac{x}{\alpha’ WD G}} \right] \]  

(15)

The range of behaviours produced by the variation in (α’t)/L are illustrated in Figure 3, which shows the calculated distance profiles of the downstream pre-harvest to post-harvest temperature change ∆T4W (x), along with

![Figure 3](image-url)
the measured $\Delta T4W (x = L)$ data for a representative sample of the study streams. Note that these curves and measured data are not plots of the absolute stream temperature as a function of downstream location, but rather plots of the change in stream temperature from pre-harvest to post-harvest as a function of downstream location ($\Delta T4W(x)$).

MODELLING DISCUSSION

Model specificity

We see in Figure 2 that the $\Delta T4W$ data deviate from the simple linear model, suggesting that the across-harvest $\Delta T3W$ may not be the only source of the measured variation in across-harvest $\Delta T4W$ and that the behaviour of any particular site can be quite different from the overall behavioural trend. The NLC model we have applied predicts this site-specific variation, indicating a significant deterministic contribution to the variation, as originally hypothesized.

Model generality

The ability of the model to reproduce the measured downstream responses using non-site-specific values for model parameters $\phi$ and $\beta$ indicates that these values are relatively constant across the streams selected for this study. This result further suggests that once these parameters values are determined by fitting of model to data for a given type of stream in a given geographic region, the model might be used to predict the future downstream response to harvest of similar streams in that region. This NLC model does not explicitly treat hyporheic flow or groundwater exchange; however, the effects of these processes on the stream temperature change are implicitly included in the fitted model parameter $\phi$. The fact that $\phi$ was held constant in this study suggests that these effects are roughly equally influential across the streams in the study, to within the resolution of this model. The value of $\beta = 1.1$ suggests that for the specific types of reaches examined in this study, the downstream reach equilibrium temperature responds to changes in climatic conditions with roughly equivalent sensitivity to that exhibited by the upstream reaches, to within the resolution of this model.

Model predictive power

The NLC model allows for intuitive analysis of stream sites, which might appear to have outlying behaviour. For example, site 7854 (indicated in Figure 3) experienced a $-0.2^\circ$C change in downstream temperature even though the harvest reach temperature experienced a relatively large measured temperature increase of $2.6^\circ$C. The model was able to predict that this site would behave well outside of the general trend defined by other sites, even when this site was not included in the LOOCV parameter determination procedure, as indicated by the proximity of its imputed value relative to its observed value, as seen in Figure 2. Examination of the stream variables in the context of the NLC model reveals that site 7854 experienced an overall decrease in the local equilibrium temperature, as seen in Table I and indicated by negative upstream control reach temperature changes across harvest ($\Delta T1W,2W = -0.2^\circ$C). Site 7854 also possessed the second smallest WD value among all sites. This combination resulted in a relatively high rate of reduction in the temperature change, as seen in Figure 3. The NLC model shows us that the outlying behaviour of this site was caused by this high rate of change coupled with a relatively long transit time for this site, due to a combination of long downstream reach length ($L = 305$ m) and third lowest gradient ($G = 0.023$). This result highlights the potential utility of the NLC model in predicting which sites may exhibit abnormal behaviour in response to harvest, before harvest ever begins.

In order to further leverage the predictive power of the NLC model, we examine how the across-harvest temperature change depends on the distance from the harvest reach, when that downstream change is caused purely by a change in the harvest reach temperature, in the absence of any climatic fluctuations. For this case, the change in equilibrium temperature is zero, leaving only the first term in the model:

$$\Delta T4W(x) = \Delta T3W e^{-\frac{x}{WDG}}$$  \hspace{1cm} (16)

Intuitively, larger harvest reach temperature changes will lead directly to larger downstream temperature changes, as can be seen from Equation (16). In order to focus on site-specific downstream behaviour, we normalize the downstream change to the harvest reach change and thus define the distance dependent ratio of $\Delta T4W$ to $\Delta T3W$ as $R(x)$. For the case of 0 change in equilibrium temperature, $R(x)$ has the form

$$R(x) = \frac{\Delta T4W}{\Delta T3W} = e^{-\frac{x}{WDG}}$$  \hspace{1cm} (17)

Using average values for $G$ and WD will allow us to estimate a characteristic behaviour of the sites in our study. The solid green line in Figure 4 shows $R(x)$ for the average values of $G = 0.047$ and $WD = 0.53$ m$^2$. We see that for these average values, the across-harvest-year change in downstream temperature drops to 56% of that
change occurring in the harvest reach after 300 m. These calculations are qualitatively supported by the result of the linear fit, which suggests a statistical 50% reduction in temperature change after \( \approx 300 \) m. However, \( R(x) \) is exponentially sensitive to \( G \) and \( WD \), and consequently, the average or statistical result cannot be used to accurately describe the behaviour of a specific site, hence the utility of the NLC model.

In order to estimate bounding behaviours for the distance dependence of the change in temperature for sites similar to those in this study, we combined the extreme values of \( G \) and \( WD \) measured from all sites and used these in the model. The maximum measured values are \( G = 0.11 \) m\(^2\) and \( WD = 1.0 \) m, and the minimal values are \( G = 0.01 \) m\(^2\) and \( WD = 0.12 \) m. The bounding behaviours calculated from these two value sets are shown in Figure 4. For the long-distance extreme case, the downstream temperature change measured 300 m from the end of the harvest reach would be 82% of the temperature change that occurred at the end of the harvest reach \( R(x) = 0.82 \). For the short-distance extreme case, \( R(x) \) is less than 1% after 300 m. Values of \( R(x = L) \) calculated using the specific stream property values and reach lengths at each study site are also shown for comparison with the bounding behaviour curves. We see that the behaviour of one site lies directly on the boundary curve because that site possessed the maximum measured values for both \( G \) and \( WD \).

In order to examine the specific effects of a change to the downstream equilibrium temperature, \( \Delta T4W_{eq} \), on the downstream temperature response, we calculate \( R(x) \) for theoretical example cases when \( \Delta T4W_{eq} \neq 0 \). In this case, the form for \( R(x) \) is more complex:

\[
R(x) = e^{-\frac{x}{WD\phi}} + \frac{\beta(0.047)}{\Delta T3W} \left[ 1 - e^{-\frac{x}{WD\phi}} \right] \quad (18)
\]

We see that calculating \( R(x) \) for \( \Delta T4W_{eq} \neq 0 \) requires input values for \( \Delta T3W \) and \( \Delta T4W_{eq} \). As seen in Table I, the range of values for \( \Delta T4W_{eq} \) extracted from the model was approximately \(-0.4 \) to \(0.4 \) °C. Figure 5 shows \( \Delta T4W \) calculated for \( \Delta T4W_{eq} \) equal to the end-range values of \(-0.4 \) and \(0.4 \) °C, each for two cases of the harvest-reach temperature change within the range typically observed, namely, \(1 \) and \(3 \) °C (solid green lines). We see that changes to \( \Delta T4W_{eq} \) within this range do not significantly affect the dependence of \( \Delta T4W \) on distance relative to the precision of typical temperature measurements. However, we see that integrated over distances of 300 m these relatively slight changes in distance dependence may affect the value of \( \Delta T4W \) by detectable levels (\( \approx 0.3 \) °C).

**Sensitivity to specific stream properties**

The wide range of downstream behaviours encompassed by the bounding behaviours exemplifies the exponential sensitivity of \( R(x) \) to \( G \) and \( WD \). These sensitivities are illustrated with greater detail in Figures 6 and 7, which show \( R(x) \) as a function of \( G \) and \( WD \), respectively, at the reach end \( (x = 300 \text{ m}) \) and half-length \( (x = 150 \text{ m}) \) for comparison. We see that the slopes of these curves are significant within the range of measured values (indicated by the shaded grey regions in Figures 6 and 7) for these stream properties, and thus, the measured behaviour is highly sensitive to these properties. This analysis indicates that blanket statements about distance required for stream temperature to return to pre-harvest...
Figure 6. Calculated ratio of downstream to harvest reach temperature changes at distances of 150 and 300 m downstream from harvest reach as a function of downstream gradient in the absence of stream equilibrium temperature fluctuations. Curves produced using both $\alpha' = 1/3$ and $\alpha' = S$ models are shown. Average measured values of $G$ (0.047) and $WD$ (0.53 m$^2$) were used. In all cases, $\Delta T_{eq}$ = 0°C, and model parameter values $\alpha = 2.2 \times 10^{-4}$ (mi), $\beta = 1.1$. The grey shaded area indicates the range of gradient values measured in this study.

Figure 7. Calculated ratio of downstream to harvest reach temperature changes at distances of 150 and 300 m downstream from harvest reach as a function of downstream cross-sectional area in the absence of stream equilibrium temperature fluctuations. In all cases, the average measured values for $WD$ (0.53 m$^2$) were used, $\Delta T_{eq}$ = 0°C, and model parameter values $\alpha = 2.2 \times 10^{-4}$ (mi), $\beta = 1.1$. The grey shaded area indicates the range of cross-sectional area values measured in this study.

Figure 8. Calculated ratio of downstream to harvest reach temperature changes at distances of 150 and 300 m downstream from harvest reach as a function of downstream shade in the absence of stream equilibrium temperature fluctuations. Curves produced using both $\alpha' = 1/3$ and $\alpha' = S$ models are shown. Average measured values of $G$ (0.047) and $WD$ (0.53 m$^2$) were used. In all cases, $\Delta T_{eq}$ = 0°C, and model parameter values $\alpha = 2.2 \times 10^{-4}$ (mi), $\beta = 1.1$. The grey shaded area indicates the range of shade factor values measured in this study.

CONCLUSIONS

For the forested streams in our study, the model suggests that, on average, pre- to post-changes in downstream temperature exist at roughly 50% of those changes in the harvest reach after ±300 m downstream, but that they do not persist indefinitely. The model also indicates that variation in stream morphology can lead to significant variability in this downstream temperature response to harvest, and it allowed us to estimate limiting-case behaviours. We estimated that for streams with relatively uniform and undisturbed riparian conditions downstream of harvest (high shade and shelter), the values of $G$ and $WD$ will primarily drive the variations in downstream temperature response.
Additional application of NLC modelling methods to stream temperature data should help to improve the NLC model accuracy and determine the range of stream, environmental and treatment conditions under which the NLC model is valid and accurate. For example, data from a set of many temperature probes within individual reaches would allow us to fit the Lagrangian NLC model to the Eulerian temperature data at each site and determine the properties with greatest influence on the stream temperature. NLC model accuracy and determine the range of stream, environmental and treatment conditions under which the NLC model is valid and accurate. For example, data from a set of many temperature probes within individual reaches would allow us to fit the Lagrangian NLC model to the Eulerian temperature data at each site and determine the properties with greatest influence on the stream temperature.

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Responses to Questions/Concerns Raised by Oregon Forest Industries Council Regarding the Protecting Cold Water Criterion of Oregon’s Temperature Water Quality Standard

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Reasons for a Protecting Cold Water Criterion:

- A natural thermal regime provides best conditions for fish & other native aquatic organisms;*
- There is ecological value in a diversity of temperatures, including streams colder than BBNC, in part because thermal diversity promotes aquatic biological productivity;*
- Prevent accumulation of heat in fish-bearing reaches;*
- Retain assimilative capacity to buffer climate variation & climate change.

*From Summary of 2003 Technical Advisory Committee findings

Responses to Forest Industry Questions/Concerns:

1. Paired watershed studies add to the body of science on the association of new harvest treatments on stream temperature & short-term fish response, but not in a way that shows a lack of need for the Protecting Cold Water Criterion.
   a. Hinkle & Alsea studies show increases in fish-bearing streams within the range of responses from RipStream.
   b. Biological inference of WRC studies is correlative, short-term, and at the sub-catchment scale in lower order tributaries, and primarily within the distribution of resident cutthroat trout.
   c. The purpose of the standard is maintenance and restoration of natural thermal regimes across the landscape for all aquatic species.
   d. Prevention of short-term, reach level effects to fish are a goal to the standard, but are not the primary purpose.
   e. Meeting the standard preserves the capacity of waterbodies to assimilate natural fluctuations in temperature due to year-to-year climate variations & to better maintain cold-water communities in a warming climate (Bisson et al 2003, Mote 2003, INR 2009, Ruesch et al 2012).
2. Thermal diversity across the landscape is biologically necessary. Small increases in stream temperature can have negative effects on fish populations, particularly when occurring across the landscape.
   a. Temperature 303(d) listings & TMDLs exist across Oregon.
   b. Heating of headwaters reduces the extent of downstream waters at optimal growth & physiological temperatures & increases the extent at high-risk & lethal temperatures for rearing & migration.
   c. Temperature effects typically occur on a continuum; increases from natural thermal potential increase risk to fish (McCullough 1999, US EPA 2001).
   d. The natural thermal regime (NTR) is dynamic & variable, promoting biological diversity & resilience among fish populations & other native aquatic organisms (e.g. Watters et al 2003, Olden & Naiman 2010).
      i. Landscape alteration & climate change alter the mean & the variance of these temperature components (Steel et al 2012).
      ii. Timing of fish life history attributes (adult migration, spawning, fry emergence, smolt migration) is partially mediated by the NTR (Vannote & Sweeney 1980).
      iii. Homing to natal streams & natural selective forces (including those imposed by NTR) result in distinct, locally adapted populations (Hillborn et al 2003).
   e. Thermal diversity promotes aquatic biological productivity.
      i. Fish use thermal diversity (temporally & spatially) so impacts to the "pattern" of temperature can be as significant as changes to the mean or maximum temperature (see DEQ 2003).
      iii. Variation in thermal regimes directly influences:
         1. Metabolic rates, physiology, & life-history traits of aquatic ectotherms (see Holtby et al 1989 for salmonid example);
         2. Rates of important ecological processes such as nutrient cycling & productivity;
         3. Indirectly mediates biotic interactions (references in Olden & Naiman 2010).
   f. Heat accumulation (& other homogenizing effects) can alter thermal heterogeneity before “average” main channel temperatures change (Poole & Berman 2001).
   g. Multiple stressors in the environment must be considered. By preventing or reducing temperature stress, we reduce the risks due to multiple stressors on fish populations (e.g. OCCCP bottlenecks; e.g. Laetz et al 2014, Ray et al 2014).
   h. When there is uncertainty, DEQ must make conservative choices to ensure protection of the resource.
3. Thermal loads do move downstream, heat loss mechanisms are much less efficient than heat gain by solar radiation, & dilution of thermal loads is not the same as dissipation, especially with multiple harvests.
   a. In open canopy streams, input of solar radiation typically composes about 50% – 90% of the total heat energy flux (Figures 1 & 2; see Johnson 2004, Benyahya et al 2012).
   b. A single source’s temperature effects become hard to track downstream, but DEQ calculates thermal loads for TMDLs & permits.
   c. DEQ HeatSource modeling indicates long distances (>1000 meters) are required to lose thermal energy via evaporation & longwave radiation (when tributary & groundwater inputs are held constant).
      i. HeatSource modeling on 2 RipStream sites (5556 & 7854) shows persistent temperature increases a kilometer or more from the end of harvest units (Figures 3, 4, & 5); and
      ii. Harvest of an additional downstream unit on 5556 creates greater increase at confluence with Drift Creek (Figure 6).
   d. Cole & Newton (2013) showed that with uncut units interspersed with harvest units, stream reaches showed overall increases in temperature trends post-harvest for 3 of 4 study reaches.

4. The current disturbance regime is very different than the pre-settlement disturbance regime in both frequency & type of disturbance.
   a. Thermal recovery post-disturbance is 7-15 years, with 10 years as a reasonable mid-range value (Johnson & Jones 2000; D’Souza et al 2011; Rex et al 2012; RipStream data, unpublished).
   b. With a 40-year rotation (assuming steady yearly harvest rate), 25% of the private industrial forestland base would be in thermal recovery.
   c. Based on change in Landsat land cover from 1985-2009 (Figure 7), the average percentage of private forestland (65.1% of total land area) in the MidCoast basin in the 10-yr thermal recovery period is 17% for the time period 1994-2009.
      i. The total for all land uses combined is 10%.
      ii. Varies over time & space.
         1. In 2008, 39.9% of private forestland in the Middle Siletz River watershed was in thermal recovery.
         2. In 1996, 5.3% of private forestland in the Drift Creek watershed was in thermal recovery. [Maximum of 34.9% in 2008]
   d. Based on change in Landsat land cover from 1985-2009, the average percentage of private forestland riparian areas in the MidCoast basin (43.8% of total riparian area (within 100ft of streams)) in the 10-yr thermal recovery period is 14.1% for the time period 1994-2009.
      i. The average for private industrial forestland is 15.6% (36.2% of total riparian area) & for private nonindustrial forestland is 10.2% (7.6% of total riparian area).
ii. The percentage of recently chronically disturbed riparian areas is 20.7% for private forestlands during the same time period (20.4% & 21.8% for industrial & nonindustrial, respectively).

iii. The average recent disturbance for riparian areas of all land uses collectively is 8.7%. The average chronic disturbance for riparian areas of all land uses collectively is 14.0%.

iv. Varies over time & space.
   1. In 2008, 36.7% of private industrial forestland riparian area in the Middle Siletz River watershed was in thermal recovery (maximum). The minimum of 14.1% occurred in 1994 (Figures 8 & 9).
   2. In 1996, 0.2% of private industrial forestland riparian area in the Drift Creek watershed was in thermal recovery (minimum). The maximum of 25.8% occurred in 2008 (Figures 10 & 11).
   3. In 1999, 9.7% of private industrial forestland riparian area in the Lake Creek watershed was in thermal recovery (minimum). The maximum of 34.5% occurred in 2008 (Figures 12 & 13).

e. Agee (1990) estimates that historically (prior to Euro-American settlement) an average 0.24% and 0.67% of cedar/spruce/hemlock and western hemlock/Douglas-fir forests, respectively, burned annually.
   i. Gives an average area in thermal recovery estimate of 2.4% for cedar/spruce/hemlock & 6.7% for western hemlock/Douglas-fir.

f. Wimberly (2002) estimates that a median of 17% of Oregon’s coastal province would be in early successional condition (<30 years since fire of varying severity).
   i. Using 10 years as above, Wimberly’s estimate gives 5.7% of forestlands historically in thermal recovery.

g. High-severity fires leave more wood & live vegetation than clearcut harvest, and there are differences between unmanaged terrestrial & riparian early succession compared to clearcut harvest & replanting methods (Reeves et al 1995, Reeves et al 2006, Swanson et al 2011).

h. Fire return intervals in western Oregon range from 100-400 years. Shorter intervals typically are associated with less severity (Morrison & Swanson 1990).
   i. Fire return for high severity fires is typically 200 years (Wimberly 2002), compared to harvest rotation of 40 years.

j. Periodic large scale disturbances create a mosaic of riparian & aquatic habitats (Bisson et al 2003). Pulses of sediment & large wood are delivered by post-fire erosion, in contrast to chronic inputs.
   i. It is important to conserve & restore processes by managing for natural disturbances or like natural disturbances, not merely by creating structures or conditions.

k. Generally, riparian areas along streams higher in watersheds tend to burn along with upland forests, while riparian areas lower in watersheds are less likely to burn & more prone to flood disturbance (Reeves et al 2006, Pettit & Naiman 2007).
i. Fire can be less common in riparian areas due to higher moisture content & humidity.

ii. Some studies (e.g. Tollefson et al 2004, Olson & Agee 2005) have found no difference between upland & riparian fire frequency, particularly when riparian vegetation is similar to upland vegetation.

iii. Riparian areas often have higher fuel loads (higher productivity) & in prolonged drought can become more fire-prone.

iv. Riparian fires tend to be very patchy, primarily burning fine fuels. Conditions retard fuel drying & decrease severity. Extent & spread are complicated by ecosystem heterogeneity.

v. In very dry climatic conditions, riparian corridors can act as a route for fire to spread (wind tunnel effect). More often, riparian areas act as a natural fire break.

vi. Harvesting increases fuel loads & opens up the canopy, allowing faster drying of fuels.

vii. Riparian vegetation diversity & adaptations along with better access to water lead to faster recovery.

5. If taking a non-conservative approach to the effects of a single harvest, then we must address actual landscape conditions & the effects of multiple harvests.
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Memo 3 June 2015

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Testimony for Oregon Board of Forestry, Salem, Oregon 3 June 2015

Subject: Key scientific aspects of the Oregon Department of Forestry Westside Riparian Rule Analysis

1) Meeting the Protecting Cold Water Criterion is of critical importance for Oregon's biological resources. There are at least two fundamental reasons for this. First, salmon, trout, and stream-dwelling amphibian species evolved in coldwater environments and existing summer temperature in western Oregon are for the greater part already exceed their biological optima. These species attained their present distribution in cold waters as mountain and continental glaciers and snowfields were receding. Some of these species can persist in warmer waters, but for the most part at greatly reduced productivity that cannot support fisheries and severely reduces their ability to survive natural and human disturbances. Considering the whole, any warming of summer maximum water temperature substantially harms coldwater species. Cooling of winter temperatures and cumulative changes in spring temperatures can also disrupt life history and survival of these species, but riparian forest buffers sufficient to protect against summer time warming are for the most part sufficient to also mitigate impact to winter and summer stream temperatures.

Second, temperature standards to limit warming are applied on a per-action basis—in this case, a particular timber cutting unit. If measurable increases were allowed on this basis, the cumulative increase in summer temperature that could arise from multiple actions in the same watershed could produce much greater cumulative impact on stream temperatures. Of course, cumulative temperature increases arising from multiple projects remain a potential problem even with temperature increases at less than the PCW detection level of 0.5 degrees C, but at that level the potential for cumulative temperature effects emerging is greatly reduced. Unless the State of Oregon is able and willing to adopt some sort of effective regulatory control of logging and other forest management actions at the watershed scale on private timberlands that also accounts for cutting history on adjacent public lands, a conservative coldwater protective standard will be necessary.

2) The reports prepared by DOF give a very informed, substantive, and credible analysis of the likely effects of various proposed streamside logging prescriptions. In
my opinion the core analysis of effects of tree removal on stream temperature is a state-of-art quantitative effort, well-grounded in field studies, that has never been paralleled. The relative consistency of results in RipStream analyses across drafts I have seen in recent years is further evidence of the veracity of its findings. In other words, adding more data from more streams does not change the results. The results show, broadly speaking, that only two alternatives reduce violations of the PCW criterion to low levels of likely occurrence: The no cut buffer alternative of 90 feet or greater distance from stream margin, and the Oregon State Forests Management Plan. However, see my comments below regarding the sufficiency of the 90 foot distance.

3) However, it is alarming and objectionable that the documents prepared by DOF summarizing the temperature analysis presume, without evident technical or policy justification, that "average" temperature increases of 0.5 degrees C or less constitute compliance with Oregon’s Protecting Cold Waters Criterion. In that case, around half of modeled sites and cases are in fact predicted to warm greater than 0.3 C and therefore violate the stream temperature standard. Biologically effective coldwater protection should logically protect all or at least nearly all affected waters from measureable warming. Although not reflected in the text, analyses and graphs presented by DOF in the memos for Board present well-developed, state-of-art information to ascertain the difference between "average compliance" and something nearer full compliance. Given the distribution of the data evident in those graphs, "average" compliance means nearly half of affected streams will likely be measurably warmed by logging practices. Certainly other parties regulated by water quality standards in the state of Oregon do not routinely assume that they are in compliance if they meet the standards barely more than half the time. I think the general public would find this notion outrageous. The consequences of this magnitude of adverse impact need to be clearly recognized in the analysis, and the basis for using average responses as the measure of effectiveness requires justification. The difference is significant. For example, based on Figure 1 in the document "DETAILED ANALYSIS- PREDICTED TEMPERATURE CHANGE RESULTS" to attain something nearer 95 percent compliance with PCW would require no-cut buffers of about 110 feet in width, compared to "average" compliance at 90 feet. From Figure 8, attaining 95 percent compliance with the PCW would require a retained basal area of near 365 square feet per 1000 lineal feet of stream, rather than the average PCW attainment near 275 feet. In my opinion, it does no one good to "shave the numbers" in the text that interprets their significance for policy decisions, especially without a clearly articulated rationale and an explanation of what the consequences are likely to be on the ground. My point is that while the analysis and data graphs are excellent, the text of the report appears inappropriately phrased to blunt, if not distort, the full significance of the scientific information for the regulatory decision.

4) ODF’s "DETAILED ANALYSIS" report notes that "the thermal protection offered by increasing buffer widths begins to decline beyond 50-60 feet." Again, I am concerned some could be mislead by this rather casual characterization of the
relationship graphed in Fig. 1. Yes, the line fitted to the modeled data does begin to gently inflect beyond 60 feet, so that incrementally each additional foot of riparian area width confers somewhat less contribution to total shade. But the most important feature of the analysis in Fig. 1 is that it clearly shows that as a percentage of total existing shade, the removal or loss of trees in the 100-120 feet from the stream still can measurably reduce shade and increase water temperature, even to the extent that the PCW is violated in many cases. The text of the report in appropriately minimizes this very important finding.

5) In my opinion, this analysis does include sufficient information to conclude that prescription alternatives that rely on staggered alternate-stream-side logging with “four years of greenup” to recover shade would be woefully inadequate to attain PCW compliance. For example, the analysis in Fig. 1 of the “DETAILED ANALYSIS” report makes it abundantly clear: trees at greater than 90-100 feet distance are contributing shade that significantly influences stream warming. Thus we can infer that tall, large trees standing at some distance from the streams are contributing that effective shade. If a prescription allows those large, tall streams in beyond 60 or 75 feet to be cut, it will not be four years before that shade is replaced by equally tall—rather it will be 20-40 years. Staggered prescription concept appears to be based on a fundamental misunderstanding and unrealistic assumptions about the science of thermally effective forest shade contribution. Interested parties need to recognize that ODF’s RipStream research gives us a relatively fine-grained and well-informed understanding of shade contribution and that contravenes many long-held, simplistic beliefs about stream shade, many of which were based on short-term studies with small sample size, inadequately controlled or characterized treatments, and loosely contrived thermal response criteria.

6) It appears very likely that the relative strong influence of trees beyond 75 feet from the stream to shade and stream warming demonstrated in the RipStream study results in part from the legacy of past logging impacts. The study sites incorporated are representative of riparian areas of western Oregon riparian that remain to an extreme extent depleted of mature and old growth stands and trees from first and sometimes second-rotation logging. Because large, mature trees remain relatively depleted in the immediate streamside zone, more of those trees standing farther from the stream now more often make up some of the shade that was formerly provided by near-stream trees. It’s important to note the same historical effect prevails with large wood recruitment. That is, trees standing farther from the stream may be proportionately more important for wood debris contribution and other stream ecosystem and habitat functions than they formerly might have been when abundant large conifers occurred in the near-stream zone.

After a century or more of riparian forest recovery—assuming riparian forests are fully protected to allow for natural successional processes—options could re-emerge for selective harvest of trees 50-120 feet from streams with much lesser incremental impact on water temperature and wood debris recruitment. The take-home message is that present-day rules must be more far-reaching because past logging and timber
management practices failed to be adequately protective of streamside forests. **Future rules could need to be even more restrictive if today we do not adopt practices that successfully promote the full natural successional recovery of riparian forests.**

7) **Fully protective streamside rules should be applied to all of western Oregon including the Siskiyou region.** I have conducted stream temperature and related stream habitat studies in this region, as well as elsewhere in western Oregon. Despite geologic, climate, and vegetation differences, nothing about the hydrology and physics of forest shade and stream warming changes significantly or consistently within that region compared to western Oregon as a whole.

8) **To be fully protective, to provide broadly for restoration of riparian and aquatic habitats and water quality (including not just temperature but sediment and nutrient concerns), a riparian rule sufficient to ensure attainment of the PCW should be applied to all small and medium streams in western Oregon, not just those stream segments considered to contain salmon, steelhead, or bull trout (SSBT).** While there seems to be continuing ambiguity about the specific proportion of streams in western Oregon that would be protected if a new riparian rule would only be applied to SSBT stream segments, it is clear that most small and many medium streams are not SSBT waters. It is highly likely in most field situations some magnitude of thermal impact in headwater streams propagates downstream (either via surface or subsurface pathways); this is the logical and most defensible assumption based on first principles of physics and a wide range of scientific literature. Hence, logging upstream from SSBT segments can warm SSBT waters beyond the PCW standard. Anecdotal accounts from a few small-watershed paired basin studies should not be relied on to assume that temperature impacts do not propagate downstream, because in most cases their design does not allow for unambiguous conclusions about incremental warming. Moreover, warming less that that readily detectable in headwater streams can still accumulate to detectable levels in downstream receiving waters (it may be more accurate to characterize the most biologically important effect as a reduction of the cooling influence of headwaters on receiving waters).

A conservative coldwater protective standard applied to streams contributing to SSBT waters will be necessary to assure compliance with the PCW. Unless the State of Oregon is able and willing to adopt some sort of effective regulatory control of the pattern, extent, and sequence of logging and other forest management actions at the watershed on private timberlands that also accounts for cutting history on adjacent public lands, a conservative coldwater protective standard applied to contributing segments to SSBT waters (both fish and non-fish) will be necessary to assure PCW compliance.
ATTACHMENT 5
Frissell & Nawa, 2016. 11 pages.

Protecting Coldwater for Salmon and Steelhead
on Private Timberland Streams of Oregon’s Siskiyou Region:
A Synoptic Scientific Look at Stream Warming, Shade, and Logging

Prepared for the Oregon Stream Protection Coalition by
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31 October 2016

INTRODUCTION

The Oregon Board of Forestry proposes to exclude the Siskiyou Georegion from a proposed new coldwater protection rule, citing inadequate monitoring information. This memo examines this proposition, and argues that a finding to exclude the Siskiyou region is, by scientific criteria, without merit. To the contrary, there is adequate information at hand for the Board to find that the current riparian rules do not meet the statewide limitation on stream warming set by the Protecting Coldwater Criterion (PCW) and to determine what stream protection would be adequate in the Siskiyou region.

Principal Findings:

- Salmon and steelhead are widely distributed in the Siskiyou Georegion, and a variety of large, medium and small stream provide critical habitat for them, including listed Coho salmon. Many of the most important habitats for extant populations are associated with forest lands, and private forestry under current practice is recognized as an important contributor to habitat impairment.

- The RipStream study provides a rational basis to find the PCW is not being met on small and medium salmon, steelhead and bull trout (SSBT) streams throughout western Oregon (with the possible exception of some higher-elevation streams in the Cascades), even though none of the field data specific to this study were collected in the Siskiyou.

- Evidence in the literature and available relevant studies does not indicate the relationship between shade and stream warming on Small and Medium streams (per ODF size classification) in the Siskiyou is different than the relationship established in ODF’s predictive modeling for western Oregon.
Available data suggest ecological differences between the Siskiyou and other regions of western Oregon have relatively little effect on stream temperature and riparian shade relations. Any differences that do exist certainly do not modify the basic causal relation between forest shade reduction and warming of stream thermal maxima, and they do not undermine the clear relevance of the RipStream findings to SW Oregon.

Possible exceptions to the above conclusions are Siskiyou streams draining watersheds rich in ultramafic rock types and the soils derived from them. However, forests in these streams are so sparse that for the most part they do not support commercial forestry, and most of these lands are in federal ownership as a result. Moreover, across most areas of ultramafic geologic influence, riparian vegetation is larger and denser than upland vegetation, and this together with an abundance of perched shallow aquifers contribute to moderating stream temperatures.

To the extent that geologic and hydrologic conditions contribute to differences between Siskiyou Georegion streams and those in other western Oregon regions, these conditions do not appear to inherently cause Siskiyou streams to be warmer under natural conditions; to the extent they affect shade-temperature relations, regional ecological differences likely increase, rather than decrease the sensitivity of Siskiyou streams to shade loss.

The fact that in 1994 the Board chose to set a 10ft² per acre lower minimum conifer basal area when it set standards for riparian logging in the Siskiyou does not logically relate to the Board’s decision to exclude the Siskiyou from the new rule. It simply indicates that conifer basal area is known to be less dense in some riparian forests of this region than those in wetter regions. However, even where conifer density is low, shade is nevertheless provided by hardwood species (some of which are also commercially logged). Furthermore, even where they are reduced in density, conifer trees commonly have higher crown height and therefore may contribute a greater proportion of shade to streams, as well as providing important large wood and wildlife habitat functions. These factors all taken together argue that oversimplified and unsubstantiated assumptions about shade and riparian forest conditions and relations should not be the basis of excluding Siskiyou riparian forests from improved protective rules based on regionally applicable “Ripstream” science. Until specific information is available to substantiate an hypothesized departure of stream temperature conditions and causal relationships for the region, it is irrational and unjustified to exclude Siskiyou streams from the protections afforded those in other western Oregon regions.

In summary, available monitoring and research evidence documents that degradation of freshwater resources maintained by stream shade in the Siskiyou Georegion is likely if improved riparian forest protections proposed for elsewhere in western Oregon are not adopted and implemented there.
DETAILED COMMENTS

In this report we focus on streams considered by ODF to fit in the Small and Medium size categories. By ODF criteria (ODF 1994), Small streams have an average annual flow of 2 cfs or less. Medium streams have an average annual flow greater than 2 cfs but less than 10 cfs. Large streams have an average annual flow of 10 cfs or greater. Any stream with a drainage area less than 200 acres is considered small. Average drainage area equivalents that typically produce discharge within this range were derived ODF based on mean annual precipitation. Generally, we assigned streams to size categories on an approximate basis using drainage area criteria, and in some cases based on familiarity with the channels and flows of the streams in question.

QUESTION 1: ARE RIPARIAN FORESTS IN THE SISKIYOU GEOREGION FUNDAMENTALLY DIFFERENT?

ODF Stream and Riparian Forest Monitoring Data

An ODF monitoring study (Dent 2001) assembled monitoring data from field surveys on riparian forest conditions and logging effects at 40 streams in ODF’s Small, Medium and Large size categories statewide, and the data set included two streams in the Siskiyou Georegion. While the Siskiyou area data are sparse, they offer an opportunity for a provisional look at whether obvious differences exist in riparian areas of the Siskiyou Region and those in other regions, including the Coast Range, Interior, South Coast, and Cascades regions where ODF’s currently proposed shade rules are set to apply. (Post-harvest riparian conditions were highly variable because streamside logging prescriptions were not controlled in this 2001 study, so are not considered here.)

Dent (2001) at p.37 (Table 6) reported measured values of percent cover for surveyed reaches of two Siskiyou Region streams and 22 other streams from western Oregon georegions. Dent reported cover prior to harvesting as the best measured index of natural shade in the surveyed streams. Cover was 80 percent for the Large size class Siskiyou stream (Glade Creek, stream width 16.7 feet); by comparison the range for all 8 streams in the Large category drawn from the four western Oregon georegions was 76 to 94 percent cover, with a median of 78 percent.

The Small class Siskiyou stream in the sample (Jamison Creek, stream width 4 feet) had a pre-harvest cover of 91 percent. The range for all 9 Small streams in the study sample in western Oregon was 83 to 97 percent with a median of 91 percent. So these Siskiyou region streams fall very near the western Oregon median and mean for streams of the same size class. Though sparse, the data offer no evidence that riparian forest canopy cover conditions are different in the Siskiyou region than in other western Oregon regions, and suggest the opposite.

Pre-harvest Conifer and hardwood basal area was reported by Dent (2001) in Table B-1 (p. 66). Reported conifer basal area of the Siskiyou Region Large stream (Glade Cr.) Riparian Management Area (RMA) was 248 square feet per 1000 linear feet of stream. The range for all 11 western Oregon sites was 0 to 927 ft²/1000ft, with a median of 97. Hardwood basal area in the RMA of the Large Siskiyou stream was reported as 13 ft²/1000ft, compared to a western Oregon range of 13 to 502 ft²/1000ft. At this Siskiyou site, then, a larger proportion of existing
cover (and therefore likely canopy shade) was comprised of conifers and a smaller portion of hardwoods than at the Large stream sites surveyed elsewhere in western Oregon. However, the Small stream category is of more direct interest for purposes of the present report. For the Small Siskiyou stream (Jamison Cr.), reported conifer basal area within the RMA was 97 ft²/1000ft, compared to a range of 0 to 180 ft²/1000ft and a median of 115 ft²/1000ft across 14 streams throughout western Oregon (Blue Mountains streams in the study were excluded from these calculations). Reported hardwood basal area in this Siskiyou Small stream RMA was 70 ft²/1000ft, compared to a range of 22-184 ft²/1000ft and a median of 70. Furthermore, the cumulative average basal area of conifers and hardwoods in relation to distance from the stream channel (Dent. Fig. 4, pp. 20-21) for the Small Siskiyou stream was very similar to the same curves for aggregated Small Coastal Streams from western Oregon.

These data do not suggest that the basal area of conifers and hardwoods at the Siskiyou Small stream site was in any way anomalous relative to the other surveyed western Oregon Small stream sites; rather, they suggest the opposite. Additionally, the reported basal areas for the two Siskiyou sites fall squarely within the range of conifer basal areas Dent (2001) compiled from literature sources for western Oregon Coast Range streams (Fig. 3, p.19 and Appendix A). These facts suggest there is no discernible forest ecological basis for assuming from the results of ODF’s riparian shade and stream temperature studies should not be extended to the Siskiyou Georegion.

That finding corresponds with the senior author’s own extensive field observations of riparian forests and stream channels in the Siskiyou Georegion and the other western Oregon regions. While the proportions of tree and shrub species, growth rates, and microclimates vary, as does the stem density of certain commercially valued species like Douglas-fir, overall canopy shade conditions for Small and Medium sized streams do not vary in a systematic way that corresponds with the georegion delineation. Similar near-complete crown closure in the absence or near-absence of disturbance across western Oregon likely results from the simple fact the forest vegetation develops to maximize utilization of available light wherever sufficient moisture and nutrients are available to support this, and sufficient moisture and nutrients are generally available in riparian areas throughout western Oregon. The Siskiyou region, at least outside of areas of ultramafic bedrock and in the absence of grazing, urbanization, or channelization, is capable of supporting a sufficient density of larger trees in riparian areas that tree crowns can span and overlap across the full width of most Medium-sized streams.

**QUESTION 2: ARE SMALL STREAMS IN THE SISKIYOU GEOREGION WARMER THAN STREAMS IN OTHER AREAS OF WESTERN OREGON?**

1) Regional patterns of Stream Temperature

This question could be quantitatively addressed by statistical comparison of temperature records among streams with at least several years of daily maximum temperature records. Numerous records exist, have been compiled by federal researchers, and are available for query in the data base at the NorWest stream temperature web page at [http://www.fs.fed.us/rm/boise/AWAЕ/projects/NorWeST.html](http://www.fs.fed.us/rm/boise/AWAЕ/projects/NorWeST.html). A comprehensive quantitative comparison of this kind, while feasible, is beyond the scope of this memorandum.
However, a visual test of the question can be made by inspection of the regional “Thermalscape” map produced by the NorWest project and available online at http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST/images/ThermalscapeWesternUS_StreamTemperatures082016.jpg. This map presents the results of a spatial statistical network model that predicts stream temperature based on a small set of physical characteristics and the best fit to existing field data on stream temperature for thousands of sites in the NorWest database. The mapped output is comprehensive for the Pacific Coastal, Great Basin, and Rocky Mountain areas, including all of western Oregon. For the purposes of this memo we have excerpted the Western Oregon area map and roughly outlined the boundaries of ODF’s Siskiyou Georegion (Figure 1). An inspection of this figure reveals no evidence that stream temperatures trend warmer in the Siskiyou Georegion than in the surrounding Oregon coastal and interior Willamette and Umpqua areas. Although smaller and mid-order streams in the Cascades region at higher elevations do appear cooler on average than their counterparts elsewhere in western Oregon, that pattern is well-known and is associated with geohydrologic differences, with additional influence of elevation and snowmelt runoff, and the extensive watershed areas managed under Northwest Forest Plan and federal Wilderness policies.

Figure 1. “Thermalscape Map” of stream temperatures synthesized from a spatially explicit model calibrated to an extensive set of temperature site data across the Pacific Northwest. Graphic modified to depict approximate area of the ODF Siskiyou Georegion from http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST/images/ThermalscapeWesternUS_StreamTemperatures082016.jpg.
2) Riparian Canopy, Stream Shade and Stream Temperature Relations

Clean Water Act 303d listings of stream segments impaired by elevated temperature is widespread in the Rogue Basin (ODEQ 2008). Temperature impairment listings are especially prevalent in three stream categories: 1) along larger rivers and large streams in all land ownership and use categories, 2) medium size and small streams draining agricultural and urban lands, and 3) small and medium-sized streams draining private industrial forest lands. TMDL Reports (Siskyou National Forest and ODEQ 1999, ODEQ 2002, 2003, 2007) identify forestry effects, particularly those reducing stream shade by riparian logging and near-stream roads, as a major contributor to thermal loading. These reports also project through spatially explicit, calibrated models of thermal loading under different flow and land management scenarios, how much streams have likely warmed as a consequence of past forestry activity, and conversely how much they could be expected to cool with restrictions on near-stream logging that would be necessary to allow regrowth of mature riparian forest conditions.

As an index of the magnitude of temperature change associated largely with forestry activities, in Table 1 we have excerpted relevant data from small and medium-sized streams Oregon Department of Environmental Quality (ODEQ) Total Maximum Daily Load (TMDL) studies where we could establish provisionally that the predominant land use is private land forestry. Excepting some streams where very large canopy cover reductions are likely associates with agricultural or exurban land use at lower elevations, these data suggest that recent and past forestry activities are associated with canopy cover and shade losses range from around 2 to 45 percent, with a median loss of about 15%. We note that these shade losses may be conservative relative to the losses that occur within the first few years after logging, as they represent the current stand conditions that span a range of years of recovery since last logging; but on the other hand this is offset in part by the fact that many sites represent older harvests conducted before present stream protection rules that require some shade to be left in place, particularly on fish-bearing streams. What is clear is that post-logging recovery times likely stretch to decades especially on Medium and larger streams, because full recovery of shade often requires substantial riparian forest tree height. The various TMDL reports cited here offer recovery time estimates for 303d listed streams. One example is the Applegate TMDL Appendix A, p.45 which lists recovery to full potential shade as ranging from 6 to 87 years, based on existing vegetation height and a growth model calibrated to site class.

Maximum temperature data (Table 1) are very sparse in this source (we believe they are likely available in model documentation from DEQ, but were not specifically reported in the TMDL reports), but a couple of reported values suggest canopy losses are associated with stream temperature increases of at least 1 to 4°F. This magnitude of increase in the 7-day mean daily maximum temperature is on the order of magnitude one could expect from the identified magnitude of canopy shade reduction, roughly in line with the conclusions of ODF’s stream shade and temperature (“Ripstream”) research by Groom et al. (various reports and published papers). The evidence from these TMDL data and modeling projections appear to fall well in line with Ripstream results and predictions from sites in other western Oregon streams, offering no evidence that Siskiyou Region streams operate differently with regard to the thermal effects of shade and shade loss.
Table 1. Siskiyou Georegion existing and potential canopy cover estimates for selected streams as documented in ODEQ TMDL reports (1999, 2002, 2003, 2007). Stream size class is approximate; streams reported here were selected as those known to flow largely through private forest land, though other land uses and intermingled blocks of federal ownership also occur. Measured maximum temperature and projected maximum temperature under full potential canopy cover and shade are also reported here.

<table>
<thead>
<tr>
<th>Stream Name</th>
<th>Basin</th>
<th>Size Class</th>
<th>Approx. Average Canopy Cover</th>
<th>Current Potential Difference</th>
<th>Maximum Temperature (°F)</th>
<th>Current</th>
<th>Potential</th>
<th>Difference</th>
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<td>Walker Cr</td>
<td>L. Rogue/Bear</td>
<td>M</td>
<td>41%</td>
<td>86% -45%</td>
<td>71.4 70</td>
<td>71.4</td>
<td>70</td>
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<td>Coleman Cr</td>
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<td>M</td>
<td>67%</td>
<td>89% -21%</td>
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<td>Neil Cr</td>
<td>L. Rogue/Bear</td>
<td>M</td>
<td>71%</td>
<td>88% -17%</td>
<td>68 64</td>
<td>68</td>
<td>64</td>
<td>+4</td>
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<td>L. Rogue/Bear</td>
<td>M</td>
<td>54%</td>
<td>85% -31%</td>
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<td>L. Sucker</td>
<td>M</td>
<td>88%</td>
<td>96% -8%</td>
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<td>Little Grayback Cr</td>
<td>L. Sucker</td>
<td>M</td>
<td>86%</td>
<td>96% -10%</td>
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<td>N Fk Munger Cr</td>
<td>Applegate</td>
<td>S</td>
<td>76%</td>
<td>92% -16%</td>
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<td>Goodwin Cr</td>
<td>Applegate</td>
<td>S</td>
<td>89%</td>
<td>96% -7%</td>
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<tr>
<td>Lone Cr</td>
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<td>M</td>
<td>89%</td>
<td>96% -7%</td>
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<td>Tree Branch Cr</td>
<td>Applegate</td>
<td>S</td>
<td>88%</td>
<td>94% -6%</td>
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<td>Right Hand Fk.</td>
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<td>92% -5%</td>
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<td>91%</td>
<td>93% -2%</td>
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<td>S</td>
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<td>95% -6%</td>
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<td>92% -5%</td>
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<td>97% -8%</td>
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<td>97% -3%</td>
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<td>94% -30%</td>
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<td>92% -11%</td>
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<td>90% -28%</td>
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<td>63%</td>
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<td>Applegate</td>
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<td>S</td>
<td>94%</td>
<td>97% -3%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pete’s Camp Cr</td>
<td>Applegate</td>
<td>S</td>
<td>91%</td>
<td>94% -3%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock Gulch</td>
<td>Applegate</td>
<td>S</td>
<td>86%</td>
<td>96% -10%</td>
<td></td>
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</tbody>
</table>
The Siskiyou National Forest and ODEQ Sucker Creek TMDL (1999) quantitatively related canopy cover and effective shade to observed water temperature in Sucker Creek and Tributaries (Figure 2). These data demonstrate a statistically significant inverse relationship equivalent to roughly a 4°F stream temperature increase for every 10% loss in riparian cover or effective shade. This relationship is approximately of the same magnitude as reported for other western Oregon streams in Oregon Department of Forestry’s “Ripstream” Riparian Shade and Stream Temperature (Groom et al., various articles and reports).

Fig. 2. Excerpt from Appendix G of the Sucker Creek TMDL Report (Siskiyou National Forest and ODEQ, 1999, p. G-18) displays the relationship between field-measured 7-day maximum stream temperature and percent effective canopy shade across 10 stream reaches in the Sucker Creek Watershed. This data set spans small, medium and large streams across federal and private ownerships.
QUESTION 3: IS CLIMATE IN THE SISKIYOU GEOREGION DIFFERENT?

1) Effects of Climate on Stream Temperature

Climate undoubtedly differs on average in the Siskiyou region in comparison to climate of other western Oregon regions. However, the somewhat warmer, drier prevailing condition does not conform to a discrete departure or boundary. Numerous watersheds and streams exist in the Coastal and Interior regions that have local climate and other ecological characteristics of Siskiyou region streams. Likewise, many streams within the Siskiyou region have local ecological conditions more characteristic of wetter, cooler watersheds in the surrounding western Oregon regions. However, it is important to recognize that natural riparian forest vegetation strongly buffers the local microclimates that influence stream temperature. Microclimate buffering is one of the less-well-studied aspects of riparian forest function, but one of its effects is that streams with naturally developed riparian forests are substantially protected from direct exposure to the climate stressors that prevail at larger scales (Olson et al. 2007).

The most important considerations are the aspects of climate that contribute to water temperature conditions in streams. Poole and Berman (2001) reviewed the principal environmental vectors contributing to structuring the thermal profile and warming and cooling of streams. While air temperature does exert some influence, groundwater temperature and distribution, solar insolation and the mediation of solar insulation via shade, and stream flow volume are by far the strongest determinants of stream temperature. Of these factors, the one most strongly, directly, and extensively affected by human management, whether positively or negatively, is stream shade provided by vegetation. The consequences of removal or restoration of forest shade easily overwhelm the effects of all other factors, when considered across the landscape of a large river basin. Therefore protection of forests in streamside areas is critical in virtually any region outside of the high arctic and the driest deserts—most certainly including the Siskiyou Georegion.

2) Climate Change and Stream Shade

Climate change is likely to warm groundwater by a few degrees. As a result, at their point of origin, headwater streams will warm. At the latitude of the Siskiyou, stream source temperatures will remain within the thermal range preferred by salmonid fishes, but because streams will be warmer at emergence, they will be vulnerable to being more easily and rapidly warmed to levels exceeding salmonid preference and tolerances as they flow downstream. This means shade will be even more important in the future than it is today to maintain suitable stream temperatures for salmonids and other coldwater-dependent species.

Climate change is also likely to increase peak flows and reduce stream low flows across the Pacific Northwest (in fact several published papers have documented the onset of steadily declining low flows over the past 15-20 years). Reduced low flows will increase the vulnerability of all streams to heating from sunshine, further increasing the importance of forest shade to maintain suitable temperatures.

Climate change may increase the prevalence and possibly the severity of wildfire in the Siskiyou and other regions, but the consequences of this for riparian forests and streams are not well...
understood. Stream temperatures may increase when riparian canopy shade decreases after fire, but increased groundwater discharge and low flow volume post-fire can sometimes largely offset shade effects. However, we do know that as a general rule, where and when fire reduces riparian forest cover over extensive areas, the importance of forest cover wherever it remains and the shade it offers only increases.

Climate change is a global phenomenon not easily managed or reversed by any single policy measure. That means policies that allow humans to adapt to or mitigate the effects of climate change will be vital. Restoring and maintaining maximum potential levels of shade in streamside forests and areas of shallow, near-surface groundwater is the principal management action that humans can invoke to mitigate the likely effects of climate change identified above. Excluding the Siskiyou region from improved streamside forest protection rules unquestionably renders streams in the region more vulnerable to the adverse effects of stream heating associated with climate change.
LITERATURE CITED


Good morning, Chair Imeson and Board Members. My name is Alan Henning. I'm one of the Forest Team representatives for the Watershed Unit for the US Environmental Protection Agency's Region 10 Office. Thank you for the opportunity to share my thoughts with the Board Members.

Today, I'm going to talk about EPA's role as it relates to water quality and fish in Oregon, our support for the Riparian Rule and why it's important, what we believe the rule should address, and how this relates to the approvability of the Oregon's Coastal Nonpoint Program.

EPA's Role. EPA implements the Clean Water Act in partnership with states and tribes. This includes acting on the state's water quality standards, 303(d) Integrated Report, total maximum daily loads (TMDLs), the state’s nonpoint source control programs and overseeing NPDES permits issued by the state. We work closely with the Oregon Department of Environmental Quality (DEQ) and other state agencies on these efforts. EPA is also responsible for overall implementation of the Safe Drinking Water Act in partnership with the Oregon Health Authority and DEQ.

EPA gives technical and financial support to states and tribes to help them implement programs that protect and restore surface and drinking water. Where states and tribes fail to carry out Clean Water Act responsibilities, or when directed by the Courts, EPA is required to take the actions needed to meet national water quality goals.

Why the Riparian Rule is Important. There are 12 million acres of non-federal forest land in Oregon. The management of these lands affects drinking water sources, water quality, and aquatic habitat for several species of threatened and endangered fish, including salmon, steelhead and trout. Because forest practices have direct and important effects on water quality and fish habitat, the riparian rule analysis has significant implications for EPA's work to protect human health and the environment, and we have closely tracked and reviewed this rule development process.

EPA recognizes that Oregon was one of the first states in the country to develop forest practice rules and regulations. The current riparian rule analysis is the culmination of a process that started in the
late 1990s and includes the 1997 Oregon Coastal Salmon Restoration Initiative, Oregon’s 1999 IMST report, the 2002 Sufficiency Analysis, and the recent RipStream studies. Collectively, these efforts have found that existing forestry practices do not ensure that streams in managed forests will consistently meet water quality standards, or fully provide for riparian functions important to water quality and fish. With stream temperature directly affecting fish health and behavior, a revised riparian rule with adequately larger buffers on small and medium fish-bearing streams will ensure stream temperature provide the cold stream temperatures critical to fish health. The revised riparian rules will also improve drinking water and surface water quality by reducing runoff from other pollutants such as fine sediment, toxics, and nutrients.

What the Rule Should Address. EPA supports a Rule that includes all small and medium fish-bearing streams to protect existing cold water and restore cold water in streams that currently exceed temperature standards. EPA also believes greater protection for non-fish bearing streams is warranted, especially where non-fish bearing streams contribute pollutants to fish bearing streams.

7732 miles of Western Oregon streams and rivers have been or are currently impaired for temperature which impacts fish and other organisms that rely on cold water to live and grow. EPA strongly supports a Riparian Rule that includes all small and medium fish-bearing streams, regardless of their status under section 303 of the Clean Water Act. A Riparian Rule with a scope limited to streams that are listed as unimpaired, or to streams without a TMDL in place would exclude a large universe of streams with high temperatures that need to be restored. It would be counterproductive to continue to implement existing forest practices on streams with temperature impairments when it has been demonstrated that those practices are not adequately protective of cold water.

Type "N" Streams. There are over 73,000 miles of fish and non-fish bearing streams in Western Oregon of which, only 8,351 miles or approximately 11% are Salmon, Steelhead and Bull Trout streams (SSBT). While EPA supports riparian rule revisions that will provide greater buffer protections for all

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3 The Oregon Department of Forestry and Department of Environmental Quality. 2002. Sufficiency Analysis: A Statewide Evaluation of EPA Effectiveness in Protecting Water Quality. Available at: http://www.odf.state.or.us/DIVISION/protectn/forest_practices
small and medium fish bearing streams, EPA also believes greater protection must be provided for non-fish bearing streams (Type N streams), especially perennial “N” streams. Type N streams are often headwater streams that provide critical cold water and large wood for meeting water quality standards, supporting beneficial uses and enhancing downstream fish habitat. Where Type N streams are not protected by adequate buffers and are impacted by increased temperature loading, that pollutant load can be delivered to the downstream type F streams, e.g., SSBT streams.

**Streams in Eastern Oregon.** EPA recognizes that the focus of the State’s riparian rule analysis has been on streams in Western Oregon and appreciates the level of ODF’s effort in its work. However, 303(d) temperature listings exist throughout the Oregon and where these listings occur, greater riparian protection may be needed as well.

**How Does This Relate to the Coastal Nonpoint Program/CZARA?** The Riparian Rule also overlaps with EPA and NOAA’s recent disapproval action in January 2015 of Oregon’s coastal nonpoint program. While EPA and NOAA acknowledged significant progress in Oregon’s nonpoint coastal program, we also identified gaps in Oregon’s forestry program as a basis for the disapproval. One of these was the inadequacy of current forest riparian buffers on small and medium fish bearing and non-fish bearing streams. While the current riparian rule revision process is not considering greater protection for non-fish bearing streams, a Riparian Rule with an appropriate buffer width applied to all small and medium fish bearing streams would be significant progress toward moving the State’s program to approvability. Although other areas in forestry would need to be addressed for full approval of Oregon’s forestry measures, the rule would fill a significant gap identified in EPA and NOAA’s evaluation of Oregon’s forestry program in our agencies’ disapproval action. If the Board of Forestry would like to hear more information on our CZARA findings on forestry at another meeting, we would be very happy to have a dialogue with more detail on the other areas that EPA and NOAA identified.

**Closing Words.** Riparian management areas on small and medium fish bearing streams and non-fish streams that are important cold water sources for fish bearing streams provide protection and restoration of riparian functions important for fish and water quality. We applaud the Board of Forestry for considering amending the Forest Practices Act regulations to provide greater protections on Oregon streams and urge you to move forward on adoption of such rules.

I want to thank you again for the opportunity to provide this testimony and would be happy to answer questions you may have at this time.
ATTACHMENT 7
Henning. 2015b. 2 pages.

TESTIMONY OF
ALAN HENNING, FOREST TEAM, WATERSHED UNIT,
ENVIRONMENTAL PROTECTION AGENCY, REGION 10
BEFORE THE OREGON BOARD OF FORESTRY, November 5, 2015

Good morning, Chair Imeson, and Board Members. My name is Alan Henning. I’m one of the Forest Team representatives for the US Environmental Protection Agency’s Region 10 Office and I work on the review of Oregon’s Coastal Non-Point Pollution Control Program as it relates to meeting requirements under the Coastal Zone Act Reauthorization Amendments, CZARA. Thank you for the opportunity to share my thoughts with you.

EPA has provided written and oral testimony on:

- The need for greater riparian protections for streams in both Western and Eastern Oregon;
- The need for greater protection on all fish bearing and non-fish bearing streams, not just SSBTs;
- The importance of the State’s Protecting Cold water Criterion; and
- The high value of ODF’s analysis of Ripstream results.

Today, I want to touch on a couple of key points in the Packages developed by the Board’s Subcommittee.

However, before doing so, EPA would like to express its sincere thanks to the Board and ODF’s management and staff for the work you have done on the entire riparian rule review process. I am sure you and the staff have put in countless hours beyond the call of duty in addressing this critical issue.

**Key elements of the Subcommittee’s Packages**

**Package 1**

1. EPA appreciates the fact that the Geographic regions covered in the Package 1 proposal include those areas needing to be addressed under CZARA.
2. We also appreciate that Package 1 includes protections for streams above the SSBT streams, however we are concerned that 1000’ will not be enough distance to attenuate heat loading from waters above SSBTs.

3. While we think that the 90’ no cut buffers on S&M SSBT streams moves in the right direction, 100’ and 110’ no cut buffers provide a much greater certainty that the State’s water quality standard, Protecting Cold Water Criterion, will be met.

4. Package 1, Option B, provides a thinning prescription for a 100’ RMA. At the September Board meeting, ODF indicated that a .33*C. increase would result from the application of this prescription. EPA’s analysis, using ODF’s methodology, shows that an increase of .56* C. would occur. I would be happy to provide you with a copy of our analysis.

Package 2

1. Package 2 does not include the Siskiyou Geographic Region. The Siskiyou Geographic Region is part of the State’s Coastal Non-Point Pollution Control Program and is covered by CZARA. If this region is not included in the riparian rule revisions, other steps would have to be taken to address the need for greater riparian protections in this area to meet the CZARA requirements.

2. EPA is concerned that Package 2 includes no increased riparian protections for waters above SSBTs.

3. EPA is concerned that the no-cut riparian buffers of 50’ and 70’ for small and medium sized fish bearing streams respectively will not meet the State’s Protecting Cold Water Criterion.

I thank you again for the opportunity to provide this testimony.
TESTIMONY OF PETER LEINENBACH, AQUATIC AND LANDSCAPE ECOLOGIST
ENVIRONMENTAL PROTECTION AGENCY, REGION 10
BEFORE THE OREGON BOARD OF FORESTRY, July 23, 2015

Good morning, Chairman Imeson, and Board Members. My name is Peter Leinenbach. I am employed as an ecologist with the EPA Region 10 Forest Team. Based on concepts brought up during previous Board of Forestry meetings, it is our conclusion that many features in Package 1 of the staff report, particularly the 90 foot no-cut buffer provision, will promote the protection of water quality and fish in Oregon. However, ODF research used to inform the development of Package 1 has shown that the proposed 1,000 foot upstream extent distance will need to be increased to fully protect water quality. I will present three points which support this conclusion.

The first point is that the ODF staff have presented strong evidence through the Ripstream analysis that a minimum of a 90 foot intact “no-harvest” riparian buffer is needed to ensure that streams exposed to FPA rules do not violate the PCW rule. It is important to point out that this finding is supported by other research on this subject that has been done in the Pacific Northwest over the past several decades (Figures 1a. and 1b.).

The second point is that the ODF staff have presented strong evidence that the stream reach extent above SSBT streams needs to be greater than 1,000 feet in the revised FPA rule. Specifically, the ODF analysis clearly shows that a minimum of a 1,600 foot upstream extent is needed to ensure that the water temperatures entering into SSBT streams do not, on average, violate the PCW rule.
(Table 1). However, it is important to point out that even greater stream reach extent distances are needed for streams with multiple harvest units, which is often occurring along streams in Oregon.

The **third point** is to briefly highlight that the revised rules should apply to all forests in the "western region". The Ripstream sites were collected over a large spatial range in both the Coast Range and South Coast. Similar responses should be expected in nearby geographic regions. There are numerous 303(d) temperature listings all throughout western Oregon which indicate more protection is needed throughout the region.

We would like to make an additional comment regarding the so called "South-sided" prescriptions. ODF staff have presented evidence that "south-sided riparian prescriptions" do not** ensure the protection of the PCW rule. Specifically, the ODF "Systematic Review" reported that only a few, less rigorous, south-sided prescription studies were available for review and that the study results were inconclusive. Finally, this ODF review stated that south-sided riparian prescriptions "appear to not achieve the PCW criterion"). We therefore do not support further consideration of the "south-sided riparian prescriptions" as a viable component for a revised rule.

We want to thank you for the opportunity to provide this testimony. We are also providing the Board of Forestry a hard copy of this testimony. We would be happy to answer questions you may have at this time.
Figure 1a. Observed mean stream shade response associated with "no-cut" riparian buffers with adjacent clearcut harvest.

[Only studies that employed a BACI (Before After Control Impact) design within forests of the Pacific Northwest were included in these figures. ODF Bayesian modeling was derived from data collected as part of RipStream (Groom et al 2011). The bars associated with ODF Bayesian temperature model results represent the Bayesian 98.5% and 2.5% credibility intervals of the mean, which are analogous to confidence intervals in frequentist statistics. The bars associated with the USEPA mechanistic modeling results represent the range of estimated values.]

Bayesian modeling results are predictions based on data collected at the 33 Ripstream field sites. The modeled values are estimated mean response based on these sites, however the individual site response may range outside of the credibility intervals based on unique site characteristics present at the individual site.
Figure 1b. Observed mean stream temperature response associated with “no-cut” riparian buffers with adjacent clearcut harvest.

[Only studies that employed a BACI (Before After Control Impact) design within forests of the Pacific Northwest were included in these figures. ODF Bayesian modeling was derived from data collected as part of Ripstream (Groom et al. 2011). The bars associated with ODF Bayesian temperature model results represent the Bayesian 98.5% and 2.5% credibility intervals of the mean, which are analogous to confidence intervals in frequentist statistics.]

Bayesian modeling results are predictions based on data collected at the 33 Ripstream field sites. The modeled values are estimated mean response based on these sites, however the individual site response may range outside of the credibility intervals based on unique site characteristics present at the individual site.
Table 1. Methods used to estimate the upstream extent

<table>
<thead>
<tr>
<th>Previously Presented Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODF calculated that the temperature response associated with the application of the FPA private land buffers was a 1.45°C temperature increase.</td>
</tr>
<tr>
<td>(see the June 3, 2015 Matrix presented by ODF to the BOF)</td>
</tr>
<tr>
<td>ODF staff also showed that average temperature change resulting from harvest activities at the Ripstream sites was 50% persistence at 1000 feet downstream of the end of harvest activities.</td>
</tr>
<tr>
<td>(see April 22, 2015 presentation by ODF to the BOF)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>The temperature increase associated with FPA harvesting (i.e., 1.45°C) will still result (on average) in a 0.72°C temperature increase 1000 feet downstream of the harvest activities.</td>
</tr>
<tr>
<td>[i.e., 1.45°C * 0.5 = 0.72°C]</td>
</tr>
<tr>
<td>If one assumes that the temperature dissipation loss continues linearly at the same rate downstream of 1000 feet of the harvest activities associated with, it would take 1,597 feet (1,600 feet) to reach a 0.3°C temperature increase:</td>
</tr>
</tbody>
</table>
| \[
| \frac{1000 \text{ ft}}{0.72 \degree \text{C}} = \frac{X \text{ ft}}{1.15 \degree \text{C}}
| \] |
| (Note: 1.15°C was calculated as 1.45°C - 0.3°C = 1.15°C) |

It is important to point out that there is a tremendous amount of variation around this reported response observed in the Ripstream data and in literature. The observed variability is in response to localized conditions at each site. In other words, this estimated 1,600 foot recovery distance is an average recovery distance — many sites will require a much longer recovery distance, while others will require less.
Memorandum

To: Alan Henning

From: Peter Leinenbach

Subject: Topic associated with upcoming the Oregon Riparian Rule discussions

Topic One - South-Side Buffers

Temperature Response

- There are very few examples in literature of temperature and shade response to “south-side” buffer treatment.

- The one often cited study contains only three sites and is reported in two documents (i.e., Dent and Walsh (1997) and Zwieniecki and Newton (1999)).

- ODF reviewed those studies and concluded that “Considering the difference in results, the range of variability for shade measures and the low sample size, these results are relatively inconclusive.” From page 43 of ODF Report – Czarnomski and Hale 2013.

- Large stream temperature increases (i.e., 1.4°C) have been reported for one “true” partial application of south-side buffers (i.e., Sheelee Creek (buffer widths of 62 and 31 feet for left and right buffers)).

- Although the other two sites did not have a large temperature response, it appears from the Dent and Walsh (1997) report that Mill Creek was not an application of a south-side buffer (reported buffers widths of 85 and 82 feet, for left and right respectively (From Appendix A in Dent and Walsh (1997))). In other words, the buffer width was similar between these two sides and there was not difference between the two buffer sides. In addition, it is important to point out that buffer width was much wider for both buffer sides than reported targets in these reports (i.e., 12 meters (39.3 ft) of either shrubs or trees were left for the south side only and clearcut on north side – Zwieniecki and Newton (1999)), and therefore for another reason this is not an application of a “south-side” treatment.

- The other site (Cascade) did not reported buffer widths in Appendix A in Dent and Walsh (1997), however the reported shade loss for this site (i.e., 7) was the greatest for all of the sites despite the very low temperature response (0.1°C). Thus is appears that there may be some unique site characteristics affecting the response at this location (i.e., high groundwater flow, high gradient, low or high flow volumes, etc.).

Accordingly, field data have not supported to the notion that south-side buffers provide protection against large temperature increases resulting from harvest in the north-side buffer.
Shade Response

The effects of north-side buffer width loss in a south-side buffer treatment needs to be added to the estimated effects associated with narrowing both sides of the buffer (i.e., north and south side). For example, a south-side buffer treatment which narrows the buffer on the south-side to 80 feet and allows the buffer to narrow to 20 feet on the north-side will have two shade loss estimates: 1) the estimated shade loss associated with narrowing the buffer to 80 feet which was estimated to be 7% shade loss (from the matrix of ODF BOF meeting materials); and 2) the shade loss associated further narrowing the north-side buffer from 80 feet to 20 feet – lets estimate that a 6% shade loss. Accordingly, that would result in a 13% shade loss with this treatment (7 + 6 = 13%).

Also, recall that ODF determined that a measurable temperature increase (0.3°C) resulted from around a 6 units of shade loss to a stream, and therefor north-side vegetation removal (i.e., from 20 feet to 80 feet, or 20 feet to 70 feet, etc.) can, by itself, result in stream temperature increasing greater than the PCW.

Accordingly, shade modeling has shown that loss of shade loss resulting from “additional” north-side buffer harvest could potential result in violation of PCW standard, even without the effects of shade loss associated with the south-side harvest.
Topic Two – Stream Reach Extent

ODF calculated that the temperature response associated with the application of the FPA private land buffers was a 1.45°C temperature increase (see the June 3, 2015 Matrix presented by ODF to the BOF). In addition, ODF staff also showed that average temperature change resulting from harvest activities at the Ripstream sites was 50% persistence at 1000 feet downstream of the end of harvest activities (see April 22, 2015 presentation by ODF to the BOF). In other words, the temperature increase associated with FPA harvesting (i.e., 1.45°C) will still result (on average) in a 0.72°C temperature increase 1000 feet downstream of the harvest activities (i.e., 1.45°C * 0.5 = 0.72°C). If one assumes that the temperature dissipation loss continues linearly at the same rate downstream of 1000 feet of the harvest activities associated with, it would take 1,597 feet (1,600 feet) to reach a 0.3°C temperature increase:

\[
\frac{1000 \text{ ft}}{0.72 \ ^\circ \text{C}} = \frac{X \text{ feet}}{1.15 \ ^\circ \text{C}}
\]

It is important to point out that there is a tremendous amount of variation around this reported response observed in the Ripstream data¹ and in literature: The observed variability is in response to localized conditions at each site. In other words, this estimated 1,600 foot recovery distance is an average recovery distance – many sites will require a much longer recovery distance, while others will require less.

Accordingly, the science very clearly provides conclusive support for downstream recovery distances for SSBT streams that are much greater than 1,600 feet in order to ensure that FPA harvest activities will not provide SSBT streams with source waters heated greater than 0.3 °C.

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Delineating upstream extent

1. Distance upstream of main stem: some science with lots of variance

![Diagram showing remaining temperature change downstream of harvest over distance from harvest reach (m).]
**Memorandum**

**To:** Alan Henning, USEPA  
**From:** Peter Leinenbach, USEPA  
**Subject:** Shade loss and temperature increase resulting from the implementation of Option A and Option B of the proposed Oregon Forest Practices Rule for SSTB streams in sections of western Oregon.

**Results**

Medium SSBT Streams - Option A (Two Bank Harvest)

<table>
<thead>
<tr>
<th>Category</th>
<th>Shade Loss (97.5% Credibility Interval)</th>
<th>Source</th>
<th>Temperature Increase (97.5% Credibility Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearcut Effect</td>
<td>6.7% (3.6 to 10.1)</td>
<td>2015 ODF Bayesian Modeling</td>
<td>0.4°C (0.2 to 0.7)</td>
</tr>
<tr>
<td>Option A Total Effect</td>
<td>6.7%</td>
<td></td>
<td>0.4°C</td>
</tr>
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Medium SSBT Streams - Option B (Two Bank Harvest)

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<tr>
<th>Category</th>
<th>Shade Loss (97.5% Credibility Interval)</th>
<th>Source</th>
<th>Temperature Increase (97.5% Credibility Interval)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>6.7% (3.6 to 10.1)</td>
<td>2015 ODF Bayesian Modeling</td>
<td>0.4°C (0.2 to 0.7)</td>
</tr>
<tr>
<td>Thinning Effect</td>
<td>2.7%</td>
<td>2016 USEPA Shade Modeling</td>
<td>0.2°C (0.0 to 0.4)</td>
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<tr>
<td>Option B Total Effect</td>
<td>9.4%</td>
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<td>0.6°C</td>
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Small SSBT Streams - Option A (Two Bank Harvest)

<table>
<thead>
<tr>
<th>Category</th>
<th>Shade Loss (97.5% Credibility Interval)</th>
<th>Source</th>
<th>Temperature Increase (97.5% Credibility Interval)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearcut Effect</td>
<td>13.1% (9.5 to 16.9)</td>
<td>2015 ODF Bayesian Modeling</td>
<td>0.9°C (0.6 to 1.1)</td>
<td>2015 ODF Bayesian Modeling</td>
</tr>
<tr>
<td><strong>Option A Total Effect</strong></td>
<td><strong>13.1%</strong></td>
<td></td>
<td><strong>0.9°C</strong></td>
<td></td>
</tr>
</tbody>
</table>

Small SSBT Streams - Option B (Two Bank Harvest)

<table>
<thead>
<tr>
<th>Category</th>
<th>Shade Loss (97.5% Credibility Interval)</th>
<th>Source</th>
<th>Temperature Increase (97.5% Credibility Interval)</th>
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<td>2015 ODF Bayesian Modeling</td>
</tr>
<tr>
<td>Thinning Effect</td>
<td>4.8%</td>
<td>2016 USEPA Shade Modeling</td>
<td>0.3°C (0.1 to 0.5)</td>
<td>Utilizing relationships from 2015 ODF Bayesian Modeling</td>
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<tr>
<td><strong>Option B Total Effect</strong></td>
<td><strong>17.9%</strong></td>
<td></td>
<td><strong>1.2°C</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Methods**

**Option A** – The effect of narrowing of the riparian buffer on both stream shade and temperature conditions resulting from the implementation of Option A were calculated using the Bayesian models developed by Oregon Department of Forestry (ODF) Staff, which they presented to the Board of Forestry (ODF 2015) (Figures 1 and 2).
Figure 1. Modeled mean stream shade response associated with “no-cut” riparian buffers with adjacent clearcut harvest.

Figure 2. Modeled mean stream temperature response associated with “no-cut” riparian buffers with adjacent clearcut harvest.

Bars associated with the Bayesian model results represent the 98.5% and 2.5% credibility intervals of the mean. Modeled values are estimated mean response calculated from data collected at the 33 Ripstream sites, however the individual site response may range outside of the credibility intervals based on unique site characteristics present at the individual site.
**Option B** – Because Option B has the same clearcut harvest actions as prescribed in Option A, the same Bayesian models were used to evaluate the effect of riparian buffer width narrowing on stream shade and temperature conditions. However, Option B contains an additional thinning harvest within the outer portion of the remaining riparian buffer.

**Estimating Shade Loss Resulting from Thinning Activities (Option B)**

Riparian thinning activities will reduce the “quality” of the shade produced by riparian vegetation. In other words, the riparian stand will become more transparent as fewer trees become available to block light transporting through the stand. Specifically, thinning activities will result in: 1) a direct loss of canopy within the outer thinned zone; and 2) an indirect loss of canopy within the inner no-harvest buffer.

**Direct Loss of Canopy within the Outer “Thinned” Zone**

The amount of riparian canopy cover loss associated with thinning activities was determined using a relationship between basal area and % skylight (i.e., canopy openness) as presented in Chan et al (2006) (Figure 3). This relationship indicated that canopy openness in the outer “thinned” zone will increase by 15.2% (or 15.2% openness units) and 9.6% for small and medium streams, respectively (Table 1). Note that the larger of canopy openness for small class streams is a direct result of greater thinning levels allowed for this stream class.

**Figure 3.** The association between basal area and percent skylight (i.e., openness) in forest stands.

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1 Specifically, preharvest basal area conditions were developed from the preharvest RipStream field data obtained from Terry Frueh at ODF on 1/15/2016. Post-thinning-harvest basal area was estimated from reported basal area targets for the “outer” zone in the proposed rule (i.e., 73 sq. ft./1,000 feet for the 20 to 60 foot zone along small streams and 138 sq. ft./1,000 feet for the 20 to 80 foot zone along medium streams). Both pre-harvest and post-harvest basal area conditions were converted into units of m$^2$/ha in order to incorporate into the Chan et al model presented in Figure 3.
Table 1. Basal Area and Estimated % Skylight within Thinned Riparian Areas

<table>
<thead>
<tr>
<th>Category</th>
<th>Basal Area (m²/ha)</th>
<th>Estimated % Skylight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Streams (60'RMA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-Harvest</td>
<td>38.7</td>
<td>3.7</td>
</tr>
<tr>
<td>Post-Thinning-Harvest</td>
<td>18.3</td>
<td>18.9</td>
</tr>
<tr>
<td>% Skylight Increase within the 20–60’ zone</td>
<td>15.2</td>
<td></td>
</tr>
<tr>
<td>Medium Streams (80'RMA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-Harvest</td>
<td>40.0</td>
<td>3.3</td>
</tr>
<tr>
<td>Post-Thinning-Harvest</td>
<td>23.0</td>
<td>13.0</td>
</tr>
<tr>
<td>% Skylight Increase within the 20–80’ zone</td>
<td>9.6</td>
<td></td>
</tr>
</tbody>
</table>

Indirect Loss of Canopy within the Inner “No-Harvest” Zone

The riparian buffer width and the riparian vegetation density influences the “quality” (or the density) of the shade produced by the riparian buffer. That is, the potential number of trees the solar load travels through decreases as the buffer width narrows as a result of clear-cut riparian harvest, along with less trees the solar load travels as a result of riparian thinning harvest (Figure 4). Beschta, et al 1987 reported that the effectiveness of a buffer strip in providing stream shade can be determined by measuring the angular canopy density (ACD). Figure 5 illustrates the relationship between ACD and the riparian buffer width (Brazier and Brown, 1973). While it is theoretically possible for natural forest vegetation to have ACDs of 100%, indicating complete shading from incoming solar radiation, the ACD of mature undisturbed stands generally falls between 75 and 95% (Park et al., 2006, Brazier and Brown 1973, Steinblums et al., 1984, Erman et al., 1977). In addition, ACD increases become negligible at some buffer strip width as a result of a “tree behind a tree” situation, and/or the vegetation in distant portions of the riparian stand not being tall enough to cast a shadow over the stream surface. Accordingly, for modeling activities associated with this document, it was assumed that the effect of harvest activities (i.e., thinning) did not influence the “inner zone” canopy cover for the 120ft wide “no touch” scenarios. The trend line presented in Figure 5 can be used as a tool to evaluate the influence that riparian buffer width reductions have on the riparian canopy density (Table 2).

Estimated canopy density reductions at the new buffer widths presented in Table 2 represent the expected loss associated with “clear-cut” harvest; for example, there is an expected 20 units of Canopy Density loss as the buffer width narrows from 80 feet to 20 feet (i.e., 74 to 54). However the proposed riparian rule for medium stream will only result in a 13% loss of the canopy density as a result of thinning activities (i.e., 9.6 (see Table 1)/ 74 (see Table 2) = 13%). Accordingly, the proportional loss of ACD within the inner “no-harvest” buffer resulting from thinning activities along medium size stream classes will be 2.6% (or 2.6 units) (i.e., 20 * 0.13 = 2.6). Similarly, the ACD loss within the inner “no-harvest” buffer along small stream classes will be 3.5%.

ACD evaluates the horizontal plane of canopy density for the portions of the riparian stand which provide shade during the mid part of the day (usually between 10 am and 2 pm).
Figure 4. Illustration of how the Riparian Buffer Width and Vegetation Density Impact Shade Density

Figure 5. The relationship between measured Angular Canopy Density (ACD) and buffer strip width (Data from Table 1 in Brazier and Brown 1973)

Table 2. Calculated Effect of Buffer Width on Canopy Density

<table>
<thead>
<tr>
<th>Buffer Strip Width (feet)</th>
<th>Percent Reduction from 120’ buffer</th>
<th>Estimated Canopy Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>0%</td>
<td>80</td>
</tr>
<tr>
<td>100</td>
<td>3%</td>
<td>77</td>
</tr>
<tr>
<td>80</td>
<td>7%</td>
<td>74</td>
</tr>
<tr>
<td>60</td>
<td>12%</td>
<td>70</td>
</tr>
<tr>
<td>40</td>
<td>20%</td>
<td>64</td>
</tr>
<tr>
<td>20</td>
<td>32%</td>
<td>54</td>
</tr>
</tbody>
</table>
Calculated Shade Loss Resulting from Thinning Activities (Option B)

Using the average observed height conditions for the Oregon Ripstream sites (25.7m) and canopy densities presented in Table 2, the “shade.xls” model\(^4\) was used to evaluate the effects of narrowing of the riparian buffer on stream shade. This built “shade.xls” mechanistic model predicted a similar pattern between buffer width reductions and stream shade loss as predicted by both a statistical linear regression model built from field data (i.e., 61.834e\(^{-0.03x}\), \(R^2 = 0.97\)), and the Bayesian Modeling results (Figure 6). Accordingly, this indicates this built mechanistic model is adequately representing processes associated with shade loss response to riparian buffer width reductions.

![Figure 6. Measured and Predicted Shade Loss Resulting from a Narrowing of the Riparian Buffer Width.](Image)

The expected shade loss associated with riparian thinning was estimated using the developed “ODEQ” mechanistic shade model presented in Figure 6. Specifically, the estimated canopy loss directly resulting from thinning activities within the outer buffer (i.e., 20ft to 80ft for medium stream, and 20ft to 60ft for small streams) was applied to the model. In addition, the indirect canopy loss within the inner buffer (i.e., 0 to 20 ft) resulting from thinning activities within the outer buffer was also applied to this model. In summary, this model estimated a 2.7% and 4.8% shade loss resulting from proposed FPA thinning activities along medium and small streams, respectively.

\(^4\) The “Shade.xls” model utilizes the same shade algorithms included in the Oregon Department of Environmental Quality HeatSource temperature model - www.ecy.wa.gov/programs/eap/models.html
Estimated Temperature Increase Resulting from Thinning Activities (Option B)

Using the results in the two ODF Bayesian models, it is possible to develop a relationship between stream shade loss and expected stream temperature increases (Figure 7).\(^1\) \(y = 6.6138x + 0.00005\). For example, this relationship shows that stream temperatures are expected to increase by 0.3°C (with a 97.5% Credibility Interval between 0.1°C and 0.5°C) when riparian management reduces stream shade by 4.8%. Similarly, this relationship indicates that a 2.7% shade loss will result in a stream temperature increase of 0.2°C (ranging from 0°C to 0.4°C).

![Figure 7. Predicted Stream temperature increase resulting from stream shade loss](image)

\(^1\) The x-axis values in Figure 5 were obtained from shade model results (i.e., Figure 1) and the y-axis values in Figure 5 were obtained from the corresponding temperature modeling results (i.e., Figure 2).
Table 3. Total Stream Shade Loss Associate with Option B

<table>
<thead>
<tr>
<th>Category</th>
<th>Shade Loss Result from Buffer Width Reduction</th>
<th>Shade Loss Result from Thinning Activities</th>
<th>Total Stream Shade Loss Associated with Option B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Streams</td>
<td>13.1%</td>
<td>4.8%</td>
<td>17.9%</td>
</tr>
<tr>
<td>Medium Streams</td>
<td>6.7%</td>
<td>2.7%</td>
<td>9.4%</td>
</tr>
</tbody>
</table>

Table 4. Total Stream Temperature Increase Associate with Option B

<table>
<thead>
<tr>
<th>Category</th>
<th>Temperature Increase Result from Buffer Width Reduction</th>
<th>Temperature Increase Result from Thinning Activities</th>
<th>Total Stream Temperature Increase(^6) Associated with Option B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Streams</td>
<td>0.9°C</td>
<td>0.3°C</td>
<td>1.2°C</td>
</tr>
<tr>
<td>Medium Streams</td>
<td>0.4°C</td>
<td>0.2°C</td>
<td>0.6°C</td>
</tr>
</tbody>
</table>

\(^6\) The median temperature increase.
Cited Literature


ODF 2015. The material in the folder titled “BOF_Handout_Material” was obtained from the Oregon Board of Forestry (BOF) website listing the June 2015 meeting materials - www.oregon.gov/ODF/Board/Documents/BOF/20150603/BOFATTCH_20150603_07_02.pdf, www.oregon.gov/ODF/Board/Documents/BOF/20150603/BOFATTCH_20150603_07_03.pdf www.oregon.gov/ODF/Board/Documents/BOF/20150603/BOFATTCH_20150603_07_01.pdf. More recent detailed modeling results were obtained from ODF staff (Groom) via emails in July 2015.


ATTACHMENT 11
Roni, P. 2016. 2 pages.

Testimony of Phil Roni, Research Scientist/Watershed Program Manager, Northwest Fisheries Science Center, NOAA Fisheries, Seattle, Washington.

Before the Oregon Board of Forestry, June 3, 2015

Good afternoon, Chairman and Board Members. My name is Phil Roni. I’m a research scientist with the NOAA Northwest Fisheries Science Center where I lead (and have led for last 20 years) a group of 20 scientists working on freshwater habitat, forestry, land-use, and restoration issues as they relate to salmon and steelhead. I wanted to testify from a scientific perspective regarding the Riparian Rule as it pertains to water quality and fish, particularly salmon.

Specifically, I want to touch on three things: 1) buffer widths needed to protect temperature, 2) extent of those buffers with particular reference to fish-bearing and non-fish bearing streams, and 3) Protecting Cold Water (PCW) criterion.

First, in regards to riparian buffers needed to protect stream temperature, the proposal for 90 to 100 ft. no-cut buffers to protect stream temperature is well supported by past and current science. For many years, the science has suggested that buffers anywhere from one to two potential tree heights are needed on fish-bearing streams to protect a variety of stream functions. This is quite a large range (100 to 300 feet in some cases) and I was excited to see the results of the RipStream study, which is an extremely well-designed study, that focused specifically on buffers needed to protect stream temperatures and on PCW criterion. It is clear from the RipStream and other studies that a no-cut buffer of 90 to 100 feet is needed to protect shade and temperature (PCW). Moreover, the Oregon Department of Forestry has analyzed the data in many different ways and came up the same answer of 90 to 100 feet no-cut buffers. This should also protect a variety of other functions (micro-climate, nutrients, etc.); even larger buffers may be needed to fully protect some other functions such as providing large wood to the stream.

Second, the science is clear that protection is needed for non-fish bearing perennial streams as well. Non-fish bearing streams make up the majority of stream miles in any watershed and are drivers of the productivity of the system. They transmit temperatures downstream. It should be noted that the science on how far downstream the temperature effects from non-fish bearing streams are transmitted is variable ranging anywhere from a few hundred meters to a kilometer. Regardless, non-fish bearing streams provide important sources of wood, sediment, nutrients and gravels to fish-bearing streams and are drivers of productivity of downstream fish habitat and a watershed. The stream network is similar to your circulatory system. It would be a mistake to only protect your arteries and ignore your capillaries or assume that anything injected into your arterioles or capillaries would have no effect on your body or wouldn’t be transmitted to your major arteries. It is similar with non-fish bearing streams and fish bearing streams. They are interconnected. and interdependent and protecting both non-fish bearing and fish bearing streams is important.
The third and final area I want to comment on is the PCW criterion of 0.3° C. This is well based in science that changes larger than this can have significant impacts on salmonid fishes. This can be either directly by making streams inhospitable for salmon and trout, or indirectly by affecting growth, feeding and reproduction. For example, small changes in temperature can significantly impact fish metabolism and their ability to feed and grow or, similarly, make them more susceptible to disease. It should also be noted that many streams, particularly at lower elevations, are on the edge of the limits of suitability for salmon and trout (particularly bull trout but also coho and cutthroat) and even small changes can make these streams or stream reaches inhospitable for salmonids. Finally, stream temperatures in many areas are predicted to increase with climate change and further increases in temperature due to removal of trees is of great concern and could further reduce suitable habitat for listed (and unlisted) salmon and trout.

In summary, 1) the science supports no-cut buffers of 90 of 100 ft. for PCW criterion, 2) this should be applied to fish-bearing and non-fish bearing streams, and 3) the PCW criterion of 0.3° C is scientifically sound and should not be increased.

I want to thank the Board for the opportunity to testify and I’m happy to answer any questions.
ATTACHMENT 12  
Scurlock, Mendoza and Frissell. 2016. 8 pages.

MEMORANDUM

TO: Riparian Rule Subcommittee and other Members of the Oregon Board of Forestry

FR: Mary Scurlock, Chris Frissell and Chris Mendoza

RE: Why leaving riparian forests unmanaged within ~100 feet can safely be presumed to be ecologically beneficial for Oregon’s aquatic and terrestrial ecosystems on both wet and dry forests

DT: 23 September 2015

Some Board members have expressed reservations about designating riparian areas as “no harvest” to meet the Protecting Coldwater Criterion because of a misguided belief that this will prevent needed, ecologically beneficial silvicultural treatments in these areas. A related concern is that instream placement of large wood will be discouraged.

This memo summarizes some key reasons why we believe these are not valid concerns that undermine the benefits of requiring substantially unmanaged buffers in either wetter Westside forests or the drier forest of the Siskiyou and the eastside.

1. **Scientific perspectives on the ecological benefits of riparian thinning in westside forests have changed to recognize that management intended to speed large tree growth does not advance what is the more broadly important goal of dead wood production.**

A seminal recent analysis by researchers at the National Marine Fisheries Service Science Center in Seattle concluded:

“Because far more vertebrate species utilize large deadwood rather than large live trees, allowing riparian forests to naturally develop may result in the most rapid and sustained development of structural features important to most terrestrial and aquatic vertebrates.” Pollock and Beechie (2014).

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Spurred by debate around large-scale federal lands ESA consultations on riparian thinning practices, an interagency panel1 reviewed current models for LWD delivery to streams within wetter forests, and determined that riparian thinning reduces LWD pieces and volumes entering streams for up to 90+ years. Only after that were remaining trees within the recruitment zone appreciably larger.

This view is consistent with research conducted as part of the Adaptive Management Program of the Washington State Habitat Conservation Plan for private forests (WDNR, 2005) where researchers concluded that “active management” (thinning) resulted in riparian stands accruing less basal area per acre (BAPA) than stands that were left unmanaged when modeled out to age 140 years in order to achieve Desired Future Condition (DFC) basal area targets. McConnell (2007). The Board may rely on these findings: McConnell’s modeling of BAPA to Desired Future Conditions at age 140 were similar to actual BAPA in riparian stands that were field validated in a related Washington research and monitoring study (Validation of the Western Washington riparian Desired Future Conditions (DFC) performance targets, Schuett-Hames et al. 2005).

An Oregon State University study of riparian thinning with the intent to improve conifer establishment and growth (Emmingham et al. 2000) concluded that very aggressive tree removal and soil disturbance measures are necessary to hasten the establishment of Douglas-fir and other conifers in Oregon Coast Range riparian areas. Where protection of water quality and stream habitat for salmonids and amphibian species are recognized to be of paramount importance, such aggressive silvicultural measures fundamentally conflict with the overarching objectives of maintaining shade and water temperature, and minimizing erosion and sedimentation to streams. Halfway silvicultural measures are highly likely to both impose some harms to aquatic habitat and fail to hasten conifer establishment or growth. The Ripstream studies conclusively demonstrate that with regard to stream shade and temperature, the zone where this balance of risks most acutely applies is the area within 100-120 feet of perennial streams.

Three decades of research have failed to clearly demonstrate that environmentally acceptable riparian stand thinning prescriptions reliably result in increased tree growth that confers net benefit to aquatic (or terrestrial) conservation objectives. Forest policymaking should not be premised on the opposite assumption and wishful thinking.

2. “No harvest” zones without human intervention will be static and unhealthy

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2 McConnell (2007) states: “DFC Model outputs were analyzed using data from 150 randomly selected, approved Forest Practices Applications (FPAs) in which timber harvest was proposed along west-side Type F streams. Stand age 140 bapa (average and standard deviation) for each prescription, for all FPAs, across all Site Classes, stream sizes and other possible covariates was: no-cut, 364.1 ± 43.7 (emphasis added), Option 1 (thinning), 335.5 ± 45.9, and Option 2 (leave trees closest to stream), 301.1 ± 40.8 with the trees in the outer part of the inner zone excluded and 333.0 ± 31.4 with the trees in the outer part of the inner zone included.” (emphasis added).
It is important to recognize that without timber harvest riparian areas will still be subject to a variety of natural disturbances that will create a mosaic of conditions within these areas. Even in the absence of human manipulation, natural disturbances such as wind, fire, insects, disease, flooding and landslides will continue to affect riparian areas, ensuring riparian forest diversity. These same disturbances are the means by which riparian areas interact with the stream to provide large wood and other organic inputs. Research indicates that self-thinning processes operating over decades in second-growth riparian forests result in mature forest conditions without thinning treatment (Pollock et al. 2012).

Silvicultural intervention is, as a general matter, simply not necessary for the attainment of natural vegetation successional pathways and mature forest conditions in riparian areas.

3. *Given the large ecological burden being placed on relatively small protected riparian areas, it is important to maximize the ecological function from riparian buffers. This is best achieved by a presumptive no harvest prescription.*

It is important to remember that riparian areas receive protection because they directly influence the quality and quantity of habitat available to aquatic and riparian-dependent species. (See e.g. IMST, 1999, Gregory et al. 1991, and many others). But because of this rule’s focus on the shade function alone, even the largest buffers being considered comprise but a fraction of the functional riparian area that contributes to aquatic and riparian health. The important functions performed by riparian forest include shade and temperature control, erosion prevention and sediment filtration, nutrient retention, and woody debris production (Gregory et al. 1991, Spence et al. 1996, IMST 1999, Frissell et al. 2014). Yet, these relatively small areas are being tasked – perhaps impossibly -- with mitigating the landscape-scale effects of industrial logging.

By taking what is essentially a “stream buffer only” approach we are already taking extreme risks with aquatic ecosystems on private lands because it is well-established that the physical and biological attributes of riparian landforms are shaped by the geomorphic processes at work within the entire watershed (Sullivan et al. 1987; Featherston et al. 1995). As Oregon’s Independent Multidisciplinary Science Team observed in 1999, the dispersal of sustained short-rotation logging activity over large areas of the landscape does not emulate natural disturbance patterns, nor does the retention of skinny strips of forest along some stream channels. Nonetheless, the current policy framework effectively limits us to a site-by-site mitigation approach that effectively proposes to use riparian functionality as a proxy for watershed functionality. It stands to reason that in order for this type of mitigation scheme to be at all effective, riparian function must be maximized.

Yet the areas that should be considered “riparian” from an ecological perspective extend well beyond the widths of restricted management areas currently being considered by the Board. If Oregon were to pursue ESA-sufficient forest practices rules on fish-bearing streams– perhaps through a statewide Habitat Conservation Plan such as Washington state private forest lands is implementing – the stream protection rules would need to restrict harvest within approximately one site potential tree-height-sized distance from the stream.
Furthermore, unstable areas should be also included in riparian delineation, such as inner gorges and other steep, unstable areas because they are an integral part of the functional riparian area due to their tight connection to physical stream processes. In fact, in many managed steep and moderately steep coastal tributary streams in central to northwestern Oregon, the best chance of large "key pieces" of LWD getting to the stream, floodplains, and riparian areas is via debris flows, unstable or potentially unstable slope failures or larger landslides. Reeves et al. (2003).

5. Post-fire and other post-disturbance "salvage" logging is inconsistent with ecological restoration even outside of riparian areas – it is double true inside them.

A no-harvest presumption in riparian areas is justified even in the face of widespread fire or insect mortality in riparian areas. There is overwhelming consensus in the scientific literature that that post-disturbance logging is not restorative and should be excluded from terrestrial and aquatic conservation emphasis areas. This most certainly includes near-stream riparian areas according to numerous sources, including: Beschta et. al. 2004, Karr et al. 2004, Lindenmayer et al 2004, Lindenmayer and Noss 2006, Donato et al. 2006, Noss et al. 2006. These studies conclude that logging after fire, windstorms, or insect outbreaks compounds the harm the initial disturbance can cause to watershed, soils, and hydrologic functions, and equally important, curtails or delays natural recovery processes that often create high-quality stream and riparian habitat after forest natural disturbances.

In drier forests, wildfire can't always be considered a threat to native fish, amphibians and other aquatic species, and this subject remains a subject of both debate and uncertainty. In every region, native species are adapted to be resilient or resistant to wildfire effects, else they would not have survived to the present day. Too often high severity fire is assumed to be a "disaster" to aquatic resources, without actual monitoring and evaluation. Many scientists argue that the variety of threats that restrict a species' range, fragment populations, and curtail recolonization are the primary causes of local extinction, and wildfire is best viewed as merely one among many proximal triggers of an inevitable response. The extensive forest treatments that disturb soils and vegetation in riparian over large areas that would be necessary in order to have the desired impact on ameliorating

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1 This research also shows that it may not be only total wood delivery that is important. Reeves et al. (2003) findings in Cummins Creek, Western Oregon, that: "About 65% of the number of pieces and 46% of the estimated volume of wood were from upslope sources. Streamside sources contributed about 35% of the number of pieces and 54% of the estimated volume of wood." Thus, LWD delivery from upslope areas outside the 1-tree-height distance for coastal 4th order streams (Cummins Creek is an unlogged reference system) may not be the "rare occurrence." Further, the location of the LWD from upslope sources appears to have high ecological value that exceeds its volume.
fires that with certainty affect only a very limited portion of the treated area is a good example of a poor tradeoff: the certainty of harm over a large area in exchange for the possibility of reduced fire severity in some small portion of the impacted area. Others suggest that disproportionately large or intense wildfire can cause patterns of impact that were seldom seen under historical conditions. But efforts to reduce wildfire impact by thinning or other silvicultural treatments are not proven to be effective in the case of large fires that burn the most acres, and they bring undesired impacts, particularly when implemented within riparian areas and slopes near streams and wetlands.

With regard to conservation implications, however, it is now well established that climate change and weather drive increased fire size and severity regardless of any appreciable or manageable fuels accumulation effect. The specific roles of fuels and fire management within aquatic reserves - such as no harvest buffers on private forestlands - remain unresolved. For example, while consensus exists that restoration of something akin to natural fire regime is desirable for ecological and other reasons, the extent and the exact nature of pre-fire fuels treatment necessary to effectively manage fire is unknown; research results on the effectiveness of fuels treatments and forest thinning are extremely variable. Proposed actions on federal lands range widely from intensive mechanical treatments intended to "mimic or replace" fire or to impose artificial large-scale firebreaks, to expansive lighter, more spatially limited fuels manipulations such as lopping of low branches and local raking of ground fuels immediately prior to prescribed fire treatments. Extensive and sustained high-investment fuels management programs almost certainly necessitate road access, in particular close to streams, with the roads themselves bringing substantial impact that would not occur had fire been allowed to burn without an attempt to manage fuels. For these critical reasons, the tradeoffs between watershed impacts and benefits of fuels treatments and their putative effect on ameliorating fire remain unresolved.

6. If alternative riparian management (e.g. silvicultural treatments) or instream placement of large wood is ecologically desirable in specific locations, there are other policy mechanisms that can be brought to bear.

Any information before the Board about how larger buffer requirements would affect large wood placement projects is anecdotal and speculative at best, and as such is a distraction from the central objective of this rulemaking. Furthermore, even if this issue were relevant, there is no rational way for the Board to weigh the tradeoffs between more retention of standing riparian forest and the benefits of hypothetical wood placement projects at unspecified locations with unmeasured benefits to aquatic species and no connection whatsoever to attainment of the PCW.

As a matter of public policy, instream wood placement and those specific cases where riparian forest management is actually needed because it is demonstrably beneficial to aquatic resources, are both better addressed through policies external to the OFPA’s programmatic stream protection rules which are the state’s compliance mechanism for attaining water quality standards under the federal Clean Water Act. These include plans
for alternate practices under the OFPA, and numerous state and federal restoration programs specifically designed to fund such efforts.

CONCLUSION

It is understandable that the Board may be confused as to how and whether it should consider a new rule’s effect on the availability of active management, either in riparian areas or to place large wood. **But in our view these concerns have been given a more elevated status as a “consideration” that they should have been given the Board’s nondiscretionary duty to meet water quality standards. The rules’ effectiveness to meet the water quality compliance goal must drive the Board’s selection of broadly applicable stream protection rules.**

Nonetheless, some Board members have expressed hesitancy to declare riparian areas off limits to timber harvest citing active management needs and large wood placement concerns. This memo has tried to explain that there is no basis in the scientific literature to presume that active riparian management is ecologically beneficial.

In sum, concerns about a perceived need for active riparian management do not provide Board with a sound basis to oppose no-harvest buffers of 120 feet or less for at least the following three reasons:

1. **The Board’s need to implement rules that meet water quality standards trumps these considerations because attainment of these standards constitutes a mandatory statutory duty under ORS 527.765.**

2. **As ODF’s July 2015 staff report observes “active management” is merely “encouraged” by rule “where appropriate.” The science indicates that active management as a rule is not appropriate or generally justified in riparian areas (see above).**

3. **Large wood placement and ecologically restorative riparian silviculture activities (such as that dropping trees onto the forest floor) cannot be effectively or fully directed solely through the Board’s stream protection rules. Both activities should be conducted in conjunction with watershed-specific restoration plans, Oregon Department of Fish and Wildlife and other experts in the art and science of ecosystem restoration.**
REFERENCES


Noss, Reed F (editor), Jerry F. Franklin, William L. Baker, Tania Schoennagel, and Peter B. Moyle. Ecology and Management of Fire-prone Forests of the Western United States. (Society for Conservation Biology, August 2006) [addresses the ecological science relevant to forest...
restoration and fuel management policy development in light of ecological variability within and among forests, concluding, inter alia that restoration priorities should be determined by ecological considerations and urgency, with areas of highest current biological value taking precedence over areas most out of kilter with historical forest conditions and that we should take care of other stressors first, before taking management actions to correct fire regime/past management, i.e. invasives and grazing pressures.


