Stand Age & Forest Evapotranspiration: Implications for Forest Management, Streamflow, and Salmonid Recovery

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Introduction

Recurring major wildfires in Sonoma County and throughout the western U.S. have emphasized the importance of forest management to reduce fuel loads and fire hazards. Fuel loads are typically reduced through a combination of thinning smaller trees, removal of other ladder fuels, and controlled burns. The objectives of commercial timber harvest could also potentially include new emphasis on management of fire risk. Wildfires consume much available fuel and affect forest stand conditions but most often modify rather than eliminate future wildfire hazards. Salvage logging in the aftermath of wildfire is common and may also be expected to affect future forest stand conditions.

Wildfires and vegetation/forest management strategies intended to reduce hazards and risks of future wildfires have the potential to significantly alter the water balance in coastal watersheds given that Evapotranspiration (ET) is typically the largest outflow in a watershed water balance, estimated to be equivalent to 19-32 inches of rainfall (48-57% of mean annual rainfall) in lower Russian River tributary watersheds (OEI, 2016, 2020 & 2021). Comparing watershed ET to human water uses from all surface water and groundwater sources, ET is approximately 15 to 160 times greater than human water use on a long-term annual basis (Figure 1). Given the level of regulation and investigation surrounding the relatively small human use component of the water balance, increasing our understanding and management of the much more significant (volumetrically) ET component appears overdue.

Experimental Watershed Results

Direct measurement of ET is difficult and not practical to implement at the watershed scale. The effect of forest management on ET has been indirectly characterized in terms of watershed runoff (streamflow) by several long-running paired watershed studies including those at Caspar Creek in Mendocino County, the Alsea River in coastal Oregon, and the H.J. Andrews Experimental Forest in the western Oregon Cascades. These studies began measuring streamflows in the 1950s and 60s in reference watersheds and in watersheds with various levels of timber harvest (primarily Douglas-fir and Coast Redwood) that occurred in the late 1960s through the mid-80s.

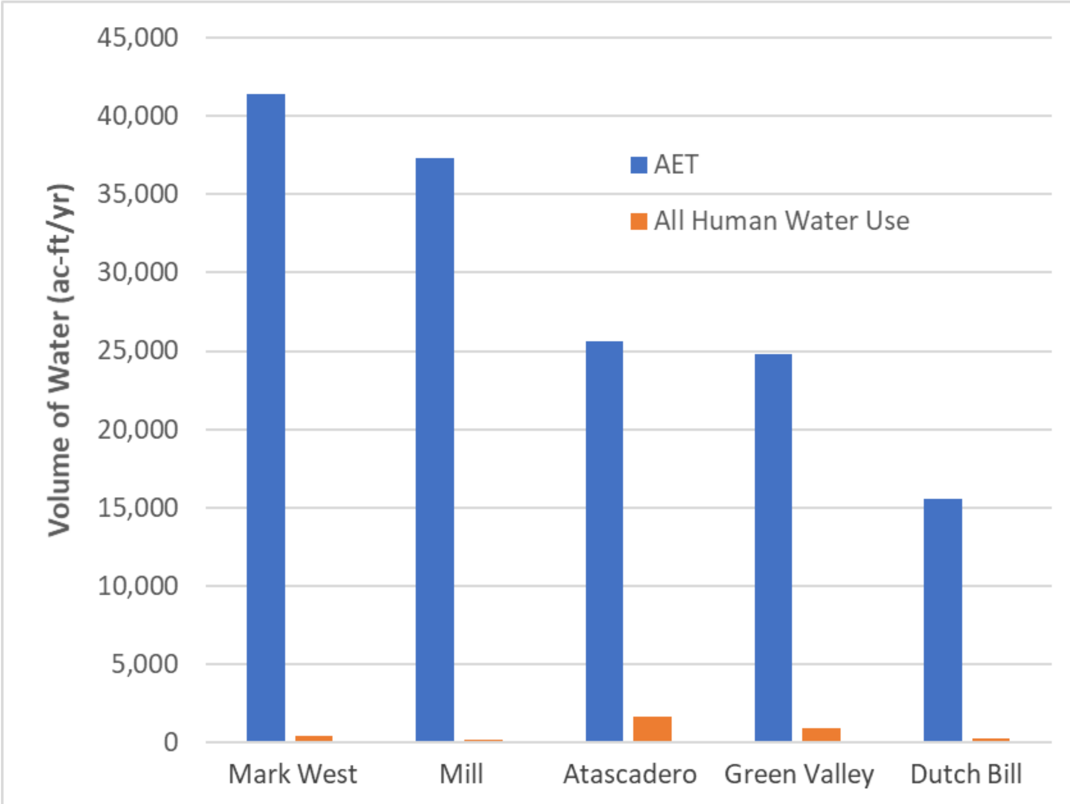

Figure 1: Comparison between Actual Evapotranspiration (AET) and all anthropogenic water use in five lower Russian River tributary watersheds. Data is based on estimates from three distributed hydrologic modeling studies (OEI, 2016, 2020 & 2021).

The pre-harvest age of forest stands in the experimental watersheds were on the order of 80-125 years except at H.J. Andrews 1 where they were ~450-yrs old. Over 50-yrs of post-harvest data are available in some watersheds which greatly improves our understanding of the long-term patterns of streamflow response to timber harvest and forest age structure.

Results from all three paired-watershed study areas show a period of increasing summer streamflows following timber harvest that typically lasts for about 5-8 years, followed by a period of transition, then a longer period of reduced summer streamflow beginning about 10 to 20-years post-harvest and continuing for an undetermined length of time (at least several decades). None of the studies documented streamflow recovery to pre-harvest conditions in the fully harvested watersheds (Figure 3). The magnitudes of the documented declines in summer streamflow are quite significant and on the order of 25 to 60% (Keppeler et al., 2008; Perry & Jones, 2016; Coble et al., 2020, Segura et al., 2020).

One conclusion that can be drawn from these studies is that very young forests use less water than 80 to 125-year-old forests and that 15 to 50-year-old forests use more water than 80 to 125-

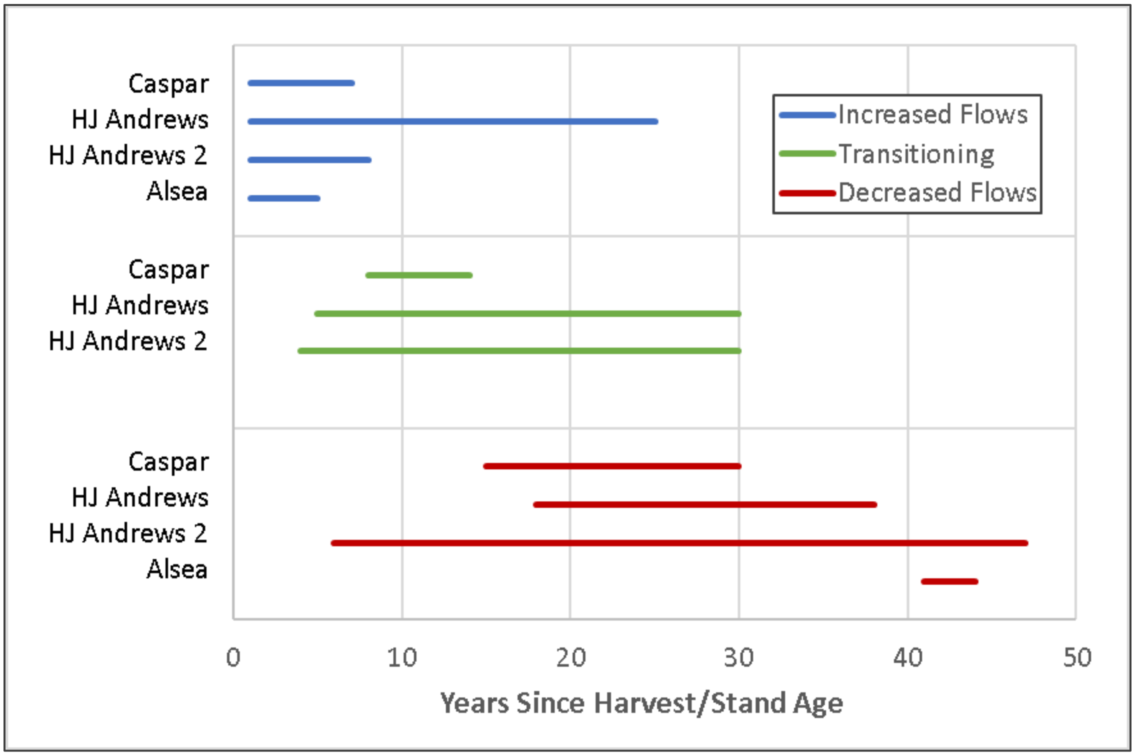

Figure 2: Summary of experimental watershed results showing the timing of summer streamflow increases and decreases resulting from timber harvest and subsequent stand maturation (data from Coble et al., 2020).

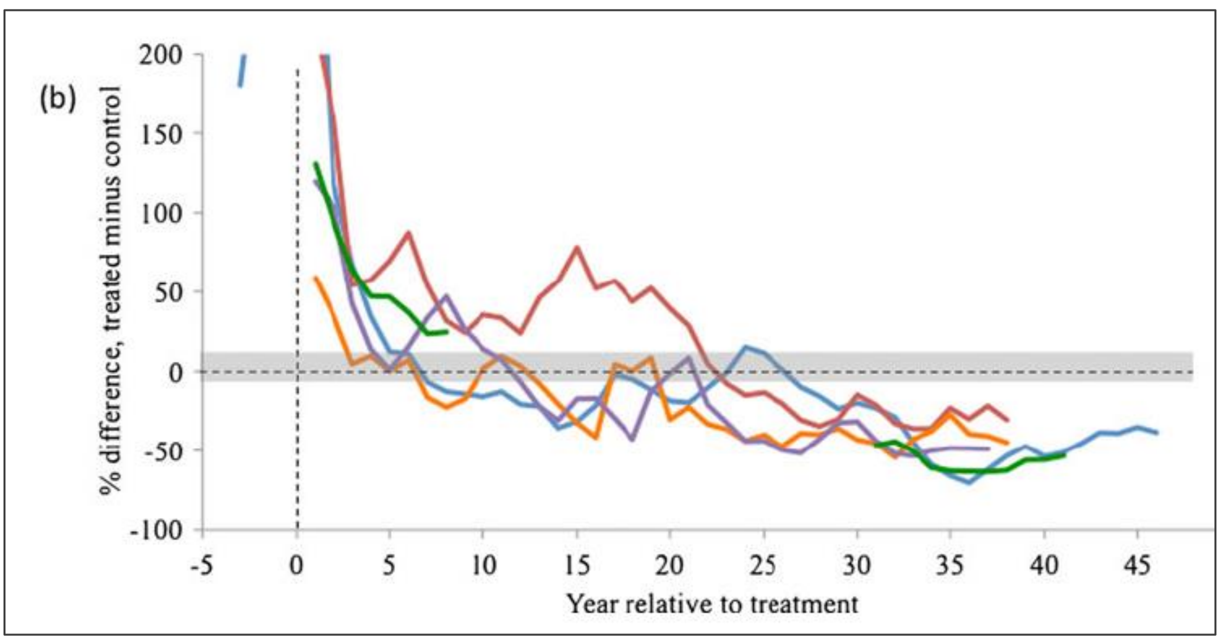

Figure 3: Percent change in summer streamflow relative to mature (125-yr old) forests following timber harvest in the H.J. Andrews experimental watersheds (figure from Perry & Jones, 2016). Each line represents a different pair of watersheds where one was an uncut reference watershed and the other was 100% clear-cut.

year-old forests. A different study focusing on measuring transpiration rates at H.J. Andrews showed 450-year-old forests used as little as a third of the water as 40-year-old forests (Moore et al., 2003) so there is some evidence that “old growth” forests also exhibit significantly lower ET relative to young forests. Additional factors such as species compositions, mixed- versus even-age stand conditions, and the frequency and types of natural and man-made disturbances are also important drivers of forest ET rates.

In the context of developing potential forest management concepts for tributaries of the lower Russian River, it should be noted that essentially all the conifer forests in key salmonid watersheds were previously clear-cut or otherwise harvested, and that these watersheds may have also been subject to extensive grazing in the European settlement era and regular burning by Native Americans who occupied the area for prior millennia. These watersheds and the forests they contain are now in various states of re-growth (like the experimental watersheds), thus the results of the above-referenced paired watershed studies are applicable to developing at least a qualitative understanding of the relationship between forest vegetation and watershed hydrologic conditions and the likely hydrologic effects of forest management interventions contemplated to reduce fuel loads and fire hazards. There may, however, also be important differences in the evapotranspiration patterns between even-aged stands in the commercially harvested experimental watersheds and lower Russian River watershed forests which, in general, have a more fragmented and diverse history of timber harvest and land-use change.

<u>Case Study: Mill Creek Watershed</u>

Forest Structure

Most of the coniferous forest stands in Sonoma County are relatively young. LiDAR-derived canopy height distributions for stands in the Mill Creek watershed show that most forests are in the 60-90-ft height range. Growth rates of Douglas Fir and Coast Redwood can vary substantially depending on local growing conditions and additional work is needed to characterize these forest stands in terms of their densities and age structures. To gain some initial perspective on the likely ages of these forests we assumed a range of growth rates of 1.5 to 3-ft/yr which, based on the canopy height data would suggest that most forests are in the 20 to 60-yr age range. LiDAR-derived Leaf Area Index (LAI) data show a clear relationship of increasing LAI with canopy height/age class for trees smaller than about 80-100 feet followed by a period of stable LAI for larger/older trees (Figure 4). LAI is an important indicator of transpiration and the LAI data appears consistent with the experimental watershed results in suggesting a period of increasing transpiration as young trees mature. Note that older trees are believed to have reduced transpiration not through reduced LAI but through changes in plant physiology (e.g., Moore et al., 2003).

The predominance of young trees in salmonid watersheds of Sonoma County suggests that the forests are and have been in a period of relatively high evapotranspiration. This condition is expected to correlate with diminished summer streamflows relative to pre-harvest conditions.

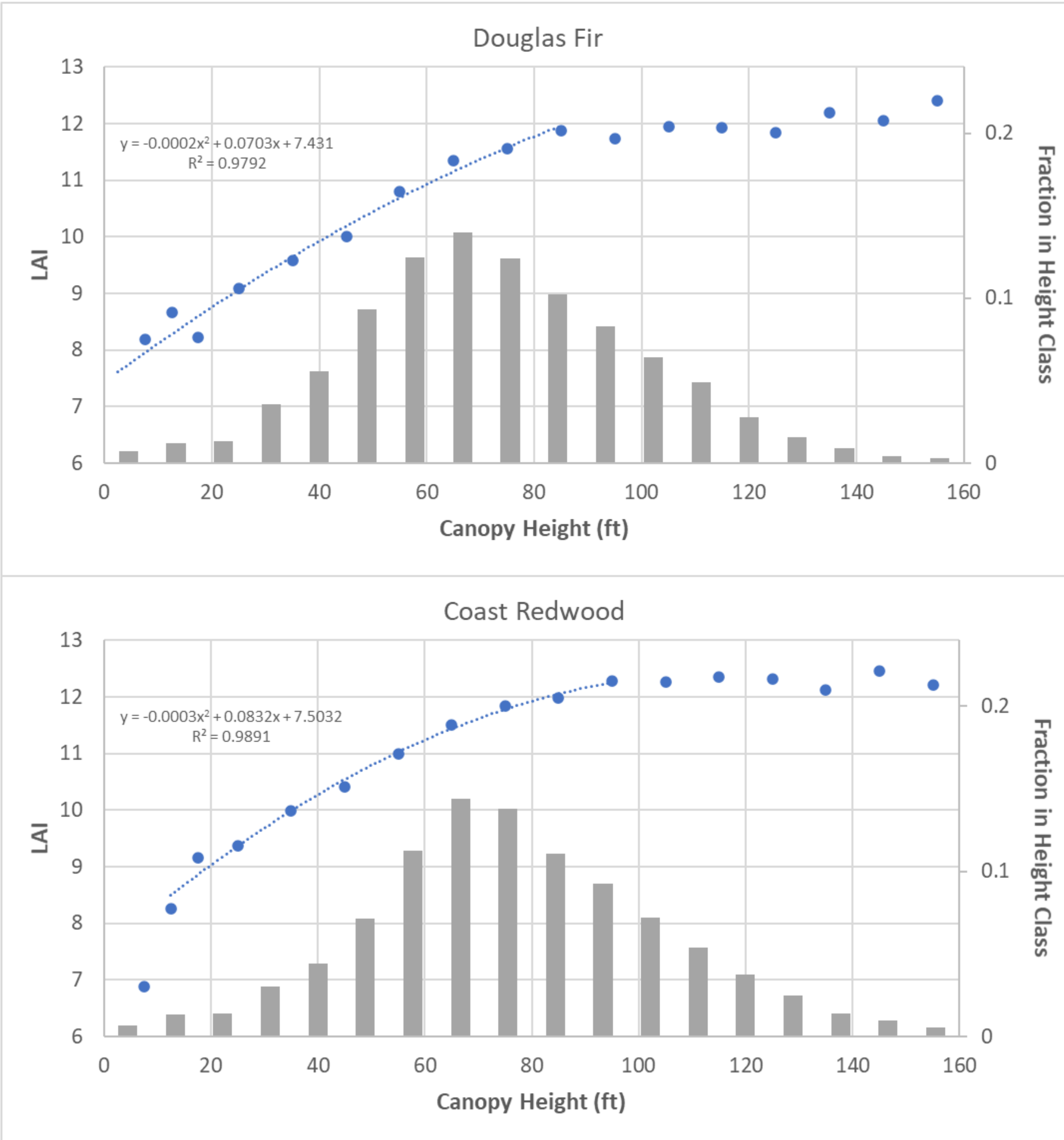

Figure 4: Distribution of Douglas Fir and Coast Redwood canopy heights (gray bars) and relationships between Leaf Area Index (LAI) and canopy height (blue points) for forests in the Mill Creek watershed.

The presumed age distributions and LAI curves also suggest the forest stands may be nearing maximum evapotranspiration rates, and that rates would be expected to decline over the coming decades if these forests develop into healthy older stands. The experimental watershed results suggest that harvesting forest stands at 40 to 60-year intervals causes a multi-decadal period of high ET/reduced streamflow that is continuously reset by harvest and regeneration of very young forest characterized by a short-term phase of low ET/increased streamflow. These findings illustrate the importance of understanding and managing the watershed-scale spatial distribution of stand ages in coniferous forests as a means of influencing long-term trends in streamflows.

There may also be additional benefits to managing for older forests in terms of increased carbon sequestration and reduced fire risk. Older Coast Redwood forests are known to be relatively resistant to high intensity wildfire as evidenced by an analysis of the LiDAR-derived canopy height data in various soil burn severity zones of the recent Walbridge Fire within the Mill Creek watershed which shows that severely burned areas had a mean canopy height of 47-ft compared to 70-ft for low severity burned areas (Figure 5).

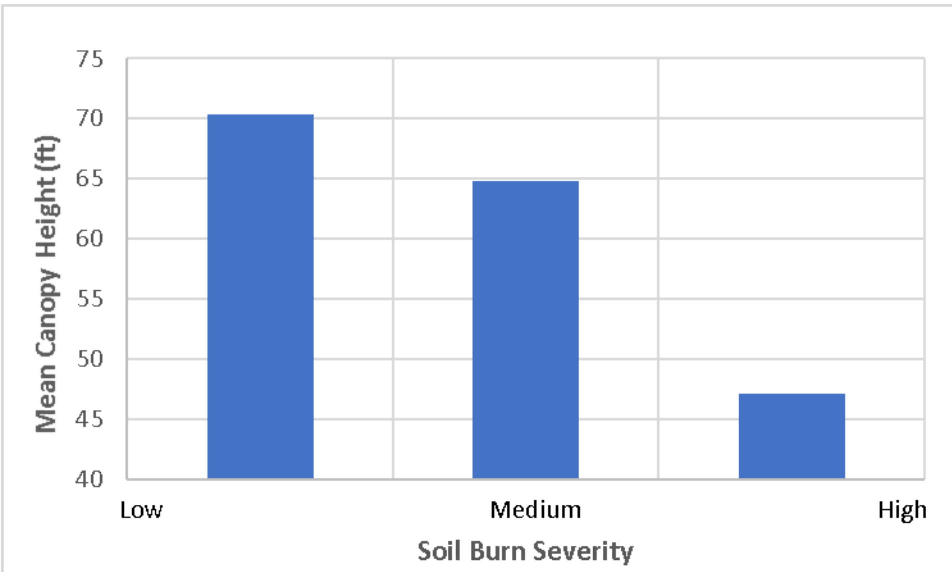

Figure 5: Mean canopy heights for Coast Redwood burned in the Walbridge Fire within the Mill Creek watershed compiled by Soil Burn Severity zone.

Streamflow Response to Reduced ET

The potential streamflow benefits of reduced ET were investigated by means of a sensitivity analysis using our existing calibrated distributed hydrologic model for Mill Creek (OEI , 2021). In this analysis, we invoked a 15% reduction in ET across all forest stands in the watershed. This scenario is not intended to represent a specific forest management approach, but rather to demonstrate the potential magnitude of streamflow and aquatic habitat benefits associated with a significant reduction in ET that could result from future forest and vegetation management and changes in stand-age compositions. Significant additional work is needed to quantify the relationships between forest age and stand structure, forest management, non-forest vegetation characteristics and management, ET, and streamflow.

During the drought of 2014, simulated summer streamflows were very low or disconnected throughout much of upper and middle Mill Creeks, and impassable conditions for fish migration developed in lower Mill Creek by the third week of April (Figure 6). Simulated spring and summer streamflows increased dramatically when forest ET was reduced by 15%. Reduced forest ET resulted in the persistence of passable flow conditions for an additional five weeks in lower Mill Creek during the period most critical for outmigrating salmonid smolts. Summer streamflow in middle Mill Creek increased by 100% during the month of July; by September, the effect was less pronounced but remained quite significant (43%) (Figure 6). Flow changes of this magnitude would likely result in dramatic improvements in summer juvenile rearing habitat quality and over-summer survival.

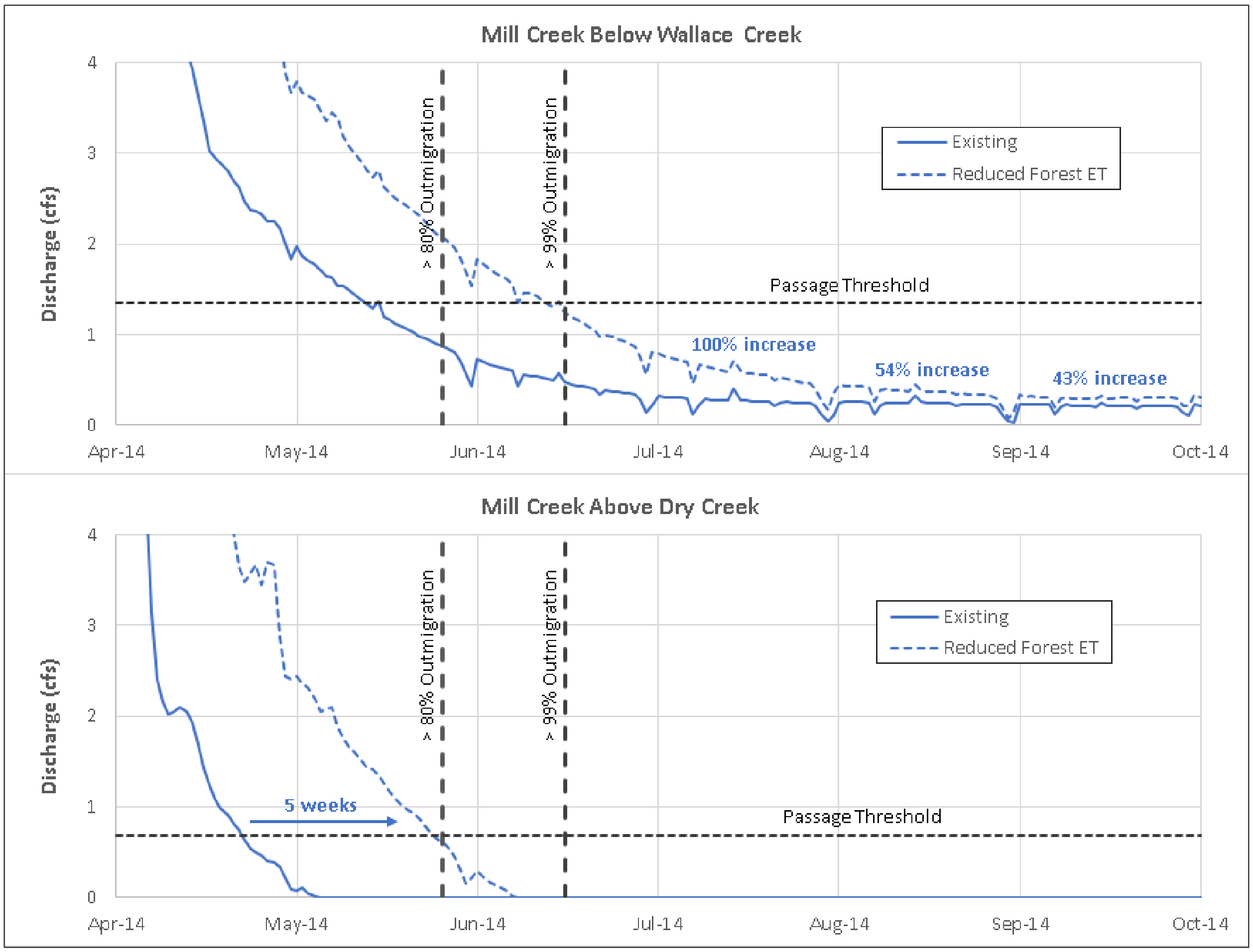

Figure 6: Streamflow response to a 15% reduction in forest ET in middle Mill Creek (top) and lower Mill Creek (bottom) as simulated with a distributed hydrologic model of the watershed (OEI, 2021).

The simulated changes resulting from hypothetical reductions in forest ET are much larger than the potential changes associated with water use modifications and other flow enhancement strategies investigated in other model scenarios such as recharge enhancement and grassland management. Of the strategies investigated, only pond releases (full utilization of existing storage) could potentially result in changes of this magnitude, though likely not with the extended duration of the reduced forest ET scenario.

Implications for Walbridge Fire Recovery

The experimental watershed studies and hydrologic model scenario described above may also be of some value as indications of potential effects of the Walbridge Fire on streamflow. Increases in summer streamflow are likely to occur in the first few years following the fire due to reduced evapotranspiration. The persistence of this effect or possible reversal will depend in large part on the degree of tree mortality and post-fire management that occurs. If there is significant tree mortality, if many damaged but living trees are removed, and/or if heavily-disturbed stands re-generate without intervention, a new younger and/or denser stand structure may develop. This would be expected to result in a short-term period of increased streamflow followed by a longer period of reduced streamflow as suggested by the post-harvest trends in the experimental watershed studies. Temporal changes in streamflow response to wildfire or timber harvest indicate that a long-term perspective is needed when considering forest management strategies in the context of streamflow, and that fire recovery efforts should focus on minimizing the fire's potential to result in development of stands with high ET characteristics.

Summary and Next Steps

The information presented here suggests that forest treatment plans focused on fuel management and wildfire risks should also be evaluated with respect to long-term effects on streamflow. Experimental watershed research suggests that older forest stands in the 80-125 year range have significantly lower ET than younger stands in the 15-50 year range, and that harvesting forests at typical 40-60 year intervals results in a multi-decadal period of increased ET and reduced streamflows. These findings illustrate that to maximize streamflow benefits over time, forest management interventions should be informed by a watershed-scale understanding of stand ages and structure so that actions can promote the development of stand structures with low ET characteristics.

The magnitude of potential streamflow and aquatic habitat improvements associated with the reduced forest ET scenario relative to other streamflow enhancement strategies suggests that ET management should become a major focus of streamflow enhancement efforts. Overall, these results provide some cause for optimism regarding the future trajectory of summer streamflows and salmonid habitat. If forest management approaches facilitate a transition to forests with lower ET characteristics that can be maintained over time, it is possible that a corresponding increase in summer streamflows could result and be maintained. Significant additional work is needed to characterize existing forest age structure and to better understand where forests lie in the range of ET conditions elucidated by the experimental watershed results. Other investigations should focus on furthering our understanding of how various forest management approaches will affect ET, streamflow, and salmonid habitat conditions.

References

Coble, A.A., Barnard, H., Du, E., Johnson, S., Jones, J., Keppeler, E., Kwon, H., Link, T.E., Penaluna, B.E., Reiter, M., River, M., Puettmann, K., & Wagenbrenner, J., 2020. Long-term hydrological response to forest harvest during seasonal low flow: Potential implications for current forest practices, Science of the Total Environment, 730, 138926.

Keppeler, E., Reid, L., Lisle, T., 2008. Long-term patterns of hydrologic response after logging in a coastal redwood forest, Proceedings of the Third Interagency Conference on Research in the Watersheds, Estes Park, CO, pp 265-271.

Moore, G.W., Bond, B.J., Jones, J.J., Phillips, N., & Meinzer, F.C., 2003. Structural and compositional controls on transpiration in 40- and 450-year-old riparian forests in western Oregon, USA, Tree Physiology 24, 481-491.

OEI, 2012. Integrated surface and groundwater modeling and flow availability analysis for restoration prioritization planning: Green Valley/Atascadero and Dutch Bill Creek watersheds, Sonoma County, CA, prepared for the Gold Ridge Resource Conservation District, 175 pgs.

OEI, 2020. Integrated surface and groundwater modeling and flow availability analysis for restoration prioritization planning, Upper Mark West Creek watershed, Sonoma County, CA, prepared for the Sonoma Resource Conservation District and the Coast Range Watershed Institute, 207 pgs.

OEI, 2021. Integrated surface and groundwater modeling and flow availability analysis for restoration prioritization planning, Mill Creek watershed, Sonoma County, CA, prepared for the Sonoma Resource Conservation District and the Coast Range Watershed Institute, (in process).

Perry, T.D., & Jones, J.A., 2016. Summer streamflow deficits from regenerating Douglas-fir forest in the Pacific Northwest, USA, Ecohydrology, 2017;10:e1790.

Segura, C., Bladon, K.D., Hatten, J.A., Jones, J.A., Hale, V.C., & Ice, G.G., 2020. Long-term effects of forest harvesting on summer low flow deficits in the Coast Range of Oregon, Journal of Hydrology, 585, 124749.