Hydrologic Influences on Stream Temperatures for Little Creek and Scotts Creek, Santa Cruz County, California[1]

Justin M. Louen[2] and Christopher G. Surfleet[2]

Stream temperature impacts have resulted in increased restrictions on land management, such as timber harvest and riparian restoration, creating considerable uncertainty for future planning and management of redwood (*Sequoia sempervirens* (D.Don) Endl.) forestlands. Challenges remain in the assessment of downstream cumulative stream temperature effects given the complexity of stream temperature dynamics. The goal of this research is to identify processes and measurements that can aid the assessment of risk of downstream temperature heating.

Stream temperature, hydrologic, climatic, and channel morphological data were collected on two, approximately 800 m stream reaches on Little Creek and Scotts Creek located in mixed coast redwood and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests of Santa Cruz County, California. Spatially and temporally explicit stream temperature measurements were collected using distributed temperature sensing (fig. 1). A fluorescent dye tracer was used to gather information on summer streamflow including the quantification of residence time and hyporheic exchange. A heat budget approach, adopted from a study by Moore et al. (2005), was used to quantify individual heat flux components and to examine the processes of stream heating and cooling. Downstream temperature change over varying distances through each study site were statistically compared against averaged heat budget components over this respective distance. Average daily maximum stream temperatures were statistically compared against measured physical channel characteristics at each 25 m location throughout the study reaches.

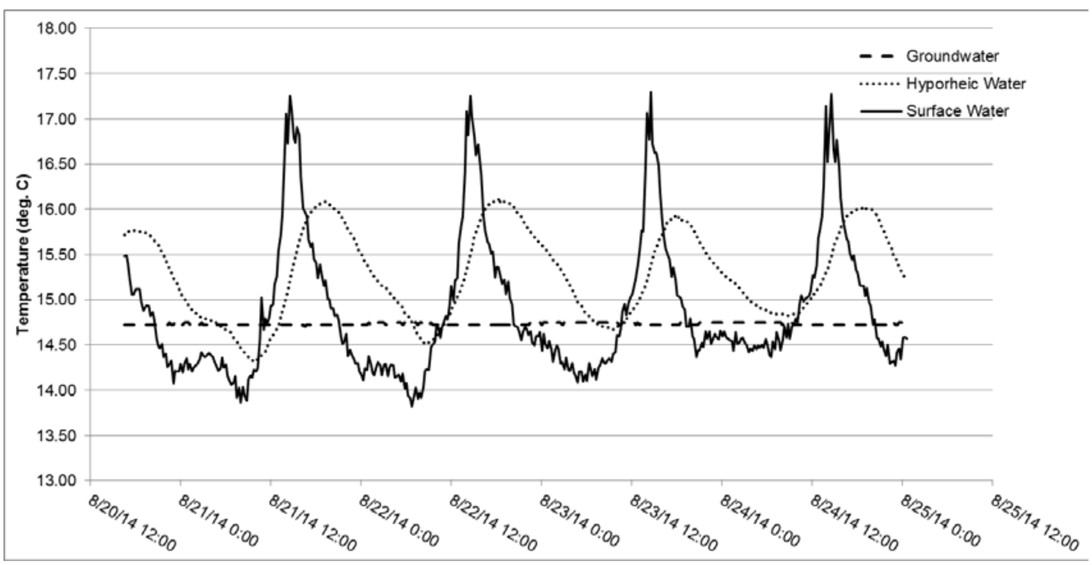

Figure 1—Measured surface, hyporheic, and groundwater temperatures (ºC) at location 390 m on Little Creek from August 20-25, 2014.

[1] A version of this paper was presented at the Coast Redwood Science Symposium, September 13-15, 2016, Eureka, California.

[2] NRES Department, California Polytechnic State University, 1 Grand Ave., San Luis Obispo, CA 93407.

Potential downstream effects were modeled by implementing hypothetical scenarios in which stream shading was reduced by 50 percent and 100 percent, via canopy reduction from timber harvest or riparian restoration, along the upper 300 m and 200 m of the Little Creek and Scotts Creek study sites respectively. These figures demonstrate the potential effects from future habitat restoration work. An additional analysis was performed by implementing hypothetical scenarios in which groundwater inflows would increase following near-stream vegetation removal, presumably from decreased evapotranspiration, along the upper 300 m and 200 m of the Little Creek and Scotts Creek study sites respectively. Stream temperatures were modeled with streamflow increases of 10 percent, 20 percent, 30 percent, and 50 percent under both the 50 percent and 100 percent shade reduction scenarios. Mean observed groundwater temperature of 14.8 ºC was assumed to be representative of groundwater inflows for modeled temperature mixing with surface water. Further information on the modeling approach taken in this study, including key assumptions, can be referenced in the thesis by Louen (2016).

Average daily maximum stream temperatures for each 5-day measurement period, were found to vary spatially (ranging from 14.95 to 17.91 ºC on Little Creek and 16.52 to 18.67 ºC on Scotts Creek) due to a variety of observed and measured cooling and heating mechanisms occurring throughout both study sites. Comparisons of observed and modeled temperatures between the two sites and the relative influences of individual heat budget components indicated that the magnitude and spatial frequency of subsurface-surface water interactions, along with incoming net radiation, played a substantial role in how heat was transferred through each system.

Relative influences of heat budget variables on downstream temperature change were found to vary between the two study sites with downstream distance (table 1). The measurement and evaluation of a stream's hydrologic characteristics, stream shading, and aspect ratio were statistically significant measurements ($\alpha < .05$) associated with downstream temperature change for Little Creek. Only weak statistical relationships were found for Scotts Creek. Weak relationships may have been attributed to very low streamflow due to drought conditions creating longer water residence times on Scotts Creek. Regression analysis indicated that hyporheic energy fluxes were negatively associated with increases in stream temperatures on Little Creek.

Table 1—Statistically significant heat budget variables on Little Creek and Scotts Creek (variables with p-value > .05 excluded) including net radiation (Nr), streambed conduction (Qc), latent heat exchange (Qe), sensible heat (Qh), and hyporheic flux (Qhyp) per downstream distance (m) evaluated

Study Site	Significant variables and corresponding β term over distance evaluated (m)			
		100	300	800
Little Creek	Nr			0.004
	Qc			
	Qe	-0.011	0.020	0.039
	Qh			
	Qhyp	-0.012	-0.041	-0.088
		50	200	825
Scotts Creek	Nr	0.004	0.029	0.032
	Qc	0.127		0.043
	Qe	0.004	0.005	0.009
	Qh			
	Qhyp	-0.005	0.003	

Observed hyporheic exchange rates and the prevalence of subsurface water mixing within the Little Creek reach appears to be associated with channel morphological characteristics of the stream which include steeper channel gradients and the predominant step-pool and cascade configuration observed in the study site. The step-pool and cascade configuration of Little Creek promotes concentrated areas of downwelling and subsurface water mixing, particularly in riffles downstream of pools as indicated by the observed statistical relationship between higher aspect ratios (width to depth ratios) and lower daily maximum temperatures. The spatial occurrences of these subsurface water interactions in Little Creek are consistent with previous research on streambed topography influences on surface-subsurface water interactions (Burkholder et al. 2008, Harvey and Bencala 1993, Moore et al. 2005). Departures from the steeper, step-pool configuration observed at Scotts Creek- with shallower channel gradients and more frequent occurrences of pools and glides compared to riffles- more than likely influenced the higher residence times of water and lower rates of hyphoreic exchange, particularly in the lower 625 to 825 m reach.

Heat budget modelling results indicated temperature increases in both study sites downstream of the hypothetical riparian canopy removal. Modeled downstream average daily maximum stream temperatures under the 100 percent shade reduction scenarios for both Little Creek and Scotts Creek resulted in increases of 1.6 and 3.1 ºC respectively (table 2). Potential increases in groundwater inflows following hypothetical canopy reduction scenarios reduced the effect of downstream temperature increases with greater reductions in stream temperature cooling with increased groundwater inputs (table 2).

Table 2—Modeled average maximum stream temperature (°C) response to groundwater inflow increases per shade reduction scenario on Little Creek and Scotts Creek

Study site	Shade scenario	Average max. temp. (deg. C)	Groundwater increase 10%	20%	30%	50%
Little Creek	Current condition (92% shade)	16.2				
	50% reduction	17.8	17.5	17.3	17.1	16.8
	100 % reduction	17.8	17.6	17.3	17.1	16.8
Scotts Creek	Current condition (86% shade)	18.0				
	50% reduction	19.8	19.3	19.0	18.6	18.1
	100 % reduction	21.1	20.5	20.0	19.6	19.0

While groundwater inflows were found to be negligible in the measured condition of each study site, the potential for increases in groundwater inflows following near stream vegetation removal can be significant (e.g., Story et al. 2003, Surfleet and Skaugset 2013). Modeled increases in groundwater inflows, as expressed by increases in overall surface water flow, dampened the effect of stream temperature increases from canopy removal with 50 percent increases in streamflow under the 100 percent shade reduction scenario. Modeled stream temperature response to near stream canopy reductions from this study provides pertinent information to land managers and policy-decision makers in the assessment of potential impacts and development of adaptive management strategies for Little Creek and Scotts Creek.

Literature Cited

Burkholder, B.; Grant, G.; Haggerty, R.; Khangaonkar, T.; Wampler, P. 2008. Influence of hyporheic flow and geomorphology on temperature of a large, gravel-bed river, Clackamas River, Oregon, USA. Hydrological Processes. 22(7): 941–953.

Harvey, J.; Bencala, K. 1993. The effect of streambed topography on surface-subsurface water exchange in mountain catchments. Water Resources Research. 29(1): 89–98.

Louen, J. 2016. Hydrologic characteristics of summer stream temperatures in Little Creek and Scotts Creek at the Swanton Pacific Ranch: San Luis Obispo: California Polytechnic State University. 82 p. M.S. thesis.

Moore, R.; Sutherland, P.; Gomi, T.; Dakal, A. 2005. Thermal regime of a headwater stream within a clear-cut, coastal British Columbia, Canada. Hydrological Processes. 19(13): 2591–2608.

Story, A.; Moore, R.; Macdonald, J. 2003. Stream temperatures in two shaded reaches below cutblocks and logging roads: downstream cooling linked to subsurface hydrology. Canadian Journal of Forest Research. 33(8): 1383–1396.

Surfleet, C.; Skaugset, A. 2013. The effect of timber harvest on summer low flows, Hinkle Creek, Oregon. Western Journal of Applied Forestry. 28(1): 13–21.