PREDICTING STREAM TEMPERATURE AFTER RIPARIAN VEGETATION REMOVAL [1]

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Abstract: Removal of stream channel shading during timber harvest operations may raise the stream temperature and adversely affect desirable aquatic populations. Field work in California at one clearcut and one mature fir site demonstrated diurnal water temperature cycles and provided data to evaluate two stream temperature prediction techniques. Larger diurnal temperature fluctuations were observed in the water flowing through the clearcut than in the undisturbed area above the clearcut site. The mature fir forest also had a large diurnal water temperature variation. A 5.6°C temperature rise was observed through a 380-m clearcut that exposed the stream channel, and Brown's equation predicted a change of 6.1°C. A regression model underpredicted the maximum observed temperature by just under 2°C at the clearcut site. A technique that includes the effect of shade recovery after timber harvest is suggested for use during long-range harvest planning.

Forest management can affect water quality and aquatic life, and riparian areas are both sensitive and easily disturbed. Streamside forest canopy removal allows direct sunlight to reach first- and second-order streams that were extensively shaded before timber harvest. Direct sunlight can increase stream temperature, which effects fish and aquatic insect species composition and growth (Feller 1981). Temperature also affects water quality parameters such as dissolved oxygen and the waste assimilation capacity of a stream.

The effects of logging on stream temperature have been the subject of considerable research and numerous reviews (Brett 1956, Brown 1969, Patton 1973, Anderson and others 1976). Direct solar insolation was found to account for at least 90 percent of a stream's temperature change after clearcutting (Brown 1970). Salmon (*Oncorynchus* sp.), brown trout (*Salmo trutta*), and brook trout (*Salvelinus fontinalis*) prosper in streams that are between 10° and 18°C, and if water temperatures exceed 24°C they may die, depending on acclimation temperatures, pH, and dissolved oxygen (Patton 1973). The replacement of these high-value, cold-water fish species by warm-water fish has been associated with timber harvest.

Early research determined that an important shading and sediment filtering role was played by the vegetation along channels, and this area was termed a buffer strip (Patton 1973). Management agencies have incorporated this concept by establishing special management areas along active stream channels that include the riparian zone and some amount of the adjoining hillslope. Limited.

harvesting may be allowed in these streamside management zones (SMZ), which may vary in width depending on hillslope angle. Although equipment entry into the SMZ is discouraged, the restrictions do not prevent the removal of shade-providing vegetation from riparian zones. In addition, the Pacific Southwest Region (California) of the Forest Service, U.S. Department of Agriculture, has established Best Management Practices (BMP), which state that no adverse temperature impacts should occur to streams during harvests. The actual effectiveness of SMZ restrictions and other BMPs is not known due to the lack of detailed or long-term monitoring.

Early efforts to predict stream temperature changes focused on predicting the maximum temperatures associated with peak summer conditions and low flows (Brown 1969). These early models were based on temperature changes caused by full exposure of the stream reach to the sun at the peak sun angle. By combining the site's latitude with field measurements such as stream temperature, channel width, depth, flow velocity, and an estimate of shading with estimates of potential cover reduction, likely temperature increases can be quantified. The estimated change in temperature, when added to the pre-harvest water temperature, provide an indication as to whether post-harvest temperatures might exceed the lethal limit for the resident fish.

Other modeling approaches include empirical models that are calibrated for one geographic region, or detailed simulation models that require extensive data pertaining to the reaches to be modeled (Schloss 1985, USDA Forest Serv. 1984). The Schloss model is typical of a regression model and was developed in western Oregon to predict maximum summer temperature based on elevation, distance above the main channel, stream order, and shading. The USDA model was developed by the Forest Service to simulate stream temperature

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response to multiple alternative harvest areas in a basin. It is a physical, energy budget-based algorithm, and has a time step that can range from 15-minute to hourly or daily intervals. Both direct and indirect (diffuse) shading is incorporated, as is stream aspect, topographic shading, groundwater influx and temperature, and flow into and out of the reach. The stream network is represented by sequentially estimating the outflow water temperature in each reach and using that information as the inflow temperature in the next downstream reach. A significant advantage to this model is its ability to handle partial shade, but obtaining the copious input data requires considerable field work.

This paper reports on field work at two streams in California that evaluates Brown's stream temperature change prediction technique and an empirical equation developed in Oregon (Brown 1970, Schloss 1985). Both partial and complete riparian vegetation removal are analyzed. A modification of Beschta and Taylor's (1988) phased vegetation recovery system is proposed as part of a multireach accounting system for basins with multiple cutting areas.

Temperature Prediction

Model Selection

Model selection should be based on the size of the area of concern and on the intended use of the water temperature prediction. Because the typical forestry use is to assess the effect of timber harvest, grazing, recreation, or road construction on large land areas, the complex and data-hungry physical simulation models are inappropriate. Empirical (regression) models may be appropriate if one has been developed for the local area of interest. In most cases, however, a relatively simple model based on the physical processes relating stream surface exposure to sunlight is most appropriate.

Exposed Surface Models

Exposed surface models combine a few crucial types of field data with tabular data dependent on site location (Brown 1969). This type of model uses only physical constants and field measurements, so it is not an empirical, "calibrated" model. Changes in water temperature T(°C) increase directly in relation to new stream surface area A (m^2) that is exposed and insolation N (cal/cm^2-min), and inversely with streamflow Q (m^3/s):

$$\Delta T = \frac{AN}{Q} * .000167 \qquad (1)$$

The coefficient contains the constants for the conversion of the flow, area, and insolation units to temperature.

Because this model predicts a change in temperature, pre-project temperatures should be measured wherever harvests are planned. Streams should be visited during California's low flow and peak heat times of July, August, and September. A simple pocket thermometer could yield representative data for several small basins with a moderate amount of effort, using measurements taken between noon and 1500 hours. Peak temperatures occur due to the interaction of declining streamflow and insolation, in spite of the decline of insolation after June 21.

The parameter A reflects the new channel area that will be exposed due to forest harvest, but topography, channel aspect, and harvest design also have a role in determining A, so subjective judgments may be needed. If 35 percent of the cover in a 100 m zone along the southside of a channel is to be removed, it may be reasonable to equate this to complete removal from about 30 m of channel.

Table 1 — Average values of net solar radiation absorbed by water surfaces in middle latitudes for a range of exposure times (cal/cm^2-min) (after List 1951, Brown 1974).

Water Travel	Latitude (degrees)		
Time (hours)	35	40	45
2	1.30	1.28	1.22
4	1.25	1.22	1.17
6	1.19	1.14	1.11
8	1.09	1.06	1.00

Solar loading N is dependent on season, latitude, and the length of time that the water is in an exposed area. California's National Forests range from 34° to 42° latitude, so N values for the appropriate latitudes have been estimated (table 1). N values could be reduced by about 1 percent for each week after July 1 to account for the seasonal decrease in insolation, but such minor adjustments are probably not warranted due to the inherent errors in area and discharge estimates. The travel times for the 160 m to 400 m openings typical of National Forest System operations and stream gradients are between 1 and 2 hours, so the N values for 2 hour travel times in table 1 should be used for most small streams.

The final requirement for equation 1 is discharge volume, and small mountain streams are difficult to gauge