***Review #3* - Dr. William C. Krueger, Department Head Rangeland Resources, OSU - 8/3/99**

The enclosed review deals primarily with the shade component of the Heat Source model and the ecological validity of the model's shade parameters.

1. The author indicates on page 18 that two parameters control the effectiveness of shading for stream temperature management. These two parameters are vegetation density and the length of the path through the vegetation buffer that solar radiation must travel. The text is unclear on the definition of vegetation density, one must assume density is the canopy coefficient (CC) defined on page 21. The text indicates that the value of the CC is determined by (1) estimation by the model user or (2) model solution by use of energy relationships. Apparently the validity of the CC has never been determined through actual measurement. The second method of determining the value for this coefficient indicates that the parameter is used for the purpose of fine tuning the model. Canopy attenuates and / or scatters incoming solar radiation. The Heat Source model also utilizes the concept of canopy transmissivity as defined by Beschta and Weatherred (1984). The canopy transmissivity coefficient is defined as TC + 1- 0.9 CC where CC is the canopy cover coefficient. The calculation of vegetation attenuation f incoming solar radiation is modeled as TC raised to the average length of the path through the vegetation buffer. Heat Source does not provide an explanation for the equation nor does the cited source. I assume this equation is derived from Beer's law governing the transmission of short-wave radiation through a substance. The decay of the flux with distance into stand of vegetation has been found to follow an almost logarithmic decay with depth of penetration. I must assume the average path length of the sun somehow relates the extinction coefficient in Beer's law along with the term representing the leaf area accumulated from the top of the canopy down to a specified level. Does it? This relationship is not specified, referenced or clarified within the text. Further explanation of this relationship as modeled in Heat Source is warranted.
2. Sensitivity analysis of the model parameters indicated that the canopy density parameter has the highest degree of sensitivity with respect to all model parameters for both positive and negative changes in stream temperature when the shade angle is 90 degrees. However, when the shade angle is 45 degrees the sensitivity of canopy density is quite low. For negative changes in stream temperature the vegetation shade angle is 90 degrees. However, when the shade angle is 45 degrees the sensitivity of canopy density is quite low. For negative changes in stream temperature the vegetation shade angle ranks as the third most sensitive parameter. The sensitivity analysis provided in the Heat Source document indicates that a –50% change in density resulted in a 182% change in temperature and that a +50% change caused a –190% change in temperature. The extreme sensitivity to a parameter that is neither defined nor field validated is disconcerting. Furthermore, with a shade angle of 90 degrees, a density value of .60 results in no stream temperature change and density values of .80 and 1.0 actually result in a decrease in stream temperature.
3. The model validation data presented in the Heat Source text emphasizes the random nature of the values assigned to the canopy coefficient, which is a critical importance when shade angles are greater than 45 degrees. The site description of Moore Creek located near Corvallis indicates that the stream side vegetation is dominated by a tall grass (3ft). Given the moist, mild growing conditions in the Willamette Valley this tall grass probably forms a dense vegetation buffer along Moore Creek. The simulation run for this creek indicates a vegetation shade angle of 59 degrees and a canopy coefficient of .20. On the other hand, Bear Creek in central Oregon is described as having one-foot tall grass, a shading angle of 24 degrees and a canopy coefficient of .30. Given the definition of canopy coefficient provided earlier we do not believe that a sparse, one foot tall buffer of grass can attenuate 10% more incoming solar radiation that 3 foot tall dense buffer of shading level and was assigned a vegetation angle of 40-70 degrees and a CC of .40 only 10% greater than the sparse grass type found at Bear Creek.

4. This apparent discrepancy in the stated definition of the canopy coefficient and its actual application suggests a serious problem in the model. Given the sensitivity of the model to this coefficient every effort should be used to assign meaningful, ecologically defined values for these shade parameters. It is obvious that this coefficient is being used to improve the fit of simulated values regardless of whether the value assigned meets the stated definition. Given the fact that this model is being used to set management goals for streamside vegetation through the TMDL process, every effort should be made to use ecologically attainable and ecologically definable parameters. The fact is the buffer density with the current manual. Until this apparent discrepancy is clarified, this model should not be used for vegetation goal setting.

Pertinent notes and references

Brazier, Jon R. and George W. Brown. 1973. Buffer strips for stream temperature control. Research Paper 15, School of Forestry, Oregon State Univ., Corvallis, OR. Pp. 1-8

Brazier and Brown (1973) stated that the relationship between buffer strip width and the effectiveness of the strips in shading stream is a complex interrelation of canopy density, canopy height, stream width, and stream discharge. On small streams the authors found the relationship between heat blocked and strip width to be asymptotic, leveling out at a width of 30ft. The quickness with which the relationship approaches some asymptote is a function of the type of vegetation contained in the strip. Vegetation such as salmonberry provides only a narrow band of shade along the stream because of its height. Strips wider than this narrow section should not improve shading effectiveness. Trees generally have canopies of lower density than species such as salmonberry and, thus require more space to provide the same shade. Furthermore the authors found that for small streams the angular canopy density reached a maximum within a width of 80 feet and that 90 percent of maximum is reached within 55 feet (17 meters). The authors conclude that buffer strip width alone is not an important criteria for control of stream temperature. ACD correlated well with stream-temperature control and was found to be the only criterion necessary for designing buffer strip width.

Steinblums, Ivars J., Froehlich, Henry A., and Joseph K. Lyons. 1984. Designing Stable buffer strips for stream protection. Journal of Forestry. January 1984 p.49-52.

Steinblums et. Al. (1984). ACD of 28 shade providing strips ranged from 15-87 percent. In 12 strips bounded on the south by uncut forest, it ranged form 26-83 percent. When ACD was regressed against width, original basal area of the timber in the strip, slope of the streambank and slope of the clear-cut adjacent to the strip a statistically significant relationship was obtained: R sq. of .56. The relation of ACD to buffer-strip width alone was curvilinear with and R sq. of 0.51. It should be noted that only 2 buffer strips were less than 40 ft in width. The 25 ft buffer width provided a higher ACD than 10 of the 11 buffers of 40 to 60 ft width and the 37ft buffer provided a higher ACD than 6 of the 11 and was greater than or equal to 8 of the 11. Buffer strips 18 m in width provided 90% of the maximum ACD.

Beschta, R.L., Bilby, R.E., Brown, G.W., Holtby, L.B., and T.D. Hofstra. 1987. Stream temperature and aquatic habitat: Fisheries and Forestry Interactions – Proceedings. Institute of Forest Resources, College of Forestry, Univ. of Washington, Seattle, Washington.

Literature review. The importance of a buffer strip for preventing increases in stream temperature can be determined by measuring its angular canopy density (ACD). ACD is a projection of the canopy measured at an angle above the horizon at which direct-beam radiation passes through the canopy. This angle is determined by the position of the sun above the horizon during the portion of the day (10am to 2pm) during which solar heating of the stream is most significant. The relative degree of shading provided by a buffer strip depends on species composition, age of stand, density of vegetation etc. Buffer strips generally are not good predictors of shade protection by themselves. Buffer strips with widths of 30m or more generally provide the same level of shading as that of an old growth forest. However, only 3 out of 34 data points had buffers equal to or greater than 30m. Eleven sites had buffers of 15 to 20m, 5 sites buffers of 20-25m, 2 sites with buffers of 25-30m and 3 sites greater than 30m.

The exact configuration and width of such buffer strips can be highly variable and site specific. In western Oregon, it appears that buffers strips 30m or more in width along small streams provide approximately the same level of shading as an old-growth forest.

Beschta, Robert. L and Jim Weatherred. 1984. Temp-84. A computer model for predicting stream temperatures resulting from the management of streamside vegetation. USDA-USFS, WSDG-AD-00009. Fort Collins, Colorado.

Heat Source references Temp-84 for solar radiation attenuation/scattering by vegetation. Beschta and Weatherred (1984) define canopy cover coefficient as the coefficient, which describes the amount of energy that is allowed to pass directly through the forest canopy without being intercepted by the canopy. It is used in the energy attenuation process when routing energy through the canopy. The canopy transmissivity coefficient is defined as TC = 1 – 0.9 CC where CC is the canopy cover coefficient for the appropriate side of the channel (0< or = CC < or = 1).

Vegetation Attenuation of incoming solar radiation is modeled as TC raised to the average length of the path through the vegetation. I assume this equation is derived from Beer's law governing the transmission of short-wave radiation through a substance. This is an example of flux convergence because the short-wave radiation incident at the surface is greater than that found at any depth below. The decay of the flux with distance into a stand of vegetation follows an almost logarithmic decay with the term representing the leaf area accumulated from the top of canopy down to a specified level somehow represented by the average path length of the sun. This relationship is not specified, referenced or clarified within the text.

Heat Source Report

P.18 states that two parameters will control the effectiveness of shading: stream side vegetation density and the path length through the vegetation by radiation. Density is not defined not appears to be used in any of the model equation. The reader must assume density is the canopy coefficient defined on p.21. The value of the canopy coefficient is determined by (1) estimation by model user or (2) model solution by use of energy relationships. Apparently this coefficient is never measured directly in the field.

Sensitivity analysis of the model parameters indicate that the canopy density parameter has the highest sensitivity of all parameters for both positive and negative changes in stream temperature when the vegetative shade angle is 90 degrees. When the shade angle is 45 degrees the sensitivity of canopy density is low. Vegetation shade angle ranks third in sensitivity with respect to negative temperature changes.

The sensitivity analysis indicates that a –50% change caused a –190% change in temperature. The extreme sensitivity to a parameter that is neither defined nor validated in the field is disconcerting. Furthermore, with a shade angle of 90 degrees, a density of value of .60results in no stream temperature change and density values of .80 and 1.0 actually result in a decrease in stream temperature which is not physically possible.

Model Validation

Model validation took place on a limited number of streams: 3 Flow rates of the three streams were very similar ranging from 0.8ft/sec. Volumes were 1.06 cubic feet per sec, .98 cubic ft, .81 cubic ft, 2.96 cubic ft, 13.4 cubic ft, .7 cubic ft. Probably most interesting is the description of the creeks;

Moore Ck stream bank vegetation consists of tall grass. Veg height 3 ft, CC=.20 Near Corvallis angle = 59degrees

Rock Ck. Stream bank vegetation not defined but is stated to provide high shading levels. CC-.40, angle = 40 – 70 degrees

Bear Ck. Stream bank vegetation consists of grass one ft in height CC=.30. Near Prineville angle =24 degrees

Klochman Ck stream bank vegetation consisted of well-spaced juniper trees and grass one foot in height. CC=.30, angle = 45 to 50 degrees

With the exception of one sampling day all simulations overestimated downstream temperature during the heating cycle by /125 to .75 degrees F. Most of the simulations underestimated nighttime cooling. Due to this patter R2 calculations appear quite high.

Site descriptions for Moore Creek located near Corvallis indicate "tall grass" bank vegetation. Although not identified by Boyd the grass probably is Reed Canarygrass or Tall Fescue, which grow quite dense along streambanks. It is interesting that this grass is assigned a lower canopy coefficient (.20) than the one-foot height, probably, Kentucky bluegrass type found along Bear Creek and Klochman creek in central Oregon. Rock Creek on the other hand was described as having high shade levels but was only given a canopy coefficient of .40. The fact that this coefficient along with shade angle is one of the most sensitive, with sensitivity increasing as shade angle increases, and the fact that there appears to be little consistency in the assigning of value to this coefficient suggests that the primary purpose of the canopy coefficient is to fine tune the model for fit. This is troublesome when model simulations are used to prescribe streamside vegetation management.

Zwieniecki, M.A. and M. Newton. 1999. Influence of streamside cover and stream features on temperature trends in forested streams of western Oregon. Wester J. of Applied Foresty, Vol. 14, No. 2.

Fourteen low-elevation streams were studied in western and northwester Oregon to determine the influence of streamside cover on stream temperature trends. Tree buffer width and density of cover provided by each buffer (measured by spherical densiometer) were of major interest. Buffer width above, within, and below each study site was measured to a maximum of 40 m. Cover provided by buffers was 78% within study sites (harvested units) and buffer width averaged 21.1m and ranged between 8.6 and 330.5m. Cover above and below treatment sites averaged 83% and buffer width averaged 34.1m and ranged from 21.9 to +40.0m. The densiometer trended to give readings of more than 70% even when buffers were fringes <10 m wide. Absolute water temperatures rose slightly and variably in the harvested units in most streams. However, absolute temperatures do not account for the rising trend of water temperature in fully covered streams with downstream direction and flow. Temperatures of all streams studied were fitted to the curves of low or high discharge streams with full cover. After subtraction of expected warming from observed change, streams with low flow rate in the harvest units showed a nonsignificant net warming of 0.21 C above the presumed uncut trend. After a modest degree of warming in the treatment units, stream temperatures in both categories decreased within the first 150m after leaving the treatment site. Harvest activity in the riparian zone has bee described as potentially leading to increases in directs radiation and therefore stream temperature (Hatten and Conrad

1995). It has also been suggested that heat inputs be translated downstream as cumulative effects (Beschta and Taylor 1988). This study did show a slight increase in rate of warming with exposure, however, the findings do not support the cumulative effect hypothesis that harvesting, with modest buffers and even gaps, leads to an accumulation of heat that persists 300 m below the harvest unit to a greater degree than expected from natural warming. Cover, as measured with a densiometer, was not significantly different within the harvested units. All streams were provided with narrow, sometimes intermittent, sometimes one –sided (south) strips of tree-dominant vegetation that substantially reduced direct radiation.

DEQ Response to Review #3 - Review Comments #1, #2, #3 and #4

These review comments, as well as points made by Bruce Cleland, EPA (Review #2, Solar Parameters) suggest canopy density should be handled differently. DEQ agrees. The reviewers correctly point out that the canopy coefficient is mislabeled as the canopy density. The canopy coefficient was developed by Beschta and Weatherred (1984) and successfully used in the temperature model TEMP86. However, there is no explicit transformation of the canopy coefficient to a field collected canopy density value.

Canopy density is preferred as model input because values can be measured in the field with a densiometer or remotely sampled from aerial photos. For this reason, DEQ has decided to replace the canopy coefficient and related methodology with algorithms derived from Beer's Law (Oke 1978) and employed by Chen (1996) in the model SHADE. This methodology relies on true canopy density values. The new methodology for calculating attenuation of direct beam solar radiation is presented below.

Shadow casting from riparian vegetation and the stream bank is calculated resulting in a percent stream surface shaded (i.e. 0% to 100%). For the portion of stream shaded, direct beam solar radiation is attenuated as function of path length through the vegetation and vegetation density.

Calculations of solar direct beam path length through riparian areas is performed via the following algorithms:

$$\text{Path}_1 = \frac{(W_{veg} + W_{hang})}{\sin(\theta_{azimuth}) \cdot \cos(\theta_{altitude})}, \quad \text{Path}_2 = \frac{(W_{veg} + W_{hang})}{\cos(\theta_{altitude})},$$

$$\text{Path} = \frac{(\text{Path}_1 + \text{Path}_2)}{2}$$

Calculations of the riparian extinction coefficient is performed via the following algorithms:

$$\lambda_{veg} = \frac{\ln(1 - \rho_{veg})}{H_{veg}}, \quad \rho_{shade} = 1 - \exp(-\lambda_{veg} \cdot \text{Path})$$

Calculations of the direct beam solar radiation after passing through the riparian area is performed via the following algorithm:

$$\Phi_{direct2} = \Phi_{direct1} \cdot \alpha_{shaded} \cdot (1 - \rho_{shade})$$

Where,

$Path_1$: First estimate of direct beam path length through vegetation (m)

$Path_2$: Second estimate of direct beam path length through vegetation (m)

Path: Direct beam path length through vegetation (m)

l_{veg}: Riparian extinction coefficient

r_{veg}: Riparian vegetation density (%)

r_{shade}: Shade density (%)

a_{shaded}: Portion of stream surface shaded (%)

H_{veg}: Riparian vegetation height (m)

$q_{azimuth}$: Solar azimuth (rad)

$q_{altitude}$: Solar altitude (rad)

W_{hang}: Vegetation overhang into bankfull channel (m)

W_{veg}: Vegetation width (m)

$F_{direct1}$: Direct beam solar radiation before entering riparian vegetation (cal m^{-2} s^{-1})

$F_{direct2}$: Direct beam solar radiation after exiting riparian vegetation (cal m^{-2} s^{-1})