Recommendations for Managing the Effects of Forest Practices on Stream Temperature in British Columbia

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Executive Summary

High stream temperatures are known to be a problem for fish during mid to late summer in some streams in B.C. The highest stream temperatures typically occur on clear days in late summer when streamflows are low and the sun is still fairly high in the sky. Direct solar radiation is the major source of stream heating so any source of shade has a moderating effect on temperature.

An important question in B.C. is the extent to which forest harvesting at mid to upper elevations can increase stream temperatures in valley bottoms. The scientific literature indicates that stream temperature is most elevated at the downstream end of the reach having reduced shade and that this is most evident in the maximum daily temperature. Several factors tend to cool a warmed stream if it flows back into a forest. For example, longitudinal dispersion and ongoing heat exchanges with the atmosphere will cause its maximum daily temperature to decrease downstream unless the amount of solar radiation falling on the stream is maintained. Therefore, the importance of shade in moderating the maximum daily temperature at any given point on a stream decreases with increasing distance upstream.

Another important point is that increases in maximum daily temperatures in a number of tributaries in a watershed are not cumulative downstream due to both longitudinal dispersion within streams and differing travel times from those streams to a point on the mainstem. However, the removal of riparian vegetation can also increase mean daily stream temperature and if it does so on several tributaries, the increases can be cumulative downstream.

A variety of tools exist for predicting changes in stream temperature as a function of changes in stream shade. These have not been adequately tested in B.C. but are potentially valuable as management tools. In contrast, there is no systematic way to determine the impact of a given temperature change on fish nor is there an objective way to determine whether a stream should be designated “temperature sensitive”. At present, this is a judgement by local managers.

The Timber Harvesting Practices Regulation provides some qualitative guidance for managing S4, S5, and S6 streams which flow into temperature sensitive streams, however, it is unclear in its objective and means of achieving the objective. If applied literally and without regard to quantitative effects, it could result in highly variable costs per unit of benefit. This report offers a recommended framework for implementing the Regulation logically and quantitatively. The key is to identify streams where temperature is a forestry issue and to manage shade in those cases so that logging related temperature increases stay within locally agreed limits. The recommended methods are not limited to areas with temperature sensitive stream designation and could even assist in determining the need for such designation. However, before they can be easily implemented, they require the results of research which is not yet funded.

Opportunities for improving our ability to manage the temperature of streams have to do mainly with developing methods for predicting stream shade and predicting changes in stream temperature as a function of changes in shade. Projects designed to achieve these objectives and their estimated funding needs are described in the last section.

Introduction

Background

The scientific literature shows that the removal of riparian vegetation changes the energy budget of streams and that this tends to increase stream temperature in the summer. Warmer stream temperature is not necessarily harmful and increased stream temperature has even been shown to improve fish habitat in some cool streams on the Coast. However, there are streams in the Interior of B.C. which reach temperatures that are higher than the optimum for salmon, trout, and char. In such cases, there is a need to minimize increases in stream temperatures due to forestry activities.

The Riparian Management Area Guidebook (Anonymous, 1995) attempts to protect stream temperature by recommending reserve zones on S1, S2, and S3 streams and by noting that further protection may be required for "temperature sensitive streams". These are described as streams "… which may experience significant increases in water temperature following extensive removal of streamside vegetation" and streams that "have a large portion of the streamside vegetation removed".

Additional protection for such streams is described in Section 22 of the Timber Harvesting Practices Regulation (THPR) which state that "A person who harvests timber in a riparian management zone for a S4, S5 or S6 stream must retain a sufficient number of those streamside trees whose crowns provide the shade to the stream that is required to prevent the stream temperature from increasing if the stream is a direct tributary to a S1, S2, S3 or S4 stream that is a known temperature sensitive stream" (British Columbia, 1998).

Clearly, there is an intent to protect riparian vegetation of some streams more than others due to stream temperature concerns. However, the RMA Guidebook does not provide an objective way to determine whether a particular stream meets the temperature sensitive criterion and the THPR does not provide a clear means of implementation.

The RMA Guidebook suggests consulting with federal and provincial fisheries agencies for information on local watersheds. This is certainly appropriate but it does not address the ambiguity of the temperature sensitive stream definition. What is needed is an understanding of the factors that affect stream temperature and tools for managing the effects of forestry activities on stream temperature. There is much useful information in the scientific literature for addressing this but additional research is needed and a considerable amount of data are required for utilizing some of the available tools.

Objectives

The objectives of this report are to:

- summarize the effects of forest practices on stream temperature,
- describe tools for managing stream temperature in the presence of forest development,
- suggest a management strategy for dealing with streams where temperature is a fisheries issue,
- identify information gaps, and
- identify research and inventory needs.

Summary of Stream Temperature Literature

This section is based on reviews of the literature on the effects of logging on stream temperature (Teti, 1998) and the effects of stream temperature on fish (in progress). The former is available at www.for.gov.bc.ca/cariboo/research/hydro/index.htm.

Significance of Stream Temperature to Fish

Being ecothermic, or cold-blooded, fish body temperatures assume the temperature of the water they are in. They are only able to adjust their temperatures by moving into different water, an activity which is impossible for the less mobile life stages (e.g., eggs), and which may result in reduced survival for juveniles and adults. In the summer when logging-related increases in stream temperatures are of most concern, an increase in temperature above the levels to which a population is adapted can increase the stress on fish if temperatures are already above those which are physiologically optimum. This stress can result in increased frequency of disease, greater energy expenditures, alteration or inhibition of spawner and juvenile migrations, reduced spawning success, reduced juvenile growth, and mortality.

Temperature is one of the most basic properties of an organism's environment. Therefore, it is one of the major factors which define ecological niches and cause different species to have different geographic ranges and behaviors. For Pacific salmon, rainbow trout, and cutthroat trout, preferred water temperatures vary among species, and among different populations or "stocks" within the same species. Observed temperatures associated with different life stages and activities span broad ranges: 5 - 20°C for adult migrations, 4 - 14°C for spawning, and 5 - 15°C for juvenile rearing. For these widely distributed species, these ranges in temperature reflect adaptations to local conditions determined by geography and season. For example, summer-run adult chinook salmon encounter and tolerate higher temperatures (e.g., 13.9 - 20.0°C) than do spring-run chinook (e.g., 3.3 - 13.3°C).

The species that are most at risk from logging related heating are those which require cool streams in mid-to-late summer when streams tend to reach their warmest temperatures due to maximum solar heating.

Bull trout are of special concern because they require cold water (e.g., 2 - 7°C for spawning, and < 10°C for rearing) and have a geographic distribution that is susceptible to fragmentation partly as a result of these temperature requirements. There is evidence that an increase in average summer temperature of 2°C could have a serious detrimental effect on bull trout. Bull trout may be displaced from a stream reach by competing rainbow trout as a consequence of this increase even if the thermal shift is within the range of temperatures that bull trout prefer.

A 2°C degree increase in monthly average temperature is considered to be much more significant to fish than a 2°C increase in the daily maximum temperature. For example, bull trout have been observed in some streams where daily peak temperatures sometimes exceed 23°C, but tend to avoid streams where mean summer temperatures exceed 15 - 18°C.

The effects of adverse stream temperatures are greatest for those species which are obliged to use streams for rearing for long periods of time, for example, bull trout and some populations of rainbow and cutthroat trout. Coho salmon are also of special interest for several reasons, but particularly because of their long stream-residence period. Unlike pink, chum, or sockeye juveniles which usually migrate from streams shortly after they emerge from the streambed, young coho rear in streams for one to two years where they depend on protective cover provided by heterogeneous channel structure, pools, and overhanging vegetation. Temperatures that are lethal to coho (23 - 25°C) are slightly higher than those reported for pink, chum, sockeye, and chinook salmon (20 - 24°C), whereas temperatures that young coho reportedly prefer (11.8 - 14.6°C) are generally similar to those of the other species. Despite this similarity, maintaining the quality of freshwater rearing habitat for coho is of increased concern to fisheries managers because the abundance of many coho stocks have been greatly reduced in recent years due to a combination of factors including unfavorable ocean conditions and both commercial and sports fishing.

Any fish species present in streams where seasonal temperatures exceed their optimum or preferred ranges are considered to be potentially at risk from reductions in riparian shade both locally and in reaches upstream. In streams inhabited by coho salmon, bull trout, or other species that reside in streams for long periods, the particular significance and/or sensitivity of these species should be taken into account when considering TSS designation.

The Effect of Shade on Stream Temperature

The scientific literature clearly shows that the summertime temperature of a stream in a temperate forested environment tends to increase if riparian vegetation is removed. Temperature increases are not directly related to the amount of harvesting in a watershed in general but rather to the reduction in shade provided by riparian vegetation.

Stream temperature exhibits a large diurnal cycle during the summer due to the large amount of energy in sunlight. The highest instantaneous stream temperatures in the BC Interior typically occur on sunny days well after the spring freshet. The most frequently observed and largest effect of reducing riparian shade is an increase in the maximum daily stream temperature. There is less of a change in mean daily temperature, an important point as discussed in a later section. Figure 1 shows the temperatures of two streams in the Horsefly Forest District over a period of three clear days in late summer. One is an S5 stream draining an unlogged watershed in the ESSF and the other is an S2 stream draining mostly SBPS and SBS where it flows through an agricultural valley bottom. Maximum daily temperature occurred on the S5 stream at 1400 hrs and on the S2 stream at 1600 hrs, Standard Time.

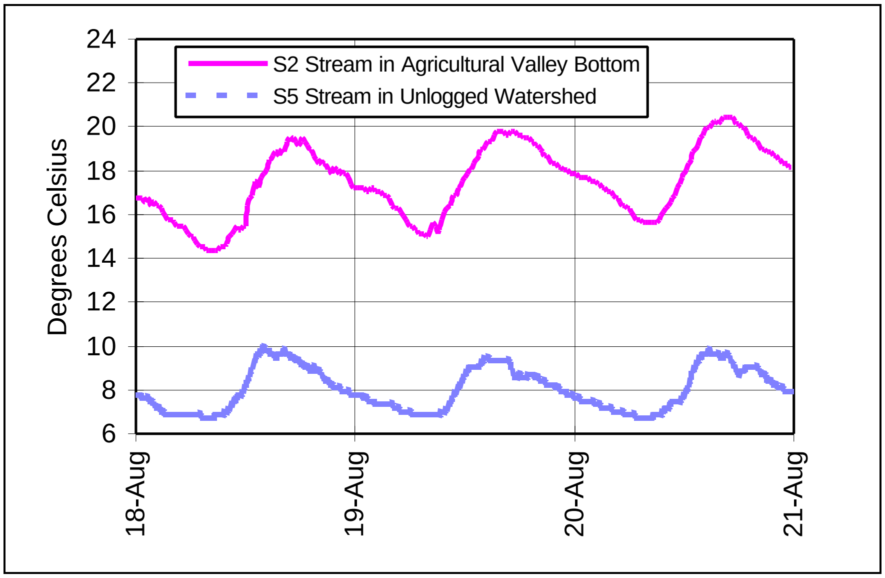


FIGURE 1. Sample diurnal cycles in stream temperature.

During the summer there are large heat fluxes into and out of a stream. These fluxes are indicated by the daytime heating and nighttime cooling typical of small to medium sized streams as shown in Figure 1. Beschta, et. al. (1987) described the heat balance per unit area of stream surface as

$$Nh = Nr + E + H + C$$

where Nh = Net heat exchange
Nr = Net radiation
E = Heat exchange due to evaporation and condensation
H = Heat exchange by contact with the air
C = Heat exchange by contact with the stream bed

They noted that the shortwave solar radiation component was by far the most important forestry related factor.

Mathematical models and empirical observations indicate that temperature increases may be prevented as long as stream shade is preserved by effective riparian buffers. Effective buffers are those which maintain stream shade close to natural levels in addition to resisting blowdown. The most cost effective buffers could be defined as those which provide the most temperature protection downstream per unit of timber left on site upstream. There are diminishing returns to be gained by having buffers that are wider than an optimum width or further upstream from a target reach than an optimum distance. The questions "how wide?" and "how far upstream?" encompass much of what is uncertain about the benefits of riparian buffers. These are discussed in more detail in later sections.

Buffer width itself is only an indirect criterion for preserving shade. A fixed width buffer on both sides of a stream is a simple specification but the amount of shade it provides varies with factors such as stream orientation, topography, and characteristics of native vegetation. Where a stream is oriented east-west, trees on the north side can provide very little shade. Therefore, fixed width buffers are not as efficient at minimizing stream temperature as are buffers designed to maximize the retention of shade, although buffers on the north side of a stream provide benefits other than shade, such as bank stability and overhead cover for fish. When addressing stream temperature concerns it is more useful to think of "buffer design" than "buffer width". The effect of shade on stream temperature is discussed in more detail under the section entitled "Temperature Change within a Reach".

Measuring Shade

A variety of methods are used for estimating the amount of shade provided by riparian vegetation but one of the more logical measurement recommended in the literature is a parameter called *angular canopy density*. This is defined as the percent canopy along that portion of the sun's path between 10 AM and 2 PM (local solar time) in mid to late summer as viewed from the water surface. Another way of defining it is "the amount of shade during the four hours at mid-day". However, this measurement is not in general use. Instead, it is common for shade to be approximated by less direct methods which have poorly documented accuracies. Shade is highly variable along a stream's width and length and any sampling procedure or approximation method needs to take this into account. Methods for measuring and sampling stream shade are currently being developed by the Ministry of Forests.

Recovery of Shade and Temperature over Time

As watersheds and stream channel networks accumulate a history of land use, the increase in shade associated with revegetation along previously logged streams becomes important. The time required for this "thermal recovery" depends on factors such as stream width and azimuth, flood plain and valley topography, and factors that affect riparian plant species and their growth rates. Two studies indicated that increased stream temperatures on the Coast lasted for 3 to 7 years. However, the time required for shade recovery has been estimated to be up to 20 years at higher elevations in the Oregon Cascades.

Incorporating thermal recovery into the long term management of stream temperature could be based on empirical relationships between stream shade and time since logging in different geographic areas. However, there is very little information in the literature which can be used to predict the long term recovery of stream shade or temperature as a function of convenient surrogate variables. More research is needed on this subject.

Changes in Temperature Downstream

The effects of timber harvesting on stream temperature have been studied in the State of Washington in the context of their forest practices regulations which set a maximum temperature of forest streams of 16.3 Celsius and a maximum increase in peak temperature of 2.8 degrees Celsius (Roberts, 2000). Using peak temperatures as their datum, Caldwell, et. al., (1991) concluded that the downstream effects of logging-related stream temperature increases in smaller, non-fish bearing streams may be small. This was attributed to a combination of factors - firstly, at an individual tributary junction, a small stream which has undergone a measurable temperature increase tends to be much smaller in discharge than the larger stream and the temperature increase tends to be undetectable within tens or hundreds of metres downstream. Secondly, the spacing of these tributaries along the fish bearing stream tends to be great enough that there is a very small cumulative effect. Thirdly, although not mentioned by the authors, maximum daily temperatures behave differently than mean daily temperatures in the way heated water can affect downstream reaches. Peak temperatures at upstream locations cannot be cumulative downstream because the peaks get attenuated as the water moves downstream due to longitudinal dispersion. On the other hand, increases in average daily temperatures can be cumulative.

Tributaries draining valley sides tend to be cooler than the mainstem in late summer, thus providing a beneficial cooling effect in late summer. They are also more likely to have average daily temperatures that are lower than the average daily air temperature. Therefore, the mean daily temperatures of these streams tend to increase in the downstream direction even without logging. A decrease in shade on such streams will cause both the maximum daily temperature and the mean daily temperature to increase by an additional amount. Although increases in maximum daily temperatures in tributaries due to logging would not be cumulative downstream, increases in mean daily temperature could be cumulative.

The Role of Lakes

Lakes represent a special case because they tend to be much wider than streams, therefore, their heat exchange with the atmosphere is relatively independent of riparian vegetation. Furthermore, their outlet temperatures can be relatively warm or cool in the summer depending on processes that are essentially absent in streams such as wind induced mixing and thermal stratification. Therefore, the potential effects of forestry activities upstream from a large lake on temperature downstream from the lake are expected to be small.

Tools for Managing Stream Temperature

The RMA Guidebook discusses the objective of protecting the temperature of a stream by retaining shade along the stream reach. The THPR further addresses the objective of protecting temperature in some streams by also retaining shade on their tributaries. However, different physical processes need to be considered in order to understand the rationale and achieve these objectives. Tools for managing temperature change within a reach and temperature change at a tributary junction are discussed below.

Temperature Change within a Reach

With the exception of tributary junctions, spatial changes in stream temperature occur gradually due to the heat capacity of water. For example, a cool stream flowing from a forest into a clearcut on a sunny summer day will not display an instantaneous increase in temperature, but rather an instantaneous increase in the rate of temperature change per unit of length of channel. The rate at which a stream's temperature can change per unit of length of channel varies inversely with stream depth and velocity. Two implications of this are:

- Stream shade can be averaged over a reach even though shade may be highly variable over short distances. The appropriate length of a reach on a small channel in a road ditch might be tens of metres while a reach on an S2 stream might be as much as several kilometres.

- A given length of stream may be too short for its temperature to fully reflect the potential effects of a change in conditions. For example, if a stream flows from a forest into a clearcut and is exposed for a length of say, 100 metres, its daily maximum temperature on a clear summer day may still be increasing at the 100 metre point. It is also important to note that a downstream increase in maximum daily temperature in a clearcut may be partly due to the stream not being in equilibrium with the atmosphere at the upstream end of the clearcut. For any given stream undergoing a downstream change in temperature under constant riparian conditions, its change in temperature per unit length of channel will approach zero in the downtream direction.

The following sections describe several stream temperature models with a wide range of data requirements.

Brown's Model

One of the simplest models for predicting stream temperature changes in response to logging was developed by Brown (1970). His method predicts the increase in maximum daily stream temperature as a function of the minimum expected summer discharge, the surface area of the stream that will be exposed to the sun by harvesting, and some simple solar radiation values. Brown claimed an accuracy of about 3 Fahrenheit degrees (1.7 Celsius degrees).

This model assumes that peak daily temperature is driven entirely by direct solar radiation, therefore, it is logical to use it to predict changes in maximum daily temperature as a function of changes in sunlight along a stream reach. Figure 2 provides sample calculations for an S5 creek based on shade and channel geometry data in a block about 5 years after logging. Shade was measured to be 60 percent in the forest upstream from the clearcut and 20 percent within the clearcut (as Angular Canopy Density). This decrease in shade corresponds with an increase in sun from 40 percent to 80 percent along the reach which was used as the model input.

Figure 2 shows the model predictions which were calculated by adding the predicted increase in maximum daily temperature to the actual maximum daily temperature where the stream entered the clearcut. Actual maximum daily temperature at the bottom of the clearcut on a sunny day in August was 11.8 compared with 23 degrees predicted. No conclusions can be drawn from this single test of the model but clearly, it should be used with caution. In this example, it greatly overestimates the rate of change of temperature per unit change in shade as well as the actual daily maximum stream temperature. In a comparison of stream temperature models, Sullivan, et. al. (1990) judged Brown's model to have low accuracy but to be useful due to its simplicity.

SSTEMP (Stream Segment Temperature Model)

This model was developed by the US Geological Survey and is characteristic of a class of stream temperature models which represent all of the major heat transfer processes between a stream and its environment. These models are more accurate but also have considerably greater input data requirements than Brown's Model. There are a number of models in this category but they are not as readily available as SSTEMP which is in the public domain and can be downloaded from the worldwide web.

SSTEMP predicts both maximum daily and mean daily temperature at the downstream end of a reach as a function of a large number of reach characteristics. However, many of the inputs can be estimated for scenarios which are of interest for planning purposes, such as the relatively simple conditions that occur on warm clear summer days when stream discharge is low and the highest stream temperatures occur. The stream shade variables can then be manipulated to estimate the effects of the removal or recovery of riparian vegetation on stream temperature. Because it predicts mean daily temperature in addition to maximum daily temperature, this model can be used to estimate both local and downstream temperature changes associated with a given amount of vegetation change.

As shown in Figure 2, SSTEMP was not significantly better than Brown's model at predicting daily maximum temperature. However, it may be good at predicting changes in mean daily stream temperature per unit change in shade as indicated by the reasonable slope of the solid line in the Figure.

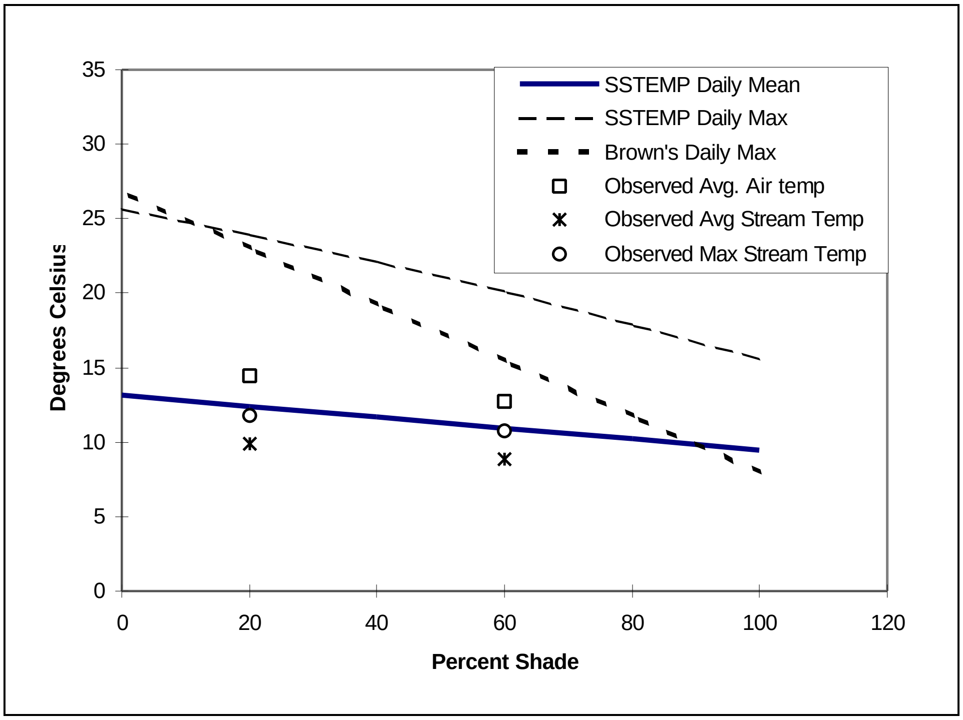


FIGURE 2. Observed stream temperatures at upstream (60 percent shade) and downstream edges (20 percent shade) of a clearcut compared with temperatures at bottom of clearcut predicted by two models. The points for comparison are the three daily maxima at 20 percent shade.

It should be noted that this may not be a fair test of SSTEMP because of the way it extrapolates conditions upstream for reaches that have a travel time of less than 24 hours, as explained in its documentation. It may be more accurate on larger streams and Sullivan, et. al. (1990) got better results. They noted that stream temperature models in general may have difficulty with small streams and also that SSTEMP and other models are particularly sensitive to air temperature.

Washington Temperature Screen

Sullivan, et. al. (1990) proposed an empirical method for determining the temperature sensitivity of streams in the state of Washington. Their temperature criterion was a maximum daily temperature target of 15.6 degrees Celsius. They suggested that maximum daily temperature was a function of shade and elevation as shown in Figure 3. Although there is a good basis for thinking that such a relationship exists, the authors did not report significance tests and the large amount of scatter suggests that the validity of the model remains to be demonstrated. Nevertheless, their results may be appropriate for their management objective.

This approach might be useful for helping to determine the temperature sensitivity of streams in B.C. if combined with fish species information but this requires more research. For example, there is preliminary evidence that stream temperatures in poorly drained uplands of the Interior Plateau may be higher than stream temperatures at mid-elevations (Henderson, 2000), thereby complicating the relation between temperature and elevation. It would be worthwhile investigating these relationships as part of a more general study on the effects of physical geography on stream temperature. There is considerable opportunity for inventory and research in obtaining data for empirical models and the testing of process based models.

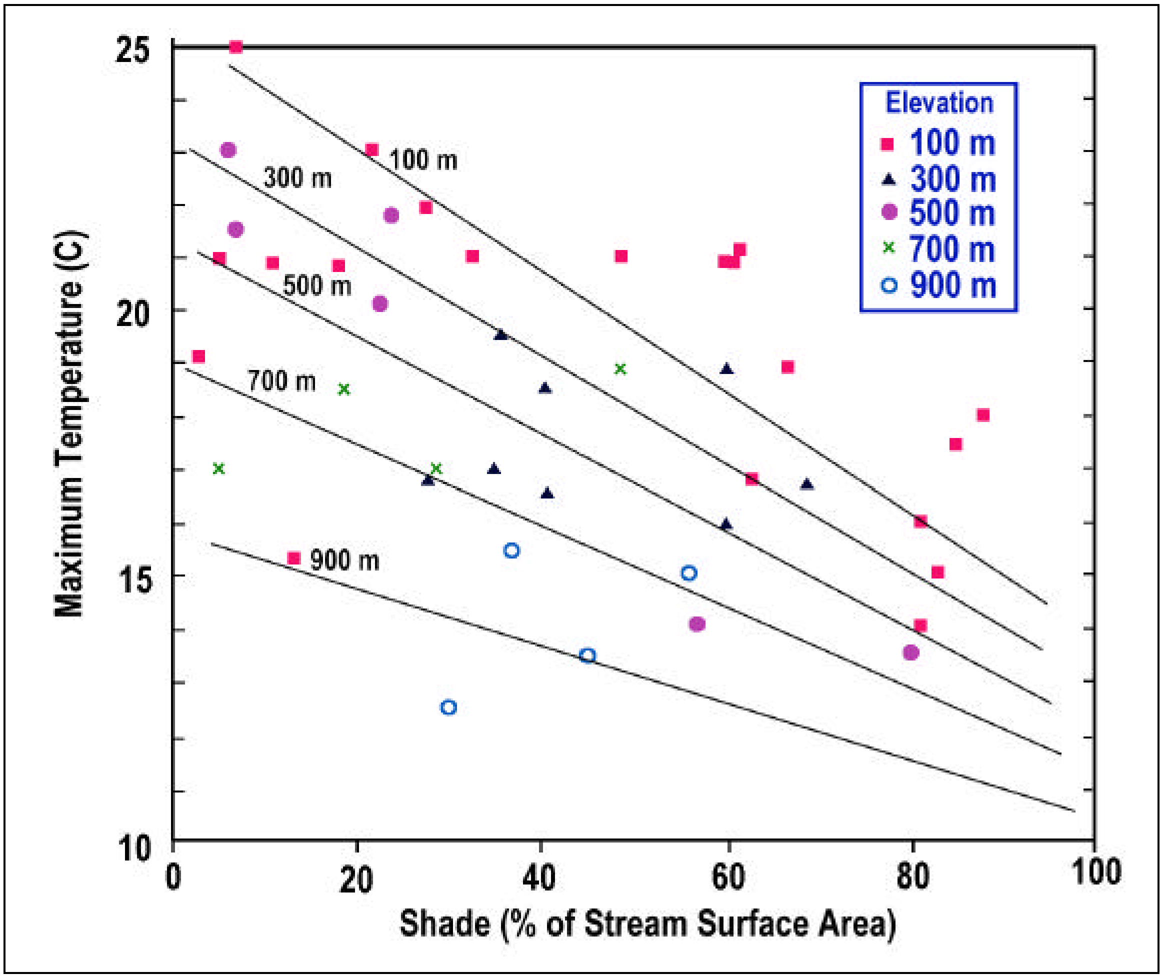


FIGURE 3. The empirical model termed “Washington Temperature Screen” by Sullivan et., al, 1990

Temperature Changes Due to Tributaries

A tributary junction is a unique fluvial environment due to the mixing of different waters. The situation is most distinct when the biological habitats and physical characteristics of the two streams are most different, for example, when a non-fish bearing stream enters a fish bearing stream.

Section 22(1) of the THPR says that the temperature of an S4, S5, or S6 stream that flows into a TSS should not be increased by logging. The fact that S5 and S6 streams are included implies that there is a desire to protect the temperature of the TSS at or below the junction rather than the S5 or S6 stream itself. Therefore, the application of the THPR to S5 and S6 streams involves considerations of what happens to stream temperature at and below a tributary junction.

The significance of a non-fish bearing tributary to a larger fish bearing stream has to be either in providing a local cool water refuge and/or a general source of cool water downstream. The importance of a cool water refuge is a site specific issue that should be addressed locally. If a non-fish bearing stream has a high value for this reason, then it would be logical for its temperature to be protected as if it were an S4 stream. If, however, it simply provides a general cooling effect downstream, then the amount by which its cooling effect might be diminished by logging should be calculated because this is relatively simple and it may rule out temperature concerns in some cases. Distinguishing between these two roles of an S5 or S6 stream is important because it can make a big difference in the most logical course of action.

This section address the effect of a tributary on the temperature of a larger stream. It shows that the effect of a temperature change in a tributary on the temperature of a larger stream after mixing depends on their relative sizes.

The temperature of a stream below a tributary junction after mixing has occurred is well defined because the heat content of water is essentially constant over a short time period. The amount of heat in a container of water is the product of its temperature and mass. However, a stream is constantly moving and its mass is represented as volume per unit of time. Its rate of heat transport is therefore the product of temperature and discharge.

Heat transport by a stream = Temperature * Discharge
and
Heat transport below a junction = Heat transport in Stream 1 + Heat transport in Stream 2

Using symbols this takes the form,

$$T_3*Q_3 = T_1*Q_1 + T_2*Q_2$$

where Q_1 and Q_2 are the discharges of two streams above a junction, with temperatures of T_1 and T_2 respectively. Because $Q_3 = Q_1 + Q_2$, the temperature of the mixed stream below the junction is defined by

$$T_3 = (T_1 * Q_1 + T_2 * Q_2) / (Q_1 + Q_2)$$

The amount by which the maximum daily temperature of a stream can be increased due to logging is normally limited to a few degrees but may be as much as 10 or more Celsius degrees in extreme cases. Using this range and an estimate of the relative amounts of discharge in the two streams, the effect of a temperature change in the tributary on the temperature of the larger stream can be calculated. As a first approximation, the ratio of discharges in the two streams can be assumed to be equal to the ratio of their respective drainage areas.

For those cases in which the temperature of a tributary is a concern only because it provides a general cooling effect downstream, it is useful to consider the actual temperature changes that would occur due to temperature changes in the tributary. As described above, the effect of a temperature change in a tributary on the temperature of its mainstem can be calculated as a function of the relative amount of flow in the two streams and the magnitude of the temperature change in the tributary. Using the example in Figure 4 as a basis for estimating discharges, the ratio of Q_1 to Q_2 at the mouth of Stream A is 3.49 and the ratio of Q_1 to Q_2 at the mouth of stream B is 8.18. The effect of a temperature change in either tributary on the temperature of the mainstem is inversely proportional to these ratios.

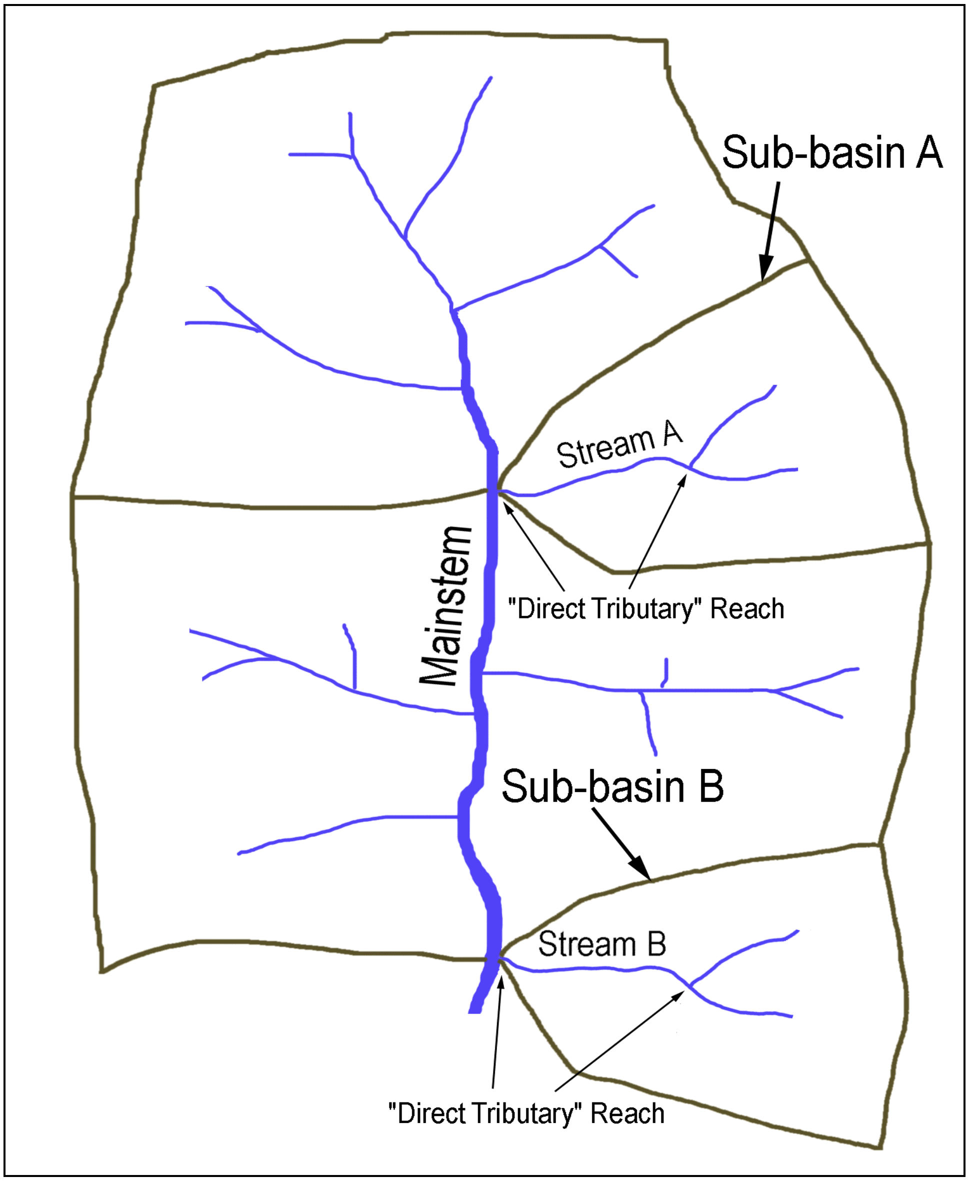


FIGURE 4. Sample watershed with labelled sub-basins “A” and “B”

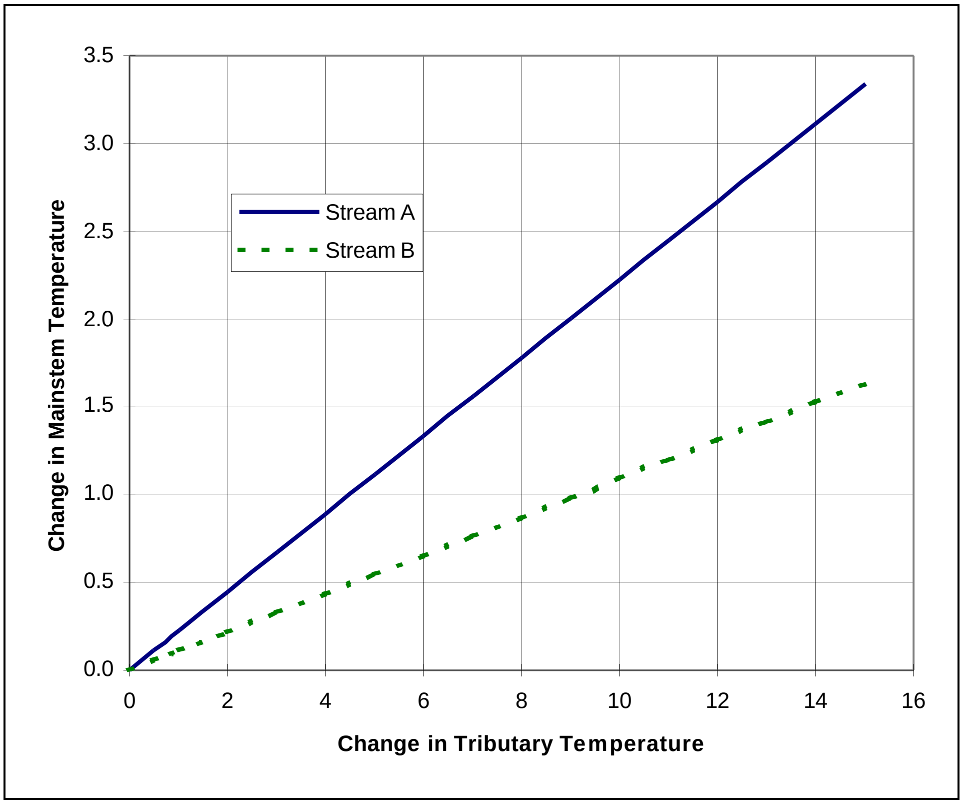


FIGURE 5. Changes in mainstem temperature as a function of temperature differentials in tributary streams A and B.

Figure 5 shows the effect of temperature changes in streams A and B on temperature in the mainstem below the junctions. It illustrates how much more sensitive the mainstem is to temperature change in stream A than it is to the same temperature change in stream B. This would have important implications for managing tributary shade for protecting mainstem temperature as discussed below.

Suppose that a certain amount of riparian logging is being contemplated along either stream A or stream B and that in both cases logging would cause a temperature increase of 2 degrees in the daily mean temperature. Using the relationship described above and illustrated in Figure 5, the effect of either of these harvesting scenarios on the temperature of the mainstem can be calculated. A two degree increase in the temperature of stream A would increase the mainstem temperature by 0.4 degrees, but the same temperature increase in stream B would increase the mainstem temperature by only 0.2 degrees. This effect needs to be considered in context with the equilibrium concept. If the large stream is in equilibrium with air temperature, then the amount by which its mean temperature is elevated would drop in the downstream direction and would not be simply additive.

Table 1 and Figure 6 provides more examples of the effect of tributary temperature on mainstem temperature as a function of temperature change in a tributary and the ratio of discharges in the two streams. It shows for example, that if the discharges of two streams differ by a factor of 20 or more, the tributary temperature has to change at least 4 Celsius degrees in order to cause a barely detectable change of 0.2 Celsius degrees on the temperature of the mainstem below the confluence.

This method can also be used to calculate the reduced cooling effect of a cold tributary that has been warmed by logging. For example, if a tributary has 1/20th the discharge of a mainstem and is 7 degrees cooler instead of 10 degrees cooler (3 degree change) than the mainstem as a result of logging, then the cooling effect on the mainstem will be reduced by 0.1 degrees.

TABLE 1. Change in mainstem temperature as a function of tributary temperature and discharge ratios

	Ratio of Mainstem Discharge to Tributary Discharge before Mixing (Q_1 / Q_2)					
	2	**10**	**20**	**100**	**200**	**1000**
DT_2 **(1)**						
1	0.3	0.1	0.0	0.0	0.0	0.0
2	0.7	0.2	0.1	0.0	0.0	0.0
3	1.0	0.3	0.1	0.0	0.0	0.0
4	1.3	0.4	0.2	0.0	0.0	0.0
5	1.7	0.5	0.2	0.0	0.0	0.0
6	2.0	0.5	0.3	0.1	0.0	0.0
7	2.3	0.6	0.3	0.1	0.0	0.0
8	2.7	0.7	0.4	0.1	0.0	0.0
9	3.0	0.8	0.4	0.1	0.0	0.0
10	3.3	0.9	0.5	0.1	0.0	0.0
11	3.7	1.0	0.5	0.1	0.1	0.0
12	4.0	1.1	0.6	0.1	0.1	0.0
13	4.3	1.2	0.6	0.1	0.1	0.0
14	4.7	1.3	0.7	0.1	0.1	0.0
15	5.0	1.4	0.7	0.1	0.1	0.0

(1) DT_2 = Temperature differential in tributary. This can be either the difference in temperatures between the two streams or the change in tributary temperature over time.

It should be noted that mixing of two streams requires some distance and this can be many channel widths for wide shallow streams. As discussed previously, if cool water at the mouth of a tributary is locally significant to fish, then the effect of tributary heating cannot be addressed entirely by the mixing relationship described above. The identification of this type of microhabitat is a local issue, however, a recommended approach for managing a stream of this type is described in a later section.

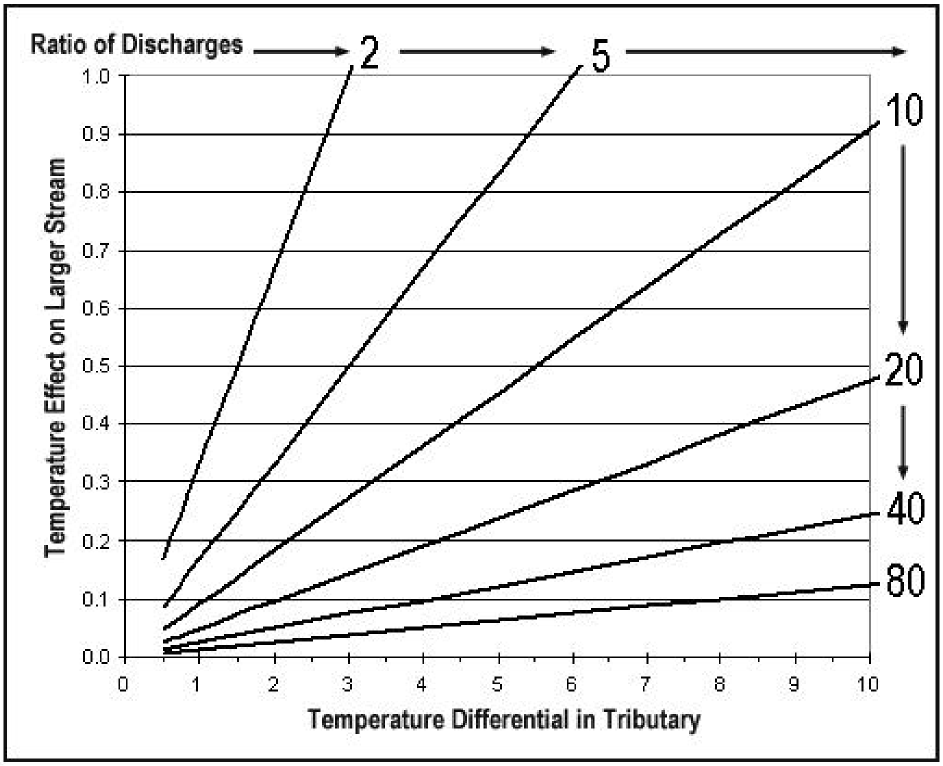


FIGURE 6. Change in mainstem temperature as a function of tributary temperature and discharge ratios.

Temperature changes in a mainstem due to tributary inflows are not simply cumulative downstream because a stream is constantly exchanging heat with the atmosphere. As noted in a previous section, researchers in Washington concluded that the small sizes of non-fish bearing tributaries in relation to the mainstem and the spacing between them tends to make cumulative effects on peak temperatures relatively insignificant.

Another factor which they did not mention is that it is impossible for increases in peak temperatures, which they were looking at, to be additive downstream. There are two reasons for this:

1. The average travel times of water from different tributaries to the same point on a mainstem can differ by hours. This causes average travel times from different tributaries to differ. Therefore, the peaks are out of phase.
2. The velocity of water passing through any given channel cross section is actually highly variable due to hydraulic resistance and turbulence. Therefore, a heat pulse associated with the peak daily temperature at any given location becomes longitudinally dispersed as it travels downstream, thereby reducing its amplitude.

The net effect is that maximum daily temperature is a local phenomenon and is most dependent on conditions a relatively short distance upstream. This distance probably corresponds with a travel time in the order of a few hours. More research is needed on this subject. An important implication is that it is impossible for increases in maximum daily temperature in tributaries to be cumulative at the watershed scale. However, changes in mean daily temperature do have the potential to be cumulative.

It is recommended that where there is a temperature concern regarding forestry activities along a small stream which flows into a large stream with high temperature, the temperature mixing model be used as a screening tool to determine the potential value to be gained by TSS designation.

Implementing the THPR

A Cautious Approach

The THPR states that sufficient shade should be retained on a direct tributary of a TSS to prevent the temperature of the tributary from increasing. However, implementation problems may arise because the Regulation does not provide any quantitative guidance and because its objective is not consistent with its scope.

The scientific literature indicates that logging in a watershed will not cause stream temperature to increase if the logging does not decrease stream shade. The literature also suggests that stream shade can be preserved by retaining 10 to 30 metre wide reserves on both sides of a stream. The width of the buffer required to maintain shade varies with stand characteristics and geography. Therefore, one interpretation of the THPR might be to leave either a generous fixed width buffer, or a buffer delineated on the ground to preserve shade along the “direct tributary” (the lowest order reach of the tributary) while also ensuring its windfirmness.

Unfortunately, this would not ensure that the temperature of the tributary did not increase because the length of channel upstream where a decrease in shade can cause an increase in temperature is not necessarily limited to the lowest order reach. Therefore, the objective of the Regulation, which is to prevent a temperature increase, cannot be ensured by its geographic scope, which is the highest order reach only. Cautious interpretation of the THPR would therefore seem to require that shade be retained, either by site specific design or by wide, fixed width, windfirm buffers along the entire tributary system that flows into the TSS, not just the highest order reach.

A Recommended Approach

A rational interpretation of the THPR suggests that different standards should be considered for the different stream classes because the biological issues differ. Different scenarios follow from the fact that the Regulation applies to both fish bearing and non-fish bearing streams. A fish bearing stream may be assumed to have an intrinsic value whereas a non-fish bearing stream has an indirect value. It is suggested that the value of a non-fish bearing tributary is in either providing a local thermal refuge where it joins a fish bearing stream or in providing a general cooling effect downstream. These criteria - fish bearing versus non-fish bearing and thermal refuge versus general cooling effect can be used to rationalize the need for temperature protection of S4, S5, and S6 streams.

Scenario 1 - S4 stream.

If an S4 stream flows into a TSS or if the S4 has a high sensitivity of its own due to a combination of temperature and fish, then its shade should be managed to minimize stream temperature increases. This should be based on a method such as that described under Item 1 below.

Scenario 2 - S5 or S6 stream that creates a high value thermal refuge in a TSS.

If a non-fish bearing stream creates a high value thermal refuge in a TSS, then it is logical to manage it as if it were an S4 stream. It should be clearly stated whether the value of the thermal refuge is documented or if it is assumed, subject to later verification. The criterion should be that the biological value of the thermal refuge is comparable to that of an S4 stream.

Scenario 3 - S5 or S6 stream that provides a general cooling effect in a TSS.

The potential effect of logging a non-fish bearing stream under this scenario is that it could increase the temperature of the tributary and subsequently also increase the temperature of the fish bearing stream after mixing. This effect is governed by a combination of stream reach effects in the tributary itself, as in scenario 1, and mixing effects. It therefore requires the following steps:

1. Firstly, it is necessary to decide on a temperature parameter of interest such as the highest mean daily stream temperature in August. Secondly, changes in the temperature of the tributary are predicted as a function of changes in stream shade for different harvesting and revegetation scenarios. This requires stream shade data and either a process model (e.g. Brown's or SSTEMP) or an empirical model like the Washington temperature screen which does not exist for B.C. at this time. However, this could require a considerable amount of work by a hydrologist. One of the major purposes of the proposed research projects at the end of this report is to simplify the prediction of stream temperature changes under different scenarios.

2. Changes in the temperature of the TSS are predicted as a function of changes in the temperature of the tributary based on step 1 and an estimated ratio of late summer discharges of the two streams. It is necessary to decide on a maximum permissible change in the selected temperature parameter in the TSS, for example, an increase in mean daily temperature of no more than 0.2 degrees Celsius.

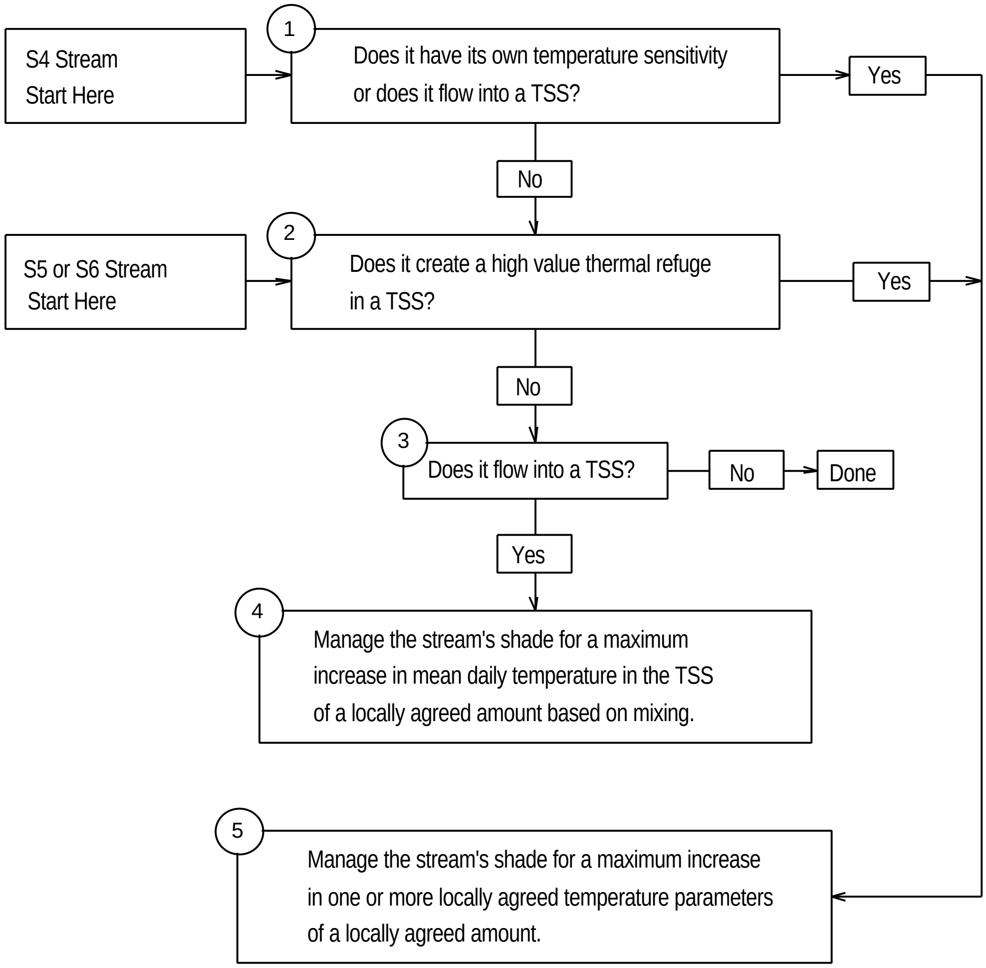
3. If the effect of temperature increases from more than one tributary on the mainstem are being considered simultaneously, then mean daily temperatures should be used because maximum daily temperatures are not cumulative.

In contrast with the present wording of the THPR, the procedures suggested above are quantitative and treat fish bearing and non-fish bearing stream differently, thereby allowing more rational management. Although there may be considerable uncertainty about accuracy, a quantitative approach allows the objectives and assumptions to be better documented. Uncertainties can be addressed by calculating best case, most likely, and worst case scenarios. Quantitative analysis also allows what is considered to be a justifiable deviation from a literal interpretation of the Regulation. This, in turn, allows the relative effects of different forest management scenarios to be weighed. The following interpretation of the Regulation is suggested as a means to address the above scenarios quantitatively:

> On an S4 stream which flows into a TSS and an S5 or S6 stream which provides a high value thermal refuge to a TSS, manage the stream's shade so that it experiences an increase in one or more locally agreed temperature parameters of no more than a locally agreed amount. This amount should be at least 0.2 degrees Celsius because this is a typical limit of accuracy and precision for temperature recording equipment.
>
> On an S5 or S6 stream which provides a general cooling effect to a TSS after mixing, manage the stream's shade so that the mean daily temperature of the TSS experiences an increase after mixing of no more than a locally agreed amount. This amount should be at least 0.2 degrees Celsius because this is a typical limit of accuracy and precision for temperature recording equipment.

The recommended courses of action for these scenarios are illustrated in the flow chart in Figure 6. The approach recommended here potentially involves managing shade along the whole tributary to the TSS, not just the highest order reach. However, it has provisions to ensure that this would be done only where there was good justification. It also has provisions for quickly eliminating streams from further consideration under some circumstances, for example, a case of proposed harvesting along an S6 tributary to a large TSS where the only concern is the overall temperature of the mainstem. On balance, it is suggested that the approach recommended here could be an effective way to focus the attention of local specialists and managers on the most biologically important sites, thereby improving our ability to manage stream temperatures.

It is possible to implement the recommended procedure at the present time, although a substantial amount of field work and professional time could be required. The purpose of the proposed research and inventory projects at the end of this report is to allow it to be carried out more quickly, cheaply, and consistently.



Notes:

1. Managers may decide to treat a stream as temperature sensitive due to local conditions in the absence of TSS designation.
2. It should be clear whether it is documented or assumed that a non-fish bearing stream has a high value for this reason.
3. If the stream does not flow directly into a TSS, then its thermal effect will be taken into account by managing the temperature of the stream that does flow into the TSS.
4. This should be based on a stream reach model plus the mixing of loads equation.
5. This should be based on a stream reach model.

FIGURE 6. Flowchart illustrating a recommended method for managing the temperature of S4, S5, and S6 streams.

Knowledge and Data Gaps

This section addresses knowledge and data gaps around the processes affecting stream temperature. There are also important information needs related to the effects of stream temperature on fish, the geographic distribution of different species, and their behaviors. However, identifying the biological information gaps is beyond the scope of this report.

Technical Issues

The physical processes and parameters which control stream temperature are well understood. However, the actual values of key parameters in actual watersheds are highly variable. Some important parameters, such as the relative discharges of two streams above a tributary junction, are relatively easy to estimate. However, others such as stream shade and groundwater discharge are more problematic.

The literature suggests that stream shade is the single most important variable because it has a major effect on stream temperature, a high natural variability, and is subject to large changes due to harvesting and revegetation of riparian areas on Crown land and the management of private land. Therefore, knowing how to measure, inventory, estimate, and manage it is critical to managing stream temperature. Methods of measuring, inventorying, and predicting stream shade represent a significant knowledge gap at the present time. Methods are currently being developed in the Cariboo Forest Region to measure and inventory stream shade.

Where there is a history of riparian logging, it is important to be able to consider the level of shade recovery. It is only through shade inventories that shade recovery on previously logged streams can be accounted for with certainty. However, it would very useful if we could estimate natural shade and the amount of shade recovery on individual stream reaches in a spatial database as a function of surrogate variables such as biogeoclimatic zone, stream width, and number of years since logging.

The availability of stream temperature data is also an important issue locally. Stream temperature has been monitored in a number of streams in B.C. but for differing purposes, periods of time, and to differing standards. It is unlikely that there is adequate temperature data for making the best possible management decisions on most streams where temperature is a potential forestry issue. Even in systems where there is a relatively good record of mainstem temperatures, the spatial coverage is inadequate for forest management purposes.

The quantitative link between stream shade and stream temperature is a stream temperature model. A model can range from a simple empirical one like the Washington Temperature Screen, to a simple process based model like Brown’s, to a more complex physical model such as SSTEMP. At tributary junctions the mixing model described previously is simple and appropriate. These models need to be used more frequently to address temperature issues on specific streams and they should be evaluated for their use in making physically based generalizations and guidelines for managers. This applies to the prediction of both stream temperature increases with different riparian logging scenarios and the prediction of stream temperature decreases with different riparian revegetation scenarios. These techniques can be used to identify temperature restoration opportunities on private land as well as Crown land.

Another problem is the selection of the stream temperature response variable itself. Stream temperature at a point is a continuous time series but researchers have not always used the same parameters when testing for the effects of logging. These include mean monthly temperature, mean daily temperature, and maximum daily temperature. This may be partly because there is no single temperature parameter which is most critical to aquatic ecology. The literature suggests that daily maximum temperature responds the most to changes in shade. However, because fish can tolerate relatively high temperatures for short periods, mean daily temperature may be a better parameter.

The change in a stream's temperature downstream is an important issue. One important set of factors is channel hydraulics which determine average velocity and the distribution of velocities. Stream velocity, which is relatively low when high stream temperatures occur, limits the length of a channel upstream from a point which can influence the diurnal temperature range at that point. In contrast, the daily mean temperature is affected by a much greater length of channel upstream. Research is needed to make general rules about the lengths of channel which have the greatest effect on mean daily and maximum daily temperature.

Operational Issues

One of the most important operational questions is the uncertainty about the process for determining whether a stream should be designated as Temperature Sensitive. There are a number of valley bottom streams in the Interior with high fish values where stream temperatures periodically exceed the biological optimum. Where the riparian areas of these streams have been cleared for agriculture, such clearing almost certainly contributes to the maximum daily stream temperature. However, the thermal connectedness between streams at mid to upper elevations where forestry activities typically take place and valley bottom streams is much poorer because mean daily temperatures are not completely cumulative downstream and maximum daily temperatures are not cumulative.

Therefore, where stream temperatures are known to be a problem for fish in valley bottoms, documenting summertime stream temperatures at a range of elevations should be a high priority. This has been initiated in the Nicola watershed and is addressed under a proposed inventory topic. One thing that is clear is that where stream temperatures are considered to be too high, the greatest benefit to be gained is through the retention or <u>reestablishment</u> of shade immediately upstream from where the high temperatures occur. The benefit provided by shade decreases with increasing distance upstream. Therefore, it is important to know the spatial distribution of fish which are subject to excessively high temperatures as well as the spatial distribution of temperatures.

There are operational questions about how to best design reserves for shade retention while also maintaining windfirmness. Simple methods are available for identifying trees which provide shade and these techniques can be practised in adaptive management trials. The purpose of this work would be to increase the awareness of stream shade among prescribing foresters and to provide case studies of results based riparian buffer design. Work is already underway in the Prince Rupert Forest Region on this subject.

Another operational issue is the use of spatial inventories for the long term management of stream temperature. Although shade data is required before this can be fully implemented, it is not too early to start developing GIS tools to manage and analyze stream shade and temperature data. This could be used to help managers visualize how information could be extracted and used for long term stream temperature planning and could help in the planning of the data collection programs themselves.

A new method for surveying stream temperature synoptically based on thermal remote sensing has been developed recently. Researchers in the U.S. have found thermal imaging of streams to be very useful in combination with a traditional temperature monitoring program because it shows spatial variations in water temperature at a resolution of less than a metre. It can be used to verify the representativeness of temperature monitoring sites and can identify sites with relatively cool and warm water. The visual output provided by this tool has been found to help scientists, managers, and members of the public understand the causes of stream heating and cooling. The technical capabilities of this tool have already been proven and projects to demonstrate its usefulness as a management tool on key watersheds in B.C. would be worthwhile.

Research and Inventory Needs

Proposed research and inventory projects designed to address the knowledge and data gaps are described in this section. The purpose is to put stream temperature information needs in the context of operational need with the expectation that forestry related stream temperature issues will increase in the future. Projects are listed in two different ways. Firstly, they are described in order of priority with different funding scenarios. Secondly, projects and their funding needs are described individually. The most efficient way of implementing most of the projects would be to integrate them rather than treat them separately. These descriptions are not intended to take the place of detailed work plans.

Activities Possible with Different Funding Scenarios

Funding Option 1 - No Incremental funding

A number of stream temperature projects are already funded and underway by government agencies, academic researchers, and forest licensees. However, no attempt has been made to summarize unpublished work that is in progress. At least three projects are underway which do address some of the key research and inventory needs, but with no new funding they would be limited in scope and would not be integrated. These are:

- Develop methods to measure and inventory stream shade. This project can be completed to a satisfactory level of detail with no incremental funding.

- Expand the geographic coverage of temperature monitoring in watersheds with high stream temperatures in the valley bottom. This has been initiated in a coordinated way only in the Nicola River watershed and is being funded by Ardew Wood Products Ltd., Aspen Planers Ltd., Gorman Bros. Lumber Ltd., Riverside Forest Products Ltd., Tolko Industries Ltd., and Weyerhaeuser Canada Ltd. .

- Test the design and effectiveness of riparian reserves in adaptive management trials in the Prince Rupert Region. Only one of two small projects is funded for this year.

The first project above is not tied to any specific geographic location and should be equally useful in all of B.C. A report is being written. The second and third projects are designed to address local issues and will likely be most useful for those geographic areas and for a limited number of individuals. Although their results can be extended, they are the types of activities that need to be repeated in other areas where there are similar concerns. Therefore, the results of those two projects will be of somewhat limited use provincially.

With no incremental funding, the knowledge and data gaps described above would be addressed at a very slow rate. There would be no substantial progress toward developing the tools needed to apply the Recommended Approach for managing streams with TSS designation.

Funding Option 2 - $50,000 to 150,000 over two to three years

This would involve collecting data that could be used for both research and inventory purposes. The priority would be to identify one or two watersheds where stream temperature is an issue in the valley bottom and try to characterize the distribution of stream shade and stream temperature. The purpose would be to identify the major features of geographic variability of stream temperature and stream shade regimes. Channel geometry and riparian features would be characterized. With this amount of funding a small number of representative sites would have to be selected for temperature monitoring. Shade surveys would be done on reaches upstream from temperature monitoring sites and might also extend over a sufficient number of sites to identify relations between shade and biogeographic variables such as channel geometry and site vegetation characteristics.

It would be most logical to do this work in watersheds such as the Horsefly and/or Nicola where there are stream temperature issues and temperature monitoring already established. At this level of funding, this work could help clarify future inventory and research needs and could provide some preliminary results on the following topics:

- Inventory riparian shade in priority watersheds.
- Develop methods to estimate riparian shade from surrogate variables.
- Stream temperature monitoring and synoptic temperature surveys.
- Develop a GIS demonstration for stream shade, stream temperature, and timber supply.

At $50,000 funding:

- The work should be considered a pilot project.
- Field work would be limited to one geographic area.
- The sample of stream shade measurements would be small and the ability to develop a model for predicting shade as a function of surrogate variables would be very limited.
- The GIS would be limited to static display.

At $150,000 funding:

- The sample of stream shade measurements may be sufficient to allow a preliminary predictive model for stream shade to be developed.
- An evaluation of stream temperature models could be started but field testing would be limited.

Funding Option 3 - $250,000 over four years

This level of funding would allow a sufficient sample of riparian shade and stream temperature to be collected so that:

- Field observations would show at least a coarse pattern of stream shade and stream temperature as a function of geography in two areas such as the Nicola and Horsefly watersheds. (This may already be possible in parts of the Nicola watershed with current privately funded projects).
- A preliminary predictive model for stream shade and other important variables could be developed. This would include a preliminary characterization of stream discharges and velocities during summer low flow as a function of geographic characteristics for use in maximum daily temperature modeling.
- Stream temperature models could be field tested.
- A stream temperature model could be integrated with a GIS on a demonstration basis to test the effects of different riparian management scenarios on long term stream temperature and timber supply.

Funding Option 4 - $350,000 over five years

This level of funding would allow all of the proposed research projects to be carried through to a scientifically defensible level.

It would also allow the proposed inventory and adaptive management work to be implemented to a level that would provide managers with useful information for several geographic areas. However, it would not cover the cost of producing thermal infrared maps of stream temperatures in priority watersheds. This is the subject of a $300,000 proposal by the MoF Research Branch for use in two watersheds.

This level would also allow activities which are not listed under individual projects such as expanded adaptive management trials, training, extension, and an integrated report.

Individual Project Descriptions

Develop a measurement method and field sampling procedure for inventorying stream shade.

Category - Research

Justification

Managing stream temperature rationally requires that stream shade be managed quantitatively. However, existing methods for measuring and inventorying shade are not well developed. Objective and accurate shade measurement would serve as the major point of reference for the effects of forestry and other land uses on stream temperature.

Status

A project was initiated in the Cariboo Forest Region in 1999 to develop a measurement and inventory method which would be technically valid and operationally practical. Work is in progress at the present time. An initial report will be produced in 2000 and further development, testing, and reporting should continue for one or two years.

Funding

Funding in 1999 was provided by the Cariboo Forest Region and Fisheries Renewal B.C. for several months of staff time and a field assistant. A first report will be produced with Regional funding but further development, reporting, and publication will require approximately $20,000 through 2002.

End Product

An initial report describing an instrument and field procedure is scheduled for 2000. Training could be provided as early as September 2000 depending on funding.

Inventory riparian shade in priority watersheds

Category - Inventory

Justification

Managing a watershed for stream temperature rationally requires that stream shade be managed quantitatively. Ideally, this requires spatial shade data in a GIS. There is currently not a good method for estimating shade indirectly so shade needs to be inventoried.

If designed in conjunction with a research project, described herein as a separate project, shade inventories could be used as input for a model which predicts shade as a function of surrogate variables, thereby allowing a shade inventory of a watershed to be based on a combination of direct measurements and model predictions.

Status

Stream shade data of the type needed for stream temperature modeling has not been inventoried in B.C. and there is currently not even a standard stream shade inventory method. However, a method for measuring and inventorying shade is currently being developed in the Cariboo Forest Region and will be ready for limited operational use in 2000.

Funding

A stream shade inventory could cost in the order of 3 person days per kilometre of stream. However, if done during other surveys such as fish habitat inventories, it could have an incremental cost of several person hours per kilometre of stream.

Instead of an inventory of all streams in a watershed, it would be desirable to sample shade in a demonstration watershed based on local needs. If done properly, this would also provide the basis for preliminary modeling of stream shade.

End Product

A snapshot of stream shade (e.g. as percent shade in late summer) for a given watershed in the form of GIS data. Accuracy would be highly variable depending on the degree to which field inventories were used and the types of interpolation methods used.

Develop methods to estimate riparian shade from surrogate variables

Category - Research

This project has two major components: predicting natural shade levels on undisturbed streams and predicting the amount of shade recovery on logged streams as a function of time.

Justification

Managing stream shade at the watershed scale requires knowing the status of shade on undisturbed streams, previously logged streams, and streams with non timber uses - particularly agriculture. Complete inventories of stream shade would be very costly. Being able to estimate natural and post-logging stream shade as a function of BGCZ, stream width, number of years since logging, and other surrogate variables would allow considerable cost savings and geographic expansion of this management tool.

Shade information could be used in combination with stream temperature models to estimate deviations from normal stream temperature for different harvesting and revegetation scenarios.

Status

There are methods for estimating stream shade in the literature but they have not been used or tested in B.C. There is almost no information in the literature for estimating the recovery of stream shade from surrogate variables as described above.

Funding

Year 1 - Preliminary product describing existing shade estimation methods based on literature review and design of a field project. $20,000

Year 2 - Field program for a limited number of BGCZ's and reporting, $60,000

Year 3 - Model testing at other locations in same BGCZ's and reporting on results. $60,000

End Product

- Written report describing case studies, accuracy and applicability elsewhere.
- GIS procedures.
- If done in conjunction with an experimental inventory as described elsewhere in this report, another product would be a GIS display of stream shade based on prediction from surrogate variables.

Investigate stream temperature models for predicting the effects of changes in stream shade on stream temperature

Category - Research

Justification

- Temperature models could be used to estimate the effect of various riparian management scenarios on stream temperature for guideline development.

- A description of tools would be useful for hydrologists.

- In combination with inventories, stream temperature models could be used to estimate the effects of different logging and revegetation scenarios on stream temperature.

Status

Considerable work has been done in the U.S. and is reported in the literature. However, most of the models are not readily available and experience with them in B.C. is limited.

Funding

1 Year - Review with minimal field testing. $20,000
3 Year - Review with substantial field testing $100,000

End Product

1 Year - Report based mostly on literature review. Discussion of simpler models.
3 Year - Full report.

Stream Temperature Monitoring and Synoptic Temperature Surveys in Watersheds with Known Temperature Issues

This would consist of summertime temperature monitoring with dataloggers in selected watersheds as well as the application of thermal infrared synoptic surveys of stream temperature on a demonstration basis in a small number of watersheds.

Category - Inventory

Justification
Stream temperature data is available for some streams in valley bottoms where stream temperatures are highest. However, there are potential problems in using this data to draw conclusions about the possible temperature effects associated with logging at mid to upper elevations. Expanded geographic coverage of stream temperature monitoring, such as that being done in the Nicola watershed, would be useful.

The visual output provided by thermal infrared remote sensing has been found to help scientists, managers, and members of the public in the U.S. understand the causes of stream heating and cooling. This would be done on a small number of selected watershed in B.C. for demonstration purposes.

Status
Stream temperature is currently being monitored in some watersheds where temperature is a fisheries issue. However, geographic coverage is very limited. There is a need to expand it to make the data more useful for answering forest management and fish habitat questions.

Thermal IR imaging of streams has not been done in B.C. and it is not a readily available service. The project needs to be done on a watershed with existing stream temperature monitoring such as the Horsefly or Nicola.

Funding
Estimated cost for equipment, servicing, and data management for 100 temperature monitoring sites for three years is $100,000

Funding of $300,000 is being sought by the MoF Research Branch for a demonstration thermal IR mapping project.

End Product
A report and GIS database of a watershed in a visual user interface with thermal and true colour images of streams with links to actual stream temperature data at reference locations.

Test the feasibility and effectiveness of implementing site specific riparian buffer designs for the purpose of shade retention

Category - Adaptive Management

Justification:
Respond to operational questions regarding the appropriate size for riparian buffers to maintain zero increase in water temperature above background heating (Project 1). Through case studies, identify the importance of riparian shade to prescribing foresters and to provide case studies of results based riparian buffer design (Project 2).

Status:
Project 1: is underway in the Morice Forest District. A methodology for assessing buffer width has been developed. Sites are being selected to test the methodology in summer of 2000.
Project 2: is underway in the Kispiox Forest District. Logging plans are being review to identify study sites. A range of buffer widths and silvicultural prescriptions are planned for effectiveness monitoring. Silvicultural prescriptions include clearcutting, 30% and 60% retention.

Funding

Project 1:	2000 – monitoring / field testing - $5,000.
	2001 – report writing, review, extension - $5,000.
Project 2:	2000 – monitoring / field testing – $2,000.
	2001 – report writing, review and extension - $5,000.

End Product
Project 1: Written report on trial finds and assessment of methodology for determining buffer widths.
Project 2: Written report on the shade effectiveness of current riparian buffers on S4 creeks.
Results of both trials will be used in extension courses to all districts, and disseminated to all regions.

Develop a GIS demonstration for stream shade, stream temperature, and timber supply

Category - Research

Justification

Managing riparian areas at the watershed scale is a natural GIS task. Predicting stream temperature requires shade and other data for stream reaches which are also spatial in nature. The development of a GIS demonstration would help managers appreciate the spatial nature of the data and how it could be used. It could also help determine the effects of stream temperature management on timber supply and help in the planning of research and inventory projects.

Look at distribution of different stream classes, "direct tributary" reaches, etc.

Status
Conceptual stage.

Funding
Preliminary version $10,000.

End Product
Written report, maps, demonstration at a GIS workstation.
Self guided demonstration on CDROM?

Other possible projects

- Investigate times of travel times and dispersion characteristics in streams of different types and generalize about the effects of channel hydraulics on the length of stream which contributes to the maximum daily temperature. This would be addressed under stream temperature modeling at higher funding levels.

- Identify the most suitable temperature parameters for biological reference (e.g. daily maximum, daily mean, monthly mean).

- Develop criteria for helping determine whether a stream is temperature sensitive.

- Determine the effect of road crossings, groundwater interception, and ditch drainage on stream temperature.

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