**Introduction:**
This Research Note is a summary of the Morice District Small Streams Temperature Project. The control of adverse stream temperature effects is recognized as an important management issue in the project area due in large part to the abundance of high value fisheries resources found there. Fish stocks of considerable economic, ecological and cultural value reside throughout the Morice Forest District. This study is an Adaptive Management project designed to understand the process of forestry induced stream warming and develop tools to provide effective temperature control. The goals of the project are to develop effective Best Management Practices for temperature control and to optimize the relationship between post-harvest environmental quality and timber supply.

**Background:**
Reach level trials of various types of riparian reserves conducted for this project confirm that reducing shade around S4 and S6 streams increases their daily heat uptake. This effect is most pronounced during periods of high heat load during late July, August and early September. Analysis of hourly temperature plots also indicates that the difference between the daily minimum and the daily maximum (diel flux) temperatures of harvested reaches is significantly greater than their undisturbed upstream analogs.

The effect of this warming is best described at two scales: reach level and watershed level. Reach level effects are those impacts that occur in cut-blocks and road rights of way and generate watershed warming. Watershed level effects are those impacts that result from the cumulative warming of all of the reach scale effects in a watershed and generate habitat quality reductions at some specific point of interest. The following two sections will outline the basic mechanisms that define these two effect types.

**Reach Level Effects:**
Reach level effects are realized following any management activity that reduces the temperature buffering capacity of a stream causing the free water surface and shallow soil water to become more exposed to solar radiation. This can result from two general categories of impact. The first, and most immediate, is canopy density reduction from riparian harvesting. The second general category is the longer-term channel change (widening and shallowing) related to machine disturbance, peak flow changes and long term woody debris deficits in woody debris dependent channels. This effect typically takes a longer time to manifest itself but can persist until woody debris deficits are remediated and channel equilibrium is re-established.

These impacts raise several management issues related to instream habitat suitability. The first is the effect of increased temperature on the oxygen carrying capacity of water. As water warms, its saturation oxygen content drops proportionately. Fish living in this environment must therefore force more water through their gills to achieve the same level of pre-warming oxygen transfer. At the same time, the virulence of microbial and parasitic organisms increases which accelerates the course of disease in fish exposed to elevated water temperatures. All this accelerated biological activity then works in concert to increase the biological oxygen demand and further reduce available oxygen.

The combined effect of these stresses is a reduction in habitat suitability and a potential increase in mortality.

**Watershed Level Effects:**

Watershed level effects are the cumulative warming impacts of many reach level effects. Ecological effects are realized when cumulative reach level warming causes ecological shifts in species diversity, abundance, and reproductive success. These effects can be point source or spatial in nature. Point source impacts are impacts that affect some specific point of interest such as a migration corridor, spawning ground or juvenile rearing area. Spatial effects are impacts that operate at large scales and generate shifts in species diversity, abundance or reproductive success. An example of this type of effect is when cumulative warming creates more favorable habitat conditions for temperature tolerant species such as Northern Squawfish that can then displace less temperature tolerant salmonid species. Salmonids are stenothermal (can only adapt to a narrow range of temperatures) in comparison to other species such as Cyprinids (minnows and carp) and Catastomids (suckers) that are more temperature tolerant. Signs of physiological stress start to develop at about 16 degrees Celsius for adult Sockeye and at even lower temperatures for sensitive species like Bull Trout.

**Photo 1: Sockeye migrating into the Nadina watershed in August each year are facing the warmest river conditions of the year. Migration success is related to the temperature of the river.**

Water temperature is a primary driving force of aquatic ecosystems. The temperature of any natural water body determines the metabolic rate of the poikilothermic (cold blooded) organisms that live in it. This, in turn, regulates their growth and the timing of much of their life cycle. A complex set of life strategies evolve as these organisms attempt to optimize their reproductive success through competition, predator avoidance and habitat selection. Salmon adapt their life cycles to coincide with thermal cues needed to initiate migration and spawning. Persistent thermo-environmental changes following shade removal and drainage alteration therefore pose a threat to the viability of fish stocks.

**Management:**

Managing to control water temperature is a complex task because of the high degree of natural variability in the parameters that determine a streams thermal response to harvesting. Canopy density, topographic shading, groundwater inflow, channel geometry and geomorphology and riparian structure are a few of the main contributing factors that determine the thermal response of a given site to forest harvesting. Natural disturbance regimes cause fluctuations in these parameters that form a part of the natural ecology of small streams. Insects, fungi, fire and mass movements can all produce natural disturbances that alter the thermal character of streams.

Temperature monitoring for this project indicates that there is a wide variation in the thermal response of streams with riparian harvesting and canopy density reductions. Clearly, reach level impacts do not occur with equal severity at all sites where there are reductions in canopy density. Thermal responses vary along a continuum from severe to subtle depending on how well a particular site is buffered against temperature change. Factors that appear to affect the post harvest thermal performance at a site include the following:

- Groundwater inflow. The ratio of inflowing groundwater to channel water determines how much "excess" heat can be diluted per unit of time. Groundwater ratios range from zero to infinity. Shallow alluvial groundwater aquifers are susceptible to warming when their canopy density is reduced by harvesting.
- Riparian canopy structure. Sites with multiplayer canopies tend to provide more post harvest shading.
- Hydro-riparian width and hydrologically connected saturated areas. Hydro-riparian areas are riparian areas that are strongly influenced by hydrologic processes due to high water tables and frequent overbank flooding. These areas can either accelerate or buffer temperature change depending on water table height, soil porosity and albedo, depression storage and post-harvest canopy structure. Streams that flow through perennially saturated forested wetlands have wide areas of potential heat exchange and intense post harvest heat absorption.
- Channel type. The distinction between gravel bed streams and other less permeable paved-till bed streams appears to be important because gravel bed streams deposit extensive, highly porous, hyporheic zones. Channel water then flows in and out of the hyporheic zone along the channel. This hyporheic water acts a cooling reservoir.

Effective Temperature Control Best Management Practices need to manage both Reach and Watershed level effects simultaneously in order to arrive at solutions that are both biologically meaningful and economically viable. This requires the ability to predict or model the severity of reach and watershed level effects prior to harvesting. Modeling can then be used to "game" different harvesting scenarios in order to arrive at a Best Management Harvesting Plan. Reach level effects in highly buffered streams may be so subtle as to be considered insignificant at that site but a large number of those same effects could generate a Watershed level effect severe enough to adversely affect some point of interest in the watershed such as a migration corridor or spawning channel.

The presence of lakes in temperature sensitive watersheds complicates their management. From a hydrologic perspective, lakes are known to dampen flood waves from flashy tributaries and are seen as moderators of flow regimes. While many lakes likely have the ability to moderate downstream temperature increases from individual tributaries with high heat outputs, a number of bathymetric factors may come into play that are not moderating in their effect. Summertime thermal stratification will likely reduce the effective volume of the lake available for heat dilution and will therefore reduce any thermal moderating effect. Lakes with shallow bathymetries are probably less effective at moderating heat increases and transfers. Wide lake outflow geometries may also affect the heat output of a lake by causing the outflow to draw from the top of the water column where the water is warmest. Lake outlets that are bedrock bound will restrict hyporheic and groundwater flow at the channel margin and may therefore not be well buffered against temperature increases below the lake.

**Project Implementation**:
The Morice District Small Streams Temperature Project is developing a number of tools to manage temperature effects while minimizing the cost in terms of timber supply. The study involves the following components;

- **Riparian Buffer Trials**. The Adaptive Management component of the study involves testing four different fixed and variable width riparian buffer types to determine their ability to minimize temperature increases on S4 and S6 streams.
- **Monitoring**. Monitoring methods are being developed and tested to assess the efficacy of the Adaptive Management treatments and for future monitoring of Best Management Practices. Methods include angular canopy density measurement, groundwater monitoring, Before - After – Control - Impact (BACI) water temperature data collection and statistical methods for detecting temperature effects.
- **Retrospective Monitoring**. This component is a study of previously harvested reaches to understand how reach level effects change over time.

**Managing To Minimize Temperature Effects:**

The thermal regime of a watershed represents an integration of many fundamental physical properties. Changes in canopy structure around streams, lakes and wet areas can be reflected in the amount of solar energy transferred into the water. Spatial variation in surficial materials across the landscape generates relatively predictable stream temperature patterns as seen by the diel flux (daily warming) differences between groundwater fed streams and channels without highly porous boundaries. Heat acts like any other environmental contaminant in that its concentration at any point in a watershed is related to the degree of dilution it receives. Therefore changes in the timing and volume of discharge will be reflected in the pattern of temperatures seen along a watercourse.

Wet sites with a high degree of soil disturbance will often show high post-harvest heat transfer thermographs. Charts 1 and 2 (below) are pre- and post-harvest thermographs for a stream with a variable width reserve zone. The pre-harvest thermograph shows this upland S4 stream in a weak downstream warming trend during the period of peak heat load. Post-harvest, the site is forced into a strong downstream cooling regime as it attempts to dilute heat inputs from the un-buffered headwater clear-cut. This kind of thermal regime reversal is diagnostic of the reach level effects seen at many headwater reaches. The upstream area at this site has been site prepared (mounded) in order to create elevated micro-sites for planting. This creates numerous water filled depressions that are perfect heat sinks. Interflow percolating from this area then enters the stream and adds to the heat load of the system.

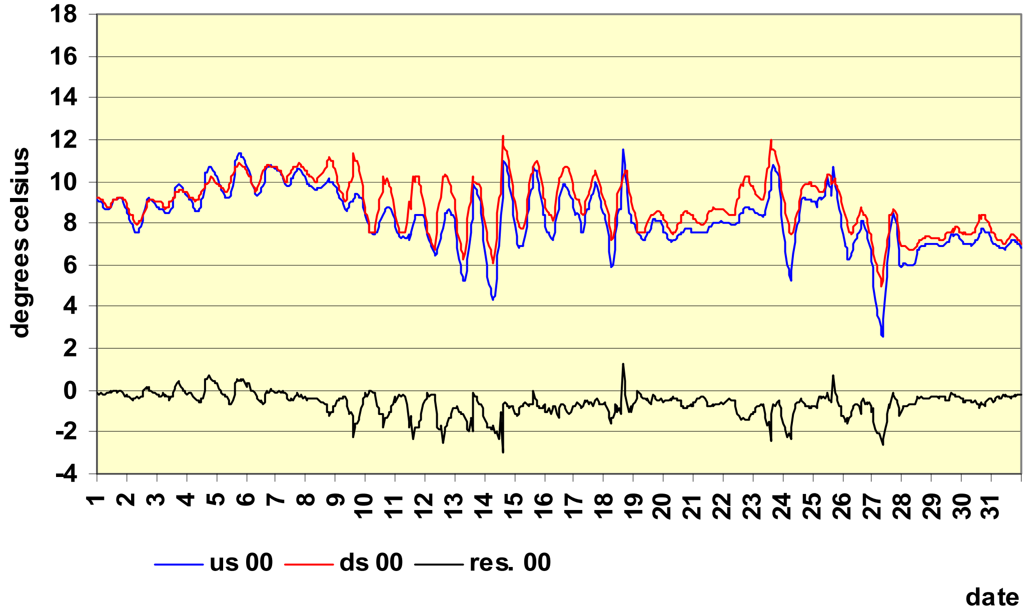
**Photo 2: Site preparation can increase heat transfer by creating numerous exposed water surfaces for heat exchange.**

Small streams often widen and shallow following forest harvesting. Factors that drive this morphological change include mechanical disturbance, woody debris reductions, sediment budget increases, peak flow changes from drainage network extension and inter-basin transfers and decay of the riparian root mass. The thermal effect of widening and shallowing is to create a more exposed stream channel with greater heat transfer potential.

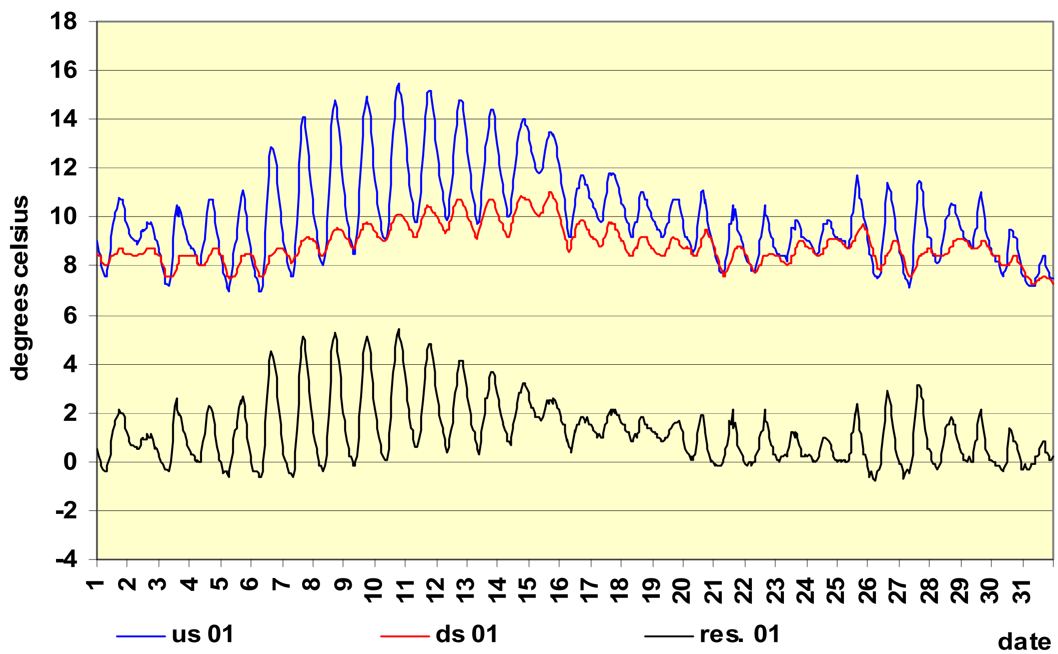
Stream temperature research often relies on finding surrogate measures to estimate the impact of stream warming. Canopy density and Index of Biological Integrity (IBI) studies are often used to infer environmental impacts associated with stream warming. Increasingly, the results of this study infer that stream temperature itself can be used as a measure of watershed health. Since changes in the thermal regime of reaches and watersheds tend to reflect changes in the riparian canopy, site disturbance, stream channel shape and flow, perhaps stream warming is better approached as a diagnostic measure than simply an adverse effect. Perhaps changes to the thermal regime of reaches and watersheds are fundamental measures of watershed health because they represent an integration of many common resource use effects.

The following two charts describe the pre-harvest and post-harvest August thermal regimes from one of the Adaptive Management trials of riparian treatments. The site was harvested with a machine free zone. A distinct change in the thermograph reflects the loss of shade over an extensive forested wetland at the headwater of the reach. Upstream temperatures for the post-harvest period are considerably higher than downstream temperatures. The residuals (differential) line indicates that the reach was weakly warming in 2000 but was forced to adopt a cooling mode in 2001 in order to dilute heat inputs from above.

Site "505-7" August 2000 Thermograph




Site "505-7" August 2001 Thermograph




Charts 1 and 2: Pre-harvest (2000) and post-harvest thermographs of a site with an extensive forested wetland at the channel periphery. High post-harvest water temperatures at the upstream end result from saturated ground that has been harvested.

Research Needs:

Information gaps exist that prevent the implementation of Best Management Practices for Stream Temperature Control.  The main gap is in the watershed level modeling of stream temperature.  A tool is needed to predict the effect of different harvesting scenarios and arrive at Best Management Harvesting Plans.  The question of lakes and wetlands and their impact on temperature needs to be researched because there is likely a wide variation in how these features store, transport and dilute heat.  A related issue is the effect of reservoirs (ie: the Fulton reservoir) on heat transfer.  Questions arise around the effects of rapid water level fluctuations and reservoir sediment storage and how these processes affect the heat transfer there.  A method of predicting the severity of post harvest temperature regimes using pre-harvest data is also required to ensure that Best Management Practices are achieving their desired results.

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