FISHTRAP CREEK WORKSHOP

Watershed Response to the McLure Forest Fire

Date: *March 6th, 2008: 8:00 am to 4:30 pm*
Location: *Thompson Rivers University, Kamloops*
(Panorama Room, International Building)

AGENDA

8:00 – 8:30	*Coffee*
8:30 - 8:40	Welcome and overview of workshop (R.D. Moore, UBC)
Session 1:	**Hydrology**
8:40 - 9:00	Snow processes (R. Winkler, MoFR)
9:00 - 9:20	Interception loss (D. Carlyle-Moses, TRU)
9:20 - 9:40	Stand water balance (D. Spittlehouse, MoFR)
9:40 – 10:00	Streamflow patterns before and after the fire (R.D. Moore, UBC)
10:00 – 10:30	*Refreshment break*
Session 2:	**Channel morphology and sediment dynamics**
10:30 – 10:50	Channel morphology (T. Giles, MoFR)
10:50 – 11:10	Rating curves for characterising patterns of channel change (J. Phillips, UBC)
11:10 – 11:30	Suspended sediment dynamics (B. Eaton, UBC)
11:30 – 11:50	Determination of fine-grained sediment sources (P.N. Owens and E.L. Petticrew, UNBC)
11:50 – 12:10	Bedload transport (J. Phillips, UBC)
12:10 – 13:00	*Lunch*
Session 3:	**Water quality and ecological response**
13:00 – 13:20	Stream temperature patterns (R.D. Moore, UBC)
13:20 – 13:40	Stream temperature processes (J. Leach, UBC)
13:40 – 14:00	Water quality (Dennis Einarson, MoE)
14:20 – 14:40	Benthic invertebrates (Brian Heise, TRU)
14:40 – 15:10	*Refreshments*
Session 4:	**Fishtrap Creek in a broader context**
15:10 – 15:30	UBC Regime Model (B. Eaton, UBC)
15:30 – 15:50	Channel response to disturbance – emerging ideas (B. Eaton, UBC)
15:50 – 16:20	Questions and discussion

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Introduction to the Fishtrap Creek Study

In August 2003, the McLure Fire burned through several watersheds north of Kamloops, including Fishtrap Creek. High fuel loads, dry initial conditions, and strong winds resulted in an extremely high intensity fire that was difficult to contain. The burn of Fishtrap Creek Watershed was extensive, affecting 70% of the catchment and killing almost all of the trees in the riparian area. Since the fire, substantial salvage harvesting has occurred.

Fishtrap Creek was chosen as a study site to document watershed response to wildfire because of its proximity to Kamloops, ease of access, and the existence of a Water Survey of Canada stream gauge, which has been operating almost continuously since the early 1970s. In addition, stand-scale snow hydrology studies have been conducted at Mayson Lake, just outside the catchment boundary, since 1995. Since the fire, the stand-level studies have been expanded to include snow hydrology and site water balance measurements in burned stands. Research and monitoring efforts have been initiated on the lower reach, including studies of suspended sediment concentrations, fine sediment sources and dynamics, stream temperature, water chemistry, benthic invertebrates, channel morphology and bed material transport. Much of this research has been funded by the provincial Forest Investment Account via the Forest Science Program.

The objective of the workshop is to present a summary of research results to date, and to present emerging ideas about patterns of hydrogeomorphic disturbance and recovery. We also wish to promote discussion about the implications of the results for management and restoration of stream habitat in the context of natural disturbance and forest harvesting.

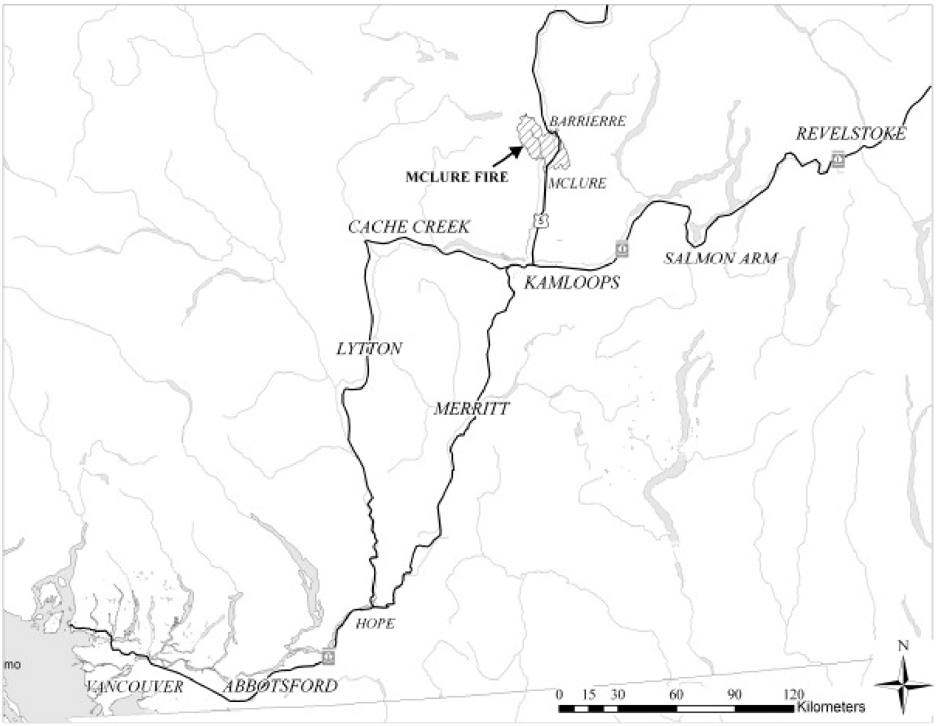

Figure 1. Location of the McLure fire. From Phillips (2007).

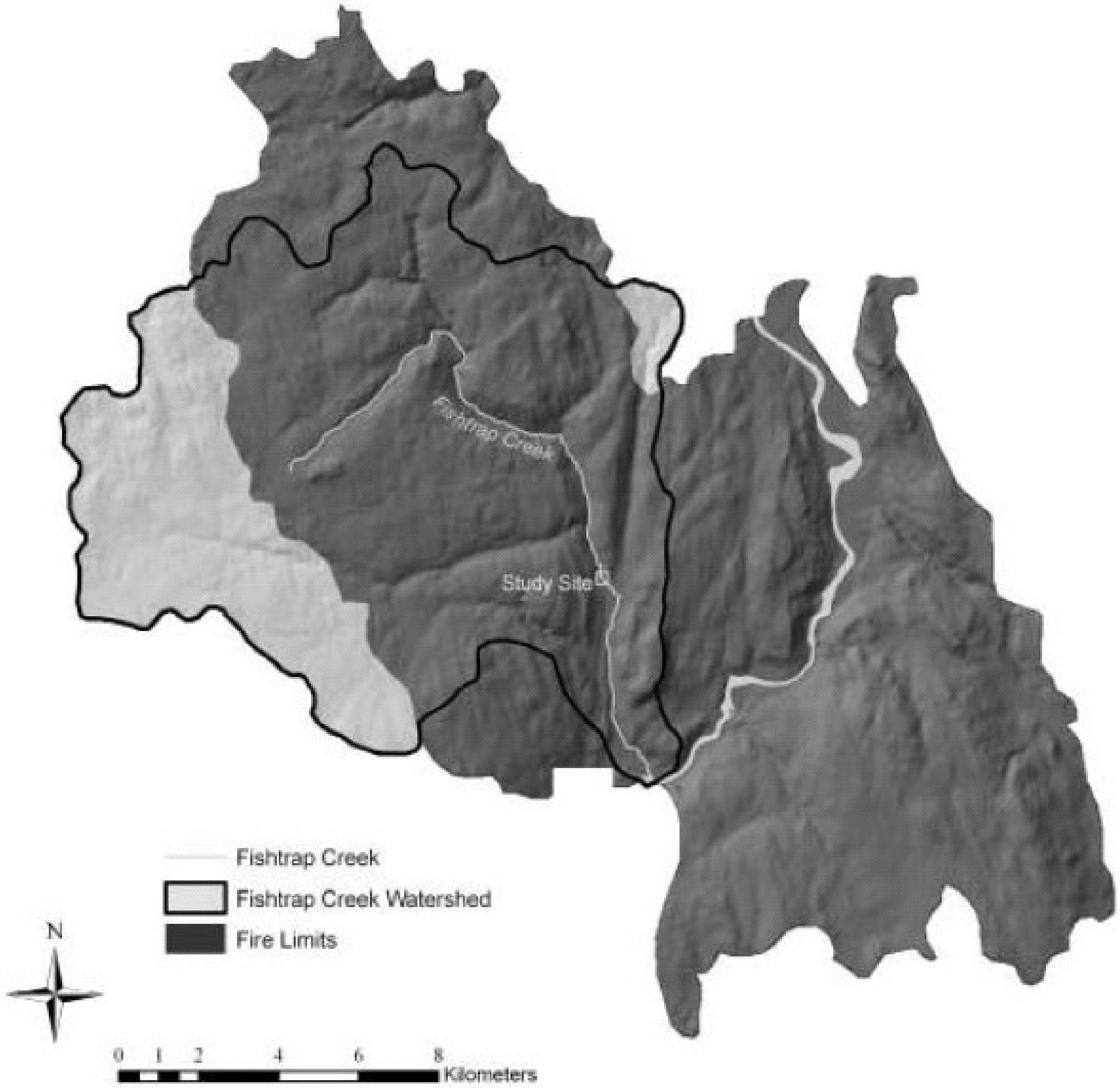

Figure 2. Limits of the McLure fire in relation to the catchment of Fishtrap Creek. From Phillips (2007).

Phillips, J.C. 2007. Post-Fire Dynamics Of A Gravel Bed Stream: Fishtrap Creek, British Columbia. Unpublished M.Sc. thesis, The University of British Columbia, Vancouver.

Presenters (in order of presentation)

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Snow processes

R. Winkler*

Forest cover affects both snow accumulation and the rate at which the snowpack disappears (ablation). The loss of forest cover, whether through insects, disease, logging or wildfire, generally results in increased snow accumulation and more rapid ablation. As forests re-grow, these changes diminish until snowpack processes in the regenerated forest approximate those prior to disturbance.

A long-term research project was established in 1994 at Mayson Lake to quantify changes in the snowpack with logging and forest re-growth. From 1995 to 1997, snow water equivalent (SWE) was measured in the mature lodgepole pine, Engelmann spruce and subalpine fir forest, intermediate lodgepole pine stands and a clearcut at this site. Surveys have continued since 2003. After the McLure fire, additional research sites were established in a severely burnt stand and a nearby clearcut approximately 5 km to the east of Mayson Lake. SWE has been measured at this site since 2006. Snow surveys are completed every two weeks in March and then weekly through the melt season. Snow measurements are made within a 1-m radius of 32 sample points in each stand using a Federal snow tube. The maximum snow depth recorded is 1.2 m. April 1st SWE, average ablation rates, and the date snow disappears in all stands and years are being compared.

In the McLure Fire clearcut, April 1st SWE was higher in 2006 than in 2007. Ablation rates were higher in 2007. In both 2006 and 2007, SWE was slightly less but not significantly different in the burnt stand than in the clearcut. Snow ablation rates were similar in the burn and clearcut in 2006 but were higher in the clearcut than in the burn in 2007. In 2006 the snow disappeared 5 days earlier in the burn than in the clearcut whereas in 2007 snow disappeared from both sites at the same time.

Snow accumulation and ablation rates were significantly lower in the mature forest at Mayson Lake than in the clearcut, over both sampling periods. SWE was 34% less in the mature forest than in the clearcut and ablation rates were 38% and 30% lower, depending on sampling period. In the 4-m tall intermediate pine stand, snow accumulation and ablation rates were reduced by 14% and 13%, respectively, relative to the clearcut. Six years later when the pine was 6-m tall, snow accumulation and ablation were 22% and 24% less than in the clearcut. By the second sampling period, the young pine in the original clearcut was 3-m tall. Snow accumulation was reduced by 8% in this stand relative to the new clearcut but no reduction in ablation was observed. When expressed as snow ‘recovery’, or the reduction in the difference in SWE and ablation between the forest and the open with re-growth, some recovery was observed once trees were over 4-m tall and crown closure at least 10%. At 25% crown closure, when trees were over 4-m tall, average recovery was approximately 40% for both snow accumulation and ablation. At 45% crown closure, when trees were over 6-m tall, recovery was 70%.

Both snow accumulation and ablation in all forest cover types varied substantially from year to year highlighting the important role of snowfall pattern and the melt-period weather in the generation of snowmelt. Surveys in the burnt stand suggest that snow accumulation and ablation can be expected to be similar to those in a clearcut and significantly higher than those in a mature forest. The results further suggest that once a second growth stand of lodgepole pine is over 6-m tall, snow accumulation and ablation ‘recovery’ can be substantial.

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Interception loss

D. Carlyle-Moses*

Interception loss - the interception, storage and subsequent evaporation of precipitation from vegetation canopies - represents an important component of the water balance of British Columbia's interior conifer forests. For example, interception loss from a healthy mature lodgepole-pine (*Pinus contorta* var. *latifolia* Dougl.) dominated stand was found to account for an average of 23.9 % of the rain that fell during the 1998 and 1999 growing-seasons at the Upper Penticton Creek Watershed Experiment (UPCr) site, while at Mayson Lake, on the Thompson Plateau, interception loss amounted to 31.1 % of the 2006 and 2007 growing-season rainfall from a mature lodgepole pine – hybrid spruce (*Picea glauca* (Moench) Voss. x *engelmanni* Perry x Engelm.) – subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) stand. The greater proportion of rainfall partitioned into interception loss at Mayson Lake is probably a consequence of the smaller average rainfall depth at this site (2006-2007 average rainfall = 4.9 mm) compared to the UPCr site (1998 – 1999 average rainfall = 7.9 mm). This assumption is supported by the fact that no significant difference ($p < 0.05$) is found between the slopes or intercepts of the power equations relating event interception loss (mm) and event rainfall depth (mm) at the UPCr and Mayson Lake stands.

Data from the UPCr and the Mayson Lake sites were combined to give a single power equation for estimating interception loss depth (mm) as a function of event rainfall depth (mm) for mature, undisturbed conifer stands in the Southern Interior of British Columbia:

$$I_c = 0.478\,P^{0.718},\ R^2 = 0.86 \qquad (1)$$

where I_c and P represent event interception loss (mm) and rainfall depth (mm), respectively.

As a percentage of event rainfall, canopy interception loss from the UPCr and Mayson Lake stands were found to decrease asymptotically with average interception values of approximately 58, 38, 30, 25, and 18 % for rainfalls of < 2.0, 2.0 – 4.9, 5.0 – 9.9, 10.0 – 19.9, and > 20.0 mm, respectively. This finding suggests that interception loss may play an important role in suppressing the amount of water reaching the forest floor for relatively large events that may be of geomorphologic importance.

During the summer of 2007 a preliminary study of rainfall interception loss within a burned stand was established near the Mayson Lake site. The study stand was burned as part of the 2003 McLure fire. Rainfall, throughfall and stemflow were measured for 14 events totaling 79.7, 72.9, and 0.2 mm, respectively; suggesting that interception loss for the 14 events was 6.6 mm (8.3 % of rainfall). Both the slope and intercept of the power equation relating interception loss depth (mm) from the burned stand to rainfall depth (mm) were found to be significantly different ($p < 0.05$) from that of Equation 1:

$$I_c = 0.089\,P^{0.946},\ R^2 = 0.74 \qquad (2)$$

Using the 2006 – 2007 growing-season rainfall depth-frequency relationship for the Mayson Lake (Figure 1) and Equations 1 and 2 average season-long interception loss was estimated for mature conifer stands in the area that are undisturbed and those that have be burned (Figure 2). Mean season-long interception loss from undisturbed, mature stands in the region is estimated at approximately 28.6 %, while the interception loss from burned stands is estimated at 8.0 %. Thus, the results of this preliminary study suggest that on a season-long basis approximately 20 - 21 % more rainfall reaches the floors of mature burned stands than their undisturbed counterparts.

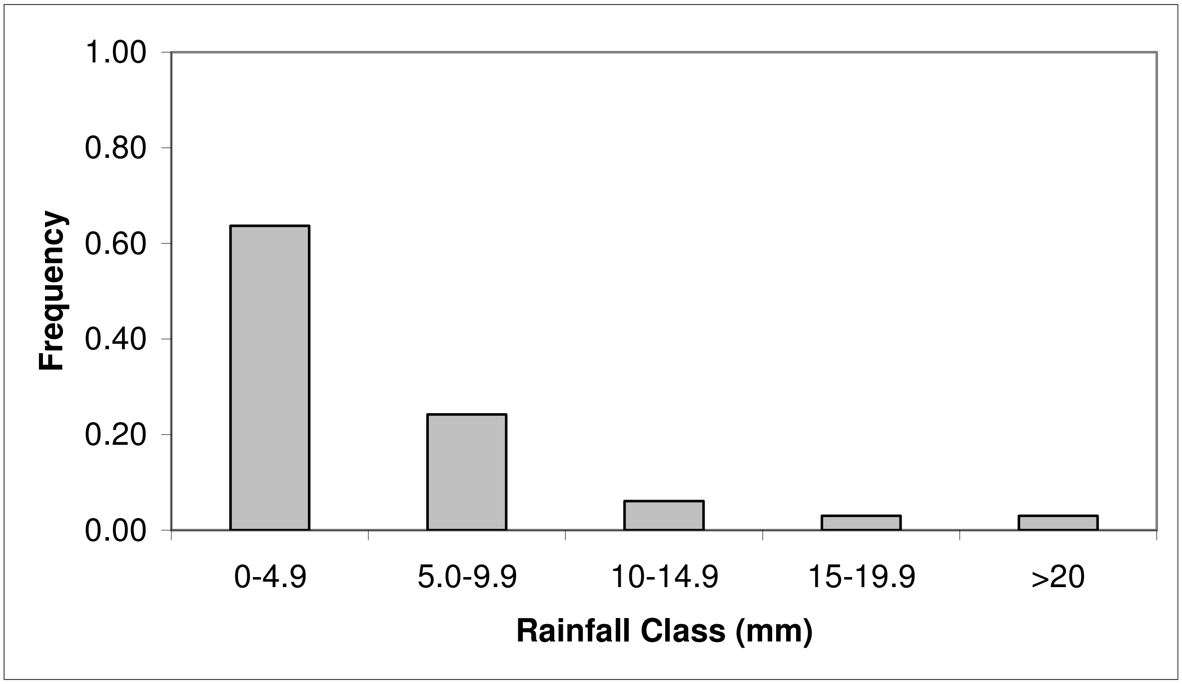

Figure 1: Rainfall depth – frequency distribution for Mayson Lake, British Columbia during the growing-seasons of 2006 and 2007.

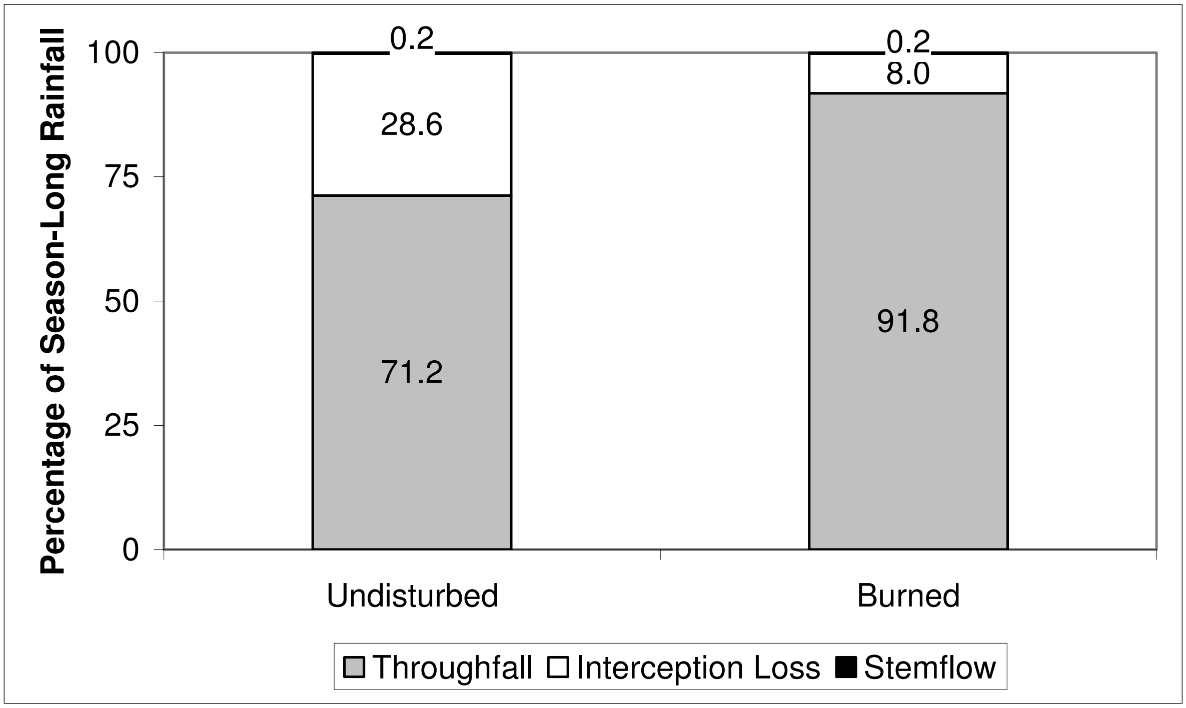

Figure 2: Rainfall partitioning by undisturbed and burned forest canopies at Mayson Lake, British Columbia during the growing-seasons of 2006 and 2007.

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Annual water balance of forest and burnt stands

Dave Spittlehouse*

Forest cover influences the balance between input of water (precipitation) and output (evaporation and drainage). It also influences how much of the precipitation reaches the forest floor and the timing of snow melt. Consequently, changes in forest cover will influence the amount and timing of water for streamflow.

Measurements of snow accumulation and melt, the surface radiation balance and hemispherical canopy photographs were made in forested and burnt areas near Mayson Lake. These data were used to parameterize a physically based stand water balance model to aid comparison of treatments under the same weather and site condition. The model and daily weather data for the area were used to evaluate the changes in interception, evaporation and drainage that result from a severe forest burn. Fire remove much of the interception capacity of the forest, and for the next few years the evaporative loss of water is mainly from the soil surface. Solar radiation reaching the snow surface or forest floor increases from around 15% in the forest to 35 to 80% depending on severity of the burn of the trees. Wind speed also increases. Changes in air temperature and humidity are small.

Simulations were done for 2002-2007 for a mature mixed pine and spruce stand, a severe burn that removed most of the branches of trees and one that left the branches intact but killed all the trees. Both burn situations lost the entire understory and exposed a substantial area of mineral soil. For the purpose of evaluating the influence of a range of weather conditions the simulations assume no regrowth for the 5 year period. Mean annual precipitation for the five years was 590 mm, close to the long term average for the area. October to April precipitation (mainly snow) varied from 240 to 350 mm and May to September from 135 to 360 mm. Monthly air temperatures ranged from an average January minimum of -13°C to a July maximum of 23°C.

For the period of the simulation, over 30% of the precipitation was intercepted by the forest, while interception in the burns was negligible for the severe burn and about 10% for the less severe burn. Evaporation of the intercepted water, transpiration and forest floor evaporation was reduced by about 50% for the burnt sites. The snowmelt season started at about the same time in the forest and the burn, but melt proceeded faster in the burn. The 5-day-average peak snowmelt rate increased by 35% in the severe burn and by about 10% in the less severe burn. As a result, snow disappeared on average 16 days earlier in the severe burn than the forests and 7 days earlier in the less severe burn. Soil moisture remained higher in the burns during the summer and into the fall and winter. Consequently, drainage from the root zone began as soon as snow melt started in the burn stands. Drainage from the forest began after the depleted storage capacity of soil was replenished.

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Streamflow patterns at Fishtrap Creek before and after the McLure fire

R.D. (Dan) Moore*

Hydrographs of mean daily streamflow following the McLure fire exhibited an earlier rise compared to pre-fire years, sometimes producing flows in early April that exceeded the 1.5-year flood. This pattern is consistent with the hypothesis that snowmelt will begin earlier in burned and salvage-logged portions of the catchment. Peak flows following the fire had return periods ranging from 1.5 to 2.5 years, based on the pre-fire record. The highest post-fire peak occurred in 2005, when minimal channel change was observed.

In an attempt to detect streamflow changes caused by the McLure fire, regression relations were developed for the pre-fire period for freshet (March-July) runoff and annual peak flow. Because there is no suitable control catchment available, climate data from Kamloops were used to develop predictor variables. For freshet runoff, accumulated winter precipitation and accumulated freshet precipitation were included in the regression model. Post-fire freshet runoff plotted near the pre-fire regression line for 2004 and 2005, but plotted substantially above the regression line for 2006 and 2007. These results suggest that freshet runoff had increased in the latter two years, possibly as a result of salvage logging and continued loss of foliage from dead trees.

For annual peak flow, the only significant variable in the pre-fire regression was accumulated winter precipitation. All post-fire peak flows plotted near or somewhat below the pre-fire regression. This apparent lack of an increase in peak flows, in combination with the indications of higher runoff (at least for 2006 and 2007), may reflect the effects of de-synchronization of melt. However, because the regression relations were relatively weak and there are only four years of post-fire data, these inferences must be taken as tentative and requiring further investigation.

Accumulated streamflow above a threshold of 6 $m^3 s^{-1}$, which is approximately the flow at which significant bank erosion occurred, was low in the post-fire period compared to the pre-fire period. For the post-fire period, this index was higher in 2005, when minimal channel change was observed, than in 2006 and 2007, when substantial bank erosion and channel widening occurred. However, the years 2006 and 2007 had relatively high values of accumulated streamflow above thresholds of 4 and 2 $m^3 s^{-1}$, the latter being approximately the threshold for bedload movement. These results suggest that streamflow changes associated with the fire were not directly responsible for initiating bank erosion, but could have prolonged the duration of bedload transport.

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Channel morphology

T.R. Giles*

Stream channels are in constant flux as streamflow, wood inputs and sediment supply vary and channel framework elements develop, erode and migrate downstream. Adjustment of the channel morphology may be a long-term evolutionary process or may be triggered by an event such as a wildfire, a landslide or a flood. Change may occur on one short reach, discontinuously on a longer reach or throughout the watershed. The temporal and spatial pattern of channel morphology alteration makes it very difficult to decide how to study change within a channel.

Permanent cross-sections provide detailed topographic survey information which, with a complementary orthoimage, present a readily repeatable and descriptive tool to monitor channel change at a reasonable scale. The Fishtrap Creek wildfire study reach, established in 2004, is located close to the WSC weir on a broad floodplain with a relatively low gradient, so as not to be directly susceptible to landslides or debris flows, and has enough streamflow to allow a wide range of fluvial processes to occur. Eleven referenced cross-sections, each 10 m apart, were surveyed with a automatic level, rod and fixed tape. A total station survey of the XS marker pins, the channel thalweg and other key channel features was completed to provide a three-dimensional survey. A camera mounted on a 9 m pole with a self-leveling gimbal was used to take a series of photographs covering the reach site. The photographs were imported into a computer program to produce an orthoimage with a digital elevation model and profile of site. The original XS have been re-surveyed each year in late summer. Sixteen cross-sections were added in 2006, 8 downstream and 8 upstream of the original reach, all at 20 m intervals. The downstream cross-sections were added to tie the reach to the weir and the upstream cross-sections were added in response to avulsion of flow into a secondary channel during the freshet of 2006.

The surveys show an interesting pattern of bed and bank erosion as well as increasing sediment accumulation in response to the post-wildfire streamflow. The freshet of 2005 had a moderately high peak flow (~9 m^3/s), but was of short duration and the channel reacted with minor erosion of the banks and aggradational and degradational adjustments to the bars. The left bank between XS3 and 4 retreated during the peak in late April 2005, but the surveyed cross-section lines did not pick this up as clearly as site photographs do. The greatest surveyed change within the reach occurred at XS9 where logs in a log jam were rearranged and the sediment wedge removed.

The freshet of 2006 saw two moderate peaks (~7.5 and 8 m^3/s), but strong flows persisted for a longer time. There was minor bank erosion and bar adjustments in the upper half of the reach (XS5 to 11), but the left bank erosion at XS 3 and 4 was quite noticeable. Over 1.5 m of ground surface was removed on the outside of the channel, the slope of the bank was steepened, and the channel base moved approximately 2 metres outwards. Two trees on the margins of the bank were undercut and fell in during May 2006. Sediment accumulation on the inside (right) of the bend created a lateral and point bar between XS3 and 5.

The freshet of 2007 saw three moderate peaks (~6 and 7.5 m^3/s), was of long duration, and substantial change was observed along the entire reach. From upstream of XS11 through to XS8 there was major bed aggradation, with up to 2 m of sediment infill at XS9. Channel overflow occurred near XS10 and a secondary channel carried water for up to a month. XS8 had two trees fall in, opening up the bank to erosion during high flows. XS2 through XS4 had continued bank erosion on the outside of the bend and expanded lateral and point bar construction on the inside. The source of the sediment was between XS15 and 19 where the channel had eroded an area approximately 10 by 20 m. XS 14 through XS12 showed significant channel aggradation, channel widening and overflow.

The morphology of the Fishtrap Creek channel post-wildfire appears to be controlled not by the peak flow but by the duration of strong flows. Riparian zone tree roots appear to be a major control on bank strength. Post-wildfire the highest peak flow occurred in 2005, and although this was associated with some bank erosion and bed adjustments, the majority of the changes occurred after long periods of strong flow in 2006 and 2007 after dead tree roots had time to decay.

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Rating curves for characterising patterns of channel change

J.C. Phillips* and B. Eaton

Rating curves are generally power-law functions that relate river stage and discharge. The stage-discharge relationship is not always static. Changing channel form, flow velocity, or channel roughness over time may lead to a shift in the relationship. Intuitively, aggradation or degradation of the channel bed will result in different stage height values for a given discharge. Therefore, in an unstable channel, if detailed discharge and stage height data are available, breaks in the rating curve may be used to document the timing, and to some extent the magnitude, of channel form adjustments.

In April 2006, nine submersible water level recorders – called divers – were installed in a variety of morphologically distinct sites in Fishtrap Creek. Rating curves generated from diver data illustrate an abrupt change in the stage-discharge relationship at many, but not all, of the sites following the first peak in the hydrograph. Our field observations and cross-sectional surveys also support the site specific changes documented by the divers. At sites where surveyed cross-sections showed significant bed aggradation, an abrupt break in the stage-discharge relationship was recorded. At sites where the channel remained stable, the stage-discharge relationship was relatively uniform.

It was not possible to separate the influence of aggradation, slope, and roughness on stage height in this analysis given the complexity of the system and measurement difficulties. However, it is likely that stage height changes due to slope and roughness, although significant, are relatively small compared to the direct effects of bed aggradation in this case.

The analysis suggests that the majority of channel form adjustments during the 2006 freshet occurred between April 2 and May 2. In fact, at several of the divers, it appears that most of the channel adjustment occurred between the first peak and second peak in the hydrograph (April 9 to Aril 30). This is an interesting observation since little is known about the timing of channel form adjustments in snowmelt-dominated systems and there are little data available largely because it is difficult to measure channel form directly at flood stages.

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Suspended sediment concentrations: four years of post-fire data

B. Eaton*, R.D. (Dan) Moore, T.R. Giles, P.N. Owens, E.L. Petticrew

Forest fires often produce an immediate, sizable increase in the volume of fine and coarse sediment supplied to a stream channel network, resulting in dramatically elevated suspended sediment concentrations (often by one or more orders of magnitude) and altered stream channel morphology. Such a response is particularly common where the fire is sufficiently hot to produce soil hydrophobocity. Suspended sediment samples collected from Fishtrap Creek between March and November in 2004, 2005, 2006 and 2007 do not show evidence of this sort of dramatic increase in sediment yield from the surrounding hillslopes, and suspended sediment concentrations (SSC) remained of the same order as monitored in an unburnt reference watershed, Jamieson Creek.

The highest SSC values in the post-fire period were recorded during the 2005 freshet, when streamflow rose to about 9 m^3/s, the highest peak flow since the fire. Despite the high peak flow, no significant channel change was observed during the 2005 freshet. The relatively high SSC values that year may represent the flushing of fine sediment that was produced during the fire and the following year, and which was not recruited during the 2004 freshet, when streamflow peaked at only 6.3 m^3/s.

In 2006, there were two distinct streamflow peaks, of about 7.5 and 8 m^3/s, respectively. During the first peak, the channel morphology remained stable and the relation between total SSC and discharge displayed clockwise hysteresis, typical of supply-limited systems. During the second peak, we observed bank erosion and associated changes in channel morphology; at the same time, the relation between SSC and became noisy. Bank erosion events within the study reach appear to be associated with suspended sediment concentrations of about 100 mg/L. For the second event in 2006, we believe that the chaotic pattern of SSC changes is linked to the random occurrence of channel adjustments and the associated random inputs of sediment to the channel. While discharges above 8 m^3/s in 2005 were not sufficient to erode the channel banks, the channel morphology in 2006 was significantly modified during flows above about 5 m^3/s, based on our analysis of the SSC data.

In 2007, three distinct peaks occurred, each of which was preceded by a peak in SSC. Channel widening and aggradation also occurred in 2007, primarily during the second peak flow event, producing a similar chaotic relation between SSC and flow for the second and third events of 2007.

The SSC data support the idea that extensive hillslope erosion did not occur at Fishtrap Creek following the 2003 fire, in contrast to the responses encountered in other parts of the southern interior. The patterns of elevated SSC during some flow events are apparently associated with endogenous channel instability driven by loss of bank strength following post-fire decay of riparian tree roots.

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Post-fire determination of fine-grained sediment sources

P.N. Owens*, E.L. Petticrew, W.H. Blake, T.R. Giles and R.D. Moore

Wildfires are important from a hydrological and geomorphological perspective because they can alter soil hydrology and increase rates of soil erosion, mass movement and channel bank erosion, which affect the delivery of water, sediment and chemicals (including carbon and nutrients) to rivers. Thus wildfires have the potential to alter the dominant sources of the sediment delivered to, and transported through, the stream network.

Visual observation of potential sediment sources in the Fishtrap watershed following the McLure wildfire in 2003 showed that the wildfire had removed much of the vegetation cover, thereby exposing soils (both topsoil and subsoil) to erosional processes and mass movement events. Furthermore, channel banks were also susceptible to erosion. In order to provide more quantitative information on changes in sediment sources following the wildfire, samples of potential sources material (topsoil, subsoil and channel bank material) and fine-grained fluvial sediment (suspended sediment and stored channel bed sediment) were collected from Fishtrap watershed in 2004. To determine the likely sediment sources prior to the wildfire, similar samples were collected at the same time from the nearby Jamieson watershed, which has similar characteristics but was not affected by the McLure wildfire. The source material samples were examined for several mineral magnetic, geochemical and organic properties, so as to establish a sediment fingerprint that is able to distinguish between potential sources. This "sediment fingerprinting approach" has been used successfully in a variety of contrasting drainage basins throughout the world in order to quantitatively determine sediment sources (e.g. Walling *et al*., 1999; Owens and Walling, 2002; Carter *et al*., 2003; Blake *et al*., 2006). Some of the fingerprint properties offer the potential to discriminate between source materials and thus to determine sediment sources in the burnt watershed. Thus, for example, Figure 1 shows bi-variate plots of the content of carbon (C) and nitrogen (N) of the source material and sediment samples collected in 2004: for simplicity the source materials were classified as topsoil or subsurface (subsoil and channel bank material). In Jamieson there is a clear distinction between the surface materials and subsurface materials, with the two sets of suspended sediment in the domain space occupied by the surface materials, suggesting that this is the dominant source of the sediment transported in Jamieson Creek. For Fishtrap Creek, there is a similar situation, although C concentrations in surface soils are substantially reduced due to the fire. The suspended sediment samples collected in June 2004 appear to be from surface material, although those collected in September 2004, while still suggesting a surface source, are different. The high organic contents of the September samples may be either due to (a) in-stream processes as a result of the reduced canopy cover overhanging the channel and the increased light, and thus the growth of periphyton on the gravel bed, or (b) the occurrence of "black carbon" due to the fire (Petticrew *et al*., 2006).

Despite the fact that some soil-sediment properties appeared able to differentiate between source materials, unfortunately, unequivocal determination of the sources of the fine-grained sediment in Fishtrap Creek following the 2004 wildfire proved inconclusive (Owens *et al*., 2006). In part this is because wildfire can both enhance and compromise the ability of certain sediment properties to discriminate between source groups. It also reflects the fairly limited number of source material and sediment samples collected in 2004.

In 2007 we collected many more source material and sediment samples, and will continue to collect more samples in 2008, in order to assess better the ability of different properties to discriminate between potential source groups. We are presently analyzing these source material and sediment samples for mineral magnetic, geochemical and organic properties, and will also analyze these samples for additional properties, such as stable isotopes and radionuclides. It is expected that the larger number of source material samples will enable a more robust and conclusive discrimination between source material groups (i.e. topsoil, subsoil and channel bank material) and thus enable the sources of the actively transported sediment in Fishtrap (and the Jamieson "reference" watershed) to be quantified. Such information will be useful for examining the geomorphological response of watersheds to wildfire.

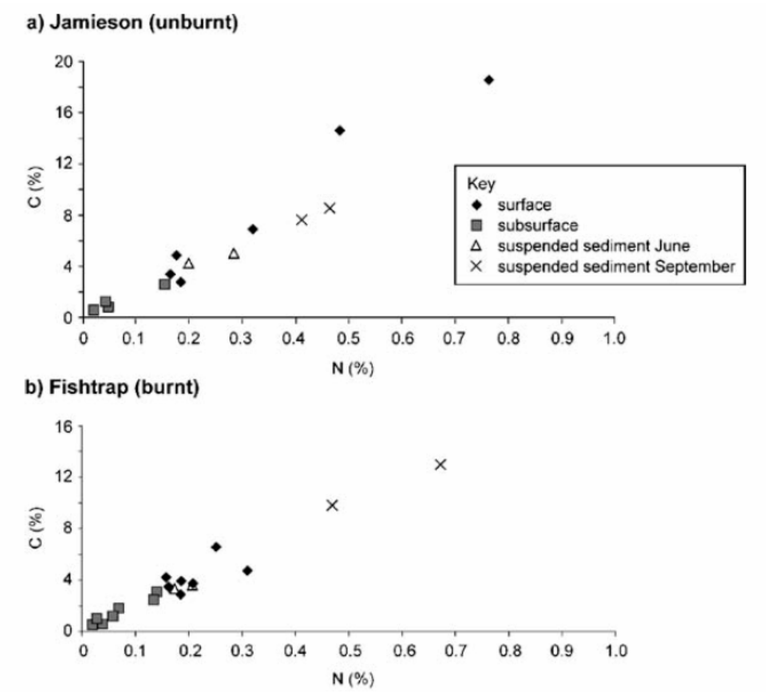

Figure 1. Plots of concentrations of carbon (C) against nitrogen (N) for the source materials and suspended sediment samples collected from Fishtrap watershed and the nearby unburnt (reference) Jamieson watershed (from Owens *et al*., 2006).

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Bedload transport: magnetic tracer stones

J.C. Phillips* and B. Eaton

Three years after the McLure fire, Fishtrap Creek is in a state of transition, triggered by the loss of bank strength and subsequent sediment input to the stream channel. Magnetic tracer stones were strategically placed to monitor bedload transport patterns during the 2006 freshet. Data from tracers provided information about the typical path length of mobile sediments, location of aggradational areas, the depth of the active layer, and bedload transport rates.

Tracer data indicates that transport distances were relatively high compared to studies from other creeks. The longest recorded travel distance reached 52 times the channel width. The mean tracer transport distance was more than twice the average pool-to-bar spacing. Such long transport distances were likely related to the long duration of competent flows, high sediment supply, and the lack of well-developed bars before the 2006 freshet. Tracer transport distances appeared to be heavily influenced by the location of bars and other depositional areas. The greatest density of tracers were recovered in one newly formed mid-channel bar.

The burial depth distribution of tracers suggests substantial scour and thorough mixing of the active layer. It is likely that the layer of mobile sediment consisted largely of loose, unconsolidated material recently eroded from the banks; these sediments were likely easily mixed and provided little resistance to vertical exchange. Field observations document the lack of well-developed surface structures on the channel bed.

Data from tracers were also used to calculate sediment transport rates using the morphologic method. The morphologic method is an alternative to standard flow-intensity-based sediment transport equations. Using this method, bedload transport rates are estimated based on changes in channel sediment storage. The method requires the total volume of erosion over a period of time and the typical path length of those eroded sediments. At Fishtrap Creek, the total volume of erosion was estimated from repeated survey cross-sections, while the tracer stones were used to record the path length of eroded sediments. Scour and fill events between channel surveys are not accounted for, which is likely the largest source of error. There is no way in this method to quantify the magnitude of underestimation due to this error. However, the amount of uncertainty is modest when compared with flow-intensity-based transport equations that tend to over-predict actual transport rates and have been reported to have errors of an order of magnitude or greater.

The extent to which current patterns of bedload transport differ from those before the fire is not entirely clear and is confounded by many factors. Continued monitoring at Fishtrap Creek using magnetic tracer stones will provide detailed information about bedload transport patterns during high sediment supply conditions as the channel responds to severe vegetation disturbance and may provide insight into pre-fire conditions as the channel recovers.

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Stream temperature patterns

R.D. (Dan) Moore*, J.A. Leach

Wildfires occasionally burn through riparian zones, resulting in a streamside zone dominated by standing dead defoliated trees. The associated reduction in shade can result in stream warming. As is the case for the effects of streamside forest harvesting, post-fire stream warming raises concerns for the potential impacts on cold-water fish species such as Bull Trout. Because the emulation of natural disturbance is frequently recommended as a paradigm for forest management, there is a need to understand how wildfire influences on hydrology and water quality compare to those of forest harvesting. Unfortunately, quantifying the impacts of riparian wildfire is more difficult than for studies employing a before-after/control-impact design, which is the most statistically powerful approach to determining impacts of forest disturbances on hydrology and water quality. Previous studies dominantly compared post-fire temperatures in disturbed streams to those in nearby unburned riparian zones to determine the influence of wildfire disturbance, or compared temperatures upstream and downstream of the disturbed area.

In summer 2004, stream temperatures were monitored at Fishtrap Creek and five other streams in the region, including two others with catchment areas disturbed by the McLure Fire and three that were not affected. There was no systematic difference in temperature between disturbed and undisturbed streams. In fact, one of the undisturbed streams was the warmest. Therefore, it appears that the natural thermal variability between streams may be too great to detect a response to wildfire disturbance using a post-fire treatment-control approach, especially for larger catchments such as Fishtrap Creek.

Stream temperature measured at the Water Survey of Canada weir was moderated by a spring that discharged into the reach several hundred metres upstream of the weir. Daily maximum temperatures measured upstream of the spring were up to 2 °C higher than at the weir. These stream-groundwater interactions can produce substantial thermal heterogeneity along a stream reach and also influence the thermal response to riparian disturbance. Therefore, a single monitoring location may not provide an accurate estimate of disturbance response at the reach scale. In addition, thermal heterogeneity complicates the use of temperature differences above and below a disturbed reach as an estimate of the change due to disturbance.

Water Survey of Canada technicians have made spot temperature measurements during visits to the Fishtrap Creek gauging station, totalling 284 before and 41 after the fire. After accounting for the effects of streamflow and air temperature using regression analysis, a statistically significant increase in post-fire summer water temperatures was detected, averaging about 2 °C. The spot temperatures were made in the late morning, and therefore likely underestimate the increase in daily maximum water temperatures.

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Effects of wildfire on stream temperature processes

J.A. Leach* and R.D. (Dan) Moore

While post-fire stream warming has been reported at a number of sites, including Fishtrap Creek, no studies appear to have addressed the processes controlling the magnitude of warming, particularly the effects of standing dead trees on net radiation at the water surface. The objectives of this study were (1) to quantify the radiation exchanges associated with standing dead defoliated riparian zone trees in comparison to pre-fire forest conditions, as well as a complete removal of riparian vegetation; and (2) to estimate the effects of different canopy conditions on stream warming.

Field studies were conducted in summer 2007 along Fishtrap Creek between the confluence of Skull Creek and the WSC weir. Field measurements included streamflow and stream geometry (width, depth, velocity) at various locations along the reach, as well as microclimatic measurements (air temperature, humidity, wind speed, solar radiation) made at two stations installed over the stream surface and at one site in a clearing. In addition, net radiation was sampled in time and space using a roving net radiometer.

A model of net radiation was developed using digitized canopy photographs to assist in modelling the transmission of solar radiation through the riparian canopy, as well as the emission of longwave radiation by the canopy, atmosphere and surrounding terrain. Over 100 canopy photographs were taken over Fishtrap Creek and processed using Gap Light Analyzer. The model was tested against measured net radiation. To simulate the effects of pre-disturbance vegetation, the model was run using canopy photographs taken at Jamieson Creek, which was not disturbed by fire and which has similar riparian vegetation to pre-disturbance conditions at Fishtrap Creek. To simulate complete loss of vegetation, the canopy photographs were modified to remove the standing dead trees and leave only topography.

A heat budget model was developed to translate the modelled net radiation (and other heat fluxes) into stream temperature changes along the study reach. The model tracks parcels of water leaving the upper end of the reach, and simulates how they change temperature in response to heat inputs and losses as the parcel flows to the lower end.

The net radiation model provided relatively accurate simulations of net radiation under current (post-fire) canopy conditions. Comparisons of modelled net radiation for the three canopy scenarios suggests that, on clear sky days, standing dead vegetation reduces net radiation at the stream surface by one-third compared to the topography-only case. In addition, they suggest that the current conditions at Fishtrap Creek provide about 50% more net radiation than would be received at the stream surface under pre-disturbance conditions.

The stream heat budget model produced a close fit between the predicted and observed downstream temperature change. The topography-only scenario resulted in a daily maximum stream temperature increase of ~0.5 °C relative to current conditions. Current conditions produced a daily maximum stream temperature about 1.0 °C higher than under pre-fire canopy conditions. This predicted change likely underestimates the total post-fire warming at the weir, because the model uses post-fire temperatures at the upper end of the reach, which are probably higher than for pre-fire conditions.

This study has demonstrated that standing dead trees do reduce net radiation and stream warming relative to what would occur with a total loss of riparian vegetation. It also highlights the utility of canopy photographs for estimating the effects of forest disturbance on incident radiation, as well as the use of a heat budget model for assessing the resulting stream temperature response.

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Benthic invertebrate responses to the McLure wildfire

Brian A. Heise*

Aquatic invertebrates live on the "front lines" of any changes in sediment and water chemistry caused by wildfire, and are therefore excellent indicators of the biological effects of fire on streams. I monitored benthic and drifting aquatic invertebrates at two sites on Fishtrap Creek, which was extensively burned, one site on Peterson Creek, which was patchily burned, and one site on Jamieson Creek, which served as the unburned control. Samples were taken in the spring (normally pre-freshet) and summer (post-freshet) from 2004 to 2007. As well, algal biomass on rocks was measured in 2006 and 2007.

The combined densities of mayflies (**E**phemeroptera), stoneflies (**P**lecoptera), caddisflies (**T**richoptera) and true flies (**D**iptera) was significantly lower than the control stream in both burned streams in April of 2004, indicating a strong response to the fire. As well as having lower numbers, Fishtrap Creek had a low ratio of mayflies, stoneflies and caddisflies (disturbance intolerant) to true flies (disturbance tolerant) (referred to as the EPT:D ratio), again indicating a negative effect of the fire. Chironomid and black fly larvae made up most of the tolerant organisms in the burned creeks. Within three months both burned streams had higher invertebrate densities than the control, indicating a very rapid recovery of biomass, but the EPT:D ratio remained much lower than the control through 2007, indicating that Fishtrap Creek continues to have a disturbed community of invertebrates following the fire.

Forest fires have the potential to alter food webs in streams, as they reduce the input of Coarse Particulate Organic Matter (CPOM), and increase the amount of light penetrating the stream, leading to increased levels of benthic algae. In Fishtrap Creek densities of shredders, which feed on leaves deposited in the stream, were significantly reduced immediately following the fire. Benthic algal biomass on rocks was 27 times greater in Fishtrap Creek than Jamieson Creek in 2006; algal biomass declined in 2007, but levels in Fishtrap Creek were still 3.8 times greater than the control. Mayfly numbers (including the algal scraper *Drunella*) were 4.5 times greater in Fishtrap vs. Jamieson Creek in 2006, and 2.3 times greater in 2007. These data on feeding groups of invertebrates, and the low EPT:D ratios, indicate that the aquatic insect community in Fishtrap Creek remains different from the control stream, and will most likely continue to change over the near future.

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UBC Regime Model: predicting the range of potential morphologic changes

B. Eaton*

In most of the documented cases of fire-related changes in channel morphology, exogenous (i.e. originating outside the study reach) changes in sediment supply appear to overwhelm any endogenous instabilities. The potential impact of endogenous (i.e. originating within the reach) instability due, for example, to loss of bank strength, is almost never considered. Tools have recently been developed which allow us to predict, even with sparse data, how channels may respond to changes in peak flow, bank strength and LWD loading, among other potentially important variables. The UBC regime model is used here to explore the potential channel response to altered peak flows, loss of vegetation-related bank strength, and to changes in the LWD loading in the stream. Specifically, we have estimated the sensitivity of the channel dimensions and the sediment transport capacity of the channel to changes in peak flow.

It was assumed that increased snow accumulation and rapid melt could increase the peak flows by as much as 50%. Alternatively, desynchronization of melt within the basin could produce a decrease in the average peak flows. The predicted effect of a ± 50% variation in peak flows on channel geometry is modest, and the effect on the transport capacity appears to be of a magnitude that can be accommodated by the fluvial system via changing surface texture for all but the largest decrease in peak flows.

The sensitivity of the stream channel to changes in bank strength due to riparian vegetation was also investigated. Initially, plant mortality is assumed to produced an exponential decline in bank strength. Root regrowth, on the other hand, will allow bank strength to recover to its former values – a process that takes about 3 or 4 decades. Assuming that up to 80% of the total vegetation-related strength could be lost, the model predicts channel widening by over 100% of the original channel dimensions and a possible transition to a multiple thread channel pattern. In this scenario, the predicted transport capacity is reduced, making the system vulnerable to exogenous increases in sediment supply, but the decline is probably not sufficient to induce net aggradation and channel instability.

The largest predicted effect on sediment supply (and the smallest effect on channel dimensions) is associated with changes in the LWD loading within the reach. We assume that the energy gradient dissipated in association with woody debris could vary by ± 0.01 m. This is equivalent to adding or removing five 50 cm tall LWD steps within our 300 m study reach. The predicted effect appears to be sufficient to drive the system into a state of persistent net degradation or net aggradation, even if the exogenous sediment supply remains constant.

The results of the sensitivity analysis suggest that loss of bank strength, leading to channel widening, and thus to LWD recruitment and a reduction in the effective energy gradient, are the most likely causes of the observed changes in channel morphology at Fishtrap Creek. However, as the bank strength recovers and the instream LWD (which is already burned and of questionable mechanical integrity) breaks down, the system is likely to switch from a laterally active, multiple thread system with bars and pools to a laterally stable, degrading system that may ultimately abandon its multiple threads by vertically incising along the main channel. The initial response is expected to lag the watershed disturbance by 3 to 10 years, while the long term response to a decline in the LWD supply is likely to occur only after several decades.

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Channel morphology, aquatic habitat and disturbance: the broader significance of the morphologic life cycle

B. Eaton*

For intermediate streams, riparian vegetation can dominate bank strength to such a degree that the channel becomes incapable of migrating laterally. The channel morphologies of these streams tend to be structurally very simple, with poorly developed pools and bars and with coarse beds. When the riparian vegetation is disturbed by fire, pest infestation or by anthropogenic activities, the vegetation-related bank strength is quickly lost, and the affected channels become capable of migrating laterally. The channel may become more complex, with moderately well developed pools and bars and with elevated large woody debris (LWD) loads due to lateral channel migration. In extreme cases, such as following forest fires, the channel may become highly unstable, developing a braided channel pattern. As the vegetation recovers, the rates of lateral migration decline and the channel becomes locked within a single, stable channel once again. The morphology of such streams likely follows a cycle related to the disturbance regime for the riparian forest upon the floodplain, shifting from one morphology to another and then back again as bank strength and LWD load varies over time.

As for forest ecosystems, the riverine habitat is intimately linked with the disturbance history. The habitat characteristics depend on both the processes acting within the channel at the present time, as well as those processes that have been active in the past. In particular, both the physical complexity and the LWD volume for a stream depend on the timing and severity of the last major disturbance to the riparian forest. Off channel habitat is likely constructed only during the brief period of accelerated lateral activity and morphologic instability that occurs following disturbance. Similarly, inputs of LWD may be dominated by windthrow and lateral erosion immediately after forest fires, particularly in environments like the interior of BC. Thus, while the unstable channel state may be undesirable, from a habitat point of view, the features that develop on the floodplain and in the channel during this phase may determine the value of the aquatic habitat in the future.

Channel disturbance, then, is probably an integral component of maintaining the overall quality of aquatic habitat for a channel network. So long as disturbances are permitted to occur but do not occur in all reaches at the same time, then the overall health of the stream network (from a physical habitat point of view) will be maintained, since habitat quality will be high in some locations, and low in others. However, if either the disturbance mechanisms are suppressed or if a single disturbance event is so widespread that all of the morphologic life cycles become synchronized, then the overall health of the system may severely compromised. The impact of the current Mountain Pine Beetle infestation may be just such a synchronization, resulting in a reduced overall habitat diversity across the landscape, with potentially disastrous impacts on the channel network as a whole, despite only apparently moderate impacts on any given reach of channel.

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