

## The Upper Penticton Creek Watershed Experiment: Integrated Water Resource Research on the Okanagan Plateau

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### Abstract

Understanding the complex interactions between forests, forest land-use, natural disturbances, streamflow, and groundwater is essential to sustainable water resource management. Throughout the dry southern interior of British Columbia (BC), both the security of water supplies and the protection of aquatic habitat are issues of ongoing concern, particularly in areas where water is limited relative to demand. In response to these concerns, the Upper Penticton Creek (UPCr) Watershed Experiment was established in 1984. The goals of this experiment are to improve our understanding of hydrologic processes on the Okanagan Plateau and to develop effective forest practices guidelines that help to sustain both timber and water resource values. This paper provides an overview of the UPCR Watershed Experiment, results, relevance to water resource management in the Okanagan, and future directions.

### Background

Studies worldwide have shown that removing forest cover in snow-dominated hydrologic regimes generally leads to larger spring peak flows and higher annual water yields. These changes occur as a result of increased snow accumulation and reduced total summer evaporation in the harvested areas (Bosch and Hewlett, 1982; Stednick, 1996; Moore and Wondzell, 2005). The magnitude of change is variable depending on watershed characteristics, the area harvested, and environmental conditions. Increased peak flows, prolonged periods of high flow, and increased soil moisture may result in slope failures, streambank erosion, accelerated channel migration, and increased sedimentation. These events may affect drinking water quality and aquatic habitat as well as put communities and infrastructure at risk (Hetherington, 1987; Gucinski, Furniss, Ziemer and Brookes, 2001). Removal of cover adjacent to small headwater

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streams may change detrital input and stream temperature, further affecting aquatic habitat (Webster et al., 1992). Late season low flows are also generally reported to increase or not change with forest cover removal and then decrease with forest regrowth as a result of changes in the interception of rainfall and transpiration (Austin, 1999; Pike and Scherer, 2003).

In BC, eight major water resource research projects have been established in snow-dominated inland watersheds. Of these, four involve intensive stand-scale studies in support of modelling (BC Forest Practices Board, 2007; Jost, Weiler and Gluns, 2007; Redding et al., 2008; Whitaker, Alila, Beckers and Toews, 2002), one is a single watershed pre- and post- disturbance study (Wei and Davidson, 1998), and three are paired watershed studies. Of the paired watershed studies, one compares a disturbed and an undisturbed watershed post-treatment (Cheng, 1989; Moore and Scott, 2005) and two have both a pre- and post-disturbance monitoring period in treatment and control watersheds (Cheng and Bondar, 1984; Winkler et al., 2004). Only one of these paired watershed experiments continues, UPCr.

## The Study Area

The UPCr watershed experiment includes the watersheds of 240, 241 and Upper Dennis Creeks. Each watershed is approximately 5 km<sup>2</sup> in size and is gentle to steeply sloping over an elevation range of 1600 to 2150 m. The area is forested with lodgepole pine (*Pinus contorta* Dougl.) and mixed stands with Englemann spruce (*Picea engelmannii* Parry) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt). In the stands of lodgepole pine, trees are generally evenly spaced whereas trees in the spruce-fir stands generally have a more clumped distribution. Canopy densities vary from 35 to 50%. Trees are over 100 years old and up to 26 m tall. The area is underlain by coarse-grained granitic rocks covered by glacial till and overlain by glacio-fluvial sand and gravel in the lower reaches. Soil textures are coarse sandy-loam over loamy-sand. All soil horizons are low in clay and high in coarse fragments with low water holding capacity and are well drained. The forest floor is generally less than 4 cm thick.

The mean annual precipitation is 690 mm, about half of which falls as snow. By late winter, the snowpack is 1 to 1.5 m deep depending on forest cover, the year, and location in the watershed. There is substantial year-to-year and site-to-site variation in snow accumulation and melt. Differences between years are often larger than those between forest cover types (Winkler and Moore, 2006). Summer forest transpiration plus soil evaporation averages 2 mm d<sup>-1</sup> when the soil is moist (Spittlehouse, 2002, 2006). Winter air temperatures occasionally drop to -20 °C. In summer, daytime high temperatures can reach 25 to 30 °C.

Annual water yield ranges from 0.8 to 3 million m<sup>3</sup> yr<sup>-1</sup> from each watershed, which is approximately 30 to 60% of the total annual precipitation. The highest daily flows occur in May during mid- to high-elevation snowmelt and may reach 1.5 m<sup>3</sup> s<sup>-1</sup>. August through April low flows are sustained by groundwater and rain, and are often less than 0.01 m<sup>3</sup> s<sup>-1</sup>. Soil water levels along hillslopes at upper elevations are highly responsive to precipitation input. At mid to lower elevations, water levels are less variable throughout most of the year. Streamflow is highly correlated with water levels in mid to low elevation riparian zones (Kuraš, Weiler and Alila, 2007). Deep groundwater recharge to bedrock is significant in terms of the overall water budget in the experimental watersheds. Early results from well data and modelling suggest that

groundwater flow from these high elevation recharge areas to the valley bottom aquifers may also be significant (Voeckler, in progress).

Chemical water quality is high with many parameters at concentrations consistently below the laboratory detection limit. The exception is colour, which is high in all three streams where total colour units range from 0 to 70. Pre-treatment physical water quality was also generally high with sediment concentration never exceeding  $20 \text{ mg L}^{-1}$  and most frequently are less than  $1 \text{ mg L}^{-1}$ . Water temperatures in the study streams average  $9 \text{ }^\circ\text{C}$  during the snow-free season and range from just above  $0 \text{ }^\circ\text{C}$  in late fall through spring to an hourly maximum of  $25 \text{ }^\circ\text{C}$  in summer. Diptera dominate the aquatic invertebrate communities of 240 and 241 Creek.

## Methods

The UPCr Watershed Experiment (Winkler et al., 2004) follows a paired watershed design, which includes pre- and post-treatment sampling periods in both the logged watersheds and in the unlogged control. Watershed-scale measurements of water yield and quality are coupled with stand-scale and site-specific hydrologic process research including measurements of net precipitation, interception, evaporation, transpiration, soil moisture, and groundwater. The effects of changing hydrologic processes on streams and aquatic habitat are being assessed through stream channel and aquatic invertebrate monitoring. Hydrologic modelling builds on the field measurements to determine watershed-scale effects beyond the scope of the study including alternative logging treatments, additional variables such as peak flow magnitude and frequency, and a broader range of weather scenarios including climate change.

From 1984 to 1995, the watersheds remained undeveloped with the exception of a small area of blowdown salvage in 1992 near the outlet of 241 Creek. Road construction and conventional clearcut logging began in late 1995. By late winter of 1996, 6% and 10% of the 241 and Upper Dennis Creek watersheds had been clearcut, respectively. A second logging pass was completed by late winter of 1999 bringing the area clearcut to 18% and 21% of the 241 and Upper Dennis Creek watersheds, respectively. In 1999, a major spruce beetle outbreak killed most of the Engelmann spruce in the Dennis Creek watershed. These trees were salvage logged and by spring 2000, 52% of the Upper Dennis Creek watershed had been clearcut. A third logging pass increased the area cut in the 241 Creek watershed to 28% by late winter 2003. The final logging pass in the 241 Creek watershed was completed by late winter 2007 so that the total clearcut area was 47%, similar to that of Upper Dennis Creek. This level of cut is intended to represent the highest levels of harvest likely to be considered operationally in most watersheds. To simplify the discussion, the progressive levels of cut will subsequently be referred to as 10%, 20%, 30% and 50%. All road construction, logging, and reforestation were completed according to the operational standards of the day. Logging was done in late fall and winter, on snow, using feller bunchers and ground-based skidding. Planting was in accordance with provincial species selection guidelines and stocking standards for the specific ecological units harvested. All non-essential roads were deactivated following logging and planting.

Since 1992, a network of six weather stations have continuously monitored rainfall, air temperature, soil temperature, relative humidity, solar radiation, wind speed, snow depth, and snow temperature. Detailed snow surveys are completed at seven sites every two weeks from

early March until the end of snowmelt. Root zone water content was measured during the summers of 1997 to 2006 in forest, clearcut and regenerating stands. Streamflow has been measured continuously since 1985 at a Water Survey of Canada gauge site on each of 240, 241, and Upper Dennis Creeks. Water samples for chemical analysis have been collected at the streamflow gauge sites every two weeks during the ice-free season since 1992. Water samples for physical analyses have been collected daily with automated water samplers since 1996. Two deep (30 m and 50 m) wells were drilled at upper elevation in the 241 Creek watershed in 2007 and are being continuously monitored. Other variables are measured using methods specific to each study. Streamflow in 240 and 241 Creek has been well simulated with a distributed hydrological model (Thyer, Beckers, Spittlehouse, Alila and Winkler, 2004).

## Overview of Results

Taking into account weather-related changes in streamflow over the study period, no significant changes in water yield, seasonal or annual, were detected at harvest levels up to 20%. Year-to-year variability in flow and the accuracy of measurement techniques makes the detection of small changes at these harvest levels difficult. Preliminary analyses suggest that clearcut logging approximately 30% and 50% of the 241 Creek and Upper Dennis Creek watersheds, respectively, has resulted in statistically significant changes in water yield over the snowmelt season. These changes are likely due to increased snow accumulation in the openings relative to the forest at low and mid elevation. High flows also appear to be occurring earlier in spring at these levels of harvest, most probably due to the earlier onset of snowmelt in the open relative to the forest and synchronisation of snowmelt runoff from mid-elevation openings with that at lower elevation. Streamflow modelling suggests that changes in peak flows may also be observed once logging extends over more than 30% of the watershed area and that increases in spring flows are unlikely to exceed 50%, on average, regardless of logging extent unless runoff is concentrated by roads (Schnorbus, Winkler and Alila, 2004).

Increases in water yield can, at least in part, be attributable to changes in the water balance post-harvest. Maximum snow accumulation expressed as water equivalent (SWE) in clearcuts averages 10% and 23% greater than in the mature pine and spruce-fir forests, respectively (Winkler, 2001). The exception to this occurs along steep, upper elevation, south-facing slopes in the 241 Creek watershed where higher SWE is measured in the forest than in the open before the onset of melt. This is likely due to periodic snow disappearance in the open during windy and warm weather prior to the main melt season. These losses potentially mitigate the effects of increased SWE at other sites across the landscape. Snowmelt in clearcuts occurs up to 10 days earlier than in the forest (Spittlehouse and Winkler, 2004) resulting in the synchronization of melt from higher elevation clearcuts with that from lower elevation forests. In stands typical of the Okanagan Plateau, including those at UPCr, surveys show that maximum SWE decreases by approximately 6% for every 10% increase in crown closure up to a maximum crown closure of 55% (Winkler and Roach, 2005). Depending on the weather, 25 to 30% of the summer rainfall is intercepted by the forest canopy (Spittlehouse, 1998). Once logged, interception of precipitation in the new clearcut becomes negligible.

Evaporation rates from a wet, bare, soil surface, such as a new clearcut, are as high as those from the forest (2 to 3 mm d<sup>-1</sup>) (Spittlehouse, 2002, 2006). During dry weather, evaporation rates

from the clearcut drop rapidly to less than  $0.5 \text{ mm d}^{-1}$ . Consequently, summer evaporation from a clearcut is about 30% less than that from the forest. Lower evaporation rates combined with a substantial reduction in interception loss results in moist soil and a potential increase in water available for streamflow (Spittlehouse, 2006). Ten years of weather data, precipitation interception and soil moisture measurements, combined with a physically based water balance model, gave an average annual evaporation from the forest of  $400 \text{ mm y}^{-1}$ , of which 43% was from intercepted rain and snow. Clearcut annual evaporation was  $200 \text{ mm y}^{-1}$ . Drainage from the site followed a reverse pattern with the clearcut averaging  $500 \text{ mm y}^{-1}$  and the forests  $190 \text{ mm y}^{-1}$ . The increase in the clearcut was mainly a result of the reduction in interception loss. Inter-annual variability of evaporation is mainly a function of variation in summer precipitation, while drainage variability depends on winter precipitation.

Chemical water quality remains high in all three study watersheds with concentrations of study parameters well below the drinking water standards throughout all phases of logging. Over 67% of the nitrate plus nitrite, phosphorus, and sulphate measurements were below the detection limit. Statistically significant ( $p < 0.05$ ) increases in magnesium, potassium and sodium were detected in both 241 and Dennis Creeks, as well as in organic and inorganic nitrogen in Upper Dennis. The magnitude of these changes, however, is small and changes have also been observed in 240 Creek, the unlogged control (Winkler and Nemeč, in progress). These changes appear to occur in response to snowmelt, individual rainstorm, or disturbance events. Concentrations quickly return to background levels following the event. Since concentrations are low, changes in individual chemical water quality parameters as a result of logging are not readily distinguishable from a general upward trend in parameter concentrations observed in all streams including the control. However, when all chemical water quality parameters are considered together, preliminary results of an ongoing analysis suggest that a shift in water quality described by groups of variables began post-20% cut (Winkler and Nemeč, in progress). Two to three years post-20% harvest, nitrate nitrogen concentrations in Upper Dennis Creek increased noticeably in the spring, just prior to the peak in streamflow. This is a result of increased losses of nitrogen in soil water drainage in the first few years post-harvest (30 to 60% higher in the clearcut than the forest), particularly during snowmelt. However, losses of all forms of nitrogen from the root zone are extremely small ( $< 0.1\%$  of the total available). As a result, even at their highest measured values, nitrogen concentrations remain very low in stream water (Hope, 2008).

These small watersheds appear to be sediment poor and any sediment available to the creek is rapidly moved through the system. Elevated concentrations of suspended sediment were observed during the spring freshets immediately following logging. Slightly elevated turbidity continues through the summer and fall and in some cases increased turbidity may occur for as long as three years following harvest. The length of time that elevated readings are observed is the result of delayed delivery to the creek from the hillslope sources and may also be related to the proximity of the source to the sample collection location. The creeks appear to lack the streampower, both in terms of strong peak flows and duration of the elevated flows, to move coarser sediment (sand size and larger) through the watershed to the weir in one season. Stream channels in the Dennis Creek watershed are controlled by bedrock ridges. The main channel is dominated by large boulders with woody debris forming jams, steps and pools. In 240 Creek, the upper portions of the watershed have few channels and these cross the structure of the bedrock. In the centre of the watershed there is a large flat area where the main stem channel

forms as the feeder channels leave the hillslopes. The channel then passes through a bedrock controlled valley for over a kilometre to the weir. The 241 Creek watershed has tributaries flowing through bedrock controlled draws in the steeper upper portions of the watershed. These come together along the base of the hillslope on the remnants a large glaciofluvial floodplain and flow across gentle ground to the weir. Despite the differences in the three watersheds, there has been very little change in any of the stream channels. The channel banks and beds have remained stable with only minor changes in wood inputs.

Aquatic invertebrate communities were found to be resilient to logging when slash was kept out of the stream channel. The number of invertebrates sensitive to change and invertebrate biodiversity stayed the same or increased post-logging, depending on the site. The proportion of shredders (invertebrates eating leaves) decreased. These results differ from those at another study location where fine logging slash left in the stream had a large deleterious effect on the aquatic insect community.

Understanding regional aquifer systems within mountainous regions requires an understanding of groundwater flow in the adjacent mountains where most of the recharge occurs. Lineament density (the number of bedrock fractures per unit area) mapping throughout the Okanagan Basin showed that fracture density in the 241 Creek watershed is relatively low (Voekler and Allen, 2008). Based on pumping and monitoring well responses, the average transmissivity of the aquifer is estimated at  $4.24 \times 10^{-6} \text{ m}^2 \text{ s}^{-1}$  and the storativity value, 0.001. Using these values in Discrete Fracture Network modelling the preliminary estimate of the bulk fractured bedrock hydraulic conductivity within the 241 Creek watershed is on the order of  $10^{-6}$  to  $10^{-7} \text{ m s}^{-1}$ . The downward movement of groundwater in the bedrock, or recharge, is estimated to be in the order of  $5.77 \times 10^{-9} \text{ m s}^{-1}$  or 182 mm per year. This amounts to approximately one-third of the total annual precipitation, a significant portion of the overall annual water budget (Voekler, in progress).

## Relevance to Water Resource Management

Field measurements combined with modelling at UPCr provide information directly relevant to water resource management in the Okanagan Basin. As forest cover is lost to over 50% or more of small upland watersheds, changes in water yield, particularly in spring, can be expected. This finding provides an indication of the potential effects of natural disturbance such as mountain pine beetle (MPB) and subsequent salvage logging on water yield from upland watersheds. The results of snow surveys across the study area show that, when planning logging operations, opportunities exist for mitigating the synchronization of snowmelt from mid-elevation openings with that from lower elevation sites as well as the importance of considering the spatial variability in hydrologic processes across watersheds. The relatively small changes in streamflow measured over the short period of record at UPCr may be more significant during wetter or drier years than occurred during this study, or when variables such as event extremes and frequencies are considered, as has been demonstrated by modelling. Measurements in regenerating stands suggest that if future water availability is calculated based on streamflow from highly developed (harvested) watersheds, long-term water supplies may be overestimated if subsequent hydrological recovery due to forest re-growth is not taken into account. Building on the existing long-term database, continuing research in the Okanagan at UPCr and Camp Creek

(Moore and Scott, 2005) is directly measuring the rate of hydrologic recovery post-harvest. These data can be used to parameterize hydrologic models in order to estimate streamflow changes across the broader landscape of interest to down-stream water users.

Work at UPCr has also shown that extensive clearcut logging can directly or indirectly affect the water quality from small upland watersheds typical of the Okanagan Plateau. Where surface runoff patterns have not been affected, where channels remain intact, and where erosion does not occur, these changes appear to be short-term, persisting through a single, or several seasons, of high flow events. Where the stream channels and banks remain relatively undisturbed by clearcutting aquatic invertebrates are not adversely affected. Identification of sediment sources, minimising stream crossings, yarding away from creeks, and limiting or avoiding areas in or leading directly to the active riparian zone, all contribute to minimising the effects of logging in headwater streams. These recommendations applied to logging through the headwaters of the Okanagan Basin and in particular where extensive pine beetle salvage is anticipated, will help to protect both water supplies and aquatic habitat downstream.

Early research results throughout the Okanagan Basin have shown that groundwater processes at high elevation in mountainous regions can be significant, but are often overlooked due to lack of data or lack of consideration for their importance. Recharge to the deep bedrock at UPCr is evident in the sustained baseflow throughout the summer and early fall season. Even though shallow soil piezometers are mostly dry during the mid to late summer months, there is measurable flow of water in 241 Creek, suggesting that streamflow derives at least partly from deeper groundwater sources. Given the high potential for groundwater recharge at high elevation, there may be a significant groundwater flow component to aquifers in the Okanagan Valley bottom (Voeckler and Allen, 2008). These results highlight the importance of groundwater contributions from upland watersheds and suggest that changes in the surface and near-surface water balance through forest disturbance could potentially also affect downslope and downstream groundwater supplies.

The long-term database provides the foundation for future research into the water resource implications of forest land use, natural disturbance, climate change and increasing water demand. The next phase of the UPCr watershed experiment will focus on hydrologic processes in young stands and the effects of reforestation on water supplies. Work will continue to develop and improve hydrologic models for watersheds typical of the Okanagan Plateau including the incorporation of deep groundwater. The long-term data legacy at UPCr also allows us to answer questions about issues that have emerged since the experiment was initiated, such as the potential consequences of MPB-related stand mortality and subsequent salvage logging and the potential consequences of climate change on water supplies and aquatic habitat. The streamflow and weather databases at long-term research sites such as UPCr also provide a unique opportunity for future field process studies and hydrologic modelling that explore questions which we have not yet considered and provide answers which will continue to enhance stewardship of water resources in the Okanagan Basin.

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