The Upper Penticton Creek Watershed Experiment: A Review at Year 20

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Abstract

The Upper Penticton Creek Watershed Experiment was initiated in 1982 to evaluate the effects of forest harvesting on water in snowmelt–dominated watersheds of south–central British Columbia. Logging 20% of the treatment watersheds has resulted in a shift in maximum and late season streamflows. Snow accumulation increased by 10 to 30% in clearcut areas relative to the forest, depending on year, site, and stand characteristics. Elevated turbidity levels were observed following road construction and in association with active logging. Increased stream temperatures have been measured in clearcut reaches. Calibration and testing of a distributed hydrology–soil–vegetation watershed scale model has been successful.

Introduction

In watersheds where streamflow is predominately generated by melting snow, changes in forest cover can affect flow volumes and timing. Forest cover removal usually results in larger spring peak flows and annual water yields due to increased snow accumulation and reduced evaporation losses in the harvested areas. The magnitude of change is highly variable, ranging from no detectable change to double the annual flow, depending on watershed characteristics, area harvested and environmental conditions (Stednick, 1996). Decreases in flow have been observed with forest regrowth, often over a period of 30 years or more. Low flows usually increase with forest cover removal and then decrease with forest regrowth, effects attributed to changes in evaporation loss (Johnson, 1998).

Increases in peak flow magnitude and duration have been shown to result in increased sedimentation from streambank erosion (Hetherington, 1987). Logging can also increase the potential for sediment delivery to stream channels from roads, skid trails, landings and slope failures (Gucinski *et al.,* 2001). Elevated sediment concentrations and the deposition of harvested material in streams can affect drinking water quality and the aquatic ecosystem. Removal of forest cover above small headwater streams changes detrital input and stream temperature, in turn affecting aquatic habitat (Webster *et al.,* 1992).

Extrapolation of results from one hydrologic environment to another is difficult, particularly where local information regarding both hydrology and the inter–relationships between forest land–use and water–based resources is lacking. In Canada, there are only eight paired–watershed experiments, which include both pre– and post–treatment comparisons, that are evaluating the effects of forest disturbance on surface water (Buttle *et al.,* 2000). Of these, the Upper Penticton Creek Watershed Experiment represents watersheds on the dry, high–elevation, interior plateau of BC where hydrologic processes

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are snow–dominated. The objectives of the Upper Penticton Creek Watershed Experiment are to improve our understanding of hydrologic processes and to develop broadly applicable forest practices guidelines that enhance our ability to sustain both the forest and water resources of the Okanagan Plateau. Data collected at Upper Penticton Creek are also being used to test predictive tools such as the Distributed Hydrology Soil Vegetation Model (DHSVM) of Wigmosta *et al.* (1994). This paper provides an overview of the first 20 years of the Upper Penticton Creek Watershed Experiment.

Study History and Design

The Upper Penticton Creek Watershed Experiment began in 1982 in response to operational requests for research that would quantify the hydrologic effects of harvesting high–elevation forests in the Okanagan. The specific objectives of the project were to "develop and test technical measures and guidelines for minimising logging effects detrimental to water resources" and "where possible, maximising effects that are beneficial" (Cheng, 1982). Three small tributary streams of Penticton Cr. were selected for study: 240, 241, and upper Dennis Creeks. Streamflow gauges were constructed on 240 and 241 Cr. in late 1983 and in Dennis Cr. in late 1984. H–flumes and Stevens A–71 type continuous water level recorders are used to measure spring streamflows and V–notch sharp–crested inserts are used during the low flow season. Streamflow from all three watersheds are recorded continuously as part of the Water Survey of Canada surface water network. The initial weather network consisted of daily maximum and minimum air temperature and daily summer precipitation at three locations adjacent to the experimental area. Ecosystem mapping was completed in 1984 (Smith, 1984). Additional projects, including water quality research beginning in 1988 (Hudson and Golding, 1997), were anticipated to provide data complementing and expanding upon the baseline information.

The Upper Penticton Creek Watershed Experiment follows a paired–watershed design in which one watershed remains the undisturbed control throughout the experiment. Hydrometric monitoring began in all three watersheds prior to development and has continued through– and post–logging. Analysis of the calibration–period data showed that streamflows from the 240 and 241 Cr. watersheds were comparable for all of the variables being considered but those from Dennis Cr. were not, likely reflecting differences in physiographic characteristics and forest cover. In 1992, a severe windstorm toppled trees over approximately 4% of the 241 Cr. watershed near the streamflow gauge, and over an extensive area adjacent to the Dennis Cr. watershed boundary. Timber from these areas was salvage–logged late that year.

Based on the calibration period data, the 240 Cr. watershed was designated as the control watershed and the 241 and Dennis Cr. watersheds as the treatment areas. Harvesting patterns were to be the same in both treatment watersheds and logging would occur in phases. With this design, the extent of forest cover removal where changes in water resources became detectable, as well as the interactions between the treatments and watershed characteristics, could be observed. Each logging–pass would remove timber from 10% of the area in each treatment watershed. Cutblocks would be winter–logged using conventional feller–buncher and skidding techniques.

Development began in 1995 with the construction of logging roads in the 241 and Dennis Cr. watersheds and with clearcutting of two blocks in the Dennis Cr. watershed. All development was conducted to the standards of the day by Weyerhaeuser Co. Ltd. These treatments, along with the area previously salvage–logged in the 241 Cr. watershed, brought the area clearcut to 4% and 8% of the total area in the 241 and Dennis Cr. watersheds, respectively. Post–first–pass measurements continued for three years, until late 1998. This short measurement period was the longest acceptable to the forest planners who were concerned about an expanding mountain pine beetle epidemic. Fortunately, this outbreak did not result in extensive mortality over the study area.

In late 1998 and early 1999, a second logging pass increased the rate–of–cut to 17% and 19% of the 241 Cr. and Dennis Cr. watersheds, respectively. In 2000, a spruce beetle outbreak killed most of the trees over 50% of the Dennis Cr. watershed. These trees were logged in the winter of 2000/01. An additional

10%–cut in the 241 Cr. watershed will be completed in late 2002 and early 2003. By freshet 2003, 30% of the 241 Cr. and 50% of the Dennis Cr. watershed will have been clearcut. No further development is planned for three to five years.

Over the past 10 years, the environmental monitoring network at Upper Penticton Cr. has been continuously improved. It now includes five active climate stations measuring solar radiation, air, soil, and snow temperature, windspeed, humidity, rainfall, and snow depth; a snow survey network covering six locations; water quality sampling; and seven permanent stream channel monitoring stations. Stream temperature work was initiated in 1996 and aquatic invertebrate surveys were completed from 1995 to 2000. Soil mapping was completed by Hope in 2001.

The Study Area

The Upper Penticton Creek Watershed Experiment is located approximately 26 km northeast of Penticton, BC. The 4 to 5 km² watersheds drained by 240, 241, and Dennis Cr. form the study area. The 240 and 241 Cr. watersheds are gently sloping from an elevation of 2025 to 1600 m and have a southerly orientation. Both watersheds have approximately 1.5 km² of valley flat (<7% slope). The Dennis Cr. watershed has a westerly orientation and ranges from 1775 to 2145 m in elevation with approximately 0.1 km² in valley flat.

All three watersheds are classified in the dry Engelmann Spruce Subalpine Fir biogeoclimatic subzone (Lloyd *et al.,* 1990). The predominant forest cover type over the 240 and 241 Cr. watersheds is lodgepole pine (*Pinus contorta Dougl.*), whereas forests in the Dennis Cr. watershed are dominated by Engelmann spruce (*Picea engelmannii Parry*) and subalpine fir (*Abies lasiocarpa (Hook.) Nutt*). Trees in the study area are over 100 years old and reach a maximum height of 20 to 26 m. Stands of lodgepole pine are evenly spaced, whereas spruce–fir stands generally have a more clumped distribution of stems. Canopy densities vary from 35 to 50%.

Soil textures over the study area are coarse sandy–loam over loamy–sand. The soils are derived from glacial–tills and coarse–grained granitic rocks. All soil horizons are low in clay and high in coarse fragments. These soils have a low water holding capacity and are well or rapidly drained. The forest floor is generally less than 4 cm thick.

The mean annual precipitation is 750 mm, approximately half of which falls as snow. By late winter, the snow pack is 1 to 1.5 m deep (Figure 1) depending on forest cover, the year, and location in the watershed. Snow water equivalents measured on April 1 average 265 mm and snowmelt from mid–April through June averages 5 mm d^{-1}. On average, 380 mm of rain falls on the watersheds from late May through October each year. The wettest year during the past decade was 1997, when May through October rainfall totalled 538 mm, 1.4 times the average.

Winter air temperatures occasionally drop to −20°C. In summer, daytime high temperatures occasionally reach the upper 20s. In the last decade, the record high was 31.1°C in July 1994 and the lowest temperature reached was −37.0°C in December 1995. The air temperature in the forest is usually a degree or two cooler than in the open during the day and are approximately equal at night. The daily minimum

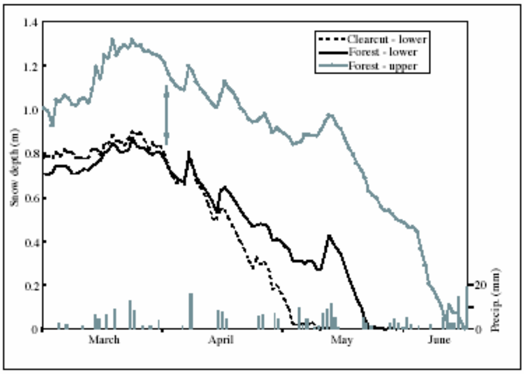

Figure 1. Daily snow depth (m) (lines) and precipitation (mm) (bars) from March 1 to June 16, 2000. Precipitation was measured at the lower snow course locations. The arrow indicates when the snow pack first reached a uniform temperature of approximately 0°C. This occurred in early April at all three sites.

relative humidity during the summer is between 20 and 50%. The daily maximum wind speed averages 22 km h^{-1} with gusts of 40 to 60 km h^{-1}. Annually, solar radiation averages approximately two–thirds of the maximum that would be possible for this latitude under clear skies.

Approximately 0.8 to 3 million m^3 of water flow from each study watershed annually. Per unit area annual water yields are largest from the 240 Cr. watershed and are 10 and 40% less from the 241 and Dennis Cr. watersheds, respectively. The highest daily flows occur in May during mid– to high–elevation snowmelt and may reach 1.5 $m^3 s^{-1}$. Average May water yields are approximately 50% higher from the 240 and 241 Cr. watersheds than from Dennis Cr. (Figure 2). The largest flows occurred in May 1997 when the total monthly flow in 240 Cr. was 1.5 times the 1985 through 2001 average. The study streams do not completely dry up at the gauge–sites at any time of the year. However, flows in August through April are often less than 0.01 $m^3 s^{-1}$, one–hundredth of the maximum. Late season streamflows are sustained by groundwater and rain. The lowest late season and total annual flows were recorded in 1987, which was an unusually dry year according to the long–term weather station at Penticton airport.

The water quality in all study streams is generally high. Over the period 1992 to 2001, concentrations of nitrate plus nitrite nitrogen and phosphorus were low, varying from undetectable to 0.42 mg L^{-1} and from undetectable to 0.32 mg L^{-1}, respectively. Pre–treatment sediment concentrations fluctuated with streamflow but did not exceed 20 mg L^{-1} of water and were most frequently lower than 5. The water in all three creeks is highly coloured, with TCU varying from 0 to 70. Water temperatures in the study streams range from just above 0°C in late fall through spring to an hourly maximum of 25°C in summer. The lowest stream temperatures occur around 7 a.m. and the highest temperatures from 2 through 4 p.m. The average stream temperature during the snow–free season is 9°C. The aquatic invertebrate community of both 240 and 241 Cr. is dominated by Diptera (primarily chironomids). Both streams contain abundant Plecoptera and Ephemeroptera, however, Ostracods have been found in much higher abundance in 241 Cr. (Figure 3).

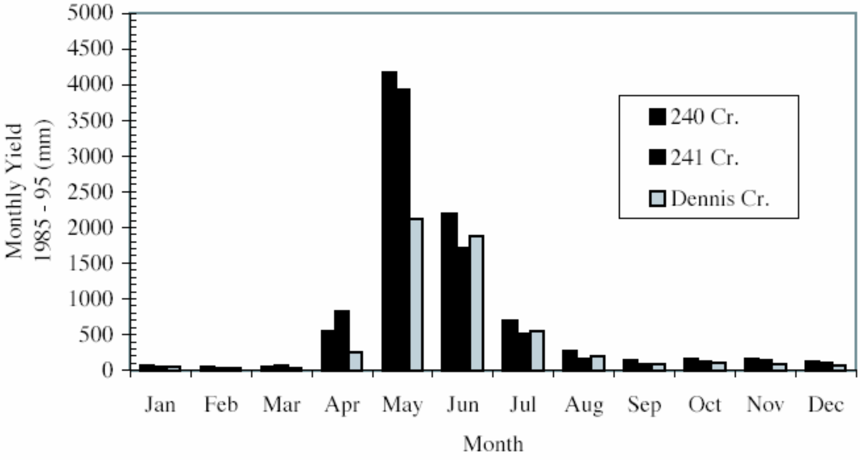

Figure 2. Average monthly water yield for 240, 241, and Dennis Creeks during the pre–treatment period 1985 to 1995.

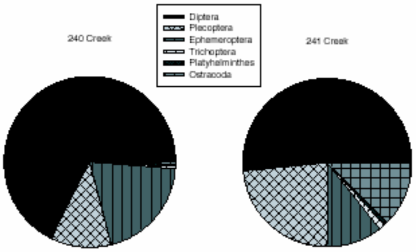

Figure 3. Proportion of aquatic invertebrate groups in 240 and 241 Creeks in 1998.

Logging Effects

Logging over 4 and 8% of the 241 and Dennis Cr. watersheds, respectively, did not result in detectable changes in the hydrograph or chemical water quality. However, some change in physical water quality following road construction, stand scale hydrologic processes, and aquatic habitat was observed (Heise, 1999; Spittlehouse, 2000; Winkler, 2001). Evaluation of the 20% rate–of–cut effects on streamflow, water balance and aquatic ecology is under way. To date, this work has primarily focussed on the 240 and 241 Cr. watersheds. Some results of these data analyses are provided in the following sections.

Streamflow

Streamflows in 240 and 241 Creeks were found to be strongly correlated ($r^2 > 0.9$ for all variables) over the pre–treatment period. Preliminary analyses suggest that logging approximately 20% of the 241 Cr. watershed has increased the highest maximum daily peak flows and decreased the lowest low flows, while average flows have remained the same. Changes in annual water yield are within measurement error. These changes were in addition to the distinct increase in annual water yield from both watersheds observed over the period 1996 through 2001 relative to the pre–logging period 1985 to 1995. Post–1995 May and June water yields from the unlogged 240 Cr. watershed averaged 16% and 60% more, respectively than during the pre–logging period, and total annual yields from both watersheds were 38% higher.

Water Balance

Snow interception and losses from the forest canopies resulted in 10 to 30% more water in the snowpack in the clearcut than in the forest at the beginning of spring melt (Winkler, 2001). The size of this loss varies from year to year, with the weather and with forest type. Warm sunny days have snowmelt of 20 to 40 mm d^{-1}, with the forest at approximately 60% of the clearcut rate under the same weather conditions. Rain is also intercepted by forest vegetation and evaporates before reaching the ground. Of the total rainfall, 20 to 30% can be intercepted, the percentage decreasing with increasing storm size. Summer evaporation averages 1.5 to 2.5 mm d^{-1}, of which approximately 30% is due to evaporation of intercepted water (Spittlehouse, 2002).

The Aquatic Environment

Turbidity in 241 Cr. typically increases with streamflow in April or early May (Figure 4). Maximum turbidity levels occur prior to the hydrograph peak indicating that the channel is sediment deficient, likely a result of the local granitic bedrock and the gentleness of the topography, and that the majority of introduced sediment will be removed prior to peak discharge. In late September and October 1998, elevated turbidity levels were measured at the weir. This increase in turbidity was attributed to the commencement of harvesting and vehicular activity in the 241 Cr. watershed.

Water temperatures in the open and in the forest were compared in Dennis Cr. Water temperatures in the clearcut were always significantly higher than those in the control stream, with the maximum differences occurring in the afternoons. The clearcut stream also experienced the greatest diel fluctuations in temperature. The largest temperature difference observed was 6.3°C.

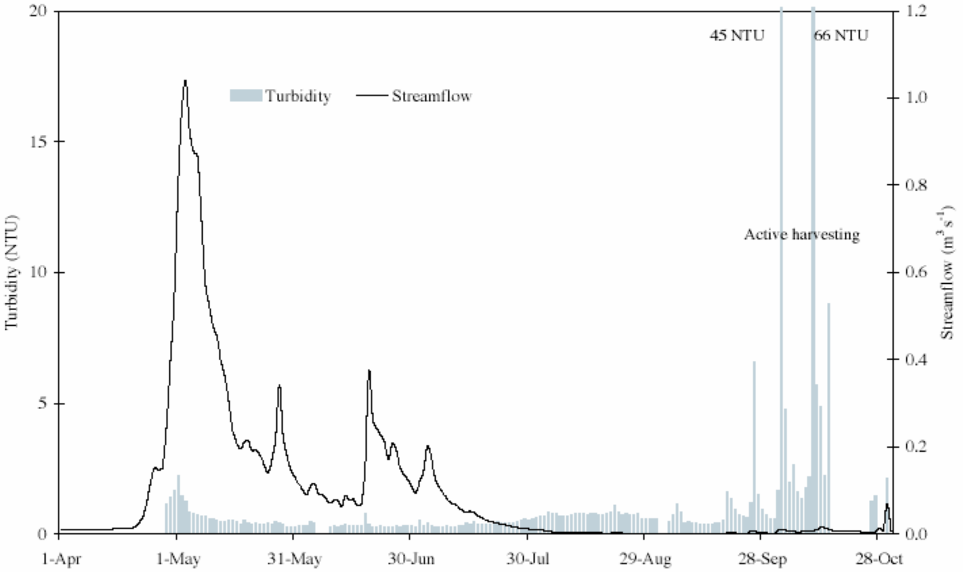

Figure 4. Average daily turbidity (five samples daily at 0900, 1200, 1500, 1800, and 2100 hours) and streamflow measured at the 241 Creek weir for the 1998 season.

Hydrologic Modelling

A three–step approach was taken in the calibration of DHSVM for the 240 and 241 Cr. watersheds. First, the parameters that affect snow accumulation and melt in the open areas were optimised, making use of the open area snow albedo, snowmelt and snow water equivalent (SWE) measurements at the lower clearcut measurement site. Secondly, the influence of vegetation parameters on snow accumulation and melt below the canopy was determined using the SWE and snow albedo measured at the low elevation mature forest site, and was verified using open and forested SWE data from upper elevation clearcut and forest sites. Finally, soil parameters affecting runoff generation were constrained using the watershed outflow hydrograph. The August 1997 to August 2001 hourly streamflow data for the unlogged 240 Cr. watershed were used for model calibration. The same years of data from 241 Cr. were used for model verification. For point calibration, a manual trial and error approach was adopted while a combination of manual and automatic calibration techniques were used for the basin calibration.

The simulated hydrograph for year 2000 with the final set of optimised DHSVM parameters closely follows the observed streamflow in the 240 Cr. watershed (Figure 5). When the same soil parameters are used for 241 Cr., the simulated hydrograph is also a reasonably good fit to the observed values. Overall, these results illustrate that the model can satisfactorily reproduce the observed hydrograph for both 240 and 241 Cr. This indicates the model will provide a reliable numerical tool for assessing the impact of changes in the hydrological regime due to forest management practices for snow–dominated forested watersheds typical of this region in BC.

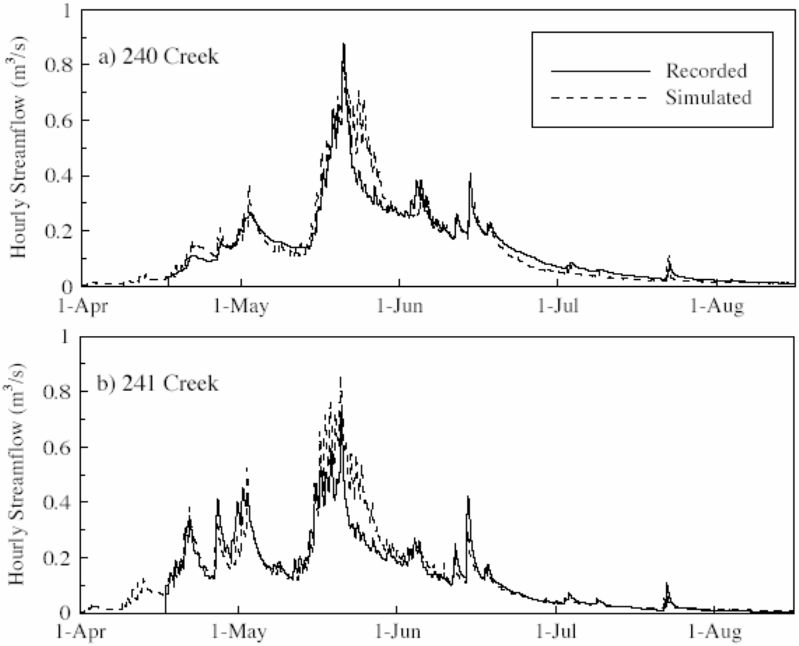

Figure 5. Comparison of recorded and simulated hourly streamflow from 240 and 241 Creeks in 2000.

Summary

This paper briefly summarizes the history of the Upper Penticton Creek Watershed Experiment, characteristics of the study basins and some preliminary results regarding the hydrologic and ecological effects of logging 20% of the 241 Cr. watershed. Shifts in maximum and late season streamflows were observed. Water balance work has demonstrated that approximately 30% of the total rain– and snow–fall is intercepted by the forest canopy. Forest harvesting substantially decreases interception and tree transpiration while increasing forest floor evaporation and drainage. Changes in physical water quality were observed following road construction and in association with active logging. No change in chemical water quality was observed at 20% harvest. Dennis Cr. stream temperatures were 2°C to 3°C higher on average in the open, and a maximum of 6°C higher, than those under forest cover. Calibration and testing of a distributed hydrology–soil–vegetation watershed scale model was successful.

Analyses of the data collected at Upper Penticton Creek is ongoing, as is modelling of harvesting and environmental scenarios beyond the scope of the experiment. These results will be used in the development of rate–of–cut guidelines for the southern Okanagan and will form the basis for continued research.

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