Low Flows in Snowmelt-dominated Watersheds

Robin Pike and Rob Scherer

Conflicts between water withdrawals and instream uses occur in many watersheds in the southern B.C. Interior. During water shortages, public concerns about forest harvesting and low stream water levels often heighten. A common perception is that timber harvesting causes streams to dry up. This article examines the potential effects of forest management on low flows in snowmelt-dominated regions, and summarizes information presented in a detailed report by Pike and Scherer (2003).

What Are Low Flows?

Low flows are the minimum flow or absence of flow in a stream during the dry season. Low flows are continuous and often characterized by lowest average flow over a defined time interval (i.e., 7-day period each year). Though sometimes confused with drought, low flows are a normal part of the yearly water cycle. Drought is distinct in that it is an unusually long period of minimal to no precipitation sufficient to produce hydrologic imbalances and economic and (or) ecological effects. In snowmelt-dominated regions, the low flow period typically extends from late summer through the winter until spring snowmelt (Figure 1). The low flow period ceases with the melting of the winter snowpack leading to the spring freshet.

Low flows are important for many reasons. Water levels can be critical to fish passage in the late summer and can dramatically alter aquatic habitat especially when streams run dry. Low water levels also limit the amount of water that can be withdrawn for agriculture or human consumption, affect recreation, and ultimately affect urban development and commercial activity.

What Factors Influence Low Flows?

Low flows are maintained through the release of water from groundwater storage, flow from channel banks, and (or) surface water discharge from lakes and wetlands. In catchments with glaciers, dry-weather flow in late summer and early autumn can be augmented by glacier melt. Factors controlling the magnitude of low flows include "the distribution and infiltration characteristics of the soils, the hydraulic characteristics and extent of aquifers, the rate, frequency and amount of recharge, the evapotranspiration rates from the basin, distribution of vegetation types, topography and climate" (Smakhtin 2001, p. 149).

Drought and climate change are critical influences on streamflow. Few studies, however, have been able to isolate the direct influence of climate change on low flows. Leith and Whitfield (1998) studied streamflow and climate trends in six watersheds in the B.C. Interior. Their research demonstrated an "earlier onset of snowmelt runoff followed by an increasingly long and dry summer, with the possibility of water shortages in late summer" (Leith and Whitfield 1998, p. 230). Increases in winter streamflows observed were attributed to a greater percentage of precipitation falling as rain versus snow.

Natural disturbances such as beetle epidemics and wildfires can also influence streamflow, although few studies have examined the sole influence of these change agents. Three studies that address low flow changes associated with beetle epidemics and (or) wildfire

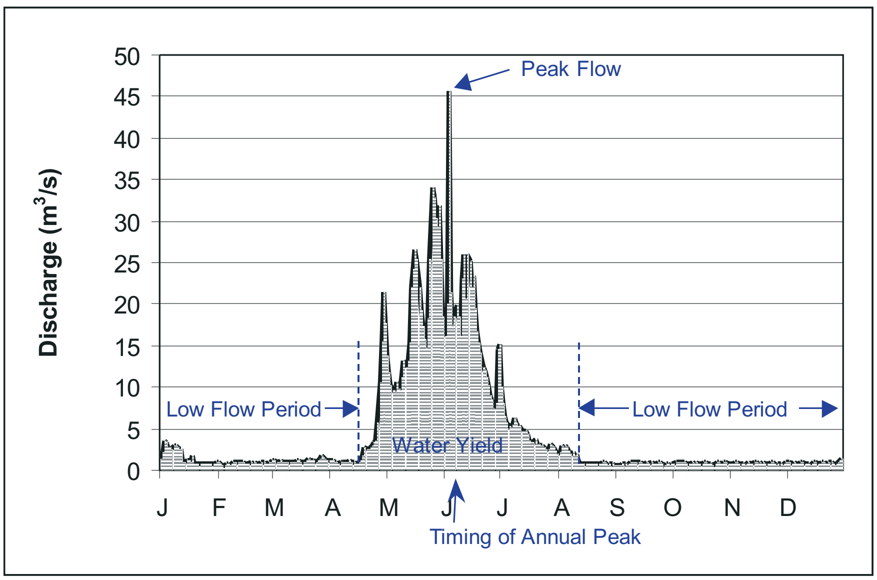

Figure 1. Typical annual snowmelt-dominated hydrograph. Water yield denoted by shaded area under hydrograph. Data source: Environment Canada, Mission Creek, B.C.

(Bethlahmy 1975; Cheng and Bondar 1984; Potts 1984) all report increases in water levels after disturbance.

Land use and human activities also influence streamflow. Smakhtin (2001) noted that human activities that both increase and decrease low flows in a watershed include:

- groundwater withdrawals;
- drainage of valley-bottom soils for agriculture or construction;
- changes to vegetation communities through clearing or planting leading to modification of evapotranspiration loss;
- urbanization through the creation of impervious surfaces;
- direct river withdrawals;
- irrigation return flow;
- industrial discharge;
- importation of water from outside of the watershed; and
- dams and impoundments.

In southern British Columbia, agriculture, mining, hydroelectric generation, reservoirs, water diversions, and forestry are the major activities that influence streamflow. Multiple factors affecting low flows must therefore be considered when determining the incremental influence of human activities on water levels beyond the natural background state.

Which Hydrologic Processes Does Forestry Affect?

Timber harvesting affects interception, evapotranspiration, snowmelt and accumulation, infiltration, soil moisture, and runoff generation in a watershed.

Interception, Evaporation, and Transpiration

Depending on forest characteristics, a portion of rain and (or) snow will be held in temporary storage on the vegetation surfaces. Interception loss is the portion of precipitation that is returned to the atmosphere by evaporation or sublimation. Numerous studies have shown that coniferous forests can intercept one-quarter of the annual precipitation but that this amount varies by storm size, intensity, duration, and weather conditions (Spittlehouse 1998). In one study in the southern B.C. Interior, Spittlehouse (1998) calculated interception losses (May–October, total precipitation 454 mm) in lodgepole pine and Engelmann spruce–subalpine fir forests to be 24%. Timber harvesting therefore decreases water losses at the site level by reducing the leaf area of a stand, leading to increased amounts of precipitation reaching the forest floor.

Timber harvesting also affects transpiration and evaporation. Transpiration is the movement of water from the ground through plant leaves (stomata) into the atmosphere. In a forested watershed, evaporation commonly occurs from plant surfaces, the ground surface, and open water. Evapotranspiration is a term frequently used to denote the combined "loss" (return) of water to the atmosphere through evaporation, transpiration, and interception. Timber harvesting modifies these processes by removing transpiring trees and by reducing interception losses (evaporation) related to the forest canopy. Overall, "reductions in evapotranspiration increase the amount of water during low flow by: (1) increasing the amount of stormflow during low flow periods; (2) reducing the extraction of soil water that is moving into the channel system; and (3) increasing the amount of water available for deep percolation to recharge soil moisture and groundwater that moves through the mantle to provide baseflow" (Satterlund and Adams 1992, p. 264).

Within a watershed, it is thought that management activities that occur within low flow source areas (i.e., riparian areas) will have a greater influence than those occurring in non-source areas. We use three studies to demonstrate the influence of riparian vegetation on streamflow (low flows), though none of these studies were conducted in snow-dominated catchments. Hicks *et al.* (1991) identified reductions in low flows in two basins, 8 and 15 years after timber harvesting. Reductions were attributed to changes in riparian vegetation to species that used more water. In another study, Berndt (1971) documented the effects of a wildfire on streamflow in three research watersheds in the east Cascade Mountains. Prior to wildfire, streamflow oscillated daily due to transpiration from vegetation rooted in the streamside capillary fringe. After the wildfire, only minor daily oscillations were observed. Berndt found that vegetation removal through wildfire lead to "general elevation of flow rates above extended normal depletion curves" (1971, p. 7). In South Africa, Scott (1999) found that clearing riparian vegetation caused a disproportionately greater gain in water yield than would have resulted from harvesting vegetation in non-riparian areas in the study areas. While the forest types of South Africa are significantly different from British Columbia's, Scott's study further illustrates the potential influence that riparian vegetation has on streamflow. In British Columbia, evapotranspiration "gains" from riparian vegetation removal should be minimal, however, as current forest practices generally designate riparian reserves for zero to limited development within low flow source areas.

Snowmelt and Accumulation

Alteration of forest canopy can also influence snow accumulation and melt (Golding and Swanson 1986; Troendle *et al.* 1988; Hardy and Hansen-Bristow 1990; Winkler 1999). The effects of forest harvesting on snow processes are complex and varied. In general, forest harvesting can produce greater accumulations of

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Example of low flow and high flow conditions at Carnation Creek, B.C. (Note: example is a coastal watershed).

snow in clearings versus an adjacent forest (Golding and Swanson 1986; Toews and Gluns 1986). As a result, increased snow accumulation increases water available for soil moisture storage and groundwater that contribute to streamflow (MacDonald and Stednick 2003).

Snow in openings created by forest harvesting has greater exposure to wind and solar radiation that causes earlier initiation of snowmelt (Winkler 1999). One may expect that this would reduce flows in the low flow period. However, this expectation is not supported by numerous North American studies completed in snowmelt-dominated watersheds. For example, Troendle and Stednick (1999) and Troendle *et al.* (2001) have shown that the primary effect of harvesting is an earlier start to the freshet period, with higher flows on the rising limb and peak of the snowmelt hydrograph, and little or no effect on the recession limb. The earlier onset of snowmelt is offset by an increased volume of water associated with increased snow accumulation and reduced evapotranspiration in the low flow period; therefore, no reductions in low flows are observed (MacDonald and Stednick 2003). As forests grow, however, and canopy densities return to pre-harvest levels, these effects should diminish to pre-harvest conditions.

Infiltration, Soil Moisture, and Runoff Generation

Forests influence the routing and storage characteristics of water in a watershed. Water readily infiltrates most forest soils; as a result, surface runoff (overland flow) rarely occurs outside of stream channels and saturated riparian areas in forested watersheds (Hetherington 1987). Lower losses of water generally lead to higher moisture levels in the soil matrix due to a higher proportion of precipitation reaching the ground. The result is typically higher water tables in cleared areas, although the upper layers of the soil may appear drier due to increased exposure to evaporation.

Road building and other activities that disturb the soil surface could locally reduce infiltration and alter surface and subsurface flow paths. If connected to the natural drainage network of a watershed, roads may lead to quicker delivery of runoff (Wemple 1996). Conceptually, if ditch lines and road surfaces interrupt natural flow paths that result in accelerated water delivery to streams, this could lead to lower low flows (and higher peak flows) due to some water bypassing the normal routing pathways. Whether roads appreciably affect low flows is debatable, as hydrologic response will differ depending on a watershed's hydrologic regime (i.e., snowmelt- or rain-dominated) and storm history. "The hydrologic effects of roads depend on several factors, including the location of roads on hillslopes, characteristics of the soil profile, subsurface water flow and groundwater interception, design of drainage structures (ditches and culverts) that affect the routing of flow through the watershed, and proportion of the watershed occupied by roads" (Gucinski *et al.* [editors] 2001, p. 19).

What Is the Overall Effect of Forest Management on Low Flows?

For the most part, forestry either leads to increases in amounts of water available for streamflow by reducing "losses" or to changes in flow paths, which depending upon the spatial area affected could conceptually reduce low flows through quickened routing (i.e., roads). A few authors have summarized the results of case studies examining the overall effect of forestry on streamflow at a watershed scale. Pike and Scherer (2003) reviewed eight studies relevant to snowmelt-dominated watersheds. Four studies identified increased low flow volumes after timber harvesting, while the remaining four found non-significant or no change in low flows. None of the studies relevant to snowmelt-dominated hydrologic regimes documented a reduction in low flows (lower water volumes).

In summarizing 28 studies describing peak flow and low flow changes following timber harvesting in the United States, Austin (1999) stated that low flows increased in 16 studies, did not significantly change in 10, and decreased in 2 coastal studies (those being Harr 1982; Hicks *et al.* 1991). Only three out of the 28 studies reviewed by Austin overlap with Pike and Scherer's 2003 review. Combined, these literature summaries indicate that, in most forest types, the overriding suggestion is for streamflow to increase during the low flow period after forest harvesting.

How Long Does the Effect Last?

The longevity of increased water quantity after forest harvesting is not generally addressed in the literature because long-term studies on low flows are rare (Reiter and Beschta 1995). It is therefore difficult to draw conclusions about longevity of effects in snowmelt-dominated regimes. Conceptually, higher dry season flows should persist until pre-harvest hydrologic conditions are restored. Specifically, persistence should depend on forest type and the rate of regrowth (re-establishment of forest canopy). However, other authors have commented on the subject of longevity based on broader analyses of literature not specific to snowmelt-dominated regimes. Austin (1999) concluded that low flows generally return to pre-treatment levels approximately 3–4 years after logging due to regrowth of forest vegetation. Similarly, Johnson (1998) concluded that low flows return to pretreatment levels approximately 6 years after logging.

Does Logging Cause Low Flows?

Scientific literature relevant to the southern B.C. Interior does not support the common perception that timber harvesting results in less water available for streamflow. The volumes of low flows generally increase or do not change measurably due to forest management.

In community watersheds, often many factors other than timber harvesting affect low flow generation. Frequently, human demands exceed supply and exacerbate the situation. In managing any watershed, it is critical to acknowledge the complexity of low flow generation processes and confounding human influences affecting them. In times of limited quantity, water conservation and education may be our best management investment in balancing instream and human demands for water.

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UPDATE

Upcoming Events

February 23–25, 2005

57th Forestry Conference and Annual Meeting of the Association of BC Forest Professionals.
"Perspectives: What's Your Passion?"

Prince George, BC.

http://www.abcfp.ca/agm57.html

February 23–25, 2005

Water - Our Limiting Resource, CWRA, BC Branch Conference.

Kelowna, BC.

http://www.cwra.org/CWRA_News_and_Events/BC_Feb_2005/bc_feb_2005.html

April 16–20, 2005

33rd Annual BCWWA Conference and Trade Show.

Penticton, BC.

Bill Harvey, Technical Program Co-Chair
E-mail: harveyb@ae.ca

April 26–27, 2005

Implications of Climate Change In BC's Interior Forests.

Revelstoke, BC.

Optional Fieldtrip April 28.

http://www.cmiae.org/

June 20–23, 2005

HeadWater 2005: Hydrology, Ecology and Water Resources in Headwaters.

Bergen, Norway.

http://www.nve.no/headwater05/

August 16–19, 2005

The Second North American Lake Trout Symposium.

Yellowknife, NWT.

http://www.laketroutsymposium2005.ca/

Recent Publications

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Streamline Reader Survey

This fall we are conducting a reader survey to ensure effective management of Streamline Watershed Management Bulletin. Specifically, we would like to assess how we are doing and what improvements you would like to see.

The survey will take 5–10 minutes to complete and is available on-line at:

http://www.zoomerang.com/survey.zgi?p=WEB2S6C7LRP3

All responses will be handled confidentially, and need to be received by December 15, 2004. If you do not have computer access, please call Robin Pike at ***(250) 387-5887*** for a paper version of this survey.