Mountain Pine Beetle and Watershed Hydrology: A Synthesis focused on the Okanagan Basin*

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Abstract

As the mountain pine beetle (MPB) infestation expands into the southern interior, changes to British Columbia's lodgepole pine forests will affect stand water balances, hillslope hydrology and streamflow in many watersheds. The large spatial extent of this disturbance has prompted research from the stand- to watershed-scales to address uncertainty about the hydrologic effects of MPB, such as an increased potential for flooding, changes in water yield, peak flows, and low flows, slope and channel changes associated with increased runoff, as well as the effects of hydrologic change on aquatic habitat and drinking water. This paper will summarize the key hydrologic changes expected and will highlight the results of long-term research in the Okanagan, such as the Camp Creek and Upper Penticton Creek watershed experiments, as well as new research underway throughout the B.C. Interior and other regions to quantify changes in hydrologic processes and potential effects of MPB-related stand mortality and salvage logging.

Introduction

The forested uplands of the Okanagan Basin are a primary water source for valley bottom ecosystems and human populations. The current mountain pine beetle (MPB) infestation and associated salvage harvesting has the potential to affect the amount, timing and quality of water originating from the forest upland watersheds. The purpose of this paper is to review the research results regarding MPB and salvage harvesting impacts on the hydrology of forested watersheds, and how that may impact the valley bottom water users.

The hydrologic changes resulting from MPB mortality and harvesting are primarily related to the loss of canopy cover. When the forest canopy is reduced (e.g. MPB mortality) or removed (e.g. salvage harvesting) hydrological processes such as interception and transpiration are affected (Figure 1). The result is generally more water reaching the ground surface and potentially more water available for streamflow. Increased streamflows may have positive (e.g. more water

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available for human or ecological needs) or negative (e.g. increased flood potential, decreased water quality) effects, so understanding the magnitude and direction of changes is critical to account for hydrological risks in management and planning for both the upland watersheds and the valley-bottom infrastructure and water availability. It is also important to note that watershed specific impacts may be difficult to accurately predict due to the variable effects of basin geology, topography, soils and vegetation on hydrological response.

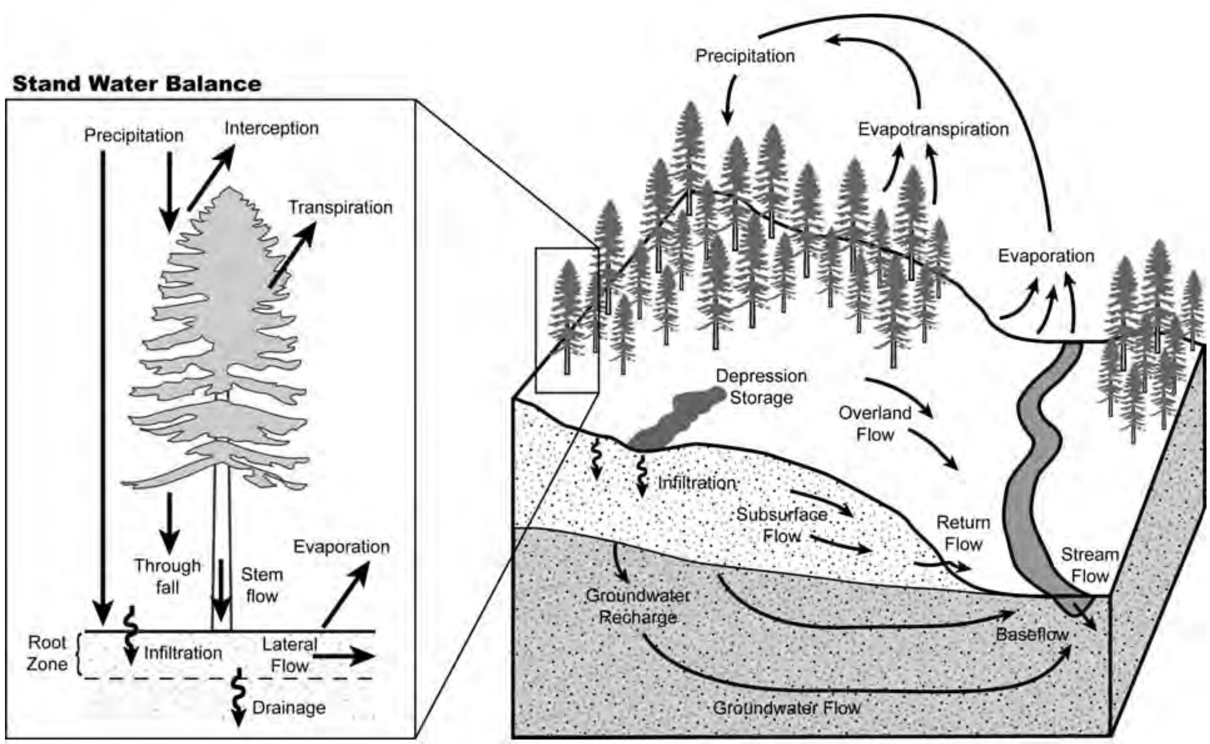

Figure 1: Hillslope hydrologic cycle and stand water balance. The loss of forest canopy influences the interception of precipitation and the subsequent loss through evaporation and transpiration. (adapted from Winkler et al. 2008a)

A generalized graphical illustration of the relative changes in hydrologic processes and watershed response to loss of canopy (e.g. through MPB, salvage harvesting, fire etc.) was developed by Redding et al. (2007) (Figure 2). This figure illustrates how hydrologic variables change along a gradient of canopy cover. While this is a useful tool for understanding the interaction of different processes, it is not meant to provide absolute magnitudes of response or address unique site conditions.

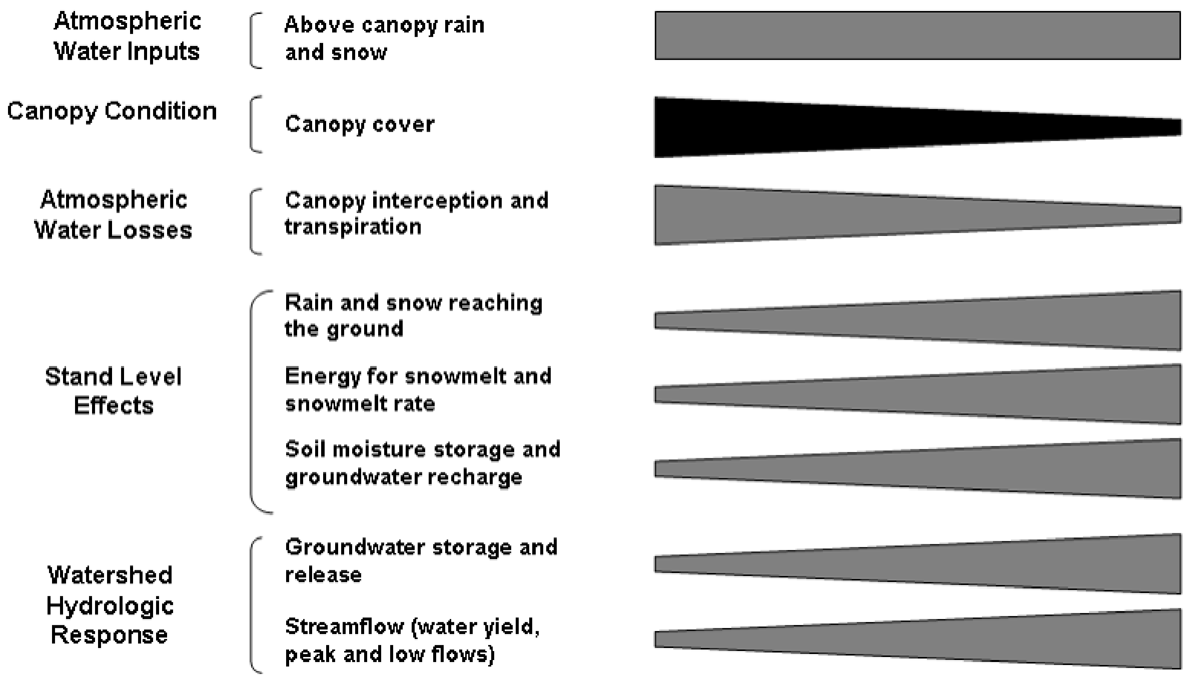

Figure 2: The influence of forest canopy alterations on water cycling. The thickness of a wedge represents the trend in a process or effect as the canopy cover (black wedge) is altered, and does not indicate the magnitude of the process or effect. Where the canopy cover is highest (wedge thickest) is representative of a well stocked healthy mature stand, and where it is lowest (wedge thinnest) is indicative of a recent clearcut. (adapted from Redding et al. 2007)

The purpose of this paper is to provide a brief summary of expected changes in water cycling as a result of MPB and salvage harvesting. For synthesis papers with greater emphasis on forest management issues, planning recommendations and available tools please see Winkler et al. (2008b) and Redding et al. (2008).

Mountain Pine Beetle in the Okanagan Valley

The upland tributary watersheds of the Okanagan basin contain significant areas of lodgepole pine. In 2006, as part of an inter-agency flood hazard mitigation initiative, the Provincial Emergency Program produced a series of overview maps for interior BC watersheds. The maps show all third-order and higher watershed boundaries, communities, public infrastructure, forests consisting of more than 40% lodgepole pine, and the area logged during the past 25 years over most of the Interior. Tables summarizing watershed area, the area of pine-dominated forest, and the area logged are also included. These maps and tables provide a useful indication of the extent of both lodgepole pine leading forest types, where significant stand mortality is expected, and past disturbance. The maps are available at: http://www.for.gov.bc.ca/hfp/mountain_pine_beetle/stewardship/. A summary of watershed data from a number of significant tributary basins is provided in Table 1. In the Okanagan River watershed, the overall proportion of pine leading (> 40%) stands is approximately 23% and the area of forest harvesting (< 25 yrs old) is 2% (Table 1).

Table 1: Area of pine leading stands and openings from forest harvesting in selected tributary watersheds to the Okanagan basin. Watersheds are listed in order of size. Pine area includes all forest cover polygons with greater than 40% lodgepole pine. Opening area includes all area logged between 1982 and 2007 (25 years). Overlap refers to the area with both greater than 40% lodgepole pine and forest havest between 1982-2007. Data from http://www.for.gov.bc.ca/hfp/mountain_pine_beetle/stewardship/hydrology/index.htm

Watershed Name	Watershed Area (km^2)	% Pine Area	% Opening Area	% Overlap
Okanagan River	1502	23	2	<1
Trout Creek	434	54	11	7
Vernon Creek	335	26	6	4
Mission Creek	285	23	12	7
Deep Creek	212	11	3	<1
Penticton Creek	184	54	11	3
Trepanier Creek	172	44	3	2
Coldstream Creek	162	22	12	6
Peachland Creek	142	47	6	5
BX Creek	131	10	3	<1

The latest forest health survey data indicates that the heaviest MPB attack in 2007 was on the west side of Okanagan Lake, with some movement south towards Peachland (Westfall and Ebata, 2007). At the northern end of the Okanagan Valley, where the infestation is most severe, the high elevation areas are dominated by mixed species stands (Englemann spruce and lodgepole pine) rather than pure pine which is more commonly found toward the southern end of valley. The impacts of infestation only in mixed-species stands likely will not have as great of hydrological consequences as pure stands (Huggard and Lewis, 2007). If mixed stands are salvaged using clearcut harvesting systems the potential impacts will increase.

Effects of MPB and salvage logging on hydrological processes and watershed response

The effects of forest disturbance (including MPB and salvage harvesting) are typically investigated at the stand and watershed scales. The stand scale effects investigated include snow accumulation and melt, rainfall interception, stand water balance, groundwater and stand-level hydrologic recovery. Watershed scale effects include impacts on streamflow, aquatic ecology and water quality.

Stand Scale Effects

Snow Accumulation and Melt

A significant portion of the total winter precipitation is intercepted by forest canopies and lost through sublimation. The forest canopy not only reduces snow accumulation relative to the open as well as influences how quickly snow disappears. Snow surveys throughout the BC Interior show large annual, geographic, and forest cover related variability in snow accumulation and ablation, even over distances of only a few kilometres (Winkler et al., 2004a; Winkler, 2007). Storm type also significantly influences canopy interception (Boon, 2007b).

Changes in snow accumulation due to changes in canopy cover have been studied at many sites in BC. At long-term research sites on the Thompson-Okanagan Plateau, the maximum snow water equivalent (SWE) in mature lodgepole pine stands averages 11% less than that in recent clearcuts while mixed species stands have up to 44% less SWE than clearcuts (Winkler, 2007). In the central interior, recently initiated studies in MPB-attacked stands have shown that at maximum accumulation, SWE in stands that have lost their needles (grey attack) and in a green stands were 25-50% and 50-70% 53% less, respectively, than that measured in adjacent clearcuts (Beaudry, 2007; Boon, 2007a). There was, however, little difference in snow accumulation between a green pine stand and a grey pine stand near Prince George during a year of low snowfall (Beaudry, 2007).

Snow ablation rates (the loss of snow through both melt and vaporization) are, on average, 15% lower, and snow persists for up to eight days longer in the forest than in the open (Winkler, 2007). Sixty percent slower ablation rates have been measured in the mixed-species stands relative to nearby clearcuts (Winkler, pers. comm. 2008). Snow ablation rates are reduced by forest canopies partly due to the reduction in solar radiation at the snow surface relative to that in the open (Spittlehouse and Winkler, 2004). Current research in British Columbia (P. Teti, pers. comm., 2008; D. Spittlehouse, pers. comm., 2008) has found that old pine stands that have not been defoliated, and mixed-species, pine-leading stands, transmit 15–30% of solar radiation in early spring depending on the canopy and stand density. This level increases as the stand deteriorates over many years. In a stand attacked in the 1980s, where the former canopy-forming trees had fallen down and natural regeneration was well established, transmittance to the snowpack was 57% (P. Teti, pers. comm., 2008). In contrast, salvage logging increased radiation transmittance to virtually 100%, for at least a decade (P. Teti, pers. comm., 2008). Transmission of radiation to the snowpack decreased rapidly after this time, dropping to approximately 20% within 35 years of logging.

Snow accumulation and ablation recovery (defined as the decrease towards that in the mature forest) were 43% and 29%, respectively, in the 20-year-old pine stands. Thinning to remove approximately one-half of the stems did not affect maximum snow accumulation but reduced snow ablation recovery to 13% (Winkler et al., 2005). On the Fraser Plateau, Teti (2007) found that for at least 12 years snow ablation rates in young stands were very similar to those in a clearcut. However, in 35-year-old forests, ablation rates were very similar to those in mature forest. Data from all snow surveys in the Thompson-Okanagan combined showed a 6% reduction in maximum SWE with every 10% increase in crown closure to a maximum of 55% reduction in SWE (Winkler and Roach, 2005).

In large openings at several steeper south-facing survey sites in the Okanagan, higher SWE is measured in the forest than in the open before the onset of melt, indicating that periodic snow disappearance occurs in the open before the main melt season (Winkler, pers. comm. 2008). These losses potentially mitigate the effects of increased SWE at other sites across the landscape, resulting in desynchronization of snowmelt and streamflow generation.

Rainfall Interception

There has been limited research on changes in rainfall interception resulting from canopy deterioration following MPB attack. In mature mixed pine, spruce, and subalpine fir forests, the canopy intercepts approximately 30% of growing season precipitation, which subsequently evaporates reducing the amount of moisture that reaches the ground (Spittlehouse, 2007). At Penticton Creek in the Okanagan Basin and Mayson Lake north of Kamloops, measurements of rainfall interception indicate 30- 40% of growing season rainfall is lost each growing season in a mature stand (Moore et al. 2008, Winkler et al., 2008a). In Colorado, a well developed understory below an old MPB killed stand intercepted as much rain as live trees (Schmid et al., 1991). Storage of rainfall in the litter and moss layers on the forest floor is 4-8 mm of water accounting for 20-30% of growing season precipitation in low rainfall regimes (Carlyle-Moses, 2007).

Stand Water Balance

Atmospheric water losses (interception, transpiration and soil evaporation) in mature pine stands at Penticton Creek typically account for 60-70% of annual precipitation inputs with 30-40% of precipitation draining below the rooting zone and available for groundwater recharge and to generate streamflow (Spittlehouse, 2007). Following MPB infestation and salvage harvesting, the proportions of the individual stand water balance components will change, resulting in an increase in drainage. Stand water balance modelling carried out for study stands at the Upper Penticton Creek Watershed Experiment indicates that after MPB attack and salvage harvesting there would be greater water available to recharge groundwater and generate streamflow (Figure 3) (Spittlehouse, 2007). When compared with mature lodgepole pine forest, red attack stands have similar amounts of interception loss, while the grey attack and clearcut stands have reduced interception. Evaporation (plant transpiration plus soil evaporation) are similar between the mature and clearcut stands, and reduced in the red and grey attack stands. The most water available for groundwater recharge and streamflow is in the clearcut and grey attack stands with the red attack intermediate and the mature stand lowest. The modelling indicated that a stand with less than 40% of the trees attacked had a similar hydrological balance to the attacked stand.

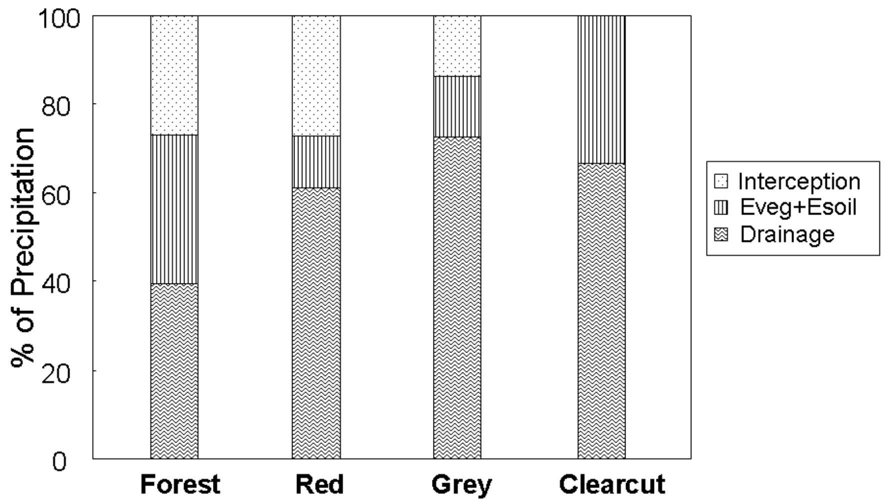

Figure 3: Modelled mean annual stand water balance for mature, red, grey and clearcut lodgepole pine stands at Upper Penticton Creek. Data are results of a process based stand water balance model run over the period of October 2002 through September 2006. Meteorological inputs (precipitation, temperature and radiation) and soil properties were held constant for all stands, and only canopy properties were varied. (adapted from Spittlehouse 2007)

Groundwater

With changes in the stand water balance resulting in greater drainage, and hence water available for groundwater recharge, it is not surprising that in some areas of heavy infestation and salvage harvesting there have been reports of rising water tables impacting trafficability and forest harvesting operations (Rex and Dube, 2006). In the Vanderhoof Forest Distict in central British Columbia, Rex and Dube (2006) have noted elevated water table levels in lowland areas (e.g., toe slopes, wetlands, or lowland landscapes) after harvesting. The risk of wet ground was found to increase with (1) decreasing drainage density, (2) decreasing understory vegetation, (3) increasing area of sensitive soils (poorly drained or fine texture), and (4) increased pine cover (Dube and Rex, 2008). Greater drainage below the rooting zone will also likely result in greater subsurface flow feeding stream channels and potentially affecting other values such as slope stability.

Hydrologic Recovery

For a given set of weather conditions, the magnitude and duration of stand-scale hydrologic change associated with MPB will depend on the percentage of overstorey that has been killed; the presence, age, and density of advance regeneration and understorey vegetation; and on the stand’s logging history. If MPB-attacked stands are left to deteriorate naturally, hydrologic change will be more gradual as trees turn from green to red, drop their needles, turn grey, lose fine branches, and eventually fall to the ground (Huggard and Lewis, 2007). At the same time, understorey vegetation may release due to increased light and reduced competition for nutrients and water. In contrast, clearcut salvage logging causes a large immediate change to the site water balance through removal of the overstorey. The hydrologic change associated with salvage logging will also vary with the amount of ground disturbance, intensity and type of site preparation, degree of drainage disruption, degree of understorey damage, and rate of forest regrowth.

To address uncertainties around MPB impacts on stand-level hydrological recovery, Huggard and Lewis (2007) used models of stand tree growth, field data on understory composition and measurements of hydrologic recovery as snow accumulation and melt to generate recovery curves for various forest management options in select IDF and MS subzones in the southern interior of BC. The results indicate that clearcut salvage harvesting and planting results in the greatest increase in equivalent clearcut area (ECA) and quickest recovery (see Figure 4 for hypothetical example). Full retention of the dead stand has the lowest maximum ECA but the longest recovery (Figure 4). In selecting a retention or salvage strategy it will be necessary to balance the risk of a more intensive disturbance with the benefit of a quicker recovery (Huggard and Lewis, 2007).

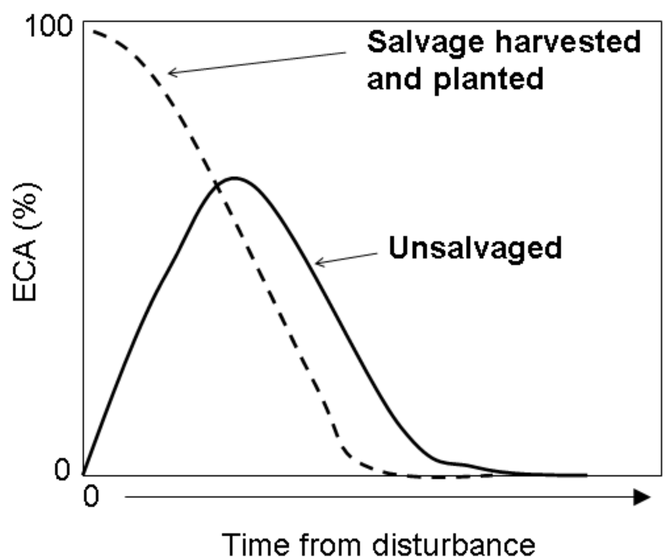

Figure 4: Hypothetical hydrological recovery trajectories for salvaged and planted and unsalvaged stands (complete retention). A lower value of ECA (equivalent clearcut area) indicates greater hydrological recovery. (adapted from Huggard and Lewis 2007)

Watershed Scale Effects

Watershed scale effects of forest disturbance can be difficult to quantify due to natural variability in climate, geology and other factors which control streamflow generation and timing. Two main approaches have been used to examine the effects of MPB and salvage harvesting effects on streamflow: retrospective streamflow analyses and numerical modelling.

<u>Retrospective Streamflow Analyses</u>

At Camp Creek in the Okanagan basin, 30% of the basin was salvage harvested in 1976-77 following MPB infestation (Cheng, 1989). Using a paired-watershed analysis it was found that annual water yields increased by 21%, peak flows increased by 21%, there was an advance in peak flow timing by 13 days, and April flows also increased (Cheng, 1989; Moore and Scott, 2005). The duration of peak flow increase lasted approximately 15 years, while elevated April flows have persisted for the length of data record. These values generally agree with stand-level measurements of hydrologic recovery of snow accumulation and melt processes (Moore and Scott, 2006). No changes in low flows were detected (Moore and Scott, 2005).

Extensive forest harvesting has taken place in both the Bowron River (related to a spruce beetle outbreak in the 1970's) and adjacent Willow River watersheds in central BC. There were no statistically significant effects of salvage harvesting on annual water yields, peak flows or low flows for the Bowron River watersheds (Wei and Lin, 2007). In the adjacent Willow River watershed, Lin and Wei (2008) found significant increases in spring and annual peak flows, and an increase in annual water yield that was attributable to harvesting. Neither watershed showed any significant changes in low flows. The reasons given for the differences in the effects of harvesting on these adjacent watersheds were differences in watershed characteristics, climate and the timing and location of harvesting (Wei and Lin, 2007).

Similar increases in peak flow and water yield have been found in Montana and Colorado. In Montana, Potts (1984) found in a watershed that was 35% defoliated that annual water yield increased by 15%. While there were no changes in peak flow magnitude, the annual peak occurred 14-21 days earlier and high flow conditions persisted longer with a greater spring monthly water yield. In addition, low flows increased by 10%. In two Colorado watersheds following defoliation of 30% of their area, Bethlahmy (1975) found increases in annual water yield of 16%. Peak flows occurred 2-11 days earlier and were 4-27% larger following defoliation and low flows also increased 10-31%.

The Fishtrap Creek watershed, near Kamloops BC, was severely impacted by wildfire during the summer of 2003. Post-fire there has been an increase in flows during the early stage of the freshet, and high flow periods are lasting longer than pre-fire. The earlier and longer period of high flows may be the result of changes in snowmelt dynamics in the basin resulting in a desynchronization of basin melt (Moore et al., 2008). The longer duration of high flows appears to be impacting channel processes and sediment movement through the burned floodplain of the watershed (Moore et al., 2008).

Modelling of MPB Infestation and Salvage Harvesting Scenarios

Two hydrologic models have been applied in the Okanagan basin to examine the impacts of MPB and salvage harvesting on streamflows. The HBV-EC model, which has relatively modest data requirements, was able to reproduce the statistical distributions of post-harvesting streamflow changes (Moore et al., 2007). Streamflows in any given year were not always accurately simulated, likely due to an overly simplistic model representation of canopy influences on snow accumulation processes (Moore et al. 2007). The UBC Watershed Model has been applied to simulate the effects of complete clearcut harvesting on peak flows and water yield for a number of Okanagan tributary watersheds (Alila and Luo, 2007). The results showed peak flow increases of 30-100% for 1 and 2 year return period events and freshet water yield increases of 40-75%.

To examine the potential effects of extensive MPB infestation and salvage harvesting on peak flows and water yield, the DHSVM hydrological model was applied to the 1570 km^2 Baker Creek Watershed near Quesnel (BC Forest Practices Board, 2007). For scenarios with extensive MPB killed stands (53% MPB, 34% harvested) and extensive salvage harvesting (80% harvested, 17% MPB), the model predicted 60% and 90% increases in peak flow and 15 and 16 day advances in peak flow respectively (BC Forest Practices Board, 2007). The results indicated the potential for a major shift in flood frequency in the watershed, with floods with a baseline return period of 20 years moving to a return period of three years with the extensive salvage harvesting scenario.

The WRENSS model was applied to four Alberta foothills watersheds between Grand Prairie and Grand Cache using a scenario of reducing pine cover by 75% within 20 years. Annual water yields were predicted to increase by 9-29%, while 2-year return period flows were increased by 7-53% and 100-year return period flows were predicted to increase by 1-20% (Rothwell and Swanson, 2007).

Impacts on Aquatic ecology

Changes in streamflow regimes following watershed disturbance have the potential to impact aquatic communities and processes (Johannes et al., 2007). Large woody debris in streams is critical for habitat formation, and harvesting in riparian zones has the potential to disrupt inputs. Source distancing studies completed in the Prince George Small Streams Study identified that the majority of active in-stream LWD originiated within 10 m of the streambank (Beaudry and Beaudry, In Preparation). In the Okanagan, Wei et al. (2007) found there were similar LWD input rates between MPB-attacked and non-attacked stands, however, the MPB attacked stands had greater LWD movement distances. In the Bowron River watershed, riparian harvesting in the 1970s is still affecting LWD recruitment and stream recovery (Nordin, 2008). Protecting riparian function and aquatic habitat will have major implications for fish populations, including salmon, throughout the interior of BC (Johannes et al., 2007).

Impacts on Water quality

Water quality impacts of the mountain pine beetle epidemic have not been well studied, however, based on knowledge from other forest disturbances, some generalizations are possible. Increased road building and stream crossings for salvage harvesting combined with potentially higher flows have the potential to increase sediment delivery to watercourses. At Fishtrap Creek in southern BC, mortality of the riparian canopy due to wildfire has resulted in a loss of bank strength causing significant channel change and associated transient increase in suspended sediment concentration (Moore et al., 2008). Chemical properties of surface waters may be impacted by MPB infestation and salvage harvesting due to changes in water fluxes and biogeochemical cycling. In Colorado, elevated stream water nitrate concentrations have been measured following MPB infestation of watersheds and have persisted for a number of years but remain below drinking water standards (Stednick, 2007). The loss of riparian cover due to canopy mortality or harvesting can lead to increases in stream temperature which may adversely affect aquatic processes and fish productivity (Moore et al., 2005). At Fishtrap Creek, the burned canopy reduced the net radiation reaching the stream surface by about 30% as compared to no standing dead vegetation and radiation under the standing dead trees was 50% greater than for pre-fire conditions (Moore et al., 2008).

Conclusions

The potential effects of the MPB infestation and associated salvage harvesting include changes in the magnitude and timing of streamflows and impacts on water quality and aquatic habitat. Changes in flow regimes will be greatest in the short term where extensive salvage harvesting is applied. In addition, the effects of increased road construction on water quantity and quality are unknown at this time. The changes in flows may have major implications for the design of infrastructure on the flood plain and draws attention to the need for planning the extent of clearcut salvage harvest in infested watersheds, designating reserve areas, and carefully designing stream crossings (B.C. Forest Practice Board, 2007). Further information on watershed planning recommendations, management tools and ongoing research are available from Winkler et al. (2008b) and Redding et al. (2008).

The unforeseen nature of the MPB infestation and the potential hydrological effects to humans and the environment highlights the importance of maintaining long-term research sites such as Upper Penticton Creek Watershed Experiment and monitoring sites such as Camp Creek. These sites have provided primary data in the early days of the infestation, and the research and monitoring results continue to inform forest management planning. Given that these upland watersheds are the primary source of water for valley bottom use in the Okanagan Valley, it is critical that we understand both the basic hydrology and the effects of both natural and human caused disturbance on these systems.

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