CPAWS
CANADIAN PARKS AND WILDERNESS SOCIETY
SOUTHERN ALBERTA CHAPTER

The Effects of Forest Harvest on Hydrology

Examining the Effects of Logging on Hydrological Processes, Streamflow, and Flood Risk in Alberta's Southern Eastern Slopes

CPAWS Southern Alberta, 2020

1 Introduction

The purpose of this paper is to review and summarize the literature on the effects of forest harvesting, specifically clearcuts, on various aspects of forest hydrology, particularly in Alberta's Southern Eastern Slopes.

The paper will first discuss the direct hydrological effects of forest harvest, separated into surface and sub-surface processes. Following that, these effects will be discussed in terms of their impacts on streamflow; in relation to peak flow, low flow, water yield, and flood risk. Other important activities associated with forestry activities on the landscape and environmental variables will then be discussed. Finally, the paper will conclude with a discussion of recovery time of these hydrological processes.

2 Direct hydrological effects of forest harvest

The first part of this paper will focus on the direct impacts to hydrological processes as a result of forest harvest. These direct impacts are defined here as surface and sub-surface hydrological processes, which subsequently impact streamflow and downstream flooding. The processes that will be discussed include: precipitation and canopy interception, evaporation and evapotranspiration, snow accumulation and ablation, and sub-surface groundwater and soil moisture effects.

Water takes many different paths as it travels through Alberta's forests; its journey is not just limited to streams, creeks and rivers. Vegetation and soil play an important role in the capture, storage, and transportation of water in the Southern Eastern Slopes of the province. When trees are removed, these pathways are significantly affected (Winkler et al., 2010).

2.1 Surface processes

In a forest, the canopy is the first point of contact for precipitation. The leaves and branches of the canopy, as well as the cover of the forest floor, intercept a fraction of the incoming rain and snow, which leads to less precipitation reaching the forest soil. The interception of precipitation is especially important in coniferous forests, which cover a significant amount of ground and have a consistent leaf area index year-round (Keenan & Kimmins, 1993). However, when the canopy cover is removed, as is the case in clearcut forest harvesting, this precipitation interception is substantially reduced at the site. In turn, the site sees an increase in precipitation that reaches the ground. The magnitude of this increase can be significant (Buttle, 2011), and results in a higher water table, especially in low-lying areas. The result of the decrease in interception alone has important implications on streamflow and downstream flooding, to be discussed in the coming sections.

Interception is not the only process that is affected by canopy removal. Vegetation reduces runoff by consuming soil water and returning it to the atmosphere through the process of transpiration. Removal of canopy cover has been found to reduce evapotranspiration rates in many environments (Martin et al., 2000; R. L. Swanson & Rothwell, 2001). Therefore, canopy removal reduces the amount of precipitation taken up by trees and transpired. This reduction in evapotranspiration causes subsequent increases in soil moisture and higher water tables, with important implications on streamflow (Buttle, 2011; Keenan & Kimmins, 1993). This reduced interception storage can increase the frequency and severity of floods (Ouellet et al., 2012).

Additionally, the removal of forest cover affects processes of snow deposition and accumulation that affect the snow water equivalent, defined as the water content obtained from melting (NSIDC, 2019). Large open areas with high wind speeds increase blowing snow, causing it to be removed and deposited on lee slopes (Buttle, 2011). It is important to note, however, that the process of snow ablation does offset this a bit, although not to a great extent (Berris & Harr, 1987; Buttle, 2011; Rothwell et al., 2016).

Another important process, especially in the forests of the Southern Eastern Slopes of Alberta, is that of the snow hydrological process. First, areas that have undergone timber harvest experience increased snow ablation, defined by the National Snow and Ice Data Center as a reduction in snow cover through processes of sublimation, melting, wind, or avalanches (NSIDC, 2019). Forest cover reduces the rate of snow ablation by minimizing the effects of both wind and solar radiation due to shading. However, when the canopy is removed, the resulting combination of increased wind speeds, exposure, and higher rates of incident solar radiation makes for increased rates of snow ablation (Berris & Harr, 1987; Rothwell et al., 2016). This process is greatly affected by the slope and aspect of the disturbed site, where steeper and more southerly aspects receive higher solar inputs and are therefore particularly sensitive to changes in shading (Rothwell et al., 2016).

Overall, in snow-dominated forests, the impacts of forest harvest can result in greater runoff due to greater snowpack and higher rates of snowmelt (Berris & Harr, 1987; Buttle, 2011; Pomeroy et al., 2012). The removal of canopy cover results in increased precipitation reaching the ground, existing either as rain or snow, leading to increased levels of surface runoff. This has important implications on downstream water flows that will be further discussed in the coming sections.

2.2 Sub-surface processes

Groundwater can be affected by forest harvest and has important implications on streamflow, especially in the headwater streams of the Southern Eastern Slopes of Alberta (Smerdon et al., 2009). When vegetation is removed following forest harvest, the evaporation and transpiration potential of the site is diminished. The removal of these processes can cause increased water storage and therefore higher soil moisture levels at the site with a subsequent increase in groundwater (Buttle, 2011; Mellina et al., 2002; Smerdon et al., 2009; Winkler et al., 2010). Increases in the water table can then result in increased groundwater recharge, and subsequently higher low flows; these effects are especially prominent in sites with coarse-textured soils and groundwater-fed streams (Smerdon et al., 2009; Winkler et al., 2010).

Subsurface processes are an important part of the forest hydrological system. However, these processes do remain a large area of uncertainty. Subsurface processes vary greatly between sites, as they are largely affected by the soil physical properties as well as the climate and microclimates of the site. Forest harvest affects all of these properties, resulting in potentially significant impacts to the subsurface hydrological processes and downstream flows.

3 Subsequent streamflow effects and flood risk

As discussed previously, forest removal results in an increase in water retention, soil moisture, and groundwater levels. This increase in water storage corresponds to an increase in baseflow, especially in groundwater-fed and snowmelt dominated streams (Buttle, 2011; Rothwell et al., 2016). Higher baseflow has important implications on annual water yield and peak flow, to be discussed in more detail below.

Forest harvest has the potential to increase downstream peak flows and decreased summer low-flows to below base flow (Nitschke, 2005; R. H. Swanson & Hillman, 1977). Hicks et al. (1991) found that clearcut logging increased summer streamflow by 159 percent for eight years, which was then followed by a 25 percent decrease in flow, which after 18 years had still not returned to pre-harvest levels. Additionally, it has been found that even moderate levels of harvest have the potential to influence the frequency, magnitude, and duration of streamflow (Green & Alila, 2012). These changes in flow, both as a result of logging and fire, can have important implications on flooding and drought, as well as water temperature, volume, dissolved oxygen, and available habitat (Green & Alila, 2012; Hicks et al., 1991; Nitschke, 2005); all of which have the potential to influence sensitive aquatic species such as native trout.

Annual water yield, defined as the total amount of water discharged from a watershed per year (Pike et al., 2010), is greatly affected by forest harvest. In general, annual water yield increases following harvest, however, the degree of increase varies by watershed and is contested in the literature (Buttle, 2011). The effects of forest harvest on water yield have been discussed for decades (R. H. Swanson & Hillman, 1977). The general consensus, as discussed above, is that water yield increases following harvest due to: increased precipitation reaching the ground (i.e. less interception), reduced evapotranspiration, increased soil moisture and groundwater levels, and increased overland flow in some situations (Buttle, 2011; Onuchin et al., 2017; Pike et al., 2010). Irrespective of the scientific and analytical approaches taken by researchers, the general result is an overall increase in annual water yield, with the degree of increase varying by site or region (Buttle, 2011). The hydrological regime in the forests of the Southern Eastern Slopes of Alberta is mainly snow-driven; therefore, the effects of snow accumulation and ablation are especially important for determining the net downstream effects of forest harvest (Rothwell et al., 2016). Based on what is known about the hydrology in the area, the degree of annual water yield increase downstream following forest harvest is likely dependent on the amount of precipitation in the watershed.

Related to this, peak flow, or the maximum streamflow post-storm or snowmelt event (Pike et al., 2010), is affected by forest harvest as well. This flow measure is greatly influenced by a plethora of other variables at play; changes in snowmelt, overland flow, drainage density, aspect, and spatial distribution of harvest cutblocks are a few examples (Schnorbus & Alila, 2013). It can be assumed that peak flow will increase following harvest, due to the variables discussed previously. However, in the words of Buttle (2011), “the debate about whether forest harvesting leads to increased peak flows and flooding is one of the most contentious in hydrology”, so it is difficult to generalize as to what the actual effects are.

The connection between increased water yield discussed previously and increased peak flow is a logical one, and a position taken by many hydrologists active in this area of research (Green, 2013; Pike et al., 2010; Pomeroy et al., 2012; Schnorbus & Alila, 2013). For example, Green (2013) found that large flooding events increased in frequency after removal of forest cover. Although somewhat debated in the literature, increases in peak flow following forest removal have been found to occur in areas of close proximity and similar characteristics to the forests of southern Alberta.

Increases in streamflow following forest harvest are well-researched and discussed in the literature (Buttle, 2011; Green, 2013; Schnorbus & Alila, 2013; Winkler et al., 2010). Therefore, the impact of forest harvest on downstream hydrology is significant, leading to floods of different magnitudes in downstream areas (Keenan & Kimmins, 1993). The magnitude of flooding downstream is related to the degree of harvest upstream (Keenan & Kimmins, 1993), therefore it is imperative that forest management is done in such a way to mitigate downstream effects. However, it is outside the scope of this paper to discuss best management practices in forest management.

It is noted that flooding is affected by many variables unrelated to upstream forests and harvest. The position of this paper is not that upstream harvest is the only variable leading to floods and increased flows; rather, that harvest has an impact on downstream flooding, and is one of several variables that may impact flood risk. Downstream impacts are also greatly affected by the size of forest harvest, the location, and the site-specific characteristics of where the clearcut occurs. For this reason, better upstream management of forests is essential.

4 Associated activities/variables

There are a number of activities associated with forest harvest that are separate from the physical removal of trees that also have important impacts on the hydrological regime of the area. The construction of forestry roads, heavy machinery, and the process of log skidding are all activities that compact soil and decrease its ability to absorb water. These activities also cause changes to rate, number and pathways of surface flow, the impacts of which can take a significant amount of time to recover (Pike et al., 2010).

Forestry activity results in an increase in logging roads in the area, regardless of how the cutblocks are planned out. Although activities like long-term integrated access planning can decrease the number of roads needed, there will always be new logging roads built to access these areas. Increased linear disturbances have significant impacts on many aspects of the ecosystem (e.g. wildlife, habitats, invasive species, etc.), and the hydrological regime is no exception. First, overland flow increases in areas where there are roads present (Buttle, 2011; Keenan & Kimmins, 1993; Pike et al., 2010). Water flows along the path of least resistance, and in the case of roads through the forest, this is the path that water will take. If roads are present, surface water can change course to flow down roads, resulting in gullying and erosion issues (Buttle, 2011; Schnorbus & Alila, 2013; Winkler et al., 2010). Especially if roads are located on a hillslope, sub-surface water can be intercepted and re-routed to surface flow (Buttle, 2011; Smerdon et al., 2009; Winkler et al., 2010).

The presence of machinery in the forest also has important effects on hydrology, as well as many other ecological aspects outside the scope of this paper. One of the main impacts on hydrology stemming from machinery presence and log skidding is soil compaction and soil disturbance (Keenan & Kimmins, 1993; Winkler et al., 2010). This results in higher rates of overland flow as water cannot easily infiltrate into compacted soil, and increased erosion and turbidity stemming from increased overland flow (Buttle, 2011; Keenan & Kimmins, 1993; Winkler et al., 2010).

The relationship between forest management and hydrology is complex. Removal of forest cover and other forestry activities occurs in many different locations with varying elevation, topography, geomorphology, etc. Additionally, the amount that is harvested can vary between watersheds. Due to these discrepancies, the effects of logging activities on streamflow and peak flow are impossible to universally predict, even within the same climatic region. Experts in the field are quick to caution that findings regarding hydrology should not be universally applied: “results should not be extrapolated to basins with differing topography, even in the same climate region, without careful consideration of how basin hydrology can mitigate the response of snow energetics and mass balance to forest cover change.” (Pomeroy et al., 2012). Clear and comprehensive understanding of hydrological effects of forestry in southern Alberta is needed in forest management planning.

It should also be noted that this paper focused solely on the streamflow effects of the hydrological cycle. There are many other hydrological variables that can be, and are affected by forest harvest and associated activities, but were outside the scope of this paper. For example, other important hydrological variables that are affected but were not discussed include; water quality, stream temperature, soil stability and erosion, aquatic organisms, and turbidity or sediment loading.

5 Conclusions

The water cycle in Alberta’s Southern Eastern Slopes follows a complex path. There are many variables that operate in tandem to affect the overall health of the hydrologic system. From reducing the canopy cover, interception and transpiration, compressing and degrading the soil, increasing erosion to deteriorate water quality, and increasing the frequency and magnitude of floods and droughts, forest harvesting has a serious effect on our water systems.

To state that there is no direct relationship between timber harvesting and flooding is a short-sighted and incomplete characterization of the situation. Our headwaters need responsible forest management practices that consider the hydrologic system in a holistic manner.

6 Literature Cited

Berris, S. N., & Harr, R. D. (1987). Comparative Snow Accumulation and Melt During Rainfall in Forested and Clear-Cut Plots in the Western Cascades of Oregon. In *Water Resources Research* (Vol. 23, Issue 1). http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.474.5240&rep=rep1&type=pdf

Buttle, J. M. (2011). The Effects of Forest Harvesting on Forest Hydrology and Biogeochemistry. In *Forest Hydrology and Biogeochemistry* (pp. 659–677). Springer. https://doi.org/10.1007/978-94-007-1363-5_33

Green, K. C. (2013). *Forests, floods and channel processes: illuminating links between forest harvesting, the flood regime and channel response in snowmelt headwater streams*. *December*, 216.

Green, K. C., & Alila, Y. (2012). A paradigm shift in understanding and quantifying the effects of forest harvesting on floods in snow environments. *Water Resources Research*, *48*(10), 1–21. https://doi.org/10.1002/2013WR013613

Hicks, B. J., Beschta, R. L., & Harr, R. D. (1991). LONG-TERM CHANGES IN STREAMFLOW FOLLOWING LOGGING IN WESTERN OREGON AND ASSOCIATED FISHERIES IMPLICATIONS. *Water Resources Bulletin, American Water Resources Association*, *27*(2). https://journals-scholarsportal-info.proxy.library.brocku.ca/pdf/1093474x/v27i0002/217_lcisflwoaafi.xml

Keenan, R. J., & Kimmins. (1993). The ecological effects of clear-cutting. *Environmental Reviews*, *1*, 121–144. www.nrcresearchpress.com

Martin, C. W., Hornbeck, J. W., Likens, G. E., & Buso, D. C. (2000). Impacts of intensive harvesting on hydrology and nutrient dynamics of northern hardwood forests. *Can. J. Fish. Aquat. Sci.*, *57*(2), 19–29. https://doi.org/10.1139/cjfas-57-S2-19

Mellina, E., Dan Moore, R., Hinch, S. G., Stevenson Macdonald, J., Pearson, G., Mellina, E., Hinch, S., Moore, R., Macdonald, J., & Pearson Canadian, G. (2002). Stream temperature responses to clearcut logging in British Columbia: the moderating influences of groundwater and headwater lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, *59*, 1886–1900. https://doi.org/10.1139/F02-158

Nitschke, C. R. (2005). Does forest harvesting emulate fire disturbance? A comparison of effects on selected attributes in coniferous-dominated headwater systems. *Forest Ecology and Management*, *214*, 305–319. https://doi.org/10.1016/j.foreco.2005.04.015

NSIDC. (2019). Cryosphere Glossary. In *National Snow & Ice Data Center*. https://nsidc.org/cryosphere/glossary

Onuchin, A., Burenina, T., Pavlov, I., Onuchin, A., Burenina, T., & Pavlov, I. (2017). Hydrological Consequences of Timber Harvesting in Landscape Zones of Siberia. *Environments*, *4*(51). https://doi.org/10.3390/environments4030051

Ouellet, C., Saint-Laurent, D., & Normand, F. (2012). Flood events and flood risk assessment in relation to climate and land-use changes: Saint-François River, southern Québec, Canada. *Hydrological Sciences Journal*, *57*(2), 313–325. https://doi.org/10.1080/02626667.2011.645475

Pike, R. G., Redding, T. E., Moore, D., Winkler, R. D., & Bladon, K. D. (2010). *Compendium of Forest Hydrology and Geomorphology in British Columbia Volume 1 of 2*. www.publications.gov.bc.ca

Pomeroy, J., Fang, X., & Ellis, C. (2012). Sensitivity of snowmelt hydrology in Marmot Creek, Alberta, to forest cover disturbance. *Hydrological Processes*, *26*, 1892–1905. https://doi.org/10.1002/hyp.9248

Rothwell, R., Hillman, G., & Pomeroy, J. W. (2016). Marmot Creek Experimental Watershed Study. *The Forestry Chronicle*, *92*(1). https://pubs.cif-ifc.org/doi/pdfplus/10.5558/tfc2016-010

Schnorbus, M., & Alila, Y. (2013). Peak flow regime changes following forest harvesting in a snow-dominated basin: Effects of harvest area, elevation, and channel connectivity. *Water Resources Research*, *49*, 517–535. https://doi.org/10.1029/2012WR011901

Smerdon, B. D., Redding, T. E., & Beckers, J. (2009). An overview of the effects of forest management on groundwater hydrology. In *BC Journal of Ecosystems and Management* (Vol. 10, Issue 1). www.forrex.org/publications/jem/ISS50/vol10_

Swanson, R. H., & Hillman, G. R. (1977). *Predicted increased water yield after clear-cutting verfied in west-central Alberta*. http://www.cfs.nrcan.gc.ca/pubwarehouse/pdfs/12115.pdf

Swanson, R. L., & Rothwell, R. H. (2001). Hydrologic recovery of aspen clearcuts in northwestern Alberta. *Sustaining Aspen in Western Landscapes: Symposium Proceedings*. https://digitalcommons.usu.edu/aspen_bib

Winkler, R. D., Moore, R. D., Redding, T. E., Spittlehouse, D. L., Smerdon, B. D., & Carlyle-Moses, D. E. (2010). The Effects of Forest Disturbance on Hydrologic Processes and Watershed Response. In R G Pike, T. E. Redding, R. D. Moore, R. D. Winkler, & K. D. Bladon (Eds.), *Compendium of Forest Hydrology and Geomorphology in British Columbia*. B.C. Ministry of Forests and Range, Research Branch.

CPAWS
CANADIAN PARKS AND WILDERNESS SOCIETY
SOUTHERN ALBERTA CHAPTER

Become a Steward for Alberta's Forests:

https://cpaws-southernalberta.org/forest-stewards/