Impacts of wildfire and post-fire salvage logging on sediment transfer in the Oldman watershed, Alberta, Canada

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Abstract The 2003 Lost Creek fire burned 21 000 ha of forested land in the Oldman River basin, Alberta, Canada. Seven watersheds, with varying degrees of natural and man-made land disturbance (burned, post-fire salvage logged, unburned) were monitored for three years to assess sediment concentrations and production (export and yield) over a range of flow regimes (spring melt, baseflow and stormflow). Suspended sediment concentrations were 6-times higher in burned watersheds and 11-times higher in post-fire salvage logged watersheds than in unburned watersheds. Sediment availability was greater in both burned and post-fire salvage logged watersheds but varied with flow condition; particularly during the snowmelt freshet and stormflow. In burned watersheds, sediment yield was 5-times higher during snowmelt and 13-times higher during stormflow than in unburned watersheds. Post-fire salvage logging produced much greater impacts than wildfire alone, with mean sediment yield 19-times higher during snowmelt and 9-times higher during stormflow compared to unburned watersheds.

Key words Canada; Rocky Mountains; salvage logging; sediment concentration; sediment export; sediment yield; wildfire

INTRODUCTION

It is widely recognized that vegetation change in forested watersheds, resulting from either natural (e.g. wildfire, pine beetle infestation, drought) or anthropogenic (e.g. prescribed burns, logging, recreation) disturbances can significantly alter a range of physical and biogeochemical processes that influence both source water quality and quantity. Accordingly, these changes often adversely impact the condition of downstream water supplies, potentially requiring optimization of drinking water treatment operations and associated increasing costs. Moreover, fire modified sediments are predominantly fine-grained and can negatively influence aquatic ecology in downstream environments (DeBano *et al.*, 1998).

In recent decades, many forested regions in North America have experienced an increase in the frequency and severity of large-scale natural disturbances, primarily due to warmer spring and summer temperatures and drought (Westerling *et al.*, 2006). Because of the severity and magnitude of landscape disturbance related to wildfire, sediment fluxes are modified at rates and magnitudes that are increasingly causing profound and often irreversible changes in river system function (DeBano *et al.*, 1998). From a geomorphic perspective, wildfire associated vegetation changes can lower erosion thresholds thereby increasing runoff and erosion rates (Benavides-Solorio & MacDonald, 2001). The magnitude of post-fire erosion and sediment supply depends on factors such as the sensitivity of the watershed to erosion, precipitation regime, geology, vegetation and the severity, geographical extent and frequency of burns (Robichaud, 2000; Martin & Moody, 2001). Sediment and nutrient fluxes in watersheds may also be greatly influenced by fire-induced water repellency and changes in infiltration and runoff properties of hill slopes (Blake *et al.*, 2004; Desilets *et al.*, 2007). Post-disturbance land management (e.g. salvage logging) can produce additional effects on sediment delivery to streams, because the timing of these activities is coincident when forests are most vulnerable to the impacts of additional, especially anthropogenic, disturbances (DellaSala *et al.*, 2006).

In critical water supply regions (e.g. in southern Alberta), the effects of wildfire on water quality and aquatic ecology are related to increased amounts of organic matter, sediment and sediment-associated contaminants both stored and transported in fire impacted river channels and flood-plain systems. Little is known about the post-fire effect on the hydrological regime (seasonal variation in flow conditions) on the concentration and production (export and yield) of suspended sediment at the watershed scale, especially in headwater regions of the southern Rocky Mountains. Improved knowledge of wildfire impacts on the erosion and transport of fire-modified aggregates is necessary so that appropriate source water protection and management protocols can be developed for use by utility managers and other relevant stakeholders (e.g. regulators, consulting engineers), including land managers making decisions regarding post-disturbance activities (e.g. salvage logging). Further, the temporal trends in recovery of post-fire sediment supply must also be better understood to make informed decisions for integrated watershed management.

The objective of this paper is to quantify the effects of wildfire on sediment concentration and production in seven headwater basins located on the eastern slopes of the Rocky Mountains in southern Alberta. The sediment data are related to the effects of land disturbance (burned, post-fire salvage logged, unburned) and flow regimes (spring melt, baseflow, and stormflow). The early trajectory of recovery of sediment supply is also characterized for the first three years after severe wildfire.

MATERIALS AND METHODS

Site description

From July to September 2003, the Lost Creek wildfire burned more than 21 000 ha in the Crowsnest Pass, Rocky Mountain region of southwestern Alberta (49°37′ N, 114°40′ W). It was one of the most severe wildfires in the upper eastern slopes forests of Alberta in many decades. The fire burned as a near contiguous crown fire, consuming virtually all forest cover and forest floor organic matter across a large proportion of the headwater regions of both the Castle and Crowsnest rivers (Fig. 1). These headwater rivers produce some of highest water yields in the province of Alberta, in one of the most water-stressed regions (Oldman River basin). Beyond the important ecosystem services provided by this area, it also supports a broad spectrum of human uses, from domestic and agricultural water supply to water-based recreation. Thus, water quality issues are a primary concern both within the municipality of Crowsnest Pass and downstream reaches of the Oldman River.

Seven study watersheds were instrumented in an area without significant logging disturbance prior to the 2003 Lost Creek wildfire. Initially, three burned watersheds (Lynx Creek, Drum Creek, and South York Creek) and two unburned watersheds (Star Creek and North York Creek) were instrumented from March to April 2004 (Fig. 1). Two post-fire salvage logged watersheds were added to the study in early 2005 (Lyons Creek West and Lyons Creek East). Salvage logging began in winter 2003/04 and continued through winter 2004/05, covering 261.8 ha in Lyons Creek West (63.4% of the burned area) and 238.2 ha in Lyons Creek East (22.2% of the burned area).

Streamflow in the study watersheds is very high. Unit area discharges up to 1200 mm year^{-1} were measured from 2004 to 2006. The high water production is due to very high annual precipitation (up to 1500 mm year^{-1}) combined with extremely high annual runoff ratios. Approximately 80% of annual precipitation is routed as streamflow.

Hydrometric and sediment instrumentation

Fifteen meteorological stations were located throughout the watersheds and hydrometric/water quality monitoring stations were established at the outlet of each of the seven study basins (Fig. 1). Manual streamflow and water quality was measured every 7–10 days during snowmelt freshet, at 2-week intervals during the remainder of the summer, and at intervals of 30–40 days during the winter. Suspended solids were collected using depth integrated grab sampling using 1-L acid-washed Nalgene bottles. In the laboratory, sediment concentration was determined gravimetrically. Sediment concentration and discharge data were used to calculate sediment export and yield.

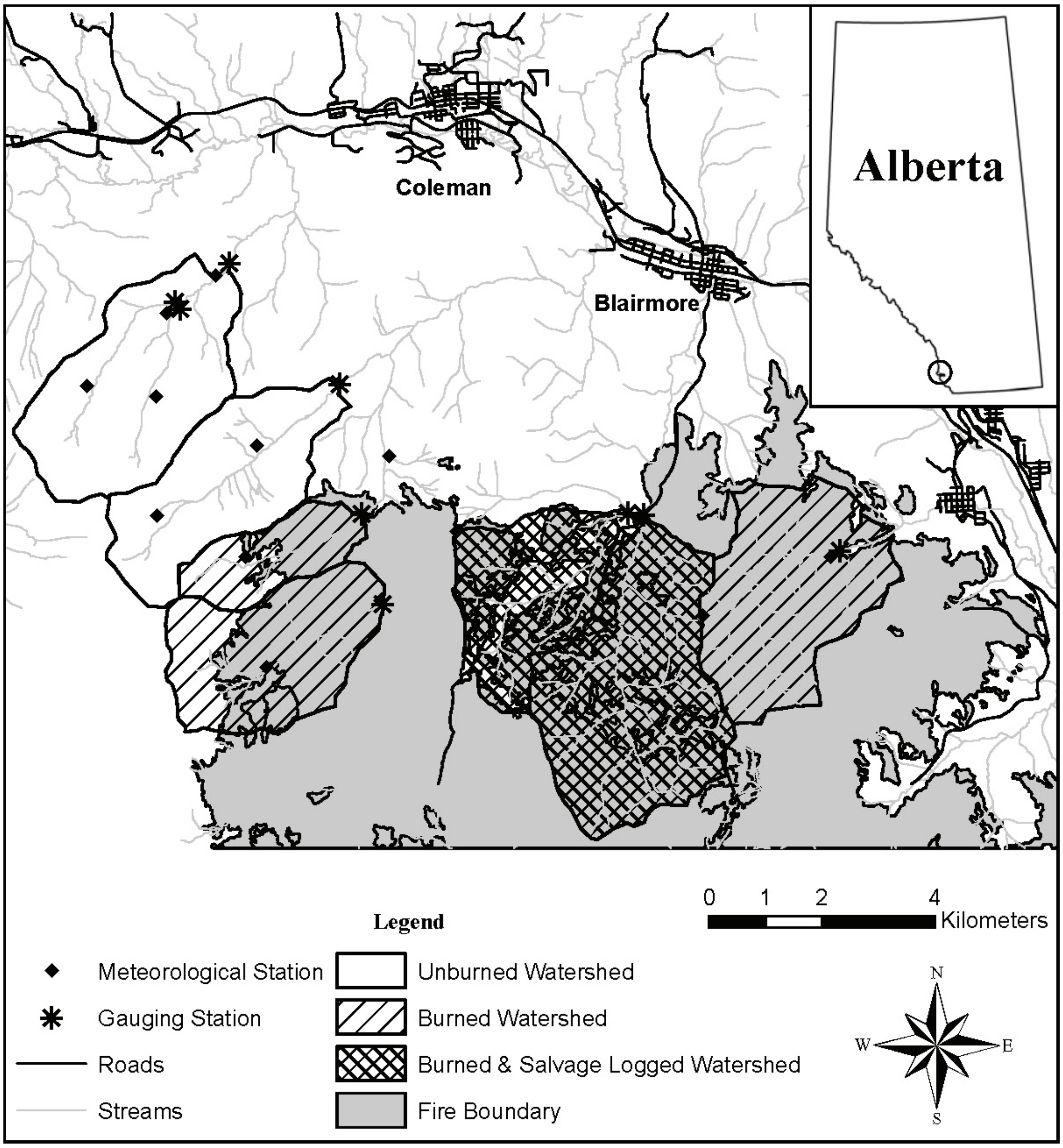

Fig. 1 Map of the 2003 Lost Creek fire boundary, streamflow gauging stations, meteorological stations, and research watersheds (From West to East: Star, North York, South York, Lynx, Lyons West, Lyons East, and Drum).

RESULTS AND DISCUSSION

In the three years following a severe wildfire in the Rocky Mountain region of Alberta, suspended sediment concentration and production (export and yield) varied with disturbance type and year across the study region (Fig. 2). The highest sediment values were measured in the watersheds impacted by wildfire and post-fire salvage logging. Over the first three years of the study, the mean sediment concentration in the unburned watersheds was 3.1 mg L^{-1} ± 0.9 (standard error of the mean), but were 26.2 mg L^{-1} ± 10.2, and 36.8 mg L^{-1} ± 8.6 in burned and salvage logged watersheds, respectively. Sediment export was 5.8-times greater in burned watersheds and 10.6-times greater in salvage logged watersheds, while sediment yields were 9.4-times greater in burned watersheds and 10.2-times greater in salvage logged watersheds.

Sediment concentration and production were highly variable during the first three post-disturbance seasons (Fig. 2(a)), but no pattern of initial recovery was evident. In particular, several

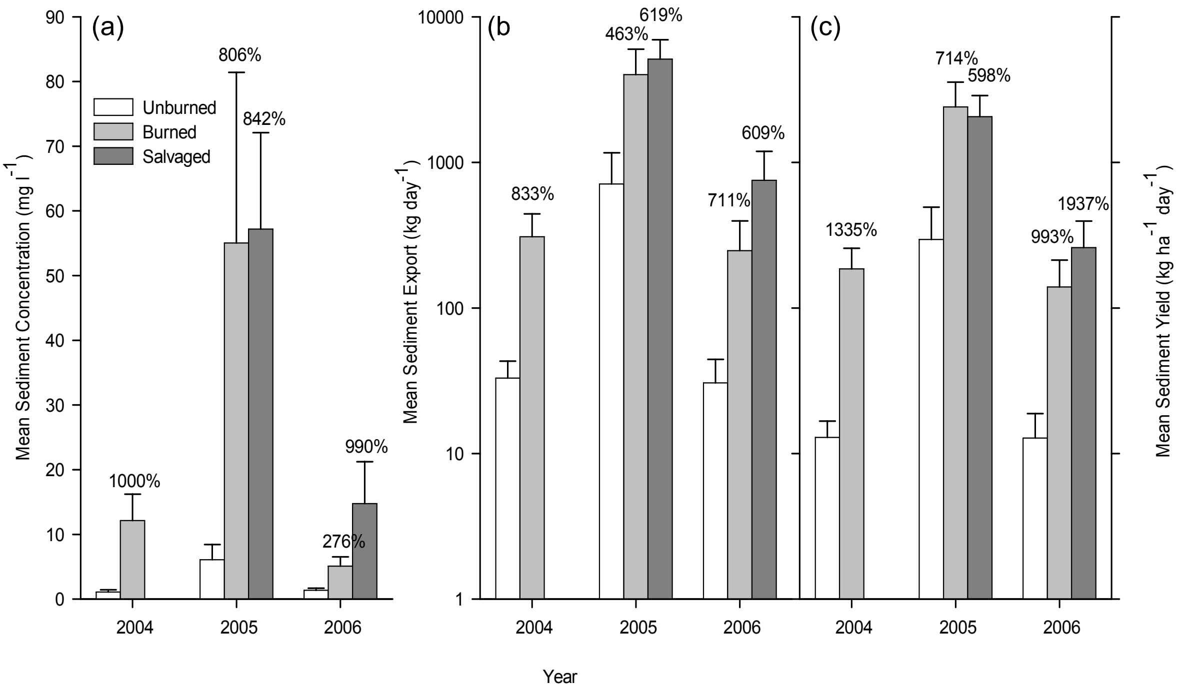

Fig. 2 A comparison of: (a) mean suspended sediment concentration, (b) sediment export (kg day^{-1}), and (c) sediment yield (kg ha^{-1} day^{-1}) in the unburned, burned, and salvage logged watersheds from 2004 to 2006. Values in percent indicate increases relative to unburned watersheds. Error bars are the standard error of the mean.

extremely large rainfall events in June 2005 (150–175 mm over 8 days) saturated soils and produced large streamflow responses for a range of smaller, subsequent precipitation events throughout the month. These events coincided with some of the highest sediment concentrations, exports and yields observed during the course of the study. In contrast, the first post-burn season of 2004 was cool and moist, but generally without severe summer storm events (55% of days in growing season with 0.1–5 mm/day), and the summer of 2006 was dry with no measurable precipitation observed from early June until late September. Sediment concentrations, exports and yields in 2004 and 2006 were similar, and notably lower than those observed in 2005 (Fig. 2).

Sediment concentrations and production clearly varied with flow regime (baseflow, stormflow, and spring freshet) (Fig. 3). The largest differences in sediment production among undisturbed and disturbed landscapes were observed during the snowmelt freshet and periodic stormflows; however, differences were still evident during lower flows (non-event periods). During higher flows (snowmelt freshet and stormflow), the range of sediment concentrations and production in burned watersheds was 6 to 15 times greater than in unburned watersheds. The additional disturbance from post-fire salvage logging produced considerably more sediment during these same events, resulting in sediment concentrations, exports and yields 17 to 42 times greater than those observed in the unburned watersheds. The results and field observations indicate that post-fire collapse of stream banks, channel storage of sediment, and additional soil disturbance associated with post-fire salvage logging (particularly with linear features such as skid-trails and in-block roads) are the dominant sources of sediment. During the snowmelt freshet and stormflow events, increased sediment production may have been related to increased runoff due to reduced infiltration rates resulting from burn associated increased soil hydrophobicity. Decreased interception and transpiration losses resulting from the burn also contributed to the observed increases (Legleiter *et al.*, 2003). While increased sediment production during stormflows and snowmelt periods may not be an unexpected result of severe disturbances such as wildfire, increased suspended sediment concentrations during prolonged late summer dry periods (Fig. 3) indicate that

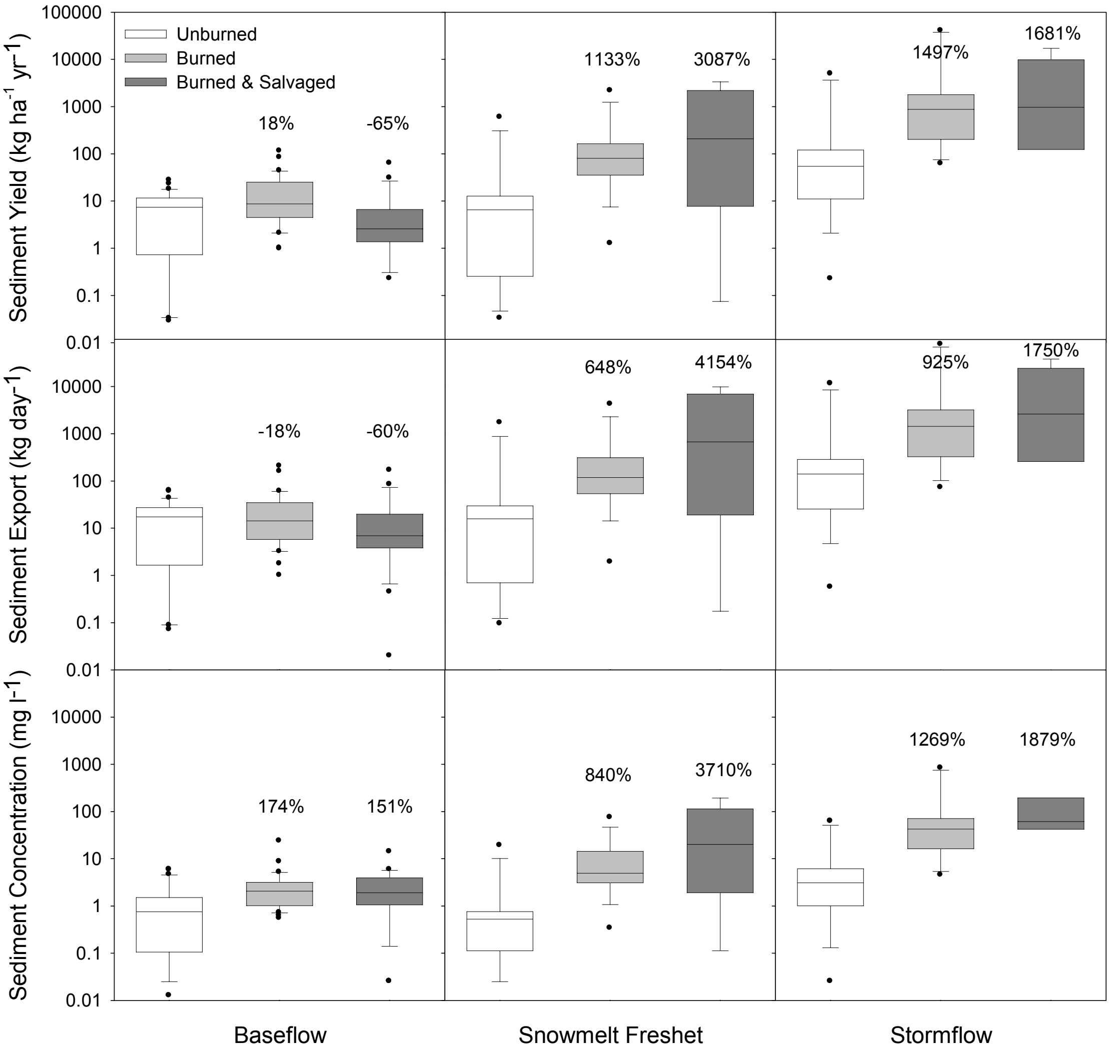

Fig. 3 Box plots of suspended sediment yield, export, and concentration during baseflow, snowmelt freshet, and stormflow events. Values in percent indicate increases in the median relative to unburned watersheds.

there was a significant accumulation of post-fire sediments in stream channels and shows that a broad shift in post disturbance sediment regime has occurred within the 3 years since the wildfire.

CONCLUSIONS AND IMPLICATIONS

Significant increases in the frequency and magnitude of wildfires (Westerling *et al*., 2006), as well as forest pest epidemics such as mountain pine beetle, have already been observed in forested regions of North America (Stahl *et al*., 2006). These disturbances have been driven primarily by increased temperatures and earlier spring snowmelts in many forested regions, supporting the idea that these types of disturbances are likely to become increasingly important sources of water quality deterioration in the future. The present study shows that wildfire has substantially altered both the availability and transport of sediment in streams draining the eastern slopes of the southern Rocky Mountains. Accordingly, improved knowledge of the downstream impacts of sediment and associated pollutants from this fire impacted region will be required to improve integrated source water management planning and engineering strategies for the long-term supply of safe drinking water.

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REFERENCES

Benavides-Solorio, J. & MacDonald, L. H. (2001) Post-fire runoff and erosion from simulated rainfall on small plots, Colorado front range. *Hydrol. Processes*. **15**(15), 2931–2952 .

Blake, W., Wallbrink, P., Doerr, S., Shakesby, S. & Humphreys, G. (2004) Sediment redistribution following wildfire in the Sydney region, Australia: a mineral magnetic tracing approach. In: *Sediment Transfer Through the Fluvial System* (ed. by V. Golosov, V. Belylev & D. Walling), 481–487. IAHS Publ. 288. IAHS Press, Wallingford, UK.

DeBano, L. F., Neary, D. G. & Ffolliott, P. F. (1998) *Fire's Effects on Ecosystems*. John Wiley & Sons, Inc., New York, USA.

DellaSala, D. A., Karr, J. R., Schoennagel, T., Perry, D., Noss, R. F., Lindenmayer, D., Beschta, R., Hutto, R. L., Swanson, M. E. & Evans, J. (2006) Post-fire logging debate ignores many issues. *Science* **314**(5796), 51–52.

Desilets, S., Nijssen, B., Ekwurzel, B. & Ferre, T. (2007) Post-wildfire changes in suspended sediment rating curves: Sabino Canyon, Arizona. *Hydrol. Processes* **21**(11), 1413–1423.

Legleiter, C. J., Lawrence, R. L., Fonstad, M. A., Marcus, W. A. & Aspinall, R. (2003) Fluvial response a decade after wildfire in the northern Yellowstone ecosystem: a spatially explicit analysis. *Geomorphology* **54**(3-4), 119–136.

Martin, D. A. & Moody, J. A. (2001) Comparison of soil infiltration rates in burned and unburned mountainous watersheds. *Hydrol. Processes* **15**(15), 2893–2903.

Moody, J. A. & Martin, D. A. (2001) Initial hydrologic and geomorphic response following a wildfire in the Colorado front range. *Earth Surf. Processes* **26**(10), 1049–1070.

Neary, D. G., Gottfried, G. J. & Ffolliott P. F. (2003) *Post-Wildfire Watershed Flood Responses* (2nd Int. Wildland Fire Ecology & Fire Management Congress and 5th Symposium on Fire Forest Meteorology). American Meteorology Society, Orlando, Florida, USA.

Robichaud, P. R. (2000) Fire effects on infiltration rates after prescribed fire in Northern Rocky Mountain forests USA. *J. Hydrol.* **231/232**, 220–229.

Shakesby, R. A., Doerr, S. H. & Walsh, R. D. P. (2000) Erosional impacts of soil hydrophobicity: current problems and future research directions. *J. Hydrol.* **231/232**, 178–191.

Stahl, K., Moore, R. D. & McKendry, I. G. (2006) Climatology of winter cold spells in relation to mountain pine beetle mortality in British Columbia, Canada. *Climate Res*. **32**(1), 13–23.

Westerling, A. L., Hidalgo, H. G., Cayan, D. R. & Swetnam, T. W. (2006) Warming and earlier spring increase western U.S. forest wildfire activity. *Science* **313**(5789), 940–943.