Streamline
Watershed Management Bulletin
*Volume 12 Number 2 Spring 2009*

**Peer-reviewed Research Article**

# Alberta's Southern Rockies Watershed Project—How Wildfire and Salvage Logging Affect Water Quality and Aquatic Ecology

Uldis Silins, Kevin D. Bladon, Axel Anderson, John Diiwu, Monica B. Emelko, Michael Stone, and Sarah Boon

The eastern slopes of Alberta's Rocky Mountains produce the vast majority of surface water supplies in the central and southern regions of the province. Population growth, industrial development, and agricultural expansion over the past two decades have dramatically increased water demand in this region. Such pressures on water resources, along with the rapid expansion of urban development into wildland areas, heavy recreational use, and public concerns over the impacts of climate change have led to a substantial increase in attention on headwater or source water protection issues in Alberta's eastern-slope forests. This new focus has created fundamental challenges for forest watershed and integrated water managers in Alberta and many other regions of North America.

Natural disturbance from wildfire and forest pest/disease outbreaks has been a common historic feature of Alberta's forested landscape. A series of unusually large and severe wildfires in the last decade, along with the recent appearance of large-scale mountain pine beetle (MPB) outbreaks beginning in 2004/05, have raised new concerns over climate change impacts on the frequency and severity of large-scale natural disturbances. The Lost Creek wildfire in the Crowsnest Pass was one of the first in a series of large wildfires in southwest Alberta and southeast British Columbia during the 2003 fire season. The wildfire burned out of control for 26 days and consumed over 21 000 ha in the headwaters of the Oldman River Basin, threatening wildlife, industry, and communities. The wildfire was unusually severe because of very dry conditions and high fuel loads, and burned as a nearly contiguous crown fire that consumed virtually all of the forest floor across extensive regions within the burn boundary (Figure 1).

The Southern Rockies Watershed Project (SRWP) was established in response to the need for information on how severe wildfire disturbance (including incremental effects of salvage logging) affects a range of "watershed values." The objectives of SRWP were to describe the immediate impacts of the wildfire on the hydrology, water quality, and aquatic ecology of disturbed watersheds and to assess the early trajectory of watershed recovery in subsequent years. To date, SRWP has produced one of the most comprehensive datasets describing both the basic hydrology

*Continued on page 2*

## Inside this issue:

*Continued from page 1*

and the impacts of severe natural disturbance on a range of watershed values in the high water-yielding, source watersheds of Alberta's Rocky Mountains (eastern slopes). The purpose of this article is to introduce this project by briefly summarizing the scope of research underway at the study area and by highlighting a small subset of results that focus on key indicators of water quality and stream health (ecologic response).

## Study Description

Research watersheds were established in the winter of 2003/04 to capture data from the first post-disturbance hydrologic events during the spring snowmelt of 2004. Seven watersheds were instrumented to enable automated and manual hydrometric, water quality, and stream ecological monitoring. Instrumentation was installed in three burned watersheds (Lynx, Drum, and South York Creeks), two


*U. Silins*

*Figure 1. High fire severity in Lynx Creek. Note the loss of forest floor.*

Published by:
**FORREX Forum for Research and Extension in Natural Resources**
Suite 702, 235 1st Avenue
Kamloops, BC  V2C 3J4

Project Manager:
**Todd Redding**
***Tel: (250) 713-1184***

Distribution/Mailing List:
**Gord Austin**
***Tel: (250) 371-3923***

Technical Review Committee:
**T. Redding, R.D. Moore, R. Pike, K. Bladon**

Technical Reviewers this Issue:
**K. Bladon, G. Hope, N. Neumann, R. Pike, T. Redding, D. Scott**

Publication and Website Support:
**Satnam Brar, Julie Schooling**

Graphic Layout: **SigZag Design**

Editing: **Susan Thorne**

Cover Illustration: **William McAusland**
McAusland Studios, Kamloops, B.C.

**This publication is funded in part by the British Columbia Ministry of Forests and Range through the Forest Investment Account–Forest Science Program and the BC Ministry of Environment.**

ISSN 1705-5989
Printed in Canada

Printed on recycled paper

***http://www.forrex.org/streamline***

FORREX
Supporting Sustainable Natural Resource Management Decisions

**Table 1. Annual precipitation (mm) in the study watersheds during 2004-2007**

| Watershed | Year | | | | |
|---|---|---|---|---|---|
| | 2004 | 2005 | 2006 | 2007 | Mean |
| Unburned (Reference) | | | | | |
| Star | 1138 | 1182 | 737 | 699 | 939 |
| North York | 1390 | 1460 | 1007 | 1056 | 1228 |
| Burned | | | | | |
| South York | 1227 | 1471 | 1203 | 1185 | 1271 |
| Lynx | 1351 | 1717 | 1025 | 1079 | 1293 |
| Drum | 740 | 1177 | 782 | 631 | 832 |
| Burned and Salvage Logged | | | | | |
| Lyons East | - | 1111 | 996 | 668 | 925 |
| Lyons West | - | 1084 | 1039 | 655 | 926 |

post-fire salvage-logged watersheds (Lyons West and Lyons East Creeks), and two unburned (reference) watersheds (Star and North York Creeks). A well-distributed network of 15 climate stations provides continuous data for precipitation, air and ground temperature, relative humidity, radiation, snowpack depth, and wind speed (Figure 1).

Study watersheds range in size from 360–1315 ha (830 ha mean) with an average elevation of 1800 m (Figure 2). The proportion of total watershed area burned in the five disturbed watersheds ranges from 53 to 100%; however, this proportion includes alpine areas that did not burn because of a lack of tree cover. Virtually all forested stands in the burned catchments were consumed by the fire. Salvage operations occurred on 63% of the burned area in Lyons Creek West (40% of the total watershed area harvested) and 22% of the burned area in Lyons Creek East (18% of the total watershed area harvested).

The region encompassed by the study is broadly characteristic of Rocky Mountain front-range physiographic settings, with all watersheds spanning upper Montane, Subalpine, and Alpine ecozones. Lodgepole pine (*Pinus contorta* var. *latifolia*), Engelmann spruce (*Picea engelmanii*), and subalpine fir (*Abies lasiocarpa*) are the dominant tree species, occurring in pure and mixed stands at ecozone transitional areas. The study area is also in one of the highest water-yielding regions of Alberta, with mean annual precipitation (2004 to 2007) across the seven watersheds of 1060 mm (range: 630–1720 mm) (Table 1). The majority (50 to 70%) of total annual precipitation falls as snow from October to April.

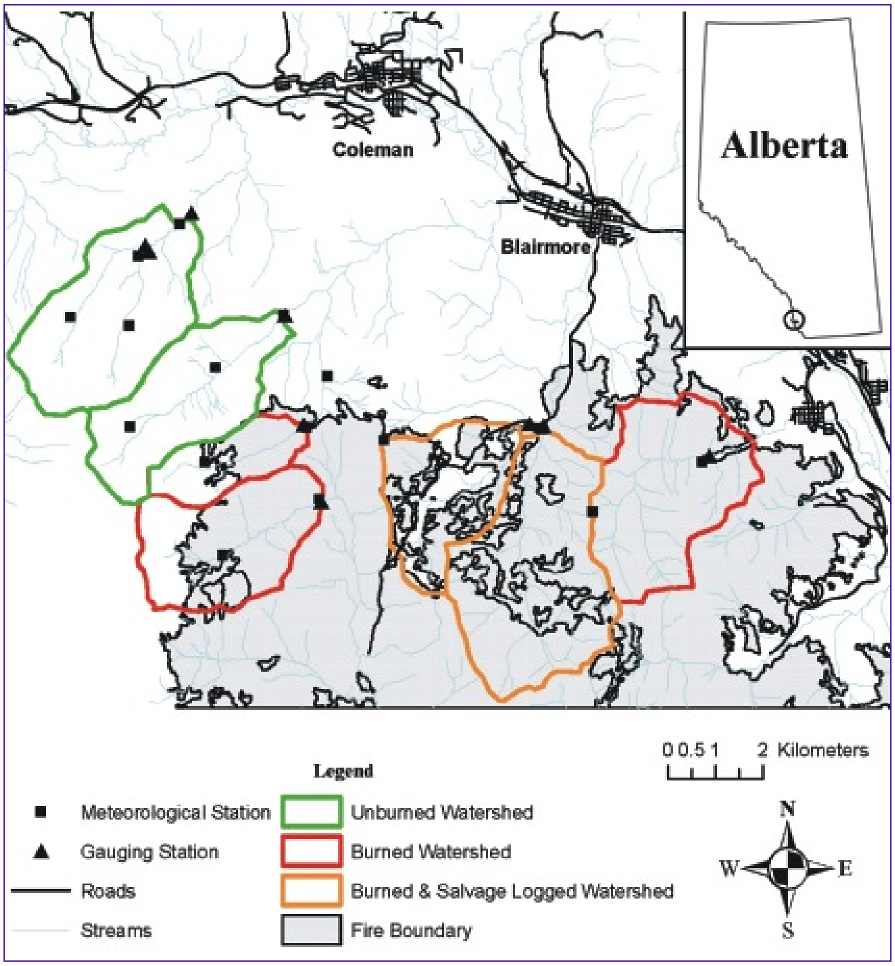

*Figure 2. Southern Rockies Watershed Project map with the 2003 Lost Creek wildfire boundary, meteorological stations, streamflow gauging stations, and study watersheds (From West to East: Star, North York, South York, Lynx, Lyons West, Lyons East, and Drum Creeks).*

The streamflow regime is snowmelt-dominated with peak streamflow usually occurring during the period of snowpack melt in mid to late May. The region also receives significant early- and mid-summer rains, which can produce large flow events. This distinguishes this region from British Columbia's East Kootenays, where both summer precipitation and

*Continued on page 4*

*Continued from page 3*

summer baseflows are lower. While the study area is geographically close to the East Kootenay region, subtle differences in climate produce important differences in regional hydrology. Both regions experience their lowest streamflows in August.

Streamflow is monitored continuously in all watersheds with pressure transducers and gas bubblers that use stage-discharge relationships at natural control sections. In addition to the seven main study catchments, six nested sub-watersheds are gauged within the two reference watersheds. Mean annual streamflow across all seven watersheds during the study period ranged from 380 to 1250 mm/year. The groundwater hydraulic gradients are strong throughout the study area, because of the steep physiography. Mean area-weighted catchment slopes range from 24.8 to

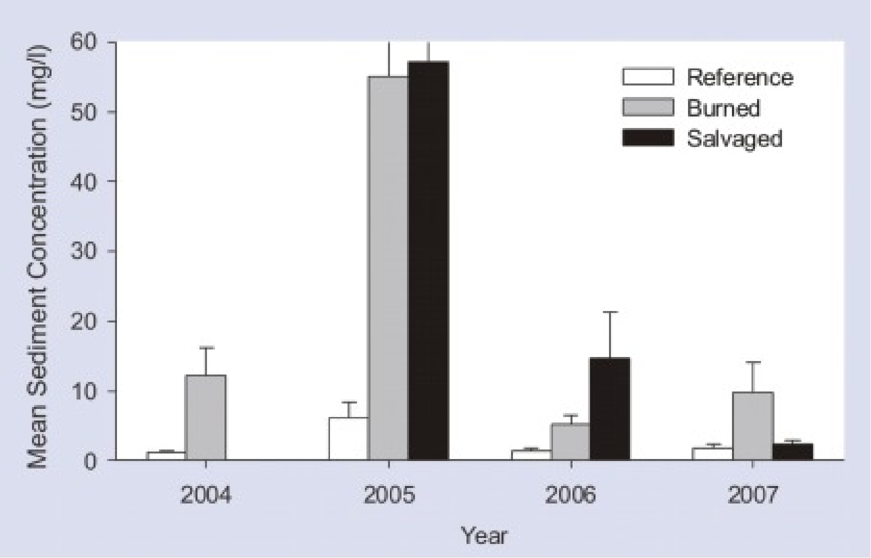

***Figure 3. A comparison of the mean total suspended sediment concentration (mg/l) following the 2003 Lost Creek wildfire between reference, burned, and post-fire salvage-logged watersheds from 2004 to 2007 (adapted from Silins et al. 2009). Bars indicate the standard error of the mean.***

*U. Silins*

***Figure 4. Streambank slumping in Lyons Creek East 2005 (1 year after the fire).***

48.8%. Qualitatively, it is evident that groundwater contributions are significant for all study streams. Given this contribution, surface streams generally flow all year, allowing year-round monitoring of the 13 hydrometric gauging stations.

In addition to baseline monitoring of climatic variables and stream discharge, insights into the impacts of wildfire on precipitation inputs to the burned landscape are provided by annual snowpack surveys and measurements of rainfall interception (throughfall and stemflow) in burned and reference stands.

Water quality monitoring is ongoing in each of the seven watersheds using a comprehensive four-stage sampling approach.

1. Water temperature, dissolved oxygen (DO), electrical conductivity, pH, redox potential (ORP), turbidity, and salinity are monitored continuously during ice-free periods using automated water quality Sondes (YSI 6820/6920).
2. Daily water samples are collected for sediment concentration and turbidity using automated samplers (ISCO 6712 Series) during the ice-free period from May to September.
3. Routine sampling for nutrients and major cations/anions is conducted every 10 days during snowmelt freshet, every 14 days after the freshet (i.e., ice-free periods), and every 1 to 2 months during winter. Analyses include total nitrogen (TN), total dissolved nitrogen (TDN), ammonium ($NH_4^+$), nitrate ($NO_3^-$), total phosphorus (TP), total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), potassium ($K^+$), sulphate ($SO_4^-$), calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), sodium ($Na^+$), iron ($Fe^{2+}$), aluminum ($Al^{3+}$), chloride ($Cl^-$), silica, dissolved organic carbon (DOC), and dissolved and suspended solids.
4. Sampling for a full-suite metals analysis (US EPA metals) occurs two to three times each year under a range of flow conditions (snowmelt, stormflow, and baseflows). Oxygen isotope samples from precipitation and surface streams are also collected in all seven watersheds throughout the study. These samples may be used to provide insight into the relative surface/groundwater components that contribute to overall streamflow.

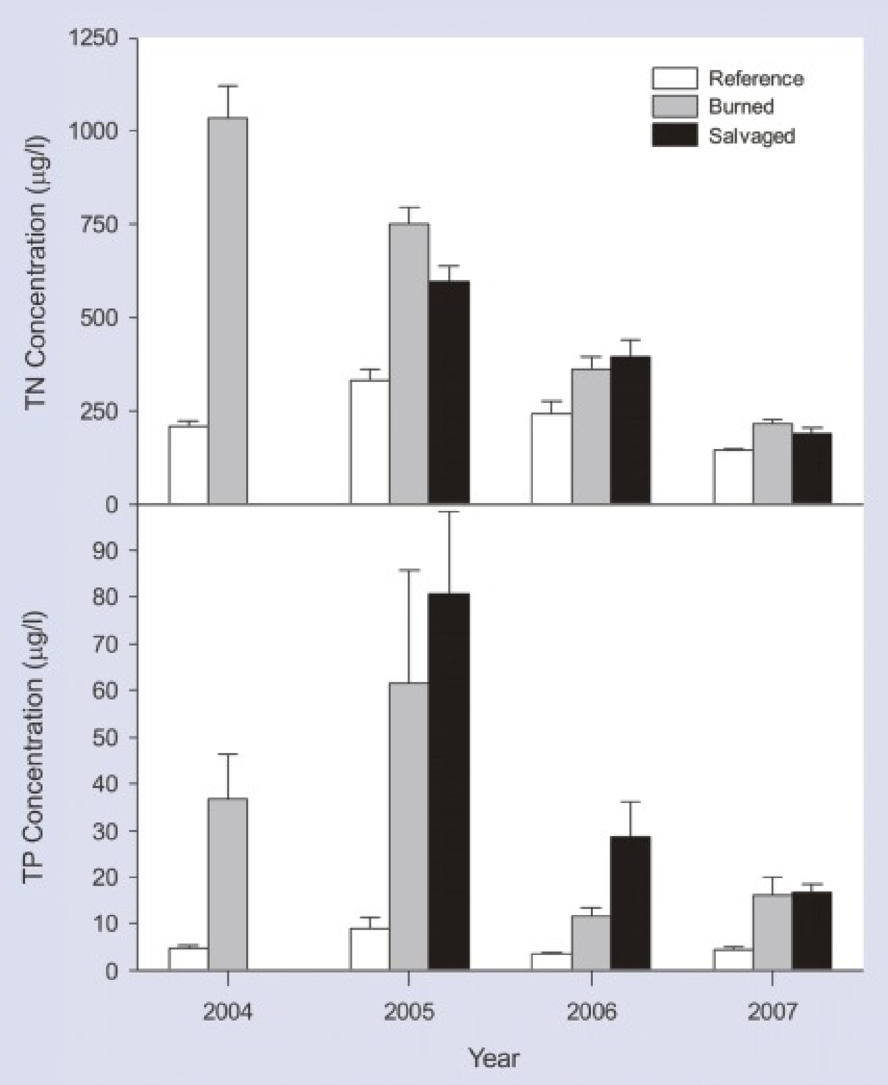

*Figure 5. Mean total nitrogen (TN) and total phosphorus (TP) concentrations (μg/l) following the 2003 Lost Creek wildfire in reference, burned, and post-fire salvage-logged watersheds from 2004 to 2007 (adapted from Bladon et al. 2008 and Silins et al. in review). Bars indicate the standard error of the mean.*

Ecological responses to wildfire and post-fire salvage logging are being assessed through studies of stream algal growth and benthic macroinvertebrate community response. Algal production is measured in all watersheds by periodic sampling from artificial streambed substrates (replicate unglazed porcelain tiles). Samples are collected monthly (May to October) for fluorometric analysis of chlorophyll *a* (Chl*a*) and determination of ash free dry mass (AFDM).

Samples of benthic macroinvertebrates are collected (Surber sampler) and identified to the lowest possible taxonomic grouping (usually family) and assigned to a functional feeding group (filterer, shredder, scraper, or predator). Stable isotope analysis (SIA) is then conducted for carbon ( $^{13}$C) and nitrogen ( $^{15}$N) to provide an indication of the overall stream ecosystem response to disturbance (wildfire and salvage logging) and evidence of changes in the structure of stream food webs (autochthonous versus

*Continued on page 6*

*Continued from page 5*

allocthonous food sources) between the watersheds.

## Water Quality Response

Only selected water quality parameters are presented here due to the large number of chemical water quality parameters measured in this study. Total suspended sediment (TSS) concentration was strongly affected by both the wildfire and salvage logging, and the magnitude of these effects varied with time after the wildfire (Figure 3). TSS concentrations across the 4 post-fire years were eight times greater in the burned and nine times greater in the salvage-logged watersheds compared to the reference watersheds (Silins et al. 2009). While the results for disturbed watersheds were significantly different than results for the reference watersheds, there were no differences in mean TSS concentrations between burned and post-fire salvage-logged watersheds during this same period. The largest differences in sediment production between undisturbed and disturbed landscapes were observed during both the snowmelt freshet and periodic stormflows. The range of sediment concentration and production in burned watersheds was 6 to 15 times greater than in reference watersheds during higher flows (snowmelt freshet and stormflows). The additional disturbance from post-fire salvage logging produced considerably more sediment during these same events, with a range of 17 to 42 times greater sediment concentrations than in the reference watersheds. While high TSS tended to coincide with high flow events, differences between the reference and disturbed watersheds were still evident during baseflow periods (non-event).

Trends in TSS production over the first 4 years post-wildfire might suggest significant recovery of sediment production during that period; however, this apparent recovery trend is confounded by climate variation over the same period. Summer 2004 was generally moist, while summer 2005 was very wet, followed by two increasingly dry years in 2006 and 2007. Even during the very dry summer of 2007, sediment production remained elevated in disturbed watersheds—presumably due to the accumulation of significant channel sediment after the fire. While additional data (2008 and onward) will help to clarify these signals, significant existing stream bank failures (Figure 4) and new sediment sources suggest that the decrease in sediment production in the disturbed watersheds to concentrations similar to what has been observed in the reference watersheds will be slow.

The high-elevation Rocky Mountain headwater streams of the SRWP study area are generally oligotrophic or nutrient poor. However, during the first post-fire year, concentrations of the various forms of nitrogen (N) were 1.5 to 6.5 times higher in burned streams. Mean total N concentration was 5.3 times higher (Figure 5) compared to the reference streams the first year after the fire (Bladon et al. 2008). Nitrogen production and its relationship with stream discharge indicated very rapid recovery in the burned watersheds, with almost full recovery 3 years after the wildfire (Bladon et al. 2008). However, recovery of nitrogen production was somewhat slower in the salvage-logged watersheds, with elevated concentrations still evident 4 years after the wildfire.


K. Bladon

***Figure 6. High post-wildfire algal production in Lynx Creek in summer of 2007 (4 years after the wildfire).***

Similar to N, concentrations of all forms of phosphorus (P) were greater in the burned streams compared to the reference streams in the first post-fire year (2004) (Silins et al., in review). From 2005 to 2007, the general trend was greater concentrations of all P forms in the post-fire salvage-logged streams, followed by concentrations in the burned streams. However, unlike the pattern of post-disturbance recovery in nitrogen and other water quality parameters, return of P concentrations in the disturbed watersheds (both burned and salvage-logged) to values similar to the control watersheds has been very slow. This is likely due to the strong interactions (sorption/desorption) of P with sediments and, thus, recovery of P is likely linked to the post-fire stream sediment loading and recovery of sediment production.

## Ecological Response

Elevated nutrient production after both wildfire and post-fire salvage logging has had a significant impact on stream ecology, and may have been intensified because undisturbed streams in this region are generally nutrient poor. Primary productivity (algal production) increased dramatically immediately after the fire and remains elevated in the burned and post-fire salvage-logged watersheds. Mean annual algal biomass ranged from 7.2 to 14.3 times higher and chlorophyll *a* concentration was 17.4 to 71 times higher in the burned streams compared to the reference streams (Silins et al., in review). Four years after the fire, algal biomass was still 9.8 times greater in the burned streams and 11.1 times higher in the salvage-logged streams compared to the reference streams. Differences in nutrient inputs and algal production have produced greater abundance and diversity of species in the benthic macroinvertebrate communities in both burned and salvage-logged streams compared to the reference streams. Scrapers (primarily *Ephemeroptera*) were the dominant functional feeding group in reference streams, while there was a more even distribution of predators, shredders, and scrapers in the burned streams. The increase in species diversity in disturbed streams generally reflected the influx of additional disturbance-adapted strategists or trophic generalist species.

## Downstream Implications

Forested headwater areas are an important water supply source in southern Alberta, as they are in most parts of the country. Thus, while impacts to source water quality can affect a broad range of water uses, evaluating downstream impacts is often challenging because of widely differing requirements for downstream users (e.g., drinking water, stockwater, and industrial process water). However, downstream impacts of upstream disturbance can be evaluated by focusing on particular water uses. For example, operating downstream municipal drinking water utilities can become more difficult and costly after upstream disturbances from wildfire. The elevated concentrations of several water quality parameters observed in the SRWP study of burned and salvage-logged watersheds (turbidity, suspended solids, dissolved organic carbon, etc.) could potentially result in increased chemical coagulant demand, sludge production, and disinfection requirements for acceptable drinking water treatment (Emelko et al. 2009). In most cases, regardless of the specific technology use and/or the required plant size/production capacity, the treatment costs would need to increase to meet regulatory requirements. Additional public health concerns arising from wildfire-associated water quality changes include increases in microcystins (microbial toxins) and disinfection by-products, which are potentially harmful to human health. Thus, dramatic changes in source water quality can have significant cost, compliance, and public health implications for downstream municipal water use (Emelko et al. 2009)

In future research at SRWP, we plan to address numerous critical questions around what proactive measures can be taken to protect source water supplies and the treatment process performance from the deleterious impacts of disturbance. Evaluating the critical vulnerabilities within source watersheds and treatment processes will provide the opportunity for researchers to develop adaptive strategies that improve the flexibility and resiliency of drinking water treatment systems.

## Providing Knowledge

To date, SRWP has provided basic information that was previously lacking on the impacts of wildfire and post-burn salvage logging on a broad range of "watershed values." These include the strong initial effects on water quality parameters, which can have ecological effects on primary and secondary producers. As expected, strongly differential patterns in early recovery have been observed among individual water quality parameters. While salvage logging did have small to moderate additional effects on water quality, the more important incremental impacts of this secondary disturbance may be related to slower rates of post-disturbance recovery because of sediment–nutrient interactions.

Forest managers require this type of information when making decisions about fire suppression priorities in critical source water regions or about post-fire management interventions such as salvage logging. Knowledge of the incremental effects of salvage logging on a range of watershed values is important in evaluating the resource trade-offs that accompany such decisions.

In the next phase of this project, the comparative effect of several harvesting strategies (including patch cutting and commercial thinning) will be studied in a paired catchment study using the two reference watersheds. The previous 5 years of study of these two watersheds for climate, discharge, and water quality parameters will form the pre-treatment calibration period for the upcoming paired basin study. Monitoring of burned and salvage-logged watersheds will continue to describe the trajectory of post-disturbance recovery of water quality parameters that have not recovered during the first phase of the research. This knowledge will continue to fill information gaps so that informed decisions may be made to improve water management practices and ensure a healthy environment in western Canada.

## Acknowledgements

The Southern Rockies Watershed Project (SRWP) thanks Michael Wagner, Chris Williams, Catherine McCarthy, Jamie Farkvam, Jessica Sneddon, Jocelyn Howery, Ian Tichkowsky, and Lance Steinke for excellent field and laboratory assistance.

SRWP was funded by Alberta Sustainable Resource Development, Natural Sciences and Engineering Research Council of Canada (NSERC), Oldman Watershed Council, Alberta Ingenuity Centre for Water Research, Alberta Environment, Canadian Foundation for Innovation, and Fisheries and Oceans Canada.

### References

*Bladon, K.D., U. Silins, M.J. Wagner, M. Stone, M.B. Emelko, C.A. Mendoza, K.J. Devito, and S. Boon. 2008. Wildfire impacts on nitrogen concentration and production from headwater streams in southern Alberta's Rocky Mountains. Canadian Journal of Forest Research. 38:2359–2371.*

*Emelko, M.B., U. Silins, K.D. Bladon, and M. Stone. 2009. Enabling assessments of source water and treatment vulnerability to land disturbance and climate change: A wildfire case study. Journal American Water Works Association. In press.*

*Silins, U., M. Stone, M. Emelko, and K.D. Bladon. 2009. Sediment production following severe wildfire and post-fire salvage logging in the Rocky Mountain headwaters of the Oldman River Basin, Alberta. Catena. In press.*

*Silins, U., K.D. Bladon, M.J. Wagner, E. Esch, J.R. Spence, M.B. Emelko, M. Stone, C. Williams, and I. Tichkowsky. Linked water quality and biological responses in plant and macroinvertebrate communities in oligotrophic Rocky Mountain streams after severe wildfire and salvage logging. Journal of Hydrology. In review.*

### For further information, contact:

**Uldis Silins**
University of Alberta
***uldis.silins@ualberta.ca***

**Kevin Bladon**
FORREX

**Axel Anderson**
Alberta Sustainable Resource Development

**John Diiwu**
Alberta Sustainable Resource Development

**Monica Emelko**
University of Waterloo

**Michael Stone**
University of Waterloo

**Sarah Boon**
University of Lethbridge