Utikuma Region Study Area (URSA) – Part 1: Hydrogeological and ecohydrological studies (HEAD)

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ABSTRACT

The Utikuma Region Study Area (URSA) was initiated to develop spatially explicit modelling tools to predict the cumulative impacts of land use and natural disturbance on the Boreal Plains (BP) ecozone of the Western Boreal Forest. Research comprised several multi-year projects, spanning wet and dry climate periods that combined intensive detailed process studies at seven watersheds with extensive long-term ecohydrological and hydrogeological studies conducted across a 60-km transect representing the range of glaciated landforms characteristic of the sub-humid boreal forest in Alberta. These studies have improved our conceptual understanding and capacity to numerically model how climate and geology influence water and energy flow, and the hydrologic linkages and natural variability of the key processes influencing BP ecosystems. Eco-hydrogeological frameworks have been developed for designing, conducting, interpreting, and extrapolating research results for watershed management and construction across the Boreal Plain ecozone.

RÉSUMÉ

Le site d'étude de la région d'Utikuma (URSA) a été créé dans le but de concevoir des outils de modélisation spatialement explicite permettant de prédire les effets cumulatifs de l'utilisation du territoire et des perturbations naturelles dans l'écozone des Plaines boréales (BP) de la forêt boréale de l'Ouest. Les travaux de recherche comportaient quelques projets s'étalant sur plusieurs années et couvrant des périodes de climat humide et sec, et combinaient des études intensives des processus détaillés de sept bassins hydrographiques, notamment des études éco-hydrologiques et hydrogéologiques exhaustives à long terme entreprises sur un transect de 60 km représentant l'ensemble des caractéristiques de la topographie glaciaire de la forêt boréale sub-humide de l'Alberta. Ces études ont amélioré notre compréhension conceptuelle et notre capacité de modéliser l'influence du climat et de la géologie sur leau et le flux d'énergie, de même que les relations hydrologiques et la variabilité naturelle des principaux processus qui affectent les écosystèmes des Plaines boréales. Des cadres éco-hydrologiques ont été élaborés afin de concevoir la cueillette, l'interprétation et l'extrapolation des résultats de recherche pour l'aménagement et la construction de bassins versants dans l'ensemble de l'écozone des Plaines boréales.

Introduction

Forest harvesting and oil sands development in the Western Boreal Forest (WBF), in particular the Boreal Plain ecozone (BP), are major components of the Albertan and Canadian economies. Collectively, resource activities have considerable potential to impact surface water quantity and quality. The challenge of resource industries, governments, and NGOs is to manage these important economic activities while simultaneously protecting or minimizing impacts on water resources. Moreover, wildfire represents the largest natural disturbance in Canada's WBF and is predicted to increase in both severity and area burned in the future. The Boreal Plain ecozone represents important wildlife habitat and the second largest waterfowl breeding and staging regions in North America.

The Utikuma Region Study Area (URSA) was initiated to develop spatially explicit modelling tools to predict the cumulative impacts of land use and natural disturbance. The primary research objective was to improve our conceptual understanding and numerically model how climate and geol-

ogy influence water and energy flow, and the hydrologic linkages and natural variability of the key processes influencing WBF ecosystems (Devito *et al.* 2012). Research was conducted to increase our fundamental understanding of how water moves at the landscape scale, how land-use activities may intersect or impact water movements, and how WBF ecosystems recover from land disturbance. Furthermore, a hydrogeological framework was developed for conducting, interpreting, and extrapolating research results for watershed management across the WBF (Devito *et al.* 2005).

Research at URSA comprises several multi-year projects combining intensive detailed process studies at seven watersheds (Fig. 1) with extensive long-term ecohydrological and hydrogeological studies conducted across a 60-km transect that represents the range of glaciated landforms characteristic of the sub-humid boreal forest in Alberta (Table 1). These projects also temporally span a large portion of the climate cycle, and the hydrologic responses are spatially characteristic of the WBF ecoregion.

Numerous projects have been conducted at URSA, most

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Fig. 1. Site of the URSA indicating location of detailed catchment eco-hydrological studies and of regional meteorological stations, deep piezometer nests, and study lakes.

notably in the Hydrology Ecology and Disturbance (HEAD) research programs (Devito *et al.* 2012; Table 2). Early work (Phase 1) focused on identifying the natural variation in hydrogeology of landforms and the hydrology, chemistry, and biology of pond-wetland-forestland sequences across the landscape (Ferone and Devito 2004, Petrone *et al.* 2007, Redding and Devito 2008, Smerdon *et al.* 2008, Plach *et al.* 2016). Later studies (Phase 2) focused both on issues of scale and on the experimental manipulation of watersheds or landforms. These studies were designed to test hypotheses regarding key hydrologic drivers and the effects of management initiatives (including harvesting and road construction) on the dominant ecohydrological and hydrogeological processes (e.g., Brown *et al.* 2010, Chasmer *et al.* 2011, Carrera-Hernandez *et al.* 2012). In May 2011, a wildfire burnt through 75 % of the study lakes and four of the seven process study watersheds at URSA (SWF-060, ~ 90 000 ha; Petrone *et al.* 2014). This provided the opportunity to collaborate on wildfire research with the McMaster University Ecohydrology Laboratory (Kettridge *et al.* 2012, Thompson and Waddington 2013). This has generated knowledge on the vulnerability of ecosystems to wildfire that is being applied to inform the control of landform on wildfire susceptibility within the boreal forest landscape, and the potential for ecosystem recovery (Fig. 2; Olefeldt *et al.* 2013, Hokanson *et al.* 2015, Lukenbach *et al.* 2015).

Important Scientific Advancement

Over 50 publications have been generated from studies at URSA and much of this is synthesized in Devito *et al.* (2012). Through comprehensive long-term field studies, this suite of research has parameterized the ranges associated with the hydrologic variables of boreal forest and wetland ecosystems. Key hydrologic processes and features of the landscape that maintain diverse and resilient ecosystems across a wide range of landscape scales have been identified. Critical insights were gained into the influence of the spatial arrangement of landforms, harvesting, and fire on local and regional ecohydrological and hydrogeological systems.

The field and modelling studies have been integrated with conceptual models to provide objective delineation and determination of landscape units characterized by the geology and climate of the BP producing knowledge that is directly transferable to land reclamation. Key findings thus far include:

- WBF climate has a regional moisture deficit ($P \leq PET$) and decadal wet and dry cycles that influence ecohydrological and hydrogeological response to rainfall and disturbance (Redding and Devito 2008, Smerdon *et al.* 2008, Mwale *et al.* 2009, Carrera-Hernandez *et al.* 2012);
- There are dynamic and complex surface and groundwater interactions because the landscape is made up of large spatial Hydrologic Response Areas (HRAs) characterized by

heterogeneous deep glacial deposits with different storage and water transmission properties (Ferone and Devito 2004, Devito *et al.* 2005, Smerdon *et al.* 2005, Redding and Devito 2011);

- These HRAs are below a mosaic of surface Hydrological Units (HUs) of deciduous and conifers forests. Up to 50 % of the surface is covered by wetlands ecosystems – mostly peatlands;
- Lake hydro-chemistry is strongly influenced by the interaction of climate, surficial geology (HRAs), landscape position, and forest land to wetland connectivity (HUs) (Olefeldt *et al.* 2013, Plach *et al.* 2016);
- Distribution of waterfowl species type and diversity, waterfowl breeding and staging location, and pond food web dynamics show relationships with climate, surficial geology (HRAs), landscape position, and forest land to wetland connectivity (HUs);
- Groundwater functions, dominant water balance processes, forest land-wetland interaction, and potential susceptibility to climate cycles and land-use disturbance all vary with landform (Redding and Devito 2011, Smerdon *et al.* 2012);
- The long residence time of ponds, variations in surficial geology and groundwater-surface water connectivity appear to mask the initial impact of disturbances such as

fire on the hydro-chemistry of lake ecosystems (Olefeldt *et al.* 2013).

Forested areas infrequently generate runoff at the local scale because of high storage capability of the deep soils and effective transpiration capabilities of the trees (Redding and Devito 2010, 2011). In contrast, wetlands saturate readily due to lower soil storage capacities and less effective evaporative processes. This results in persistent lateral surface or near surface runoff from wetland complexes to adjacent ponds and forested areas (Thompson *et al.* 2015); and,

- The interaction among the wetland and forest HUs, the glacial landform HRAs and decadal climate cycles result in

Table 1: Location, physiography and climate of the Utikuma Region Study Area (URSA)

Watershed Location Data	
Location (descriptive)	URSA is located north of Utikuma Lake, north-central Alberta (approximately 400 km north of Edmonton). The glacial landforms drain into the Wabasca and then the Peace River drainage.
Location (geographic)	56° 7' N, 115° 48' W to 55° 51' N, 115° 6' W
Biogeoclimatic zones	Boreal Plains, Central mixed-wood, Utikuma uplands
Watershed area	Topographic watersheds are poorly defined; 60 km long transect covers 3 dominant surficial geologic landforms (Hydrologic Response Areas, HRAs).
Elevation range (a.s.l.)	640 to 695 m
Precipitation (mean annual)	483 mm
PET / AET (mean annual)	PET = 519 mm, AET ranges widely with vegetation and soil types, and flood conditions with climate cycles.
Runoff (mean annual)	67 mm (range: 4 to 246 mm)
Temperature (mean annual)	1.2 °C

Table 2: Summary of study approaches, design and sampling protocols of the research program at URSA

Research Design	
Study type	Detailed ecohydrological process studies conducted at 7 locations in 3 major surficial geology units. Extensive monitoring of hydrogeology across the URSA transect.
Treatments	Limnological, waterfowl and invertebrate, geochemical and hydrological studies of 30 lakes across the transect. Follow ecohydrological and hydrological response through wetting and drying climate cycles.
Controls	2006 and 2011 burns, with a range of intensities and percent coverage. Spatial and temporal controls for several studies within surficial geologic units and (antecedent) climate conditions. Reference ponds, peatlands and riparian-upland transects for burn sites in all three surficial geologic units present at URSA.
Study duration	Lake and hydrogeology studies 1999-present Processes studies vary 2001-present. Fire recovery study 2006-present Waterfowl studies 1998-2003.
Variables measured	Climate (3 stations, middle and ends of transect). Lake biota (water fowl, invertebrates, botany), water levels, nutrient, geochemical and isotopic (¹⁸ O & D) characteristics. Hydrogeology (deep and shallow piezometer nests across all landforms), groundwater geochemical and isotopic (¹⁸ O & D) characteristics. Water and energy balance of detailed study catchments (eddy flux water vapour and CO ₂ ; Penman and Priestley-Taylor of various land covers); interception of canopy, shrub, and soil; soil moisture content and tension; aspen hydraulic lift (isotopes and root excavation); hillslope and stream runoff; groundwater dynamics; riparian dynamics; carbon and nitrogen in soil, water, vegetation dynamics. Fire severity across peatlands and forests, water and energy balance ecohydrological studies (as above) in all surficial geology units (landforms).

Fig. 2. Aspen forest – peatland edge, **(a)** smoldering one month after the fire and, **(b)** end of second growing season.

a strong threshold response of local and regional runoff. Annual runoff (mm) and runoff efficiency were poorly correlated with annual precipitation, but showed a strong threshold relationship with multi-year cumulative moisture deficit (CMD). The differing CMD states altered the hydrologic connectivity among different portions of HRAs and HUs within catchments.

- Integration of CMD with the configuration of wetland-forestland HUs and the type of glacial landforms (HRAs) represents water cycling and sink-source dynamics that control runoff in low relief glaciated landscapes (e.g., Boreal Plain) more accurately than topographic drainage networks.

Management/Operational Results

Understanding of the hydrologic linkages and natural variability of key processes led to the development of a hydrogeological framework for conducting, interpreting, and extrapolating research for watershed management across the Western Boreal Forest (Devito *et al.* 2005, 2012). From this, the development of landscape indices has begun that provide information on the scale at which forest, wetland, and aquatic systems are linked to their surroundings and their potential response to disturbances.

The hydrogeological framework and development of HRAs and HUs provides hydrologists and non-hydrologists with essential tools to assess both the hydrologic impacts of Forest Management Practices (FMPs) on harvested sites, and material storage and forest succession on reconstructed and reclaimed landscapes. These have been used to develop:

- effective planning tools that can be used to maximize harvesting and hauling efficiencies (Spafford and Devito 2005);
- rigorous and objective scientific criteria and recommendations for cumulative risk assessment of the hydrologic consequences of FMPs at a given scale to ensure economic and environmentally friendly use of forest resources (Carrera-Hernandez *et al.* 2011, Smerdon *et al.* 2012);

- design criteria that optimize landscape configurations in reclamation procedures and direct appropriate model application to assess both engineering stability and best ecosystem and environmental conditions for closure planning of oil sands leases (Devito *et al.* 2012); and,
- provincial water and wetland strategies to serve as guidelines for integrated land management at the provincial level by participating NGOs.

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