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Climatic controls on groundwater–surface water interactions within the Boreal Plains of Alberta: Field observations and numerical simulations

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SUMMARY

Hydrologic data were collected over eleven years at a catchment situated in low permeability glacial terrain within the Boreal Plains (Alberta, Canada) to evaluate the hydrologic interactions occurring between landscape units (i.e., shallow pond, extensive peatlands, aspen forested hillslopes). Two-dimensional numerical models were developed using a fully-integrated groundwater–surface water model to evaluate key landscape features that allow these ecosystems to persist within the sub-humid climate. Study results show that the dynamic interactions between the pond and peatlands are driven by precipitation and evapotranspiration. As a result, pond and peatland water levels reflect recent climatic trends. Limited hillslope contributions to the peatlands occur, indicating they are not required within this climatic setting for long-term maintenance. Instead, the peatlands conserve water within the landscape and supply it to adjacent landscape units. By contrast, the pond and the aspen forested hillslopes are dominated by high rates of evapotranspiration, and represent net water sinks within the landscape. Further simulations indicate these hydrologic systems are sensitive to pond and peatland evapotranspiration rates, and the hydraulic conductivity of the underlying glacial till substrate.

1. Introduction

The Boreal Plains of northern Alberta, Canada, are host to numerous wetlands, small lakes, and ponds interspersed within forested uplands. The wetlands provide important seasonal habitat for migratory birds and also represent a significant carbon pool (Smith and Reid, 2013; Gorham, 1991). However, they are under significant development pressures as a result of expanding petroleum developments and timber harvesting (Devito et al., 2012). Furthermore, large areas have been disturbed by open-pit mining of oil sands which will require reclamation on an unprecedented scale over the next 30–50 years (Kelln et al., 2008). Consequently, characterization of the processes governing the movement of water within these ecosystems is of pressing importance for both managing existing ecosystems and restoring those which have already been disturbed.

Ecosystems within the Boreal Plains are sustained by sub-humid climatic conditions, where annual precipitation (P) is commonly less than potential evapotranspiration (PET; Marshall et al., 1999). Water deficit conditions occur frequently, making them highly vulnerable to developments that may alter their water budget. A large portion of annual P falls during the summer months (Marshall et al., 1999) when the PET is greatest (Petrone et al., 2007; Brown et al., 2014). Therefore, in contrast to more humid regions such as the Boreal Shield, limited water is available to replenish the subsurface during the growing season in most years. Instead, the majority of groundwater recharge is derived from spring snowmelt and rain events occurring outside the growing season (Smerdon et al., 2008; Redding and Devito, 2011), particularly in the forested uplands where evapotranspiration (ET) by species such as aspen may exceed growing season P (Brown et al., 2014).

The elevated upland ET, combined with the deep glacial soils within the region (Vogwill, 1978), result in deep upland water tables that do not follow topography and often decline away from adjacent ponds and peatlands (Ferone and Devito, 2004; Smerdon et al., 2005). Consequently, following snowmelt and rain events the

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upland hydrologic response is dominated by fluctuations in storage, with little potential for generation of overland flow (Devito et al., 2005; Redding and Devito, 2008). Thus, pond and peatland water levels are dominated by the atmospheric fluxes of P and ET (Ferone and Devito, 2004; Smerdon et al., 2005), with upland contributions occurring infrequently, particularly in lower permeability settings.

Despite their primary reliance on P for maintenance within the dry sub-humid climate, pond and peatland ecosystems comprise a large and essential portion of the landscape within the Boreal Plains. Restoration of these ecosystems will represent an important challenge in the coming years, particularly in the oil sands mining region where complete reconstruction of the landscape will be required (Devito et al., 2012). The re-establishment of peatland terrain has not been previously attempted (Price et al., 2010), thus questions remain regarding the key features that may ultimately lead to successful reclamation, particularly within the context of the relatively dry sub-humid climate. Research aimed at addressing these questions has been primarily process-based, with most studies focusing on hydrological aspects of individual landscape units (i.e., pond, peatland, and hillslope; Devito et al., 2012) for relatively short periods of time (i.e., 1–2 years) with variable climatic conditions.

This study evaluated the hydrologic linkages occurring between landscape units at a pond–peatland complex characteristic of Alberta's glaciated Boreal Plains region. A multi-year hydrologic dataset was collected over eleven years at a heterogeneous low permeability catchment within the region to assess the interactions occurring between landscape units and to evaluate how they vary over a range of climatic variability. The empirical dataset was used to develop numerical models capable of representing the dominant hydrological processes and to evaluate the key features of the landscape that allow these ecosystems to persist within the sub-humid climate. The goals of the study were to assess how the interactions vary between landscape units within the observed climatic cycles, to evaluate the sensitivity of the system to a range of soil characteristics and catchment configurations commonly found within the Boreal Plains, and to address how catchment hydrology within the region is influenced by the configuration of landscape units to improve the design of (re)constructed landscapes.

2. Study area

The study was conducted within the undisturbed catchment of Pond 43 (20 ha; Lat: 56.07 N, Long: 115.5 W; Fig. 1), situated within the Utikuma Region Study Area (URSA). The URSA is located within the plains region of the western Boreal Forest approximately 350 km northwest of Edmonton, Alberta, Canada, and approximately 150 km south of the discontinuous permafrost region (Woo and Winter, 1993). Previous studies at the URSA have investigated pond water budgets situated in a range of glacial landforms (Ferone and Devito, 2004; Smerdon et al., 2005); groundwater–surface water interactions in glacial outwash terrain (Smerdon et al., 2007); groundwater recharge and runoff dynamics (Smerdon et al., 2008; Redding and Devito, 2008, 2010, 2011); the variability

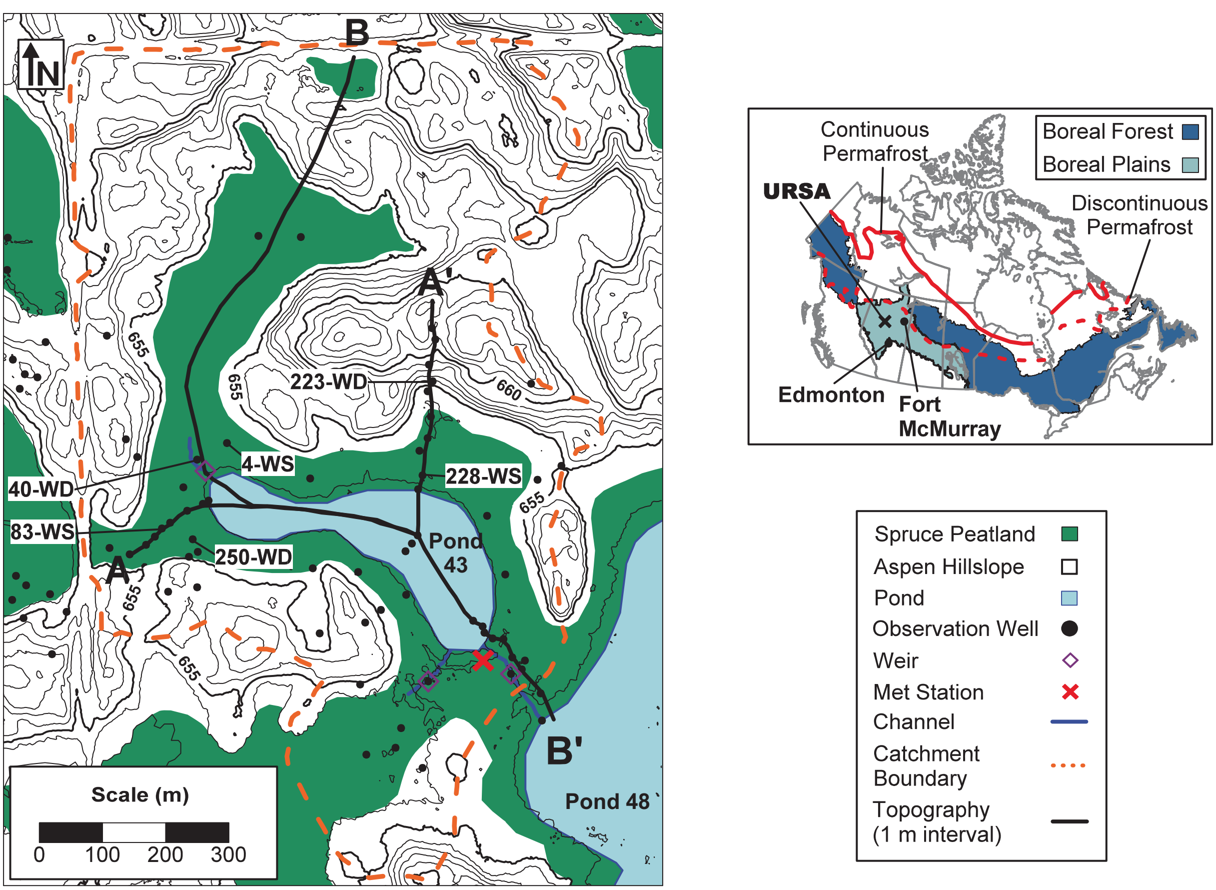

Fig. 1. Location of the Utikuma Region Study Area (URSA). Right: Location of the URSA within the Canadian Boreal Plains relative to the discontinuous permafrost zone. Left: Enlarged map showing the Pond 43 study area including instrumentation, vegetative cover, selected monitoring well locations, surface water catchment boundaries, and the locations of the 2D numerical models.