Effects of depth-permeability distribution on groundwater exchange and water balance of prairie wetlands

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ABSTRACT
Prairie wetlands exist in numerous topographical depressions, which are closed with respect to surface water drainage. The water balance of prairie wetlands is strongly influenced by groundwater exchange. Clay-rich glacial tills, covering much of the Canadian prairies, have very low (0.001-0.01 m/yr) hydraulic conductivity, except for the top several meters where the fractures and macropores increase conductivity up to 1000 m/yr. Evapotranspiration in the wetland margin induces infiltration and lateral flow of shallow groundwater from wetland ponds through the high-conductivity zone. The shallow lateral flow is a major component of the water balance and, hence controls the permanence of wetland ponds. In contrast groundwater flow in the deeper, low-conductivity till has minor effects on the water balance, but has a critical influence on salinity because the flow direction determines if the salts accumulate in wetlands (upward flow) or are leached out (downward flow) under wetlands.

RÉSUMÉ
Il existe plusieurs milieux humides situés dans des dépressions topographiques qui sont renfermés par rapport au drainage d'eau de surface. Le bilan hydrologique des milieux humides est grandement influencé par l'échange des eaux souterraines. La conductivité hydraulique des tills glaciaires riches en argiles, un matériel géologique qui parcoure la majorité des Prairies canadiennes, est très basse (0.001-0.01 m/an). Par contre, les fissures et les macropores situés dans les quelques premiers mètres sous la surface du sol augmentent la conductivité hydraulique jusqu'à 1000 m/an. L'évapotranspiration en marge du milieu humide induit l'infiltration ainsi que le débit sortant latéral de l'eau souterraine peu profonde des milieux humides à travers la région de haute conductivité hydraulique. Ce débit sortant latéral est un élément majeur du bilan hydrologique et par conséquent, contrôle la permanence des milieux humides. Cependant, l'écoulement souterrain profond dans le till glaciaire a des effets mineurs sur le bilan hydrologique car il a une basse conductivité hydraulique. L'écoulement souterrain a plutôt une importante influence sur la salinité de l'eau souterraine parce que la direction de l'écoulement détermine si les sels s'accumulent dans les milieux humides (écoulement ascendant) ou sont lessivés (écoulement descendant) sous les milieux humides.

1 INTRODUCTION

The northern prairie wetland region, or prairie pothole region, has unique hydrological and hydrogeological characteristics due to the combination of semiarid, cold climate and the glacial deposits that blanket the area. The glacial tills have low hydraulic conductivity at depth and groundwater flow out of or into each drainage basin is generally a minor component of the water balance of the basin. This combination of dry climate, land forms and geology has resulted in the formation of numerous prairie wetlands, mostly within small drainage basins that are hydrologically isolated from each other (Winter 1989).

The ponds at the centre of prairie wetlands have a variety of seasonality, ranging from ephemeral to permanent, depending on the water balance; and even a single wetland typically has completely different conditions between dry year and wet year. Hydroperiod, or duration of surface water is an important factor affecting the flora and fauna of the wetland (Swanson and Duebbert 1989). Previous studies have shown that wetland water balance is primarily controlled by surface flow to and between wetlands and on the exchange of water between the centre of the wetlands and the surrounding areas (Rosenberry and Winter 1997; Hayashi et al. 1998a; Parsons et al. 2004). Therefore, a sound understanding of wetland-groundwater interaction is essential for the management and conservation of prairie wetland ecosystems. This paper presents a brief summary of a review paper by van der Kamp and Hayashi (in press). For more detailed discussion on the topic, the readers are referred to the original review paper available from the author (hayashi@ucalgary.ca).

2 HYDROLOGY AND HYDROGEOLOGY OF PRAIRIE WETLANDS

Prairie wetlands exist in numerous topographic depressions that are ubiquitous in the northern prairies region. These depressions have no inflow or outflow streams except during very wet periods when water may spill over from one wetland to another. Numerous studies have examined the water balance of prairie wetlands (e.g. Meyboom 1966; Shjeflo 1968; Woo and Rowsell 1993; Winter and Rosenberry 1995; Hayashi et al. 1998a; Su et al. 2000). Water derived from melting snow is critical to the existence of the wetlands. Summer precipitation directly on the wetlands is also an important source of water, roughly equivalent to the input from spring runoff.

However, potential evapotranspiration in summer greatly exceeds precipitation, meaning that without the contribution of water from snowmelt runoff there would be very few wetlands in the northern prairie region.

The glacial deposits covering much of the northern prairie region are generally tens of meters to hundreds of meters thick and consist largely of clay-rich glacial tills, with interspersed deposits of glaciolacustrine clay and silt, and glaciofluvial sand and gravel. Virtually all the groundwater flow relevant to the hydrology of prairie wetlands occurs within the glacial deposits. The hydraulic conductivity of clay-rich tills and clay is generally in the range of 0.001 to 0.01 m/year when the materials are not fractured (Keller et al 1988). However, numerous studies in the northern prairies region and elsewhere have shown that clays and tills are commonly fractured and that they have higher hydraulic conductivity when they are fractured (van der Kamp, 2001). As a result, the hydraulic conductivity of the tills at any particular site generally decreases with depth, ranging from values of 1000 m/year just below the ground surface to less than 0.1 m/year at depths below 4-5 m and even smaller values at greater depths as demonstrated by an example from the St. Denis National Wildlife Area in Saskatchewan (Fig. 1).

The decrease with depth of the hydraulic conductivity of the glacial till (Fig. 1) has a controlling influence on the patterns of groundwater flow near prairie wetlands. Water infiltrating under wetland ponds can move readily through the relatively permeable fractured material within a few meters of the ground surface. Thus evapotranspiration losses from the moist riparian margins of the wetlands are replenished by recharge, via shallow lateral flow, from the pond. The shallow groundwater flow has a critical influence on hydroperiod, especially for small wetlands with seasonal ponds.

In contrast, the deep groundwater flow in low conductivity till has minor effects on water balance and hydroperiod. However, over a long time, it controls the salinity of wetlands, as the upward hydraulic gradient under discharge wetlands prevents solutes from exiting the wetland basin, thereby serving as a hydraulic containment mechanism. For proper understanding of wetland hydrology and its effects on the ecosystem, it is important to recognize the different roles played by surface water, shallow groundwater, and deep groundwater.

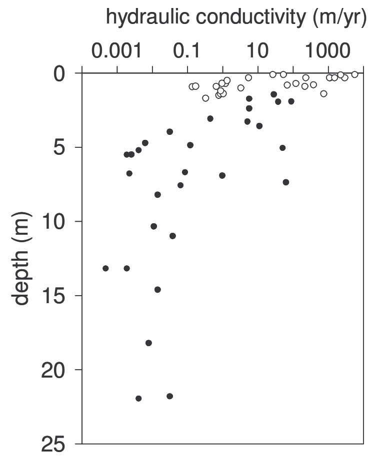

Figure 1. Hydraulic conductivity at the St Denis site, as measured by slug tests on piezometers (Hayashi et al. 1998a), and permeameter tests on soil cores (Parsons et al. 2004). Solid circles represent piezometer data, and open circles represent core permeameter data.

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