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Review papers

Sulfate salt dynamics in the glaciated plains of North America

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SUMMARY

The semiarid glaciated plains of the North American continent, known as the prairies, are characterized by an undulating terrain rich in sulfate salts in the subsurface, with ephemeral streams and large numbers of wetlands containing seasonal or semi-permanent ponds. Salinization is a potential concern for the diverse community of vegetation, aquatic ecosystems, wildlife and agricultural production supported by the prairies, especially as a result of land use changes and climate change. In this paper, a literature review of prairie salt dynamics and distribution is presented. On the basis of observations from past field studies, a conceptual model describing prairie sulfate salt dynamics is proposed, which identifies a number of important zones of salt accumulation in the subsurface and in surface water. As is the case in any other environment, the distribution of salts is determined by the hydrological conditions, in particular subsurface flow pathways and evapotranspiration front locations. However, the semi-arid climate and glacial geology of the region result in unique and characteristic hydrological conditions and distributions of accumulated salts. The hydrology of the prairies is sensitive to land use, with the major changes over the past 100 years or so being conversion of prairie grasslands to annual dryland crops and drainage of wetlands. Moreover, in semi-arid environments the hydrological system is highly sensitive to climate variability and change. Hence, even small hydrological changes may result in mobilization of salts concentrated in the shallow subsurface, and, if sustained, may generate ground surface, wetland and surface water salinization. However, these changes are difficult to predict, involving multiple interacting processes, and it is therefore necessary to develop an improved, quantitative understanding of the coupled hydrological and geochemical processes in order to manage or adapt to future changes.

Contents

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1. Introduction

'The Prairies' – The semiarid glaciated plains of the North American continent (Fig. 1) are characterized by undulating terrain, rich in sulfate salts, with ephemeral streams and a large number of wetlands marked by seasonal or semi-permanent ponds (Winter, 1989; Hayashi et al., 1998a; van der Kamp and Hayashi, 2009). The prairie region supports a diverse community of wildlife species, as well as a major agricultural industry, which are both highly sensitive to the hydrological conditions of the wetlands (Wienhold and van der Valk, 1989; Batt et al., 1989; Winter, 1989). Climate variability and land use changes associated with agricultural activities have had major impacts on prairie hydrological processes (Leitch, 1989; Poiani and Carter, 1991; Euliss and Mushet, 1996; Mitch and Hernandez, 2012; Todhunter and Rundquist, 2008; Winter and Rosenberry, 1998; Shook and Pomeroy, 2011).

High salt concentrations in subsurface amplify the potential hazard associated with changes in the hydrology, as these changes may result in salinization of the soils, surface and subsurface water (Eilers et al., 1997; Florinsky et al., 2000; Wiebe et al., 2006). It is well known from other places in the world that changes in the hydrological regime can result in severe environmental and economic problems associated with salt dissolution, migration and crystallization. Examples include soil salinization in Australia (Dehaan and Taylor, 2002) and sink-hole formation in the Dead Sea region (Shalev et al., 2006). Fig. 2, taken near Kindersley (KN in Fig. 1), shows efflorescent salt accumulation in a typical cultivated prairie landscape, away from any pond.

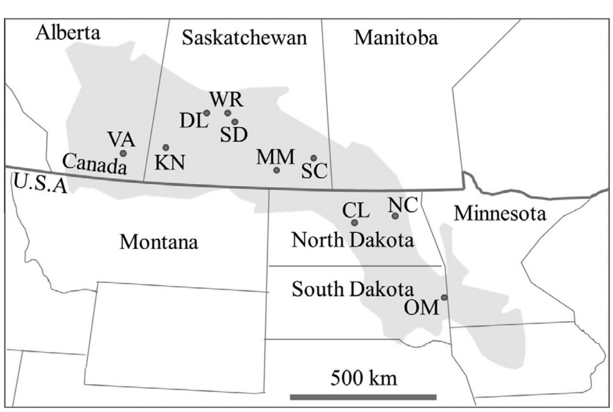

Fig. 1. Map of the prairie region, indicated by the gray area. Nine sites that are referred to in this paper include: Vauxhall (VA); Kindersley (KN); Dalmeny (DL); Warman (WR); St. Denis (SD); Moose mountain (MM); Smith Creek (SC); Nelson County (NC); Cottonwood Lake (CL); and Orchid Meadow (OM).

Fig. 2. Efflorescent salt accumulation (white material) in an agricultural field and an unaffected adjacent natural grassland. The dashed white line indicates the location of the division between cultivated land and natural grassland (lower part of the picture). Vegetation is restricted in the saline area.

Such efflorescence salt formations are not rare in the prairies (Timpson et al., 1986). A large scale survey of soil salinity in the Canadian prairies was carried out by Agriculture and Agri-Food Canada (http://sis2.agr.gc.ca/cansis/publications/surveys/sk/). Pham et al. (2009) reported on electrical conductivity (EC) from 70 closed-basin lakes in southern Saskatchewan. The measured values varied from 285 μS/cm (fresh) to 137,800 μS/cm (saline) with a mean of 17,201 μS/cm (subsaline). For perspective, sea water EC is in the order of 33,000 μS/cm (saline) (Stewart and Harold, 1972; Wynn and Fleming, 2012). Therefore, understanding the coupled hydrological, hydrogeological and geochemical system of the prairies under various climatic conditions and land use scenarios and the consequences for salt migration and accumulation is an important aspect of water and land management.

Here, a review of prairie hydrology and hydrogeology (Section 2) and geochemistry (Section 3) is given, drawing heavily on past field studies. A conceptual model of prairie salt dynamics, taking as a specific example the distribution of sulfate salts (the most abundant salts in the prairies), is presented in Section 4. This model identifies the unique and characteristic salt accumulation and redistribution processes attributable largely to the climatological and geological conditions of the region. In Section 5 the potential impacts of environmental changes on salt dynamics and distributions, based on the conceptual model, are discussed and gaps in understanding are identified. Finally, Section 6 provides a summary.