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Wetland drainage in the Canadian prairies: Nutrient, salt and bacteria characteristics

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ABSTRACT

Intensification of agriculture has led to renewed efforts to drain wetlands throughout North American prairies. It is perceived to threaten downstream ecosystem health through enhancing nutrient, bacteria and salt loading. An experiment was conducted to determine temporal variations in wetland solute storage and export upon drainage. Water quality along seven ditches and five natural spills that form between wetlands was also compared. The experimental wetland acted as a solute storage zone prior to its drainage. Variations in salts and DOC were influenced by hydrological processes, whereas variations in nutrients and bacteria were also influenced by biotic and/or sorption processes. Wetland water quality was an important control of drainage water quality as the wetland ditch acted as a simple conduit. Concentrations of TDN, DOC, HCO_3^-, K^+, and Ca^{2+} were higher in ditches than spills. Minimal changes in water quality along ditches and spills occurred, likely due to low spring temperatures that can restrict biotic processing and sorption. Since ditches connect wetlands to streams, they have a greater potential to contribute to downstream solute loading than spills. Wetland drainage efficiency and wetland water quality were deemed the factors critical to determining solute exports via ditches.

1. Introduction

Small wetlands that often have no natural outflow under normal flow conditions, known as 'sloughs' or 'potholes', are a common phenomenon of the northern glaciated terrain of North America. The 780,000 km^2 area dotted by these wetlands, which extends throughout three Canadian provinces (Alberta, Manitoba, Saskatchewan) and four American states (North Dakota, South Dakota, Iowa, Minnesota), is referred to as the Prairie Pothole Region (PPR; Conly and van der Kamp, 2001). Pothole wetlands are typically no bigger than 15 ha, are often <1.5 m deep, and have a density of 5–90/km^2. These wetlands produce half of the continent's waterfowl in an average year (Smith et al., 1964), and are important locations for water (Gleason and Tangen, 2008) and solute (Neely and Baker, 1989) storage on the landscape as they tend to be hydrologically isolated. In extremely wet years though, wetlands may connect to one another or to the stream network through the fill and spill process (Spence, 2006), hereafter termed natural spills. Since 1900, 40–70% of the wetlands located in the northern prairies were drained and converted to cropland (Dahl, 1990). Recently, there have been renewed efforts to drain potholes to increase agricultural production (Watmough and Schmoll, 2007). Drainage impacts remain a critical information gap for the agricultural community, with the potential to affect wetland policies and subsequently economics. Pothole drainage conflicts are typically centered around attempts to balance the social benefits and private costs associated with potholes on agricultural lands (Cortus et al., 2011). Social benefits of potholes are believed to be water storage and flood attenuation, wildlife habitat, and improvements to downstream water quality. Costs accrued by private landowners include the foregone opportunity to increase agricultural production, delayed seeding in inundated areas, and the nuisance cost of farming around potholes.

Wetland drainage ditches create new surface water connections between isolated wetlands and other wetlands, roadside ditches, or streams. These new connections transform the hydrological conditions of the prairies such that previously non-contributing areas now contribute to streamflow (Fang et al., 2010). Wetland drainage has been shown through modeling work to increase stream flood frequencies and magnitudes (Yang et al., 2008). Pothole wetlands are the main storage zones on the landscape for nutrients, salts and bacteria derived from a combination of excess fertilizer application, soil weathering and animal waste (Neely and Baker, 1989). Leibowitz and Vining (2003) hypothesized that stream water quality would be adversely affected by wetland drainage. To date, there is no field evidence to support or refute this conjecture.

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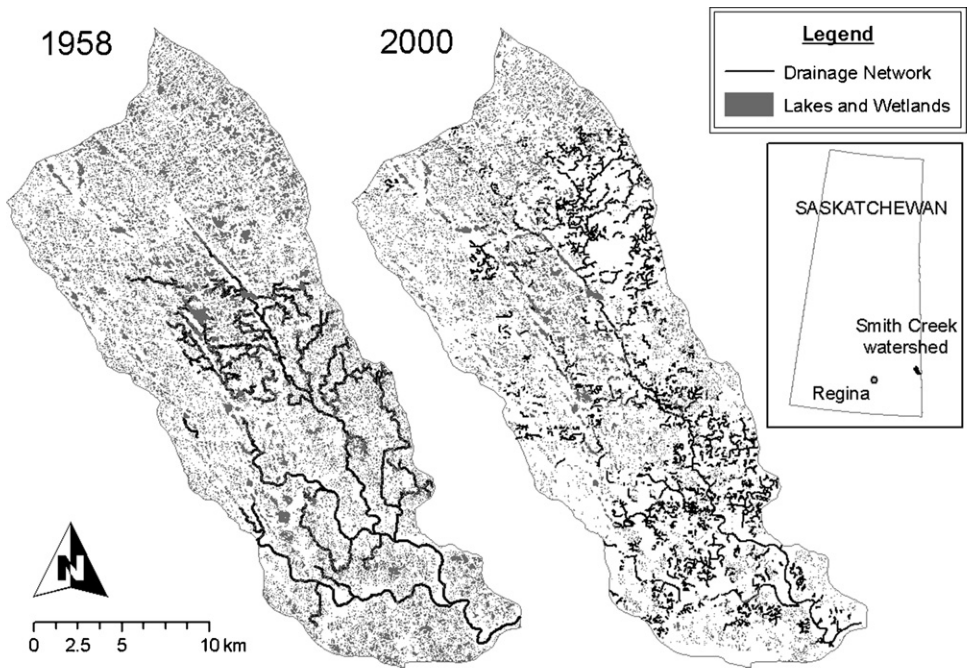

Fig. 1. Location of Smith Creek watershed in Saskatchewan, Canada (inset) and the watershed's historic (1958) and current day (2000) distribution of the drainage network, lakes, and wetlands, produced in conjunction with Ducks Unlimited Canada.

Considerable field-based research has been directed toward the study of nutrient flows along tile-drained agricultural systems used to channel runoff away from poorly drained fields (e.g. Skaggs et al., 1994). These works have demonstrated relatively high retention of P, as well as some N, in drains where soils have substantial sorption or retention capacities (Sharpley et al., 2007). Ditch-dwelling macrophytes and algae can also temporarily store nutrients (Needelman et al., 2007), and may play an indirect role in contaminant retention by reducing flow velocities and re-suspension rates, and increasing sedimentation rates (Birgand et al., 2007). Periodic high flow conditions that occur during snowmelt and significant rainfall events increase velocity, shear force and scour along the ditch bottom, which can cause the re-suspension of sediments and organic matter and consequently their downstream transport (Sharpley et al., 2007; Birgand et al., 2007).

Drainage conditions in the PPR differ from those reported in studies conducted in other agroecosystems. Soils in the PPR tend to be comprised of heavy clays with very low infiltration capacities, especially when frozen (Gray et al., 2001). The hydrology of the prairies is dominated by snowmelt, when 80% or more of the annual runoff occurs over mostly frozen soils (Gray and Landine, 1988). Convective storms occur in summer months, but they generate little local runoff as most of the rainfall is consumed by evapotranspiration (Armstrong et al., 2008). Drainage ditches are ephemeral, flowing only during the snowmelt period or in late fall when water and soil temperatures are near freezing. Thus wetland drainage ditches tend to lack well-established aquatic plants. It is thus unknown whether the knowledge of upland agricultural ditch hydro-biogeochemical function can be directly transferred to wetland drains across the PPR. Further, solute transport along natural spills has yet to be quantified or compared to that in wetland drains.

The goal of this paper is thus to investigate the role of wetland drains as conduits of nutrients, salts and bacteria and compare them to natural spills. Specific objectives are to: (1) identify factors influencing temporal patterns in wetland water quality as it is expected to be an important control of drainage water quality; (2) quantify solute export along the length of a experimentally constructed wetland drainage ditch in relation to total solute mass stored in the wetland; and (3) compare solute export along drainage ditches and natural spills. The work forms part of a larger study focused on assessing wetland drainage effects on prairie stream hydrology and water quality (Fang et al., 2010; Westbrook et al., 2011).

2. Materials and methods

2.1. Study site

Field work was conducted at Smith Creek watershed (50°50′4″N 101°34′48″W, Fig. 1 inset), which is located within the PPR in southeastern Saskatchewan, Canada. Smith Creek is a tributary of the Assiniboine River which flows east into the Red River. It is an ephemeral stream, typically flowing only between April and June. The watershed is ~445 km^2 with a highly variable effective contributing area that is continuously increasing as farmers drain more potholes to increase agricultural production (Fig. 1). (National Wetlands Working Group, 1988). The region is typical of the prairie landscape with glacial deposits consisting mostly of clay with low permeability overlain by loam soils. Soils are naturally rich in P (Anderson, 1988). Basin elevation ranges from 490 m to 540 m, with gentle slopes of 2–5%. Frozen soils and wind-driven snow redistribution occur over the winter. Peak streamflow occurs in late April and snowmelt runoff is the main annual streamflow event in the basin. Much of the meltwater accumulates in wetlands and roadside ditches. Local farmers regulate water flows through the roadside ditches and drained wetlands in the spring through the use of control structures.

The regional climate is semi-arid. The mean monthly temperatures are −17.9 °C in January and 17.8 °C in July, measured ~50 km west at the Yorkton airport. The mean (1942–2009) annual precipitation is 438 mm of which 121 mm occurs mostly as snow in November to April (Environment Canada, 2009). Precipitation prior to the 2008 study period was in the 53rd, 34th, and 26th percentile for winter 2007, summer (May–October) 2007, and winter 2008, respectively. The summer 2008 precipitation was in the 60th percentile. Precipitation for the months of May 2008 (18 mm) and July