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Long-term changes in pond permanence, size, and salinity in Prairie Pothole Region wetlands: The role of groundwater-pond interaction

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A R T I C L E I N F O

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A B S T R A C T

Study Region: Cottonwood Lake area wetlands, North Dakota, U.S.A.
Study Focus: Fluctuations in pond permanence, size, and salinity are key features of prairie-pothole wetlands that provide a variety of wetland habitats for waterfowl in the northern prairie of North America. Observation of water-level and salinity fluctuations in a semi-permanent wetland pond over a 20-year period, included periods when the wetland occasionally was dry, as well as wetter years when the pond depth and surface extent doubled while volume increased 10 times.
New hydrological insights for the study region: Compared to all other measured budget components, groundwater flow into the pond often contributed the least water (8–28 percent) but the largest amount (> 90 percent) of specific solutes to the water and solute budgets of the pond. In drier years flow from the pond into groundwater represented > 10 percent of water loss, and in 1992 was approximately equal to evapotranspiration loss. Also during the drier years, export of calcium, magnesium, sodium, potassium, chloride, and sulfate by flow from the pond to groundwater was substantial compared with previous or subsequent years, a process that would have been undetected if groundwater flux had been calculated as a net value. Independent quantification of water and solute gains and losses were essential to understand controls on water-level and salinity fluctuations in the pond in response to variable climate conditions.

1. Introduction

The northern prairie of North America contains a remarkable variety of wetlands known as prairie potholes or sloughs that serve as an important resource for waterfowl, producing as much as 50–80 percent of these birds in the continent (Batt et al., 1989). Biota in these wetlands change in response to dynamic fluctuations in water levels and salinity, thereby resulting in a mosaic of different community types and vegetation cover (Stewart and Kantrud, 1971) that influence waterfowl use of the wetlands (Swanson and

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Duebbert, 1989; Weller, 1978). Understanding factors controlling fluctuations in water levels and salinity in the ponds of these wetlands, therefore, is of interest to managers of these natural resources (Euliss et al., 2004, 2014; Renton et al., 2015; Robarts and Bothwell, 1992), as well as those who study Earth surface processes (Arndt and Richardson, 1989; Goldhaber et al., 2014), wetland hydrological characteristics (Winter and Woo, 1990; Woo and Rowsell, 1993), wetland vegetation dynamics (van der Valk, 2005) and waterfowl habitat (Swanson and Duebbert, 1989).

Prairie-pothole wetlands occupy depressions capable of storing water. These depressions are found within end moraines, ground moraines, stagnation moraines, outwash plains, and lake plains formed during the advance and retreat of the continental ice sheet (Eisenlohr et al., 1972; Winter 1989). Most of these depressions lack interconnection by natural surface channels, however, water levels in the ponds can increase to points in their basins where water can spill overland to adjacent wetland depressions (Eisenlohr et al., 1972; Rosenberry and Winter, 1997; Shaw et al., 2012).

The ponded portion of the wetlands, where surface water is present in the prairie pothole depressions, originates primarily from snow that melts in the spring and rainfall; most of the water lost from the ponds is through evapotranspiration (Shjeflo, 1968). Groundwater interaction with wetland ponds mainly involves localized, shallow groundwater flow (Eisenlohr et al., 1972; Sloan, 1972) within the depressions containing the wetlands (Lissey, 1971). In cases where groundwater flow is generally toward a wetland pond, reversals in groundwater flow directions at the periphery of the pond can occur due to two processes, transpiration and water input from intense rain and snowmelt. Transpiration by vegetation at the pond perimeter can cause a localized depression in the water table immediately adjacent to the pond, thereby causing water to flow out of the pond into groundwater (Berthold et al., 2004; Meyboom, 1966; Meyboom et al., 1966; Mills and Zwarich, 1986; Rosenberry and Winter, 1997). Episodes of intense rain and snowmelt can raise the water level in the pond above the adjacent groundwater level also causing water to temporarily flow out of the pond, particularly for temporary ponds (Johnson et al., 2004).

Water stored in prairie-pothole wetland ponds varies in salinity from less than 300 ppm (fresh water) to greater than 35,000 ppm (saline water) (Barica, 1975; Bierhuizen and Prepas, 1985; Hammer, 1978; Last, 1992; Petri and Larson, 1973; Rozkowski,1969; Swanson et al., 1988). Wetland ponds that have surface or groundwater outlets are relatively fresh; those that have no outlets are more saline (Sloan, 1972). Solutes are concentrated in prairie-pothole wetland ponds in two ways. When evapotranspiration is greater than precipitation, wetland pond water levels decline and solutes are concentrated in the ponds (Jones and Deocampo, 2003). Solutes also are concentrated during ice formation. As pond water freezes, solutes are excluded from the ice and concentrated in the remaining liquid water. When freezing continues into the sediments, solutes are concentrated in the pore water in sediments below the maximum ice extent (Ficken, 1967). After the sediments thaw, diffusion of solutes from the sediment pore water into the pond contributes to pond salinity (Ficken, 1967; Heagle et al., 2013).

Evapotranspiration by plants at the edge of ponds can lead to localized increased salinity of shallow groundwater at the pond periphery (Arndt and Richardson, 1993; Miller 1969), and salinization of soils (Arndt and Richardson, 1989). Within the more permanent zone of soil salinization, Arndt and Richardson (1993) noted the increased salinity in the shallow groundwater at the pond periphery can be transient because periodic recharge events result in groundwater flow that moves the accumulated solutes from the periphery into the pond. Solutes are also added to the ponds from groundwater flow originating from the adjacent uplands (Arndt and Richardson, 1993; Eisenlohr et al., 1972; Hayashi et al., 1988b; Heagle et al., 2007; Miller, 1969; Rozkowski, 1969). Rain, snow, and surface runoff are other hydrologic sources of solutes to the ponds (Eisenlohr et al., 1972; Hayashi et al., 1988b). Decomposing vegetation also can contribute to solutes in pond water (Biondini and Arndt, 1993).

Solutes are removed from wetland ponds by several mechanisms. Water flows overland from a pond to an adjacent wetland basin when the pond level rises to its basin's "spill" point (Eisenlohr et al., 1972) thereby removing solutes from the pond (Leibowitz and Vining, 2003; Nachshon et al., 2014; Leibowitz et al., 2016). When the pond level is below the surface spill point of the depression it occupies, no loss of solutes by surface-water flow can occur. Movement of pond water into groundwater (outflow seepage), however, can remove solutes from the pond when the water level in the pond is higher than the water levels in the adjacent groundwater (Sloan, 1972). Processes within a pond can favor removal of solutes from pond water by chemical precipitation (Goldhaber et al., 2014) or by gas flux (Biondini and Arndt, 1993; Mills et al., 2011). When wetlands are dry, salts can be removed from the wetland sediment surface by wind (Eisenlohr et al., 1972; Jones and Deocampo, 2003; LaBaugh et al., 1996; Luba et al., 1988), similar to loss of salts that occurs from closed lakes (Langbein, 1961).

The semi-arid region occupied by prairie-pothole wetlands is subject to considerable variation in climate (Laird et al., 2003; van der Valk, 2005). Episodes of drought commonly recur; less common are episodes of very wet conditions and deluge (Winter and Rosenberry, 1998). Observation of changes in pond water levels and salinity in the past few decades have begun to document how variations in water level and salinity are related to the processes controlling the hydrologic and chemical characteristics of these ponds, both during the onset of drought and transition to wetter conditions (LaBaugh et al., 1996), as well as during persistent wet conditions and high water levels (LaBaugh et al., 2016; Nachshon et al., 2014). Simple water balance models (rainfall and runoff) have been used to relate wet and dry episodes to fluctuations in water levels of prairie-pothole wetlands (Carroll et al., 2005; Huang et al., 2013; Johnson et al., 2005, 2015; Liu and Schwartz, 2011; Poiani et al., 1996). Quantification of the contribution of each of the various processes affecting variations in pond water levels and salinity in prairie-pothole wetlands, however, are rare and are only of several years duration (Hayashi et al., 1988a, 1998b; Heagle et al., 2007, 2013; Shjeflo, 1968; Woo and Rowsell, 1993).

Published water and solute budgets provide an initial foundation regarding the quantification of the factors controlling fluctuations in water levels and salinity in the ponds of these wetlands that influence use by waterfowl. The several years' duration of published budget studies (Hayashi et al., 1988b; Heagle et al., 2007; Shjeflo, 1968; Woo and Rowsell, 1993) have not yet quantified the full cycle of wet and dry conditions that have such an important influence on wetland habitat dynamics (van der Valk, 2005). Measurement of the components of the water and solute budgets of the pond of Wetland P1 in the Cottonwood Lake area, North