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Placing prairie pothole wetlands along spatial and temporal continua to improve integration of wetland function in ecological investigations

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SUMMARY

We evaluated the efficacy of using chemical characteristics to rank wetland relation to surface and groundwater along a hydrologic continuum ranging from groundwater recharge to groundwater discharge. We used 27 years (1974–2002) of water chemistry data from 15 prairie pothole wetlands and known hydrologic connections of these wetlands to groundwater to evaluate spatial and temporal patterns in chemical characteristics that correspond to the unique ecosystem functions each wetland performed. Due to the mineral content and the low permeability rate of glacial till and soils, salinity of wetland waters increased along a continuum of wetland relation to groundwater recharge, flow-through or discharge. Mean inter-annual specific conductance (a proxy for salinity) increased along this continuum from wetlands that recharge groundwater being fresh to wetlands that receive groundwater discharge being the most saline, and wetlands that both recharge and discharge to groundwater (i.e., groundwater flow-through wetlands) being of intermediate salinity. The primary axis from a principal component analysis revealed that specific conductance (and major ions affecting conductance) explained 71% of the variation in wetland chemistry over the 27 years of this investigation. We found that long-term averages from this axis were useful to identify a wetland's long-term relation to surface and groundwater. Yearly or seasonal measurements of specific conductance can be less definitive because of highly dynamic inter- and intra-annual climate cycles that affect water volumes and the interaction of groundwater and geologic materials, and thereby influence the chemical composition of wetland waters. The influence of wetland relation to surface and groundwater on water chemistry has application in many scientific disciplines and is especially needed to improve ecological understanding in wetland investigations. We suggest ways that monitoring *in situ* wetland conditions could be linked with evolving remote sensing technology to improve our ability to better inform decisions affecting wetland sustainability and provide periodic inventories of wetland ecosystem services to document temporal trends in wetland function and how they respond to contemporary land-use change.

1. Introduction

Informing decisions affecting wetland sustainability requires knowledge of the ecosystem processes and functions. A requisite step is to identify wetland functional types that are ecologically unique so we may better measure their location and extent in our contemporary landscape and thereby understand how changing land use practices alter their functions and concurrent delivery of ecosystem services. Many wetlands have been lost, and most remaining wetlands are embedded within highly modified landscapes where basic ecosystem functions have been compromised by anthropogenic disturbance (Euliss et al., 2008). To support the needs of a rapidly expanding human population that the United Nations has forecast to peak at 9.1 billion by 2050, further modification of contemporary landscapes is likely. Consequently, sustaining wetland ecosystems and the ecosystem services they provide

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will challenge decision makers in ways that are without historical precedent. This will pose new challenges to managers, policy makers, and other stakeholders seeking to sustain ecosystem services.

It is well-documented that wetland ecosystem functions and delivery of ecosystem services vary spatially among unique wetlands and temporally within wetlands in relation to inter-annual climate variations (van der Valk and Davis, 1978; Winter and Rosenberry, 1998; Euliss et al., 2004; and many others). However, none of the current wetland classification systems can place wetlands into functional groups or account for temporal change from inter-annual climate cycles. The Hydrogeomorphic Method (HGM) developed by Brinson (1993) uses geomorphic setting, water source, and hydrodynamics to define unique wetland functional types; however, in some cases, HGM schemes have failed to group wetlands together that perform similar functions (e.g., Cole et al., 2002, 2008; Azzolina et al., 2007). The National Wetlands Inventory (NWI) classifies wetlands using Cowardin et al. (1979), but it does not account for unique spatial and temporal variation in wetland function (e.g., Euliss et al., 2004). Recently, Brooks et al. (2011) suggested an improved system by enhancing the NWI with an HGM system to emphasize geomorphic characteristics important in defining wetland function. This system has been used in a few states (Tiner, 2011; Tiner et al., 2013), but it does not account for temporal variations in inter-annual climate, a major determinant of temporal change in wetland function and ecology (Euliss et al., 2004). Although conceptual, the wetland continuum (Euliss et al., 2004) is an approach that recognizes spatial changes in abiotic and biotic features along continua of a wetland's hydrologic relation to surface and groundwater, as well as the influence of atmospheric water on temporal change in wetland function. Placing wetlands along continua that reflect spatial and temporal change in ecosystem function is an important step toward developing the process-based approach needed to manage wetlands that sustain delivery of valuable ecosystem services. More importantly, a process-based approach provides the context needed to understand how anthropogenic change has altered ecosystem functions, a requisite step to identify solutions to sustain wetland ecosystem services in today's altered landscapes (Euliss et al., 2008).

Conceptually, placing wetlands along a continuum of a wetland's relation to surface and groundwater is a straightforward and efficient way to inform decisions affecting wetland sustainability because managers can manipulate wetland processes that affect ecosystem functions and their delivery of ecosystem services (Euliss et al., 2004, 2008). In practice, however, defining the specific relation a wetland has with surface and groundwater can be technically difficult, requiring long-term monitoring and careful evaluation of water surface elevation of the wetland pool in relation to water levels of the adjacent shallow groundwater (Winter, 2003). In areas like the prairie pothole region (PPR), determining wetland relation to surface and groundwater based on a salinity proxy is especially problematic because salinity can be altered or obscured by dynamic inter-annual climate variation. For management applications, determining wetland function with detailed hydrologic observations would be impractical. An alternate approach that is showing recent progress is the development of remote sensing and GIS tools to classify the relation of individual wetlands to surface and groundwater at a landscape scale (Rover et al., 2011); however, it may take years for this technology to be widely available to managers. In contrast, there is an immediate need to improve the ecological value of scientific investigations by defining the relation wetlands have with surface and groundwater to improve understanding. In areas like the PPR of North America, the interplay between groundwater and subsurface geology may result in variation in chemical composition and concentration in wetland waters of sufficient magnitude to identify relation of individual wetlands to surface and groundwater (i.e., recharge, flow-through, and discharge; see Winter, 2003; Euliss et al., 2004).

A basic overview of what is known about the general hydrological characteristics of prairie pothole wetlands, and how those characteristics relate to salinity, is essential to understand the complex interplay between hydrologic function and spatially unique geologic features that are the basic abiotic drivers of ecosystem function for individual wetlands. The major sources of water to prairie pothole wetlands are atmospheric deposition (rain, snow) and runoff from snowmelt, and the main loss of water is by evapotranspiration (Shjeflo, 1968; Parkhurst et al., 1998; Hayashi et al., 1998a,b). With respect to the contribution of groundwater, Sloan (1972) found that three different configurations of the water table exist around prairie pothole wetlands. Where the water level in the wetland is higher than adjacent groundwater levels in all directions around the wetland perimeter, the water table slope is downward and away in all directions around a wetland, water flows out of the wetland to groundwater, and the wetland is defined as a recharge wetland. Where the groundwater levels are higher than the water level in wetland in one part of the wetland's perimeter (the water table slopes toward the wetland), and at the same time in another part of that perimeter groundwater levels are lower than the level of water in the wetland (the water table slopes away from the wetland), groundwater flows into the wetland at the same time that wetland water flows out into groundwater, and the wetland is defined as a flow-through wetland. Where the groundwater levels around the entire perimeter of the wetland are higher than the water level in a wetland, the water table slopes toward the wetland from all directions and therefore groundwater flows into the wetland, and the wetland is defined as a discharge wetland. For those wetlands receiving groundwater flow, the amount of water received from groundwater is small (Eisenlohr et al., 1972; Winter and Rosenberry, 1998). Eisenlohr et al. (1972) also noted "ground-water movement near potholes in a till terrain is a local phenomenon" and this local phenomenon is associated with a rapid decrease in the hydraulic conductivity with depth of the till (van der Kamp and Hayashi, 2009). The direction of flow can change within weeks during a season (Meyboom, 1966; Eisenlohr et al., 1972; Gerla and Matheney, 1996; Winter and Rosenberry, 1998). In the PPR, groundwater contribution to wetland water balance is minimal due to the low hydraulic conductivity of the glacial till (Sloan, 1972; Winter, 2003). Groundwater flowing into the wetlands contributes solutes to the wetland because of weathering of the till that groundwater flows through before discharging to the wetlands (Eisenlohr et al., 1972; Arndt and Richardson, 1993a,b). The importance of weathered till to groundwater flow and solute transport also is described in Keller et al. (1989), van Stempvoort et al. (1994). The geochemical evolution of solutes in these wetlands is described in Rozkowski (1969) and LaBaugh et al. (1987). Salinity in the prairie pothole wetlands varies as a function of their hydrological characteristics (see Eisenlohr et al., 1972; Sloan, 1972) that can be summarized as follows: (1) recharge wetlands are relatively fresh, (2) discharge wetlands are relatively saline, and (3) flow-through wetlands are intermediate with respect to salinity of the water within them. Wetlands that also lose water and solutes through a surface outlet tend to be less saline than those having no surface outlet. In certain areas of the PPR, surface-flow transport of solutes has been shown to be a major contributor to the salt load in wetlands receiving surface flow, especially during periods of abundant precipitation when open-basin wetlands are most likely to overflow (e.g., Shaw et al., 2012). Solutes also are concentrated when wetlands lose water by evaporation, the concentration being more pronounced when there is no loss of water and solutes through a surface outlet or by flow of wetland water into groundwater. The importance of the lack of an outlet for water and solutes as a factor