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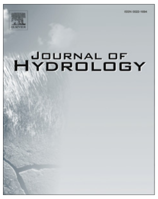

Climatic and hydrologic processes leading to wetland losses in Yellowstone National Park, USA

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SUMMARY

Wetlands are vital habitats and can be used as landscape indicators because they integrate catchment-scale processes. Wetland drying during the recent decades in Yellowstone National Park's Northern Range has incited concern among National Park managers and the public at large. Our research was focused on developing an understanding of the processes controlling wetland water levels and the changes contributing to wetland decline in the Northern Range. We integrated analyses of hydrology, climate, soils, and vegetation. In 2009, 24 study wetlands were instrumented each with an average of five shallow groundwater monitoring well and piezometer nests. We mapped hydric soils, analyzed aerial photographs, and identified geomorphic indicators of higher water to quantify historic wetland area. The Trumpeter Lake study site was intensively studied to resolve watershed processes driving water table changes through time, and it was used to identify the timescale on which a regionally critical wetland varies. Climate data indicated that warming and drying occurred during the last century, but that this pattern was within the natural range of variation for the study region over the past 800 years, as determined from tree ring data. Hydrologic data revealed that study sites included locations of groundwater discharge, recharge, and flow-through as well as water perched above the regional water table. Hydrologic regimes were classified using a shape-magnitude framework and seven wetland classes were characterized, and the robustness of this classification is assessed using longer-term datasets. Aerial photographs and hydric soil delineation both confirmed formerly greater wetland abundance. Changes varied by wetland class and the presence or absence of surface water outlets. Wetland plant species inhabited distinct habitats of water table depth and variation, and can be used to infer subsurface hydrologic regime in the absence of extensive monitoring well networks. A subset of long-term monitoring wells has been instrumented with groundwater pressure transducers, enabling further understanding of wetland hydrologic processes, promoting additional assessment of the wetland classification, and aiding in identification of wetlands especially vulnerable to climate change.

1. Introduction

Wetlands are among the most valuable yet vulnerable habitats on Earth (Bates et al., 2008; Poff et al., 2002; Winter, 2000). They are formed and sustained by hydrologic processes driven by climate, geology, and landscape setting (Hunt et al., 1996; Mitsch and Gosselink, 2000). Wetlands typically occur at low points in their watersheds, and the flow paths sustaining them integrate catchment-scale processes and environmental conditions (Bates et al., 2008; Williamson et al., 2008). Close proximity of the water table and land surface makes wetlands susceptible to changing hydrologic, landscape, and climatic conditions (Bates et al., 2008; Brooks, 2009). Each wetland integrates its unique environmental setting, and generalizing about the hydrologic functioning of basin wetlands can result in erroneous assumptions.

Distinguishing the role of surface water and groundwater processes that form wetlands is complex because they interact at multiple spatial and temporal scales (Devito et al., 2005; Schot and Winter, 2006; Winter, 1999). Basin wetlands can be supported by groundwater or surface water alone or their dynamic interaction, and the direction of groundwater flow can change seasonally (Rosenberry and Winter, 1997; Woo and Rowsell, 1993). Playa wetlands in the southern Great Plains of the United States (Osterkamp and Wood, 1987) and vernal pools in California (Zedler, 2003) are typically hydrologically isolated from continuous ground- and stream water contributions, and driven by runoff, snowmelt, precipitation, and evapotranspiration. In contrast, wetland basins in the Nebraska Sandhills (Winter, 1986) and Great Sand Dunes in

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Colorado (Wurster et al., 2003) are supported largely by groundwater flows through highly conductive sediment. The groundwater sustaining a wetland may originate hundreds of kilometers away, such as those supporting desert oases in Argentina (Jobbágy et al., 2011) and springs in Death Valley, California (Belcher et al., 2009). Identifying the source of water is further complicated in glaciated landscapes because drainage networks are often poorly developed. In the Northern Rocky Mountains, some wetlands located in a dead-ice glacial moraine complex are connected by near-surface flow while adjacent wetlands are hydrologically isolated (Cook and Hauer, 2007). Similar appearing wetlands can differ in their seasonal and interannual range of water table variance and response to climate change.

Climate changes result in altered temperature and precipitation patterns that affect wetland physical and ecological processes. Wetland disappearances in Alaska (Klein et al., 2005) and Siberia (Smith et al., 2005) have been correlated with recent climate changes, and the trend is predicted to continue (Bates et al., 2008; Sorenson et al., 1998). Wetlands in the North American prairie pothole region with different hydroperiods are variably susceptible to climate change because of the interacting effects of watershed flow paths and evapotranspiration processes (Johnson et al., 2010). Understanding the effects of a changing climate on wetland biotic and hydrologic processes is challenging due to the spatial and temporal complexity of wetland habitats (Bates et al., 2008; Brooks, 2009). However, land management should be based on an understanding of wetland functional types.

Classification is commonly used to group entities, including wetlands. Ecosystem type and climate are primary considerations in large scale classification systems (e.g., Cowardin et al., 1979; Devito et al., 2005; Junk et al., 2011). At regional scales, bedrock composition, geomorphic history, and soil characteristics more strongly influence wetland processes (Brinson, 1993; Devito et al., 2005; Merkey, 2006). At the scale of kilometers, water table data may be the most effective way to develop a wetland classification since this method isolates water as the key abiotic driver of wetlands (Rains, 2011). A classification based on hydrologic regime should be supported by other environmental variables, and compatibility with the other components can be used to validate the classification.

A pronounced lowering of surface water levels has been reported for many wetlands in Yellowstone National Park (YNP), USA. However, quantitative and process-based information explaining the phenomenon are lacking. Wetland decline negatively affects many native species, including trumpeter swans whose nesting habitat has been lost in recent decades (Proffitt et al., 2010). Regional climate models for YNP forecast an ecological shift unprecedented in the Quaternary, making the future of the park's terrestrial and water-based ecosystems uncertain (Bartlein et al., 1997; Westerling et al., 2011). As the world's first national park and a key conservation area, preserving YNP's ecosystem is a priority for the public and resource managers.

To develop an understanding of YNP wetlands, we created a framework based upon hydrologic regime supported by other environmental factors. Our study objectives were to: (1) develop and test a wetland classification based upon hydrologic regimes, (2) determine the patterns and magnitude of water level changes that occurred during the late 20th and early 21st centuries and assess whether these changes are within the natural range of variation, and (3) investigate a wetland complex that has recently experienced substantial water level changes to develop a more detailed understanding of the physical processes affecting the site. To address these objectives we analyzed wetland and watershed hydrology, climate, soils, and vegetation to create an integrated view of the processes supporting YNP wetlands.

2. Study area

2.1. Site description

The 1400 km^2 Northern Range comprises much of northern YNP in Wyoming and Montana (Fig. 1). Our study sites receive an average of 41 cm of annual precipitation, with over half falling as snow (NCDC, 2013). Most of the study area was covered by Pinedale Era glaciers that melted approximately 15 kya. The modern landscape form was created by glacial scour and till deposition that created a heterogeneous hummocky landscape with abundant depressions that support wetland basins. We define basin as a topographic depression that at least periodically contains surface water. Study sites are located within clay rich mollisols and inceptisols (YCR, 2009).

In 2009, 24 non-riparian wetlands at 1783–2284 m elevation were selected to characterize Northern Range wetland types (Appendix, Table A1). Most wetlands had mineral soils but a few had organic soils. The most common wetland plant species include *Carex atherodes*, *C. utriculata*, *Juncus arcticus*, *Eleocharis palustris* and *Schoenoplectus acutus* (nomenclature follows USDA PLANTS (USDA, 2013)). Study wetlands receive water from direct precipitation, groundwater, and overland flow. Through the 20th and early 21st centuries, some Northern Range wetland water levels remained relatively constant, while others varied greatly (Engstrom et al., 1991). Several wetlands exhibit indicators of former high water levels, including dead relict marsh vegetation, lichen trim lines, and eroded former shorelines. Direct modification to the hydrologic landscape from dams, irrigation, and groundwater pumping does not occur in the study area. Trumpeter Lake was selected for a detailed wetland analysis because large water level declines are thought to have occurred in this former trumpeter swan nesting habitat. The lake is located near the confluence of the Lamar and Yellowstone Rivers in dead-ice moraine. Its watershed has hummocky topography comprised of low-permeability unconsolidated till with a high density of granitic glacial erratics (Pierce, 1979). Upland soils are loam and lake-bottom soil is clay-loam.

2.2. Study period weather

Climate data for the Northern Range have been collected since 1931 at the Mammoth and Tower weather stations (Fig. 1) and were averaged to characterize study area weather (NCDC, 2013). All study wetlands are located within 12 km of one station and 350 m elevation of both stations (Fig. 1). 2009 and 2010 annual temperatures were both within 0.3 °C of the 1931–2012 average. Total precipitation in water year 2009 (1 October 2008–30 September 2009) was 97% and snow 120% of average, while 2010 total precipitation was 83% and snow 53% of average. Additional data were collected in 2011, when total precipitation was 110% and snow 150% of average, and in 2012 when total precipitation was 97% and snow 93% of average.

In summer 2010 a HOBO tipping bucket rain gauge (Onset Computer Corp.) measured precipitation near Trumpeter Lake. We used linear regression to compare 2010 weekly precipitation among the Tower, Mammoth, and HOBO rain gauges to analyze spatial variability within the study area. Regression analysis indicated that sites throughout the study area experienced similar precipitation ($0.84 \leqslant R \leqslant 0.97$). We used regression models between the two stations to estimate missing historical monthly precipitation values (Iglesias et al., 2006).