Journal of Hydrology: Regional Studies 3 (2015) 87–105

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

Effects of groundwater pumping on the sustainability of a mountain wetland complex, Yosemite National Park, California

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A R T I C L E   I N F O

Article history:
Received 8 March 2014
Received in revised form 6 October 2014
Accepted 10 October 2014
Available online 26 November 2014

Keywords:
Fen
Groundwater pumping
Modeling
Mountain meadow
Water table
Wetlands

A B S T R A C T

Study Region: We analyzed the effects of groundwater pumping on a mountain wetland complex, Yosemite National Park, California, USA.
Study Focus: Groundwater pumping from mountain meadows is common in many regions of the world. However, few quantitative analyses exist of the hydrologic or ecological effects of pumping.
New Hydrological Insights for the Region: Daily hydraulic head and water table variations at sampling locations within 100 m of the pumping well were strongly correlated with the timing and duration of pumping. The effect of pumping varied by distance from the pumping well, depth of the water table when the pumping started, and that water year's snow water equivalent (SWE). Pumping in years with below average SWE and/or early melting snow pack, resulted in a water table decline to the base of the fen peat body by mid summer. Pumping in years with higher SWE and later melting snowpack, resulted in much less water level drawdown from the same pumping schedule. Predictive modeling scenarios showed that, even in a dry water year like 2004, distinct increases in fen water table elevation can be achieved with reductions in pumping. A high water table during summers following low snowpack water years had a more significant influence on vegetation composition than depth of water table in wet years or peat thickness, highlighting the impact of water level drawdown on vegetation.

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http://dx.doi.org/10.1016/j.ejrh.2014.10.002
2214-5818/

1. Introduction

Mountain meadows are groundwater dependent ecosystems with seasonally or perennially high water tables and highly productive herbaceous vegetation that limits tree invasion (Lowry et al., 2011; Loheide et al., 2009). Meadows provide vital ecosystem services by maintaining the biotic and geochemical integrity of mountain watersheds. They are critical habitat for many plant (Hajkova et al., 2006; Jimenez-Alfaro et al., 2012) and animal (Semlitsch, 2000) species, support regional biodiversity (Stohlgren et al., 1998; Hatfield and LeBuhn, 2007; Flinn et al., 2008; Holmquist et al., 2011), form carbon-rich soils (Chimner and Cooper, 2003), and filter water by storing or transforming mineral sediment and nutrients (Hill, 1996; Knox et al., 2008; Norton et al., 2011). In most mountain regions in the temperate zone meadows cover less than 2% of the landscape, and their persistence is threatened by human activities such as road building and logging that can increase sediment fluxes, overgrazing by domestic livestock that can alter meadow vegetation and cause soil erosion, and dams, diversions, channel incision, ditching and groundwater pumping that alters meadow hydrologic regimes (Patterson and Cooper, 2007; Loheide and Gorelick, 2007; Chimner et al., 2010). The effect of hydrologic alteration on meadows is poorly understood, however hydrologic changes are often identified as the main cause of conifer tree invasion into meadows (Jakubos and Romme, 1993; Vale, 1981).

Several ecological processes maintain mountain meadows in their treeless state, including seasonally or perennially high water tables and highly productive vegetation (Lowry et al., 2011), climate and landform (Jakubos and Romme, 1993; Zald et al., 2012), fire regime (Norman and Taylor, 2005), and herbivory (Manson et al., 2001). In the Sierra Nevada of California many mountain meadows receive sufficient groundwater inflow to maintain areas of surface soil saturation throughout the nearly precipitation-free growing season (Cooper and Wolf, 2006).

Two main types of mountain meadows occur in western North America: wet meadows that have seasonal saturation in the root zone, and fens that are perennially saturated (Cooper et al., 2012). Organic matter production and decomposition are nearly equal in wet meadows, which limits organic matter accumulation in soils. Fens form where the rate of organic matter production exceeds the rate of decomposition due to waterlogging, allowing partially decomposed plant matter to accumulate over millennia, forming organic, or peat soils (Moore and Bellamy, 1974). Fens support a large number of plant, amphibian and aquatic invertebrate species that rely on permanent water availability. They are uncommon in steep mountain landscapes because slopes are excessively well drained (Patterson and Cooper, 2007). However, where hillslope aquifers recharged by snowmelt water support sites of perennial groundwater discharge, fens have formed (Benedict, 1982). Radiometric dating indicates steady peat accumulation in mountain fens in western North America through the Holocene, suggesting long-term hydrologic stability in groundwater-fed fens (Wood, 1975; Bartolome et al., 1990; Chimner and Cooper, 2003).

Seasonal and inter-annual variation of groundwater level and water chemistry influences the floristic composition and productivity of fen vegetation as well as the rate of peat accumulation (Allen-Diaz, 1991; Cooper and Andrus, 1994; Chimner and Cooper, 2003). Even short periods of water table decline allow oxygen to enter soils, increasing organic matter decomposition rates and initiating soil and vegetation changes (Cooper et al., 1998; Chimner and Cooper, 2003). Ditches and water diversions are commonly constructed to lower the water table of fens (Glaser, 1983; Glaser et al., 1990; Wheeler, 1995; Fisher et al., 1996; Chimner and Cooper, 2003), however, groundwater pumping may also influence water levels in fens and other wetlands (Johansen et al., 2011).

Previous studies have addressed the effects of groundwater pumping on riparian ecosystems, coastal wetlands, prairie potholes, and intermittent ponds (Winter, 1988; Bernaldez et al., 1993; van der Kamp and Hayashi, 1998; Alley et al., 1999). Groundwater pumping in riparian areas can result in the death of leaves, twigs and whole trees, such as cottonwoods (Cooper et al., 2003). However, little is known about the long-term effects of groundwater pumping on mountain meadows. Quantitative models developed to analyze pumping in mountain valleys and basins must consider the characteristic steep terrain and bedrock outcrops in these watersheds, as well as the limited volume of aquifer sediments and strong seasonality of precipitation inputs.

More than 3 million people visit Yosemite National Park each year, most during the dry summer months. Providing a reliable public water supply for staff and visitors is a critical issue. The California