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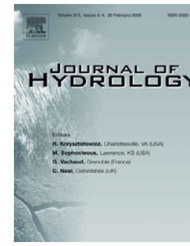

Ground water discharge by evapotranspiration in wetlands of an arid intermountain basin

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Summary To improve basin-scale modeling of ground water discharge by evapotranspiration (ET) in relation to water table depth, daily ET was measured using the Bowen ratio energy balance method during 1999–2005 in five herbaceous plant dominated wetlands in an arid intermountain basin in Colorado, USA. Three wetlands were wet meadows supplied primarily by regional ground water flow and two were playas supplied primarily by local stream flow. In wet meadows, mean daily water table depth (WTD) ranged from 0.00 m (ground surface) to 1.2 m, with low inter-annual variability. In wet meadows, annual actual ET (ET_a) was 751–994 mm, and ground water discharge from the shallow aquifer (ET_g) was 75–88% of ET_a. In playas, mean daily WTD ranged from −0.65 to 1.89 m, with high inter-annual variability. In playas, annual ET_a was 352–892 mm, and ET_g was 0–77% of ET_a. The relationship of annual ET_g to WTD was compared to existing ET_g–WTD models. For wet meadows, ET_g decreased exponentially as WTD increased from 0.13 to 0.95 m ($r^2 = 0.83$, CV = 5%, $p < 0.001$). In comparison with our findings, existing models under- and over-estimate ET_g by −30% to 47% at WTD of 0.13 m, and they under-estimate ET_g by −12% to −42% at WTD of 0.95 m. This study found that as the water table declined from near the soil surface to 0.95 m, ET_g decreased only ~26% versus 39–55% estimated by existing models. The magnitude of ET_g decrease was 220 mm, whereas existing models predicted decreases up to 700 mm (218% greater). In playas, there was no clear ET_g–WTD relationship. Instead, ET_g was strongly dependent on the surface water supply. When sufficient surface water inputs occurred to meet ET demand, ET_g was ≈0 mm/yr and independent of WTD. When inputs did not meet ET demand, ET_g was positive though highly variable at WTD up to 1.68 m.

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Introduction

In arid region intermountain basins, evapotranspiration (ET) is often the primary mechanism of water loss from shallow aquifers (Emery, 1970; Nichols, 1994, 2000; Laczniak et al., 1999, 2001; Reiner et al., 2002; DeMeo et al., 2003; Cooper et al., 2006; Groeneveld et al., 2007; Moreo et al., 2007). In hydrologically closed basins (Snyder, 1962) virtually all water loss is through ET (Huntley, 1979), and a large proportion of this may be ground water from the shallow aquifer. In parts of the Great Basin of the western US, for example, 73–100% of actual evapotranspiration (ET_a) is ground water (Laczniak et al., 1999).

The ground water fraction of ET_a, termed ET_g, is a critical component of hydrologic models used to estimate water fluxes and storage in shallow aquifers. Since ground water models such as MODFLOW (Harbaugh et al., 2000; McDonald and Harbaugh, 2003) estimate WTD, relationships between ET_g and WTD are valuable for estimating ET_g across large landscapes. Several models have been proposed relating ET_g to WTD (Emery, 1970, 1991; Nichols, 2000). However, these models are based on relatively few studies and vegetation types (Emery et al., 1973).

ET data are particularly lacking for wetlands in arid regions (Laczniak et al., 1999, 2001; DeMeo et al., 2003). Despite extremely low mean annual precipitation on the floor of intermountain basins, abundant surface and ground water may flow into basins from adjacent high mountains (Walton-Day, 1996; Cooper et al., 2006) and support large wetland complexes with high ET rates (Drexler et al., 2004; Sanderson, 2006; Sanderson et al., in press). Potential ET (ET_p) can exceed mean annual precipitation by up to 10–30 times (Mifflin, 1988) and wetland ET rates can be >10 times greater than that of surrounding uplands (Laczniak et al., 2001) making wetland ET an important component of arid region water budgets. Wetland ET rates are influenced by the short- and long-term presence of surface water, variations in WTD controlled by climate variation, and human alterations of stream flow and ground water pumping (Cooper et al., 2006).

Wet meadows (Gosselink and Turner, 1978; Cooper, 1986; Carsey et al., 2003; Moreo et al., 2007) and playas (Malek et al., 1990; Laczniak et al., 2001; DeMeo et al., 2003; Sanderson, 2006; Sanderson et al., in press) are two major types of wetlands common in arid regions such as the western US. Wet meadows are ground water supported and typically have shallow WTDs throughout the year (Cooper, 1986; Carsey et al., 2003). Ground water storage varies gradually and subsequently inter-annual changes in WTD are typically small. Wet meadows are often seasonally shallowly flooded (Carsey et al., 2003), but surface ponding is only infrequently deep or prolonged. Playas occur in depressions with fine-grained soils and are filled by streams and surface runoff from snow melt or rain events (DeMeo et al., 2003; Kappen, 2004; Sanderson, 2006). In playas, surface runoff and variation in WTDs can be highly variable between years (Sanderson et al., in press). In some years water may pond deeply (up to 0.65 m in this study) for weeks or months, yet in other years there may be no ponding (Laczniak et al., 2001; Sanderson et al., in press).

Accurate estimates of ET rates are required for modeling the water budget of individual wetlands and entire intermountain basins (Poiani and Johnson, 1993; Devitt et al., 2002; CDSS, 2005), and methods and models have been developed for estimating ET_a in wetlands, many based on estimates of potential evapotranspiration (ET_p) (Winter et al., 1995; Rosenberry et al., 2004; Drexler et al., 2004). Models of ET_p have been derived using theoretical principles (Penman, 1948, 1963; Monteith, 1965), empirical relationships (Blaney and Criddle, 1950; Thornthwaite, 1948), and a combination of theory and empiricism (Priestley and Taylor, 1972). Independent measurements of ET_a for calibrating ET_p are performed using a variety of field methods (Drexler et al., 2004), including the Bowen ratio energy balance method (BREB), which is among the most commonly used and robust (Winter et al., 1995; Rosenberry et al., 2004).

Several models of ET_p have been successfully applied to wetlands (Drexler et al., 2004; Rosenberry et al., 2004) after calibration with independent measures of ET_a (Souch et al., 1996; Jacobs et al., 2002). Calibration is required for a variety of reasons. First, ET_a is strongly influenced by vegetation characteristics such as leaf area, plant height and roughness, and total plant cover and albedo (Peacock and Hess, 2004), all of which vary during the year. Second, ET_a is influenced by the presence of surface water, WTD, and soil water content, all of which vary by wetland type and may change during the year (Jacobs et al., 2002).

The objectives of this paper are to present data on ET_a and ET_g for wet meadows and playas in a large intermountain basin region of the western US, and to analyze ET_g as a function of water source and WTD. We specifically address the following questions: (1) What rates of ET_a and ET_g occur in intermountain basin wetlands? (2) How does ET_g vary with WTD? (3) Do ET_g–WTD relationships differ between wet meadows and playas? To address these questions, we measured daily ET_a and related environmental attributes over a period of 7 yr in five wetlands in Colorado's San Luis Valley (SLV).

Study area

Regional setting

The SLV is a high elevation intermountain basin covering ~8400 km^2 in southern Colorado, USA (Fig. 1; Huntley, 1979). The valley floor averages ~2350 m elevation and has little topographic relief. Peaks rise above 4000 m in both the Sangre de Cristo Mountains to the east and the San Juan Mountains to the west. In the SLV, summers are warm (July mean = 17 °C), winters are cold (January mean = −9 °C), and insolation is high all year (Doesken and McKee, 1989; Western Regional Climate Center, 2005).

Orographic effects result in high mountain precipitation and low valley floor precipitation. Mean annual precipitation at Wolf Creek Pass (elevation 3290 m, Fig. 1) is 1153 mm, while at Center on the SLV floor (elevation 2350 m, Fig. 1) it is 177 mm (Western Regional Climate Center, 2005). The SLV is the most arid region in Colorado, and it also supports Colorado's highest concentration of wetlands (Walton-Day, 1996). This results from the abundant mountain snowfall contributing abundant surface and ground water inflows to the relatively flat valley floor.