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Regional scale estimates of baseflow and factors influencing baseflow in the Upper Colorado River Basin

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ABSTRACT

Study region: The study region encompasses the Upper Colorado River Basin (UCRB), which provides water for 40 million people and is a vital part of the water supply in the western U.S.
Study focus: Groundwater and surface water can be considered a single water resource and thus it is important to understand groundwater contributions to streamflow, or baseflow, within a region. Previously, quantification of baseflow using chemical mass balance at large numbers of sites was not possible because of data limitations. A new method using regression-derived daily specific conductance values with conductivity mass balance hydrograph separation allows for baseflow estimation at sites across large regions. This method was applied to estimate baseflow discharge at 229 sites across the UCRB. Subsequently, climate, soil, topography, and land cover characteristics were statistically evaluated using principal component analysis (PCA) to determine their influence on baseflow discharge.
New hydrological insights for the region: Results suggest that approximately half of the streamflow in the UCRB is baseflow derived from groundwater discharge to streams. Higher baseflow yields typically occur in upper elevation areas of the UCRB. PCA identified precipitation, snow, sand content of soils, elevation, land surface slope, percent grasslands, and percent natural barren lands as being positively correlated with baseflow yield; whereas temperature, potential evapotranspiration, silt and clay content of soils, percent agriculture, and percent shrublands were negatively correlated with baseflow yield.

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1. Introduction

The Colorado River and its tributaries are an important source of water in the western United States, supplying water across seven states and Mexico. The river sustains communities and economies by providing municipal water for 40 million people, irrigating 20,000 km^2 of land, generating 4200 MW of hydroelectric power, and sustaining terrestrial and aquatic ecosystems (U.S. Bureau of Reclamation, 2012). Roughly 90% of the streamflow in the Colorado River originates from snowmelt from precipitation in the three upper basin states of Colorado, Utah, and Wyoming (Jacobs, 2011), making the Upper Colorado River Basin (UCRB) a vital part of water supply in the West.

To inform management of water resources in the UCRB, the hydrologic budgets of surface water and groundwater need to be quantified; however, the groundwater component of streamflow, or baseflow, in the UCRB has not been estimated extensively across the basin and is not well understood. Baseflow is groundwater that is discharged to streams, and it integrates groundwater from multiple flow paths of varying scales, from deep regional groundwater to shallow near-stream flow paths (Miller et al., 2014; Price, 2011). Declines in groundwater storage volumes documented in the UCRB during the past decade of drought (Castle et al., 2014) could affect the baseflow component of streamflow, potentially leading to decreases in streamflow volumes. To better assess and plan for this possibility, as well as the effects of groundwater development in the UCRB, it is necessary to quantify baseflow discharge to streams across the basin and to assess basin characteristics that influence its magnitude and distribution.

Many approaches have been developed to quantify baseflow, including graphical hydrograph separation approaches such as low-pass filters (Nathan and McMahon, 1990; Wolock, 2003) and recession curve analysis (Barnes, 1939; Tallaksen, 1995), as well as chemical mass balance hydrograph separation methods (Miller et al., 2014; Stewart et al., 2007). Chemical mass balance methods rely on conservative chemical constituents and streamflow to estimate baseflow, while graphical methods use only streamflow. Using readily available specific conductance (SC) data as the chemical constituent in chemical mass balance hydrograph separation allows for baseflow estimates to be made for larger basins over long periods of time (Stewart et al., 2007). Furthermore, the conductivity mass balance (CMB) method has been shown to work well for many types of watersheds, including snowmelt dominated systems like the UCRB (Miller et al., 2014).

In the past, application of the CMB method has been restricted either to locations that had continuous SC data or to small research watersheds that were intensively sampled for multiple chemical constituents (Stewart et al., 2007; Wels et al., 1991). Sanford et al. (2012) provides an example of using chemical mass balance hydrograph separation with continuous SC data to estimate baseflow at a large scale in Virginia. More recently, Miller et al. (2015) successfully estimated baseflow using regression derived estimates of daily SC from discrete SC measurements combined with a CMB approach. They show that for snowmelt dominated watersheds, baseflow can be estimated for the period of record using the CMB method with discrete SC data and daily stream discharge data. Additionally, they suggest that this new approach could be applied to a greater number of rivers and streams, allowing for investigation of watershed and climatic drivers that influence baseflow across large spatial scales.

Baseflow originates as precipitation that infiltrates to the subsurface and eventually discharges to streams. The amount of baseflow discharged to streams is influenced by many basin characteristics, including climate, soils, topography, and land cover. Conceptually, baseflow is greater in watersheds where there are high rates of infiltration, recharge, and groundwater storage, while high rates of evapotranspiration and runoff reduce baseflow (Brutsaert, 2005; Gardner et al., 2010; Price, 2011). Catchment geology dictates subsurface storage and drainage network structures (Farvolden, 1963; Price, 2011; Smith, 1981), while soil characteristics influence the rate of infiltration, hydraulic conductivity, and groundwater recharge (Pirastru and Niedda, 2013; Price et al., 2011; Wolock et al., 2004). Topographic characteristics such as land slope affect how water moves across the surface and in the subsurface, thereby influencing infiltration, flow processes, and rates of water transmission (McGuire et al., 2005; Price, 2011; Price et al., 2011). Land use alters vegetation which can decrease baseflow generation by increasing interception and evapotranspiration rates, or can increase baseflow by improving infiltration and recharge of subsurface storage (McCulloch and Robinson, 1993; Nie et al., 2011; Robinson et al., 1991). Lastly, climatic factors such as temperature and precipitation influence