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LETTER

Availability of high-magnitude streamflow for groundwater banking in the Central Valley, California

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Abstract

California's climate is characterized by the largest precipitation and streamflow variability observed within the conterminous US This, combined with chronic groundwater overdraft of 0.6–3.5 km^3 yr^{-1}, creates the need to identify additional surface water sources available for groundwater recharge using methods such as agricultural groundwater banking, aquifer storage and recovery, and spreading basins. High-magnitude streamflow, i.e. flow above the 90th percentile, that exceeds environmental flow requirements and current surface water allocations under California water rights, could be a viable source of surface water for groundwater banking. Here, we present a comprehensive analysis of the magnitude, frequency, duration and timing of high-magnitude streamflow (HMF) for 93 stream gauges covering the Sacramento, San Joaquin and Tulare basins in California. The results show that in an average year with HMF approximately 3.2 km^3 of high-magnitude flow is exported from the entire Central Valley to the Sacramento-San Joaquin Delta often at times when environmental flow requirements of the Delta and major rivers are exceeded. High-magnitude flow occurs, on average, during 7 and 4.7 out of 10 years in the Sacramento River and the San Joaquin-Tulare Basins, respectively, from just a few storm events (5–7 1-day peak events) lasting for 25–30 days between November and April. The results suggest that there is sufficient unmanaged surface water physically available to mitigate long-term groundwater overdraft in the Central Valley.

1. Introduction

California's groundwater resources have been in decline since the early 1920s (Faunt 2009, USGS 2014). For most of the 20th century, statewide groundwater storage loss was estimated between 0.6 and 1.85 km^3 yr^{-1} (1960–2003) (Faunt 2009). More recent studies estimate annual losses to be between 1.4 and 3 km^3 yr^{-1} (DWR *et al* 2013), 8.9 km^3 yr^{-1} (2006–2010, Scanlon *et al* 2012) or even as high as 40 km^3 (2012–2016, Xiao *et al* 2017). During the fourth year of the 2012–2016 drought, an additional 7.4 km^3 of groundwater was pumped to balance the 10.7 km^3 shortage in surface water supplies (Howitt *et al* 2014). As of 2017, California has 21 critically overdrafted groundwater basins (out of 515, which account for >80% of California's annual groundwater pumping), 14 of which are located within the Central Valley (DWR 2016). These indicators of chronic groundwater overdraft highlight the need for groundwater recharge efforts in California and availability analyses to estimate surface water resources available for groundwater banking.

California's depleted groundwater aquifers can provide ~44 km^3 of storage capacity for groundwater banking (Scanlon *et al* 2016). Groundwater banking refers to approaches that intentionally place or retain more water in groundwater aquifers than would otherwise naturally occur. These approaches include conjunctive use (substituting surface water for groundwater to reduce groundwater use), in-lieu recharge (supply surface water to users who normally use groundwater), and managed aquifer recharge (MAR) (the active recharge of groundwater with

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