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A comparison of estimates of basin-scale soil-moisture evapotranspiration and estimates of riparian groundwater evapotranspiration with implications for water budgets in the Verde Valley, Central Arizona, USA

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ABSTRACT

Population growth in the Verde Valley in Arizona has led to efforts to better understand water availability in the watershed. Evapotranspiration (ET) is a critical factor in estimating groundwater recharge in the area and a substantial component of the groundwater budget. In this study, two estimates of soil-moisture ET and two estimates of groundwater ET in the Verde Valley are presented and discussed. Basin-scale soil-moisture potential ET (PET) estimates from the soil-water balance (SWB) and basin characteristics model (BCM) groundwater recharge models are compared. Separately, riparian groundwater ET estimated from a method that uses MODIS-EVI remote sensing data and geospatial information, and from the MODFLOW-EVT ET package as part of a regional groundwater-flow model that includes the study area, are also discussed. Somewhat higher PET rates from the SWB recharge model resulted in an average annual ET volume about 17% greater than for PET from the BCM recharge model. For groundwater ET estimates, annual ET volumes were about the same for upper-bound MODIS-EVI ET for perennial reaches of streams as for the MODFLOW ET estimates, with the small differences between the two methods having minimal impact on annual or longer groundwater budgets for the study area.

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1. Introduction

Population growth in the semiarid to arid Verde Valley in central Arizona (Fig. 1A) has led to increased water demand in the area. Projected growth in Verde Valley (Arizona Department of Administration, 2014), along with plans by adjacent-basin cities to develop groundwater resources near the headwaters of the Verde River to provide for their growing populations (Barks, 2009, 2010) will place further stress on limited surface and groundwater resources in the sub-basin. To assist resource managers and policymakers concerned about water availability in the Verde River watershed, several investigations of the Verde Valley hydrologic system have been performed. Blasch et al. (2006) present results from a study of surface water and groundwater in the area. A groundwater-flow model was developed for the area by Pool et al. (2011), which was then used by Garner et al. (2013) to explore water budgets for the Verde Valley area. The Pool et al. (2011) model was also used to simulate the effects of groundwater pumping on the flow in and riparian vegetation along the Verde River (Leake and Pool, 2010). More recently, Hawkins et al. (2015) published a climate change assessment using a watershed model applied to Beaver Creek, one of the Verde River tributaries. Wyatt et al. (2015) used the Pool et al. (2011) model to examine how tree basal area reductions may impact future groundwater recharge. A number of ET studies in the Verde Valley region have been published, mostly from ponderosa pine forests in the Flagstaff, Arizona area (Dore et al., 2008, 2010, 2012). Ha et al. (2014) compare measured actual ET (eddy covariance method) for ponderosa pine forests near Flagstaff with results from 5 models. The authors found that the simplistic Priestley–Taylor model performed well at the natural vegetation site, but over and under predicted measured ET at two fire-disturbed sites. They found that MODIS ET under predicted eddy covariance ET at all forest sites.

ET is a form of water consumption by vegetation and evaporation of water from soil that is both a critical component in determining physically reasonable estimates of groundwater recharge

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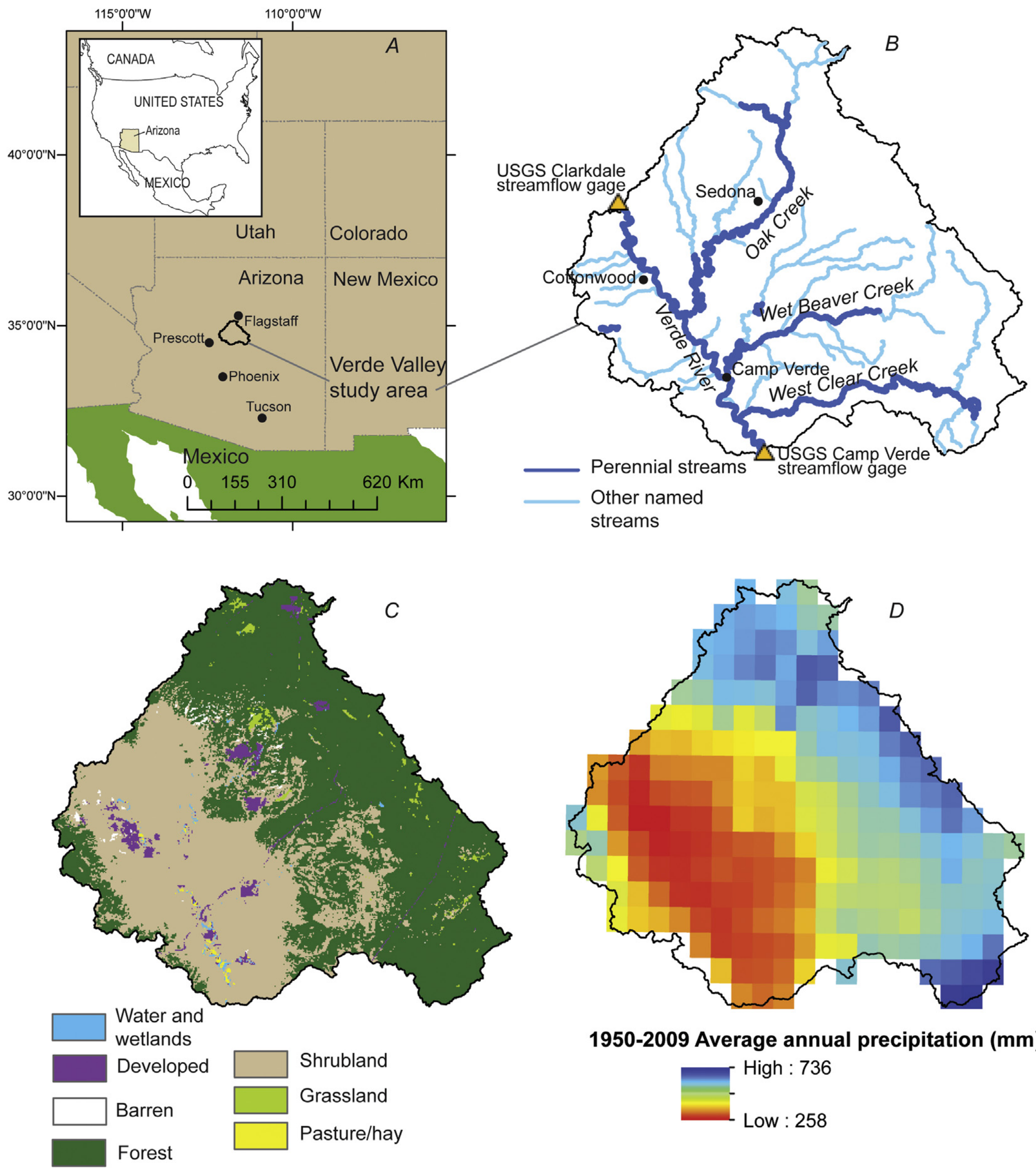

Fig. 1. (A) Location of Verde Valley, Arizona, study area, (B) surface water features (Arizona State Land Department, 1993), (C) major land-cover classifications (Fry et al., 2011), and (D) average annual precipitation (PRISM Group, 2011).

and a substantial part of most groundwater budgets. Groundwater recharge models that use a water-balance approach generally subtract sinks of water (e.g., interception, outflow, ET, increasing soil storage) from sources of water (e.g., precipitation, snowmelt, inflow) to estimate groundwater recharge (Fig. 2A). Therefore, ET in the accounting of a water-balance recharge model is presumed to occur before the infiltrating water becomes recharge and part of the saturated groundwater system. ET from this domain is referred to as soil-moisture ET in this manuscript. In contrast, ET in a groundwater budget is presumed to be derived from subsurface water that has already become part of the saturated groundwater system (Fig. 2B). Groundwater ET, as it is referred to in this manuscript, occurs in parts of a basin where vegetation like phreatophytes can access the capillary fringe of the saturated zone through deep roots and/or shallow groundwater tables, which is commonly in riparian areas in the arid southwestern U.S. Soil-moisture ET, by contrast, can occur anywhere in the basin where there is vegetation and is not limited to areas where vegetation must access the saturated zone. The distinction between soil-moisture ET in a water-balance recharge model and groundwater ET is important because they are components of different water budget domains (Fig. 2). Similar rates may be estimated for soil-moisture and groundwater ET, but the volume of water consumption could differ substantially between the two because soil-moisture ET can potentially cover a much larger area than groundwater ET.

In this study, two methods of estimating basin-scale soil-moisture ET are discussed and compared, and two methods of estimating riparian ET are discussed and compared. Basin-scale rates and volumes are presented for soil-moisture ET estimates from the basin characteristics model (BCM) and soil-water balance (SWB) groundwater recharge models. The BCM model uses potential ET (PET) in a water-balance equation to estimate groundwater recharge while the SWB model uses actual ET (AET) to estimate