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Identification of recharge zones in the Lower Mississippi River alluvial aquifer using high-resolution precipitation estimates

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SUMMARY

Water resources in the lower Mississippi River alluvial valley play a critical role in agricultural productivity due to the widespread use of irrigation during the growing season. However, the unknown specifics of surface–atmosphere feedbacks in the region, along with diminishing groundwater availability and the non-sustainable trend in irrigation draws from the alluvial aquifer, makes it difficult for water resource managers to make sound decisions for future water sustainability. As a result, it is crucial to identify spatial and temporal associations between local rainfall patterns and groundwater levels to determine the influence of precipitation on regional aquifer recharge. Specifically, it is critical to define the recharge zones of the aquifer so that rainfall distribution can be used to assess potential groundwater recovery. This project addresses the issue of defining areas of recharge in the lower Mississippi River alluvial aquifer (LMRAA) through an assessment of historical precipitation variability using high-resolution radar-derived precipitation estimates. A rotated principal component analysis (RPCA) of both groundwater and precipitation data from October through April is used to define locations where aquifer levels show the greatest variability, with a stepwise regression approach used to define areas where rainfall and groundwater levels show the strongest association. Results show that the greatest recharge through direct rainfall is along the Tallahatchie River basin in the northeastern Mississippi Delta, with recharge along the periphery of the LMRAA likely a result of direct water flux from surface hydrologic features.

1. Introduction

The lower Mississippi River alluvial valley (LMRAV) in northwestern Mississippi, known locally as the Mississippi Delta, is one of the most productive agricultural regions in the US due to the fertile soils deposited through flooding of the Mississippi River and the humid sub-tropical climate. However, despite the abundant precipitation associated with this climate zone (>1000 mm year^{-1} in many locations) (Dyer and Mercer, 2013), the convective nature of rainfall during the growing season means high intensity, localized events provide an uneven spatial distribution of atmospheric water. As a result, irrigation is often necessary to maintain crop productivity during the warm season when water demand is high.

Despite more than 1000 mm of annual rainfall and the presence of large rivers in the region, agriculture in the LMRAV is under considerable strain due to reliance on the groundwater from the lower Mississippi River alluvial aquifer (LMRAA) to supply more than 90% of water for irrigation. This has led to rapid declines in groundwater storage and subsequent water resource availability. The LMRAA is the second most productive agricultural aquifer in the US in terms of volume of water pumped for irrigation, behind only the Ogallala aquifer of the High Plains region and nearly equal with California's Central Valley. Current estimates show that roughly two billion gallons day^{-1} of water are being drawn from the shallow alluvial aquifer in northwest Mississippi alone (Stiles and Pennington, 2007), which has led to substantial drawdowns in aquifer levels across the region. While approximately 65% of crop acreage in northwestern Mississippi is currently irrigated, this percentage is increasing steadily. Pumping for irrigation already exceeds estimated recharge rates by approximately 300,000 acre-feet per year, resulting in persistent annual declines in the water table of 15–60 cm. One might expect that the abundant and relatively evenly distributed cool-season rainfall over the area could potentially mitigate aquifer drawdown if appropriate conservation practices are put into place; however, the alluvial aquifer is overlain with a 10–20 m thick impermeable silt–clay

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layer over much of the Mississippi Delta (Arthur, 1994; Fig. 1), providing few areas where direct recharge by meteoric water is possible. Thus, improved management of the aquifer, including the identification and quantification of specific recharge pathways, is critical for the sustainability of agriculture in the region.

Researchers and water resource managers speculate that recharge into the shallow alluvial aquifer could come from a variety of sources, including surface hydrologic features such as rivers and lakes that breach the confining silt–clay layer (Bordonne et al., 2009), direct infiltration from rainfall and surface runoff over areas where the aquifer units outcrop at the surface, as well as inflow from the underlying tertiary aquifer (Mason, 2010). However, quantifying the magnitude of recharge into the LMRAA from each of these various sources is difficult due to the influence of aquifer drawdown on groundwater flow direction and water levels. Although research has been done to define recharge zones of the LMRAA over northwest Mississippi (Mason, 2010; Ackerman, 1996), the exact areas have yet to be clearly outlined.

There are a number of different approaches that can be used to define areas of recharge and/or quantify the recharge rate in unconfined aquifers, many of which are based on empirical estimates of water balance and water level fluctuations within the aquifer (Sophocleous, 1991; Tan and O'Connor, 1996; Carling et al., 2012). These approaches rely on measurements of groundwater level and precipitation, with estimates or empirical functions often used to define infiltration rate within the aquifer. These methods can be augmented using statistical or analytical techniques to account for measurement uncertainty and/or spatial variability of the observations (Moon et al., 2004; Fazal et al., 2005; Mandal and Singh, 2010; Ghayoumian et al., 2007); however, each method remains sensitive to local vegetation, topographic, geologic, and climatic influences that make it difficult to apply

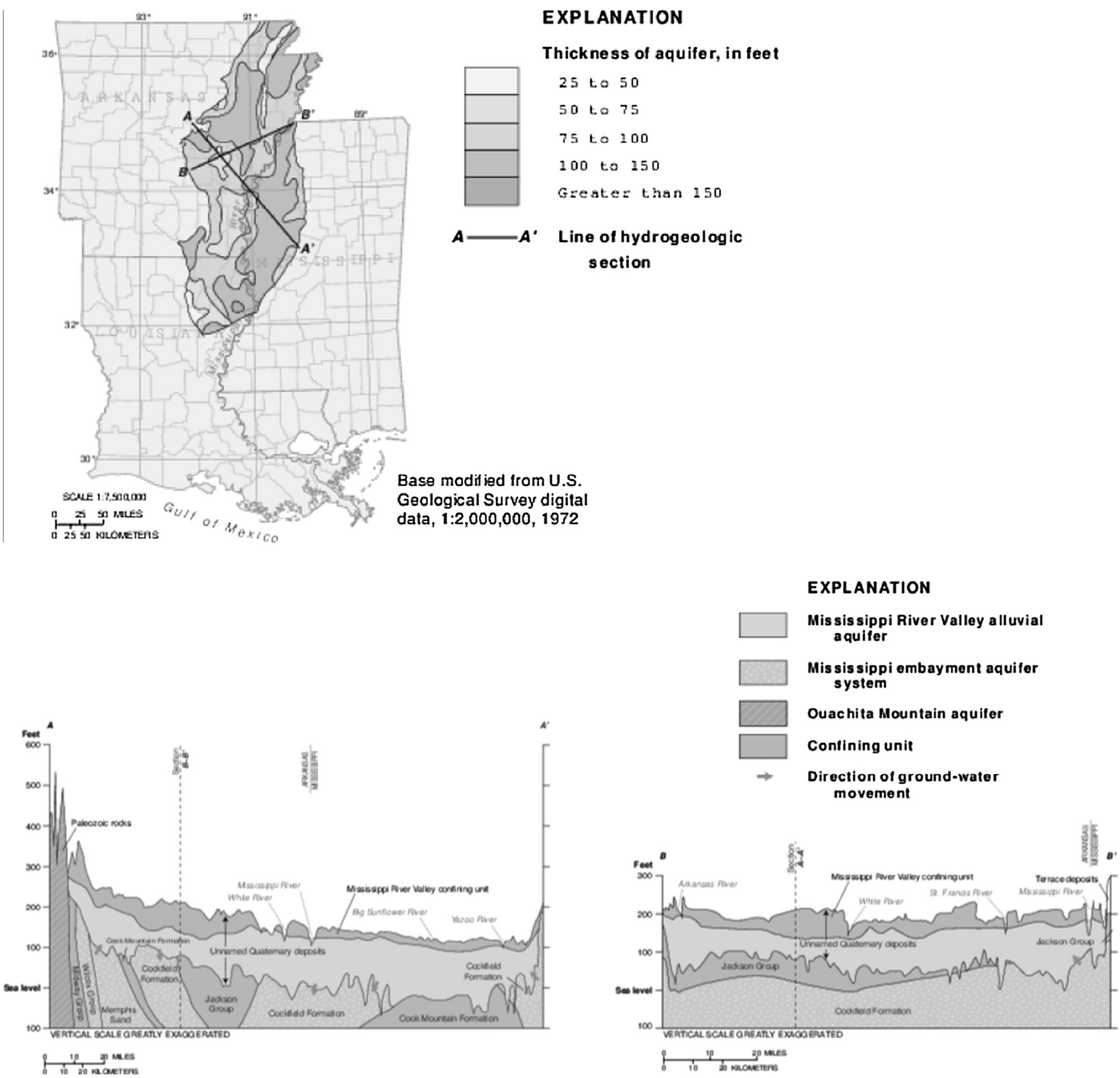

Fig. 1. Thickness of lower Mississippi River alluvial aquifer with associated hydrogeologic cross-sections (adapted from USGS, 1998).