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Trends in the construction of on-farm irrigation reservoirs in response to aquifer decline in eastern Arkansas: Implications for conjunctive water resource management

Mary A. Yaeger[a,*], Joseph H. Massey[b], Michele L. Reba[b], M. Arlene A. Adviento-Borbe[b]

[a] Arkansas State University–Jonesboro, P.O.Box 639, State University Jonesboro, AR, 72467-0639, United States
[b] USDA-ARS Delta Water Management Research Unit at Arkansas State University–Jonesboro, P.O. Box 2, State University, AR, 72467-0002, USA

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ABSTRACT

As part of conjunctive water resource management, on-farm reservoirs have been constructed to address declines in the Mississippi River Valley Alluvial aquifer, the primary source of irrigation for most of the row crops grown in eastern Arkansas. These reservoirs and their associated infrastructure represent significant investments in financial and natural resources, and may cause producers to incur costs associated with foregone crop production and long-term maintenance. A better understanding of past trends in reservoir construction can allow for more efficient resource allocation towards future adoption of this practice. Thus, an analysis of reservoir construction trends in the Grand Prairie (GP) Critical Groundwater Area and Cache River (CR) Critical Groundwater Area was conducted. Between 1996 and 2015, on average, 16 ± 5 and 4 ± 1 reservoirs were constructed per year, corresponding to cumulative new reservoir surface areas of 161 ± 49 and 60 ± 18 ha yr^{-1}, for GP and CR, respectively. In terms of reservoir locations relative to aquifer status, after 1996, 84.5% of 309 reservoirs constructed in GP and 91.0% of 78 in CR were located in areas with remaining saturated aquifer thicknesses of 50% or less. The majority of new reservoirs (74% in GP and 63% in CR) were constructed on previously productive cropland. The next most common land use, representing 11% and 15% of new reservoirs constructed in GP and CR, respectively, was the combination of a field edge and a ditch, stream, or other low-lying area. Less than 10% of post-1996 reservoirs were constructed on predominately low-lying land, and the use of this land cover decreased in both critical groundwater areas during the past 20 years. A reservoir footprint analysis indicated that 85% of the typical reservoir system consists of the reservoir pond itself with the remaining 15% of land area consisting of tailwater recovery ditches, and other associated features. The disparities in reservoir construction rates, locations, and prior land uses between the two critical groundwater areas is likely due to groundwater declines being first observed in GP as well as the existence of two large-scale river diversion projects under construction in GP that feature on-farm storage as a means to offset groundwater use. Results of this analysis can be used in the development of targeted resource allocation initiatives and conservation efforts in critical groundwater areas and other similarly water-scarce regions.

1. Introduction

In the U.S., the Mississippi River Valley Alluvial Aquifer (MRVAA), as part of the Mississippi Embayment (ME) aquifer system, is the second most-utilized aquifer in terms of irrigation withdrawals and the most-utilized aquifer in terms of international virtual water transfer (Marston et al., 2015). The Lower Mississippi River Valley (LMRV), the region overlaying the ME, has over four million ha of irrigated cropland that depends mainly on the MRVAA for water supply (Massey et al., 2017). Within the LMRV, in the state of Arkansas, there are two million ha of irrigated cropland, nearly 80% of which is comprised of a rice-soybean rotation (USDA-NASS, 2014). Thus, agricultural water resource management in the LMRV impacts not only the U.S., but the many nations that receive rice exported from the region.

Groundwater-based irrigation has been a part of the agricultural landscape in east-central Arkansas since the early 20th century because of the discovery that rice was ideally suited to the soils of the region due to a shallow clay layer that held water at the surface and prevented percolation to deeper layers (Vories and Evett, 2014; Gates, 2005). In spite of the more than 1000 mm yr^{-1} average annual precipitation in

* Corresponding author at: Tel.: +1 870 680 4380; fax: +1 870 972 2026.
E-mail addresses: myaeger@astate.edu (M.A. Yaeger), joseph.massey@ars.usda.gov (J.H. Massey), michele.reba@ars.usda.gov (M.L. Reba), arlene.advientoborbe@ars.usda.gov (M.A.A. Adviento-Borbe).

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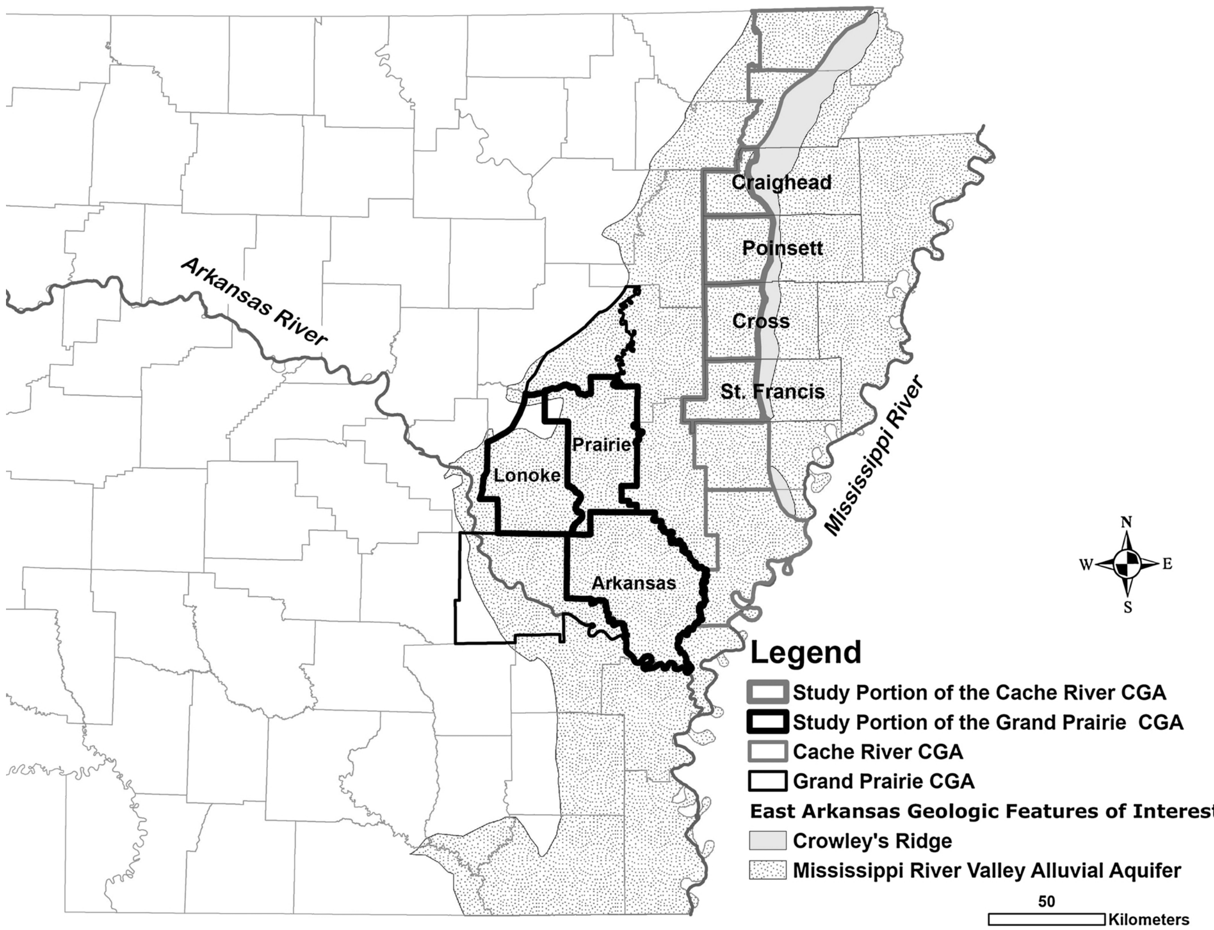

Fig. 1. Location of the Mississippi River Valley Alluvial Aquifer and study areas in eastern Arkansas.

this region, only half occurred during the growing season (Evett et al., 2003; Henry et al., 2016). Furthermore, unlike upland crops such as corn or soybean, rice required flooded fields throughout the growing season, so that irrigation was necessary for successful cultivation (Evett et al., 2003; Gates, 2005). This early adoption and subsequent extensive development of irrigation in eastern Arkansas (Vories and Evett, 2010) was facilitated by the easily-accessible MRVAA, which underlies most of the area (Fig. 1).

The MRVAA is a sand and gravel aquifer overlain in most parts by a confining clay layer of varying thickness (Hart et al., 2008; Renken, 1998). The hydrologic conductivity of the aquifer ranges from 60 to 75 m day^{-1} west of the Crowley's Ridge outcrop (Fig. 1), and decreases to the southwest, where it ranges from 30 to 60 m day^{-1}. The thickness of the MRVAA is spatially variable, ranging from about 23–46 m in the north to 15–46 m in the west-central area, and becoming thinner in the south at 15–23 m (Renken, 1998). The confining unit also varies in thickness throughout eastern Arkansas, being thinner in the northeast (3–12 m) and thicker in the southwest (9–21 m). Because of this confining layer, recharge from surface water and precipitation to the Arkansas portion of the MRVAA is limited, occurring mainly where the layer itself is not present or where larger rivers have incised the confining layer (Renken, 1998). The lower Arkansas River (Fig. 1) and the lower White River, which forms the eastern boundary of Arkansas County (Fig. 1), both provide recharge to the aquifer in this way. Water quality in the MRVAA is fairly good relative to drinking water standards, although hardness and higher concentrations of iron, etc., limit domestic and industrial use but generally do not adversely affect irrigation use (Kresse et al., 2014).

From the initial 405 ha of rice harvested in 1905, rice cultivation in Arkansas quickly expanded, reaching 50,000 ha by 1916, and exceeding 100,000 ha by 1942 (USDA-NASS, 2018). As early as 1915, the US Army Corps of Engineers (USACE) noted that groundwater withdrawals from the MRVAA in portions of eastern Arkansas exceeded recharge to the aquifer (Gates, 2005). This was recognized officially by the Arkansas State Planning Board in 1939 (Vories and Evett, 2014). In spite of these early signs of aquifer depletion, irrigated agriculture continued to expand, so that by 1979, there were 658,000 ha of irrigated land in Arkansas, representing 35% of the total cropland in the state (U.S. Dept. of Commerce, 1982). Of this irrigated area, 94% was comprised of rice and about 19% of the soybean now grown in rotation with rice (Tacker et al., 2010).

In 1980–1981, the southern US experienced severe drought (Andreadis et al., 2005), resulting in previously non-irrigated crops in eastern Arkansas, such as soybean, becoming increasingly irrigated (Tacker et al., 2010). Between 1984 and 1998 there were two periods of rapid expansion of both farmland and irrigation in Arkansas (Fig. 2), with irrigated area increasing 47% between 1984 and 1988, and 42% between 1994 and 1998. While rice area showed small increases (15% and 17%) during these two periods, irrigated soybean area increased 66% and 55%, respectively (Fig. 2). This rapid expansion of irrigated crops in the MRVAA region coincided with noticeable declines in groundwater (Czarnecki and Schrader, 2013; Tacker et al., 2010) so that in 1998, the Grand Prairie area in east-central Arkansas, which includes Lonoke, Prairie, and Arkansas Counties (Fig. 1), was designated a Critical Groundwater Area (CGA) (ANRC, 2014). Later, as another cone of depression deepened north and east of the Grand Prairie, the Cache River area, which includes Craighead, Poinsett, Cross, and St. Francis Counties, received the same critical designation in 2009 (Fig. 1).

As noted previously, agriculture in the MRVAA region has been