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The Use of National Datasets to Produce an Average Annual Water Budget for the Mississippi Alluvial Plain, 2000–13

Overview

Water is a critically important resource for the Mississippi Alluvial Plain (MAP) region, supporting a multibillion-dollar agricultural industry. There are concerns that continued withdrawals of groundwater for irrigation may decrease future water supplies. The U.S. Geological Survey (USGS) has a history of conducting research in the MAP region and recently began an effort to integrate multiple monitoring analyses and modeling to characterize and project water availability for the region. Here, we utilize the data and results from existing national-scale datasets (Hutson and others, 2004; Kenny and others, 2009; Maupin and others, 2014; Homer and others, 2015; and Reitz and others, 2017a, b) and refine them to create long-term steady state annual water budgets at a regional scale (the MAP) from 2000 to 2013. The water budget is described and mapped as the distribution of available water into three components: (1) evapotranspiration (65 percent); (2) quickflow runoff to streams (27 percent); and (3) groundwater recharge (8 percent). We also present a comparison of long-term recharge rates with groundwater extraction rates. These results will be useful as a starting point for the water budget and evaluations of future water availability in the MAP.

Introduction

Water in the Mississippi Alluvial Plain (MAP)—More than 9 billion gallons per day of groundwater are withdrawn for irrigation in the MAP (fig. 1), supporting a nationally important agricultural region (Clark and others, 2011). Irrigation relies heavily on groundwater that, in some areas of the MAP, is showing signs of substantial change. Groundwater withdrawals have resulted in locally significant declines in water levels and reductions in base flow in streams within the MAP. Such impacts may limit well production and threaten future water availability for the region. Here, base flow is defined as the slowly varying portion of streamflow that is primarily sourced from groundwater discharge, whereas quickflow runoff (sometimes referred to as surface runoff) is the rapidly varying portion of streamflow primarily sourced from precipitation or the shallow subsurface.

Mississippi Alluvial Plain Water Availability Study—Because of the importance and complexity of water resources in the MAP, the USGS was tasked with assessing water availability for the region. The assessment is to be completed in 2022, and its primary objectives are to (1) assess current and long-term water availability and (2) provide water-resource managers with a decision-support framework. To meet these objectives, the MAP project team is working to quantify components of the water budget, update and improve water use estimates, develop an improved hydrogeologic framework, characterize water quality, and integrate these components into an existing model of regional groundwater availability. This fact sheet presents the initial results of the water budget aspect of the MAP study, which will direct planning of data-collection efforts such as evapotranspiration monitoring and groundwater-age dating. The additional data collection, in turn, will support a groundwater-flow model that will underpin a decision-support framework.

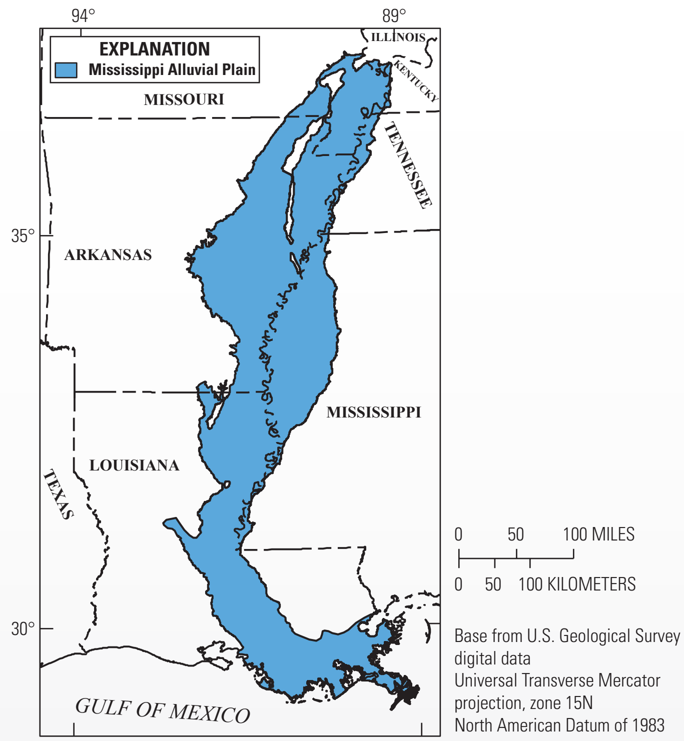

Figure 1. The Mississippi Alluvial Plain is about 44,000 square miles (about 110,000 square kilometers) and includes portions of Mississippi, Arkansas, Tennessee, Missouri, and Louisiana.

Water Budget Estimates

In the work described here, we estimated long-term annual average water budget components of evapotranspiration, quickflow runoff, and recharge. These estimates were developed together to be internally consistent and constrained by the combined amount of water available from precipitation plus groundwater-sourced irrigation. The methods for producing these estimates are fully described in Reitz and others (2017a).

Maps of the water budget components (evapotranspiration, quickflow runoff, and effective recharge) are portrayed in terms of annual data from 2000 to 2013 and the long-term annual average for the contiguous United States. Data used to produce the water-budget maps for the United States are available as a USGS data release (Reitz and others, 2017b). The evapotranspiration estimates were generated from an empirical equation calibrated against long-term water-balance data. Similarly, quickflow runoff estimates were generated from an equation calibrated against streamflow data. Combining the evapotranspiration and quickflow runoff estimates, we calculated recharge as the remainder of the water budget. The evapotranspiration estimates were evaluated using independent field data and compared to other maps for evapotranspiration (Mu and others, 2011; Senay and others, 2013). Recharge estimates were tested against rates derived from groundwater-age dating (Reitz and others, 2017a; McMahon and others, 2011). These comparisons with independent data showed good agreement, and comparisons with other methods of evapotranspiration and recharge estimation indicated the new methods yielded improved estimates (Reitz and others, 2017a; McMahon and others, 2011).

Water-Use Data

Irrigation by County—Groundwater-sourced irrigation is a significant use of water in the MAP. Contributions from irrigated water to evapotranspiration, quickflow runoff, and recharge can be appreciable and are accounted for here as added water to the water budget. We added groundwater-sourced irrigated water to precipitation to estimate the total amount of water supplied to the land surface. The irrigation data source was the county-level USGS water use data averaged from 2000, 2005, and 2010 (Hutson and others, 2004; Kenny and others, 2009; Maupin and others, 2014). We applied the amount of water reported as groundwater-sourced irrigation to the areas designated by the 2006 National Land Cover Database as “agriculture” for crop irrigation (Homer and others, 2015). The maps of the 2000–13 average annual precipitation and the irrigation rates by county are shown in figure 2*A*, *B*. These two sources were combined to create an effective precipitation map, and this amount of available water was then divided into evapotranspiration, quickflow runoff, and effective recharge components.

Groundwater Extraction by County—The USGS 2005 water use by county dataset was used to compare recharge rates with the rates at which groundwater is being extracted (Kenny and others, 2009). The total groundwater extraction rate was divided by the area of each county to estimate average rate of extraction per unit area (fig. 2*C*).

Average Water Budgets for 2000–13

Across the Mississippi Alluvial Plain, the average annual total amount of water supplied to the land surface from precipitation plus irrigation was 152 centimeters per year (cm/yr; 59.8 inches per year [in/yr]). Of that total amount, average annual evapotranspiration was 98.1 cm/yr (38.6 in/yr), average annual quickflow runoff was 41.1 cm/yr (16.2 in/yr), and average annual effective recharge was 12.7 cm/yr (5.0 in/yr). The maps in figure 3 show the distribution of water supply for each 800-meter pixel into the components of evapotranspiration (fig. 3*A*), quickflow runoff (fig. 3*B*), and recharge (fig. 3*C*). Because the estimates represent the pixel-scale contributions to these components, they are not meant to represent interpixel transfers (such as downstream quickflow runoff accumulation). The spatial variation can, however, present a useful picture of how water is being distributed into different budget components.

Evapotranspiration is the dominant component, accounting for 65 percent of available water, followed by quickflow runoff, accounting for 27 percent. Recharge, the most significant component for understanding groundwater flow and resource sustainability, accounts for the smallest portion of available water at 8 percent. Because recharge is estimated through closure of the water budget, accurate recharge estimates are dependent on accurate estimates of evapotranspiration and quickflow runoff. Relatively small errors, especially in evapotranspiration, can result in relatively large errors in recharge.

Within the MAP, the water budgets of individual States showed significant spatial variability, particularly in recharge. A southward increasing trend in temperature drives a southward increase in evapotranspiration (fig. 3*A*), and a corresponding southward decrease in effective recharge (fig. 3*C*). This results in higher effective recharge in Missouri and northern Arkansas compared to southern Arkansas, Mississippi, and Louisiana (fig. 3*C*). The water budgets for the different States’ portions of the MAP are summarized in table 1.

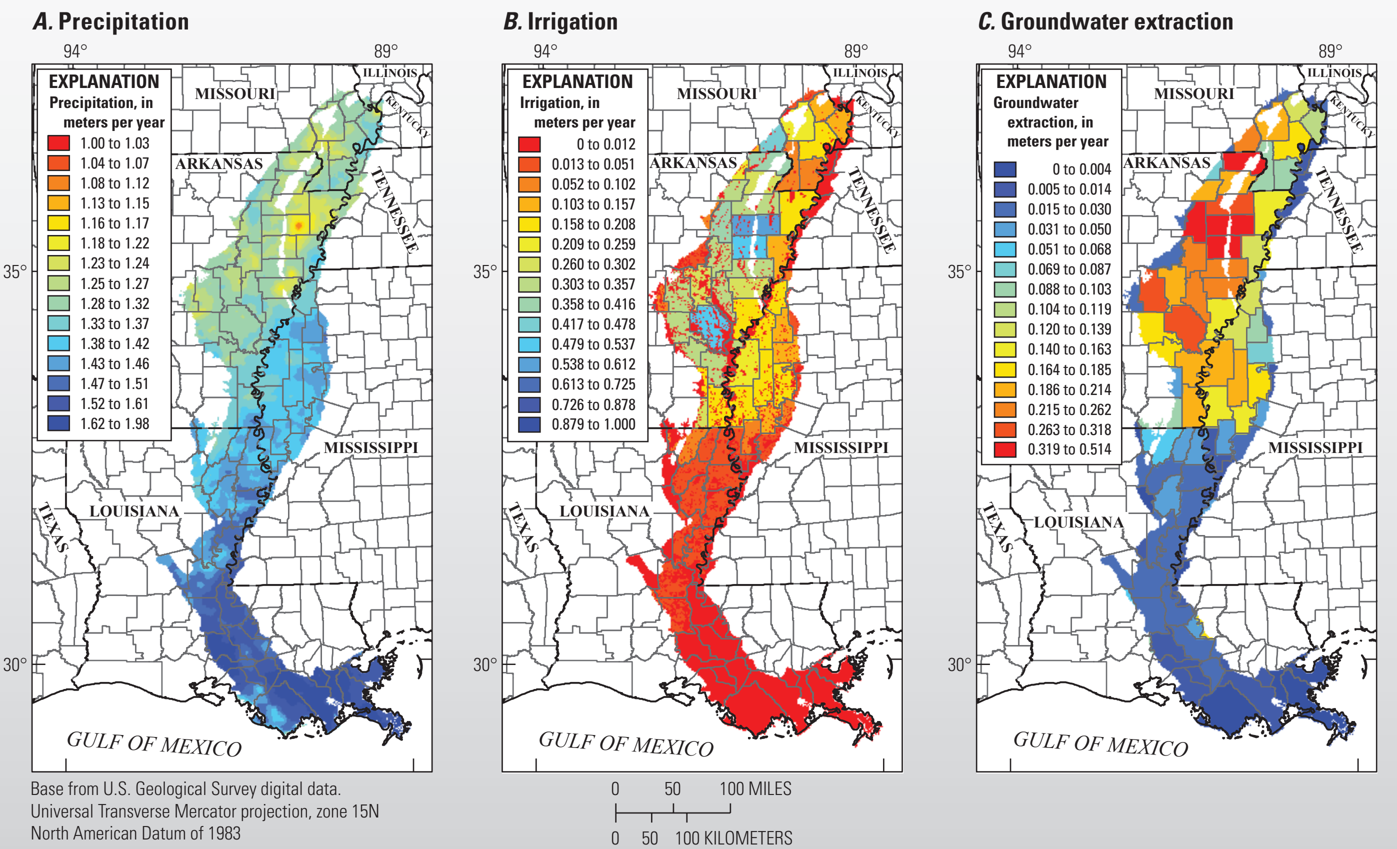

Figure 2. Water supply from precipitation and irrigation. *A*, The 2000–13 annual average water supply from precipitation, from 800-meter data (Daly and others, 2008). *B*, Groundwater-sourced irrigation by county applied to agricultural land cover areas. *C*, Groundwater extraction rate data averaged by county, from the 2005 U.S. Geological Survey water use dataset (Kenny and others, 2009).

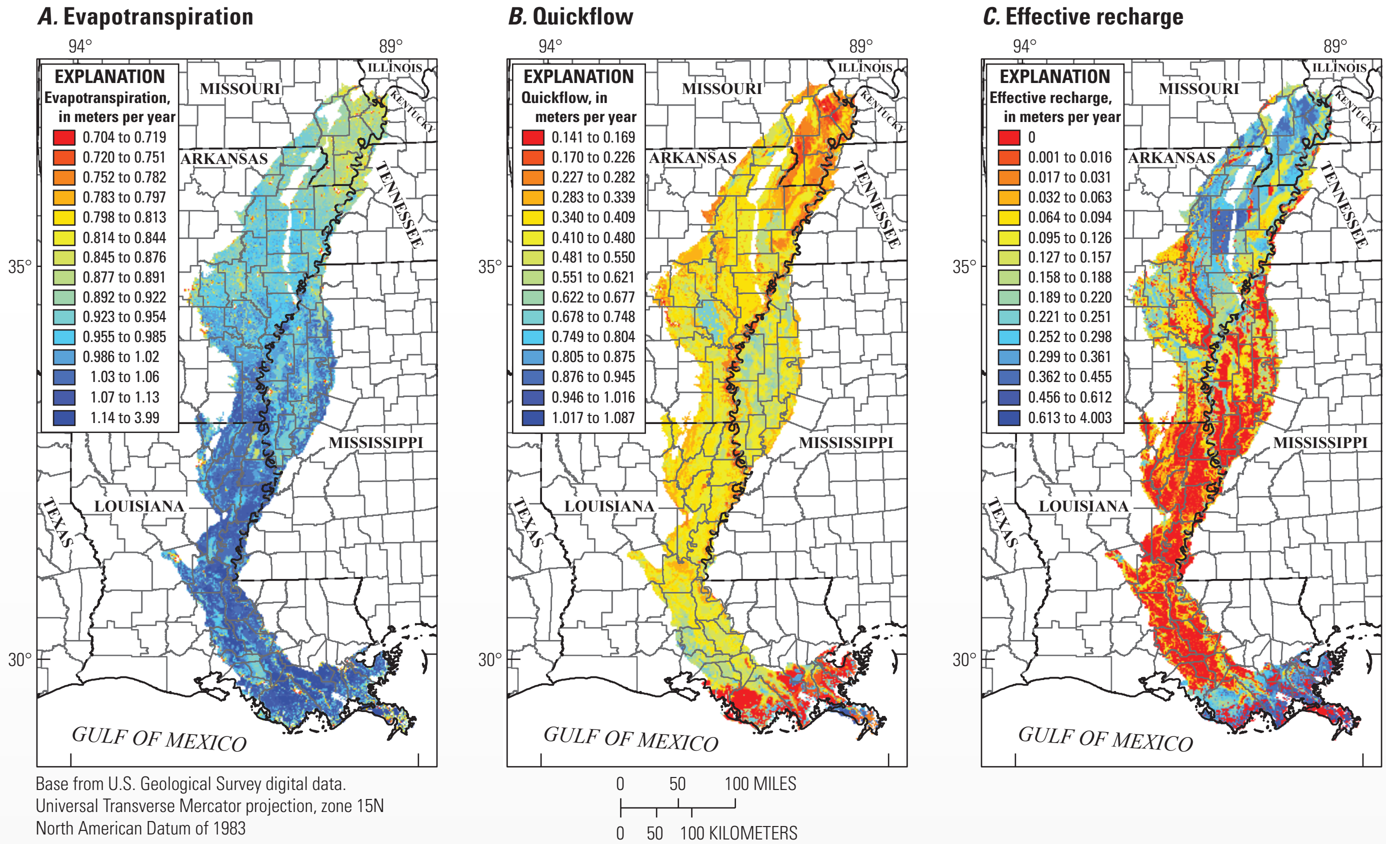

Figure 3. Maps of annual average water budget components for the 2000–13 time period: *A*, evapotranspiration, *B*, quickflow runoff, and *C*, effective recharge.

Table 1. Average water budget component percentages of precipitation and coefficients of annual variation (standard deviation divided by mean, as a percentage) for individual States' portions of the Mississippi Alluvial Plain (MAP).

[cm/yr, centimeter per year; %, percent; in/yr, inch per year; ET, evapotranspiration; precip., precipitation]

State or region	Effective precip. (cm/yr and in/yr)	ET (% of effective precip.)	Quickflow (% of effective precip.)	Effective recharge (% of effective precip.)	ET (% variation)	Quickflow (% variation)	Effective recharge (% variation)	Groundwater extraction rate (cm/yr)
All MAP	152 / 60	65	27	8.3	6.2	32	124	12
MS	151 / 59	65	30	4.3	6.8	34	160	11
LA	191 / 75	57	36	6.8	1.3	29	48	0.39
AR	153 / 60	62	27	11	4.8	30	101	23
TN	133 / 52	68	24	8.8	4.8	39	90	3.1
MO	145 / 57	61	22	17	3.9	31	63	14

Recharge to Extraction Rate Comparison

Estimates of water budgets allow comparisons to be made with water-use data that can help inform efforts toward sustainable water-use management. For example, the effective recharge percentage shown in table 1 becomes base flow in the streams, which is equal to the net recharge supply of water to replenish groundwater. However, water budgets are only one component of a sustainability analysis. Such an analysis also assumes the system is in steady state and does not include information about changes in the water table that have occurred in parts of the MAP. With the importance of the effects of these simple assumptions on water availability acknowledged, a general comparison of the amount of recharge to water extracted provides a snapshot of the potential imbalances in groundwater supply and demand across the MAP.

Comparisons of groundwater extraction data by county (fig. 2*C*) with the long-term effective recharge estimates (fig. 3*C*) averaged by county show the potential for local imbalances in the water budget (fig. 4). The resilience of the groundwater resource is expected to be reduced when groundwater is being extracted at rates approaching or exceeding the local recharge rates. Modeling and decision-support work is underway to provide (1) a more complete representation of all the factors considered in sustainability scenarios and (2) potential future scenarios.

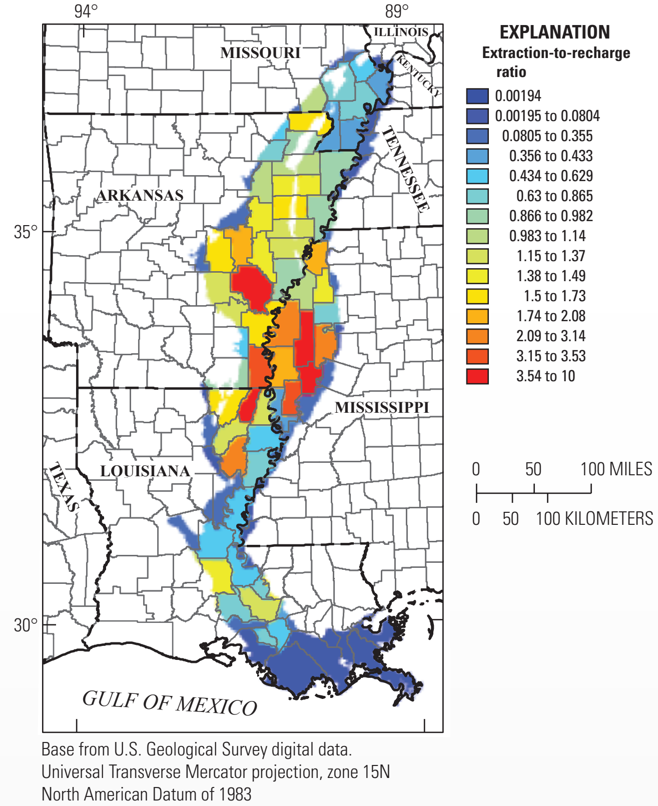

Figure 4. The ratio of the county-reported rate of groundwater extraction from the 2005 water use dataset (fig. 2*C*) to the effective recharge data shown in the map of figure 3*C*, averaged by county. Zero values indicate areas where the reported extraction rate is zero, and high values indicate extraction rates approaching or exceeding recharge rates.

Conclusions and Outlook

Estimates of evapotranspiration, groundwater recharge, and quickflow runoff from a new annual-scale water budget have improved current understanding of groundwater supplies and are being used to inform monitoring efforts in the MAP. On average, across the MAP, evapotranspiration accounted for 65 percent of the water supplied by precipitation and irrigation, quickflow runoff accounted for 27 percent, and recharge accounted for 8 percent (table 1). A southward increasing trend in evapotranspiration resulted in a southward decreasing trend in recharge.

The annual average, steady state water-budget estimates for 2000–13 can be useful for several applications, including the example presented here of comparing recharge rates with groundwater extraction rates. These estimates do not, however, take storage change into account, which is significant in the MAP, nor the effects on other ecosystem benefits. Ongoing work will improve the quantity and quality of independent field data on evapotranspiration and recharge, including data collected on shorter timescales, which in turn will improve dynamic models of water availability in the region. Although an initial step, this work will contribute toward an improved understanding of water availability in the region through the USGS MAP project's development of a dynamic model and decision-support system.

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