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Simulation of Water-Use Conservation Scenarios for the Mississippi Delta Using an Existing Regional Groundwater Flow Model

Scientific Investigations Report 2011–5019

U.S. Department of the Interior
U.S. Geological Survey

Cover photographs: Dry stream beds during the summer months due to lack of base flow for Big Sunflower River at Sunflower, Mississippi (left), and Bogue Phalia River near Leland, Mississippi (right) (photographs by Claire E. Rose, USGS).
Background image: Charts taken from figure 3 (p. 4).

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By Jeannie R.B. Barlow and Brian R. Clark

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square inch (in^2)	6.452	square centimeter (cm^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Simulation of Water-Use Conservation Scenarios for the Mississippi Delta Using an Existing Regional Groundwater Flow Model

By Jeannie R.B. Barlow and Brian R. Clark

Abstract

The Mississippi River alluvial plain in northwestern Mississippi (referred to as the Delta), once a floodplain to the Mississippi River covered with hardwoods and marshland, is now a highly productive agricultural region of large economic importance to Mississippi. Water for irrigation is supplied primarily by the Mississippi River Valley alluvial aquifer, and although the alluvial aquifer has a large reserve, there is evidence that the current rate of water use from the alluvial aquifer is not sustainable. Using an existing regional groundwater flow model, conservation scenarios were developed for the alluvial aquifer underlying the Delta region in northwestern Mississippi to assess where the implementation of water-use conservation efforts would have the greatest effect on future water availability—either uniformly throughout the Delta, or focused on a cone of depression in the alluvial aquifer underlying the central part of the Delta. Five scenarios were simulated with the Mississippi Embayment Regional Aquifer Study groundwater flow model: (1) a base scenario in which water use remained constant at 2007 rates throughout the entire simulation; (2) a 5-percent "Delta-wide" conservation scenario in which water use across the Delta was decreased by 5 percent; (3) a 5-percent "cone-equivalent" conservation scenario in which water use within the area of the cone of depression was decreased by 11 percent (a volume equivalent to the 5-percent Delta-wide conservation scenario); (4) a 25-percent Delta-wide conservation scenario in which water use across the Delta was decreased by 25 percent; and (5) a 25-percent cone-equivalent conservation scenario in which water use within the area of the cone of depression was decreased by 55 percent (a volume equivalent to the 25-percent Delta-wide conservation scenario).

The Delta-wide scenarios result in greater average water-level improvements (relative to the base scenario) for the entire Delta area than the cone-equivalent scenarios; however, the cone-equivalent scenarios result in greater average water-level improvements within the area of the cone of depression because of focused conservation efforts within that area. Regardless of where conservation is located, the greatest average improvements in water level occur within the area of the cone of depression because of the corresponding large area of unsaturated aquifer material within the area of the cone of depression and the hydraulic gradient, which slopes from the periphery of the Delta towards the area of the cone of depression. Of the four conservation scenarios, the 25-percent cone-equivalent scenario resulted in the greatest increase in storage relative to the base scenario with a 32-percent improvement over the base scenario across the entire Delta and a 60-percent improvement within the area of the cone of depression. Overall, the results indicate that focusing conservation efforts within the area of the cone of depression, rather than distributing conservation efforts uniformly across the Delta, results in greater improvements in the amount of storage within the alluvial aquifer. Additionally, as the total amount of conservation increases (that is, from 5 to 25 percent), the difference in storage improvement between the Delta-wide and cone-equivalent scenarios also increases, resulting in greater gains in storage in the cone-equivalent scenario than in the Delta-wide scenario for the same amount of conservation.

Introduction

The Mississippi River alluvial plain in northwestern Mississippi (locally referred to as the Delta), once a floodplain to the Mississippi River covered with hardwoods and marshland, is now a highly productive agricultural region of large economic importance to Mississippi (fig. 1) (Economic Research Service, U.S. Department of Agriculture, 2010). Fertile soils, a long growing season, average annual rainfall of greater than 54 inches (in.), and a productive alluvial aquifer make the Delta a prime area for agriculture. Primary crops grown in this region include soybean, corn, cotton, and rice. Water for irrigation is supplied primarily by the Mississippi River Valley alluvial aquifer (hereafter referred to as the alluvial aquifer), which is the third most used aquifer in the United States (Maupin and Barber, 2005; fig. 2). The extent of the alluvial aquifer covers parts of Arkansas, Mississippi, Missouri, Louisiana, and Tennessee, Kentucky, and Illinois. Mississippi is the second largest user of the alluvial aquifer, and Arkansas is the largest user. Both States rely largely on the

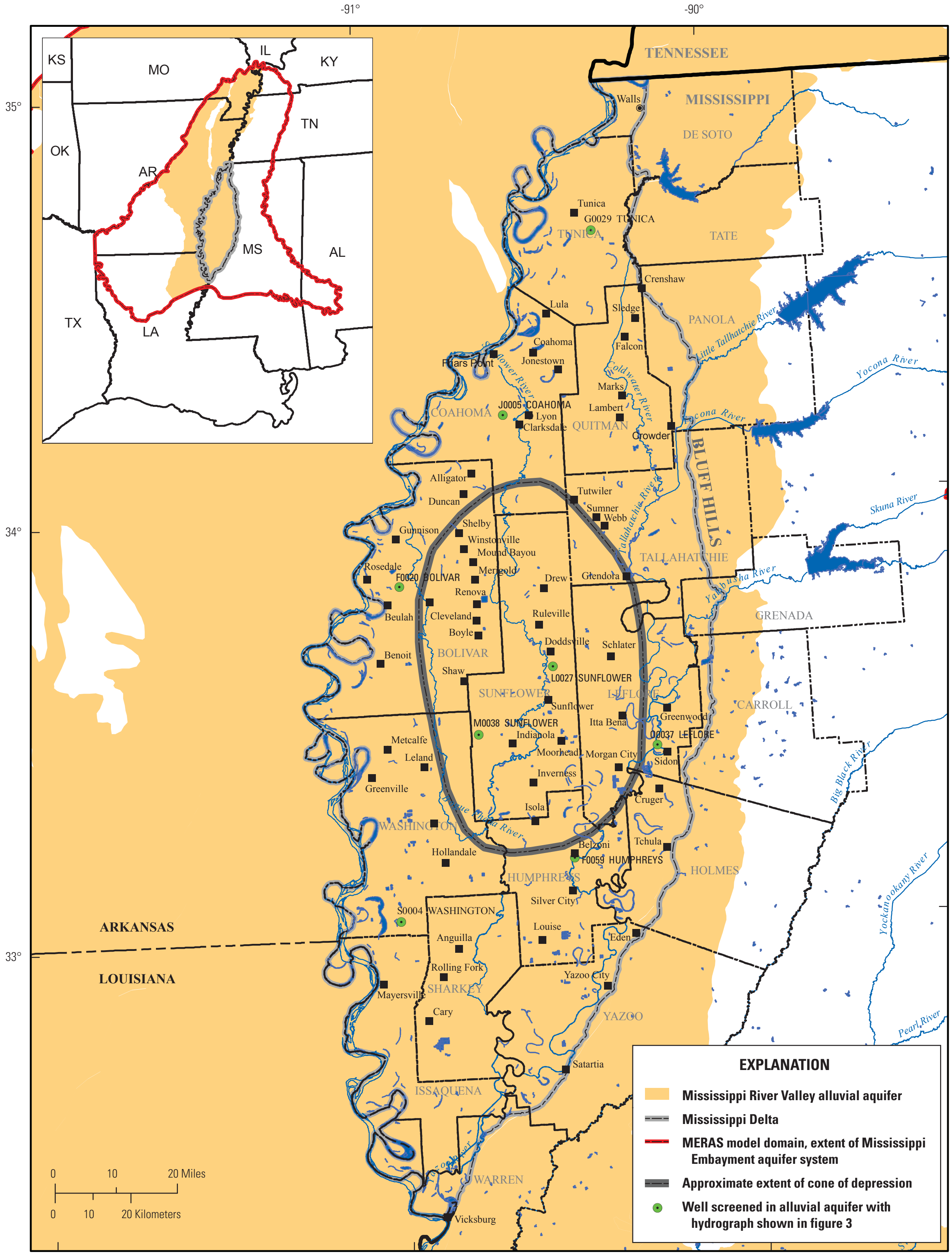


Figure 1. Location of study area, extent of Mississippi Embayment Regional Aquifer Study (MERAS) groundwater flow model, approximate extent of cone of depression, and locations of wells for which hydrographs are shown in figure 3.

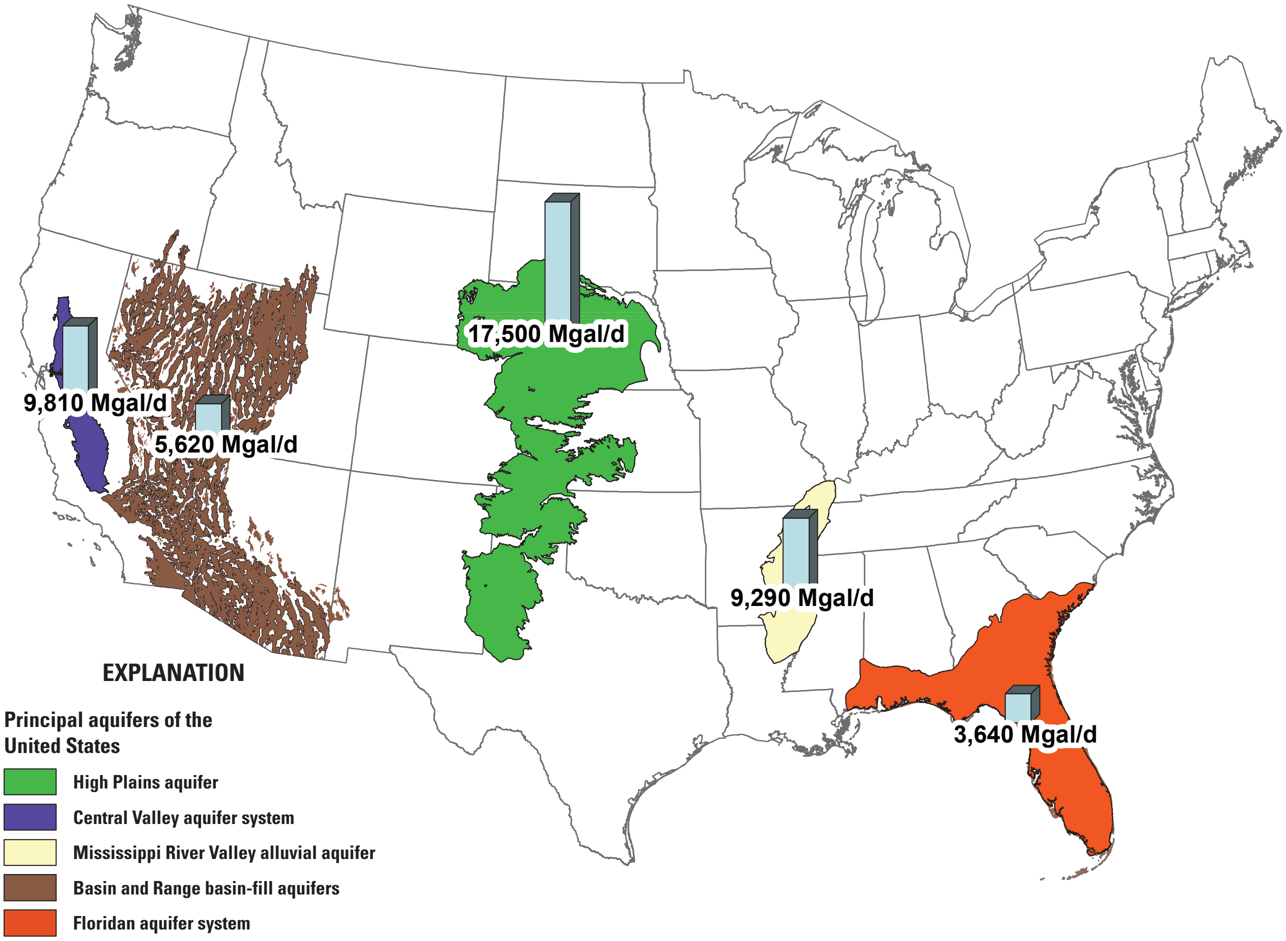


Figure 2. Principal aquifers of the United States with the five highest withdrawal rates in 2000.

alluvial aquifer to supply water for irrigation. Approximately 9,290 million gallons per day (Mgal/d) of water are withdrawn from the alluvial aquifer in Mississippi, which makes it the most used aquifer in the State (Maupin and Barber, 2005). The Mississippi River, which forms the axis of the Mississippi Embayment aquifer system, generally incises the entire thickness of the alluvial aquifer, thereby creating two independent flow systems on the west and east side of the Mississippi River (Arthur, 2001).

The alluvial aquifer consists of Quaternary-age sand and gravel deposits overlying an erosional Tertiary-age surface (Fisk, 1944; Arthur, 2001). Recharge from infiltration typically is low because of the overlying clay and fine-grained material in the upper part of the aquifer. Previous studies have reported recharge rates of 2.5 inches per year (in/yr), which is 5 percent of the average annual rainfall that falls on this region (Arthur, 2001; H.L. Welch, U.S. Geological Survey, written commun., 2010). Other sources of recharge to the aquifer include leakage from the Mississippi River and interior Delta streams and lakes, interflow from sediments and aquifers within the Bluff Hills escarpment (fig. 1) on the eastern edge of the alluvial aquifer, and flow from underlying aquifers in direct connection with the alluvial aquifer. Discharge components from the alluvial aquifer include pumpage from wells screened within the alluvial aquifer, leakage to the Mississippi River and interior Delta streams and lakes, leakage to the Bluff Hills escarpment on the eastern edge of the alluvial aquifer, and leakage to underlying aquifers. Prior to extensive development, the regional groundwater flow path was composed of two flow components—flow from the north to the south and from the east and west peripheries toward the center of the Delta. These flow paths generally followed the topography of the alluvial plain, which slopes from north to south and is bounded by the Mississippi River levees on the west and Bluff Hills on the east, both of which are topographic highs relative to the interior of the Delta. During these predevelopment conditions, water from the alluvial aquifer likely is discharged to the Sunflower and Yazoo Rivers, which are regional drains for the alluvial aquifer (Arthur, 2001). Presently (2010), the regional groundwater flow path is intercepted by a large cone of depression in the central Delta centered on Sunflower County (fig. 1), formed as a result of groundwater pumping for irrigation (Arthur, 2001).

Although the alluvial aquifer has a large reserve (Arthur, 2001), there is evidence that the current rate of water use from the alluvial aquifer is not sustainable. Water-level

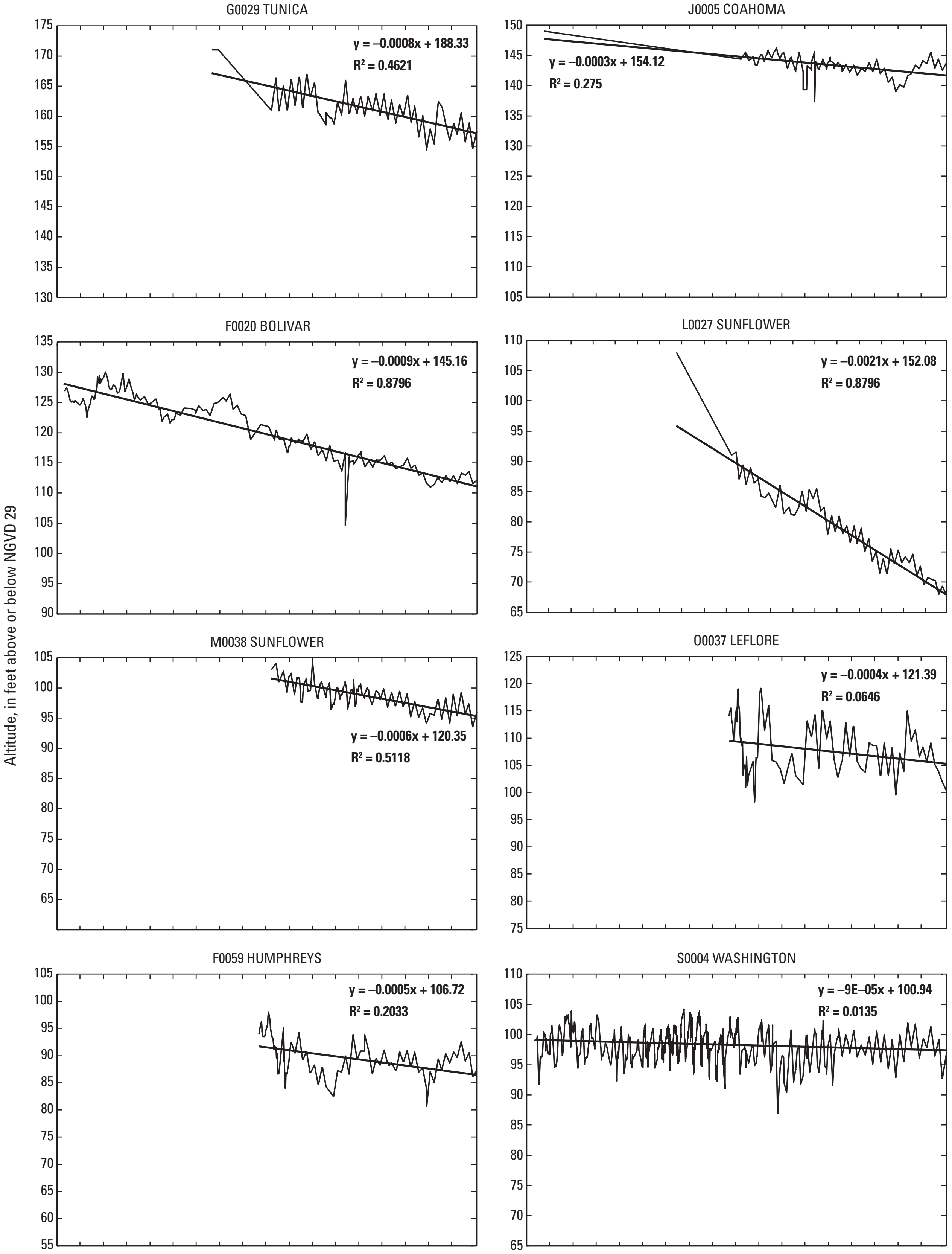


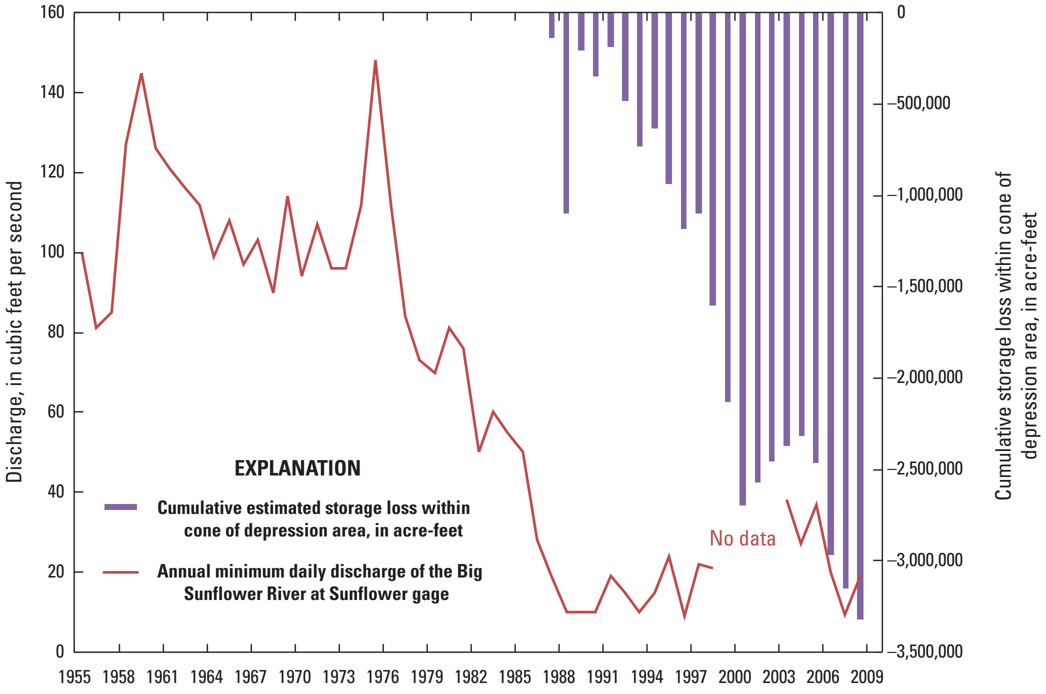
Figure 3. Hydrographs for selected wells screened in the alluvial aquifer in northwestern Mississippi. See figure 1 for well locations.

declines are variable across the Delta, and the largest declines are observed in the central part of the Delta within the area of the cone of depression (figs. 1 and 3). The Yazoo Mississippi Delta Joint Water Management District (YMD), an agency formed in 1989 to assist with the development of non-regulatory strategies for the management of water resources in the Delta region, delineated the approximate extent of the area of the cone of depression (fig. 1) to examine changes in water levels and the effects on aquifer storage within the cone of depression (Yazoo Mississippi Delta Joint Water Management District, 2007; fig. 4). Using annual water-level data within this area and a specific yield value of 0.32, YMD determined that the average fall-to-fall change in storage since 1987 is 150,750 acre-feet per year (acre-ft/yr), which has resulted in a cumulative loss of approximately 3,316,500 acre-feet (acre-ft) within the area of the cone of depression from 1987 to 2009 (Yazoo Mississippi Delta Joint Water Management District, 2010; fig. 4). Water-level declines also have resulted in decreases in baseflow in many Delta streams (fig. 4) to the extent that in the absence of rainfall or irrigation return flow, some stream reaches are dry during the summer months (fig. 5).

The YMD is currently (2010) considering several options for reducing the annual groundwater deficit including the implementation of conservation programs to use water more efficiently, which would reduce the demand for water in crop production. However, it is unclear whether conservation efforts should be applied uniformly to the Delta, as a whole, or if efforts should be focused on areas experiencing large groundwater declines within the cone of depression. Using an existing calibrated U.S. Geological Survey (USGS) regional groundwater flow model, the USGS, in cooperation with the YMD, evaluated conservation scenarios for the alluvial aquifer underlying the Delta in northwestern Mississippi. Simulations of conservation scenarios, varying in both total amount and location, were run for each year from 2008 to 2038 in order to determine the most effective implementation of conservation efforts. The purpose of this report is to document the results of the model simulations to aid the YMD in the development of water-use conservation programs for the study area.

Regional Groundwater Flow Model

Recently, the USGS, completed a large-scale regional model covering the entire Mississippi embayment and extending through the primary drinking-water aquifers as part of the Mississippi Embayment Regional Aquifer Study (MERAS) (fig. 6). This model was constructed using MODFLOW-2005, a software package developed by the USGS (Harbaugh, 2005). The construction and calibration of the MERAS model used for this study is documented in Clark and Hart (2009). The MERAS model consists of a set of discrete blocks in space



Storage data from Yazoo Mississippi Delta Joint Water Management District, 2010

Figure 4. Annual minimum daily discharge of the Big Sunflower River at Sunflower, Mississippi, and cumulative estimated storage loss in the area of the cone of depression in the alluvial aquifer as determined by the Yazoo Mississippi Delta Joint Water Management District in northwestern Mississippi. Discharge graph is blank where data are missing.

Figure 5. Dry streambeds during the summer months due to lack of base flow for (*A*) Big Sunflower River at Sunflower, Mississippi, and (*B*) Bogue Phalia River near Leland, Mississippi.

and time. The blocks represent cells of porous material within which the hydraulic properties are the same. In plan view, the cells have a uniform horizontal spacing of 1 mile on a side, but have variable thicknesses in the vertical direction. A set of finite-difference equations describes groundwater flow through each cell. These equations can be solved to simulate either equilibrium (steady-state) conditions or transient conditions, which simulate changes in stresses (such as water withdrawal from wells) over fixed periods of time. The finite-difference grid is oriented north-south and consists of 414 rows, 397 columns, and 13 layers.

The MERAS model simulates 137 years (1870–2007) of system response to stress divided into 69 stress periods. The first stress period is simulated as steady state to represent predevelopment conditions. Stress periods 2 through 27 are variable in length to reflect embayment-wide changes in groundwater withdrawals. Stress periods 28 (beginning in 1986) through 69 are each 6 months in length to reflect spring–summer (April–September) and fall–winter (October–March) conditions related to irrigation (Clark and Hart, 2009).

Areal recharge is applied throughout the MERAS model area using the MODFLOW-2005 Recharge Package (Harbaugh, 2005) and represents net recharge. Net recharge is defined as “the entry into the saturated zone of water made available at the water-table surface, together with the associated flow away from the water table within the saturated zone” (Freeze and Cherry, 1979) because evapotranspiration (ET) is not explicitly simulated. A total of 19 recharge zones were classified for the MERAS model; 3 of these zones cover the alluvial aquifer within Mississippi. Each recharge zone was assigned a recharge fraction, which was used to estimate daily recharge rates by multiplying the recharge fraction by precipitation. Recharge rates across the three zones for the alluvial aquifer in Mississippi range from 0.1 to 3.25 in/yr.

Pumpage from irrigation, municipal, and industrial wells were simulated using the Multi-Node Well (MNW) Package (Halford and Hanson, 2002). The MNW Package allows for simulation of flow in wells that are completed in multiple aquifers or model layers. There are 43 streams included within the MERAS model. Each stream in the MERAS model area was represented using the Streamflow-Routing (SFR) Package of MODFLOW (Prudic and others, 2004). The initial criterion for the inclusion of streams in the MERAS model was a mean annual flow of 1,000 cubic feet per second (ft^3/s) or more. Other streams were added based on inclusion by previous model studies that demonstrated the interaction of the streams with surficial aquifers.

The perimeter of the MERAS model area and the base of the flow system are represented as no-flow boundaries. The MERAS model simulation assumed that the density of water remained constant in time throughout the flow system. The downdip limit of each model layer is a no-flow boundary, which approximates the extent of water with less than 10,000 milligrams per liter (mg/L) of dissolved solids.

Conservation Scenario Development

Conservation scenarios were developed to simulate where the implementation of water-use conservation efforts might have the greatest effect on storage in the alluvial aquifer—either uniformly throughout the Delta, or focused in the area of the cone of depression. The scenarios were simulated with the MERAS model by extending the simulation period by 30 years, to 2038. Sixteen stress periods were used to represent the projected 30-year period. The first stress period is 275 days in length, to extend the MERAS model to the end of 2007. Each stress period following 2007 is 2 years in length. For each scenario, recharge to the alluvial aquifer underlying the Delta is held constant by multiplying the recharge fraction assigned to each of the three recharge zones within the Delta by the long-term average precipitation value for the Delta (54 in/yr). Calibrated recharge fractions from the three recharge zones within the Delta were 0.00342, 0.038, and 0.0446, resulting in recharge rates (for 54 in/yr of rainfall)

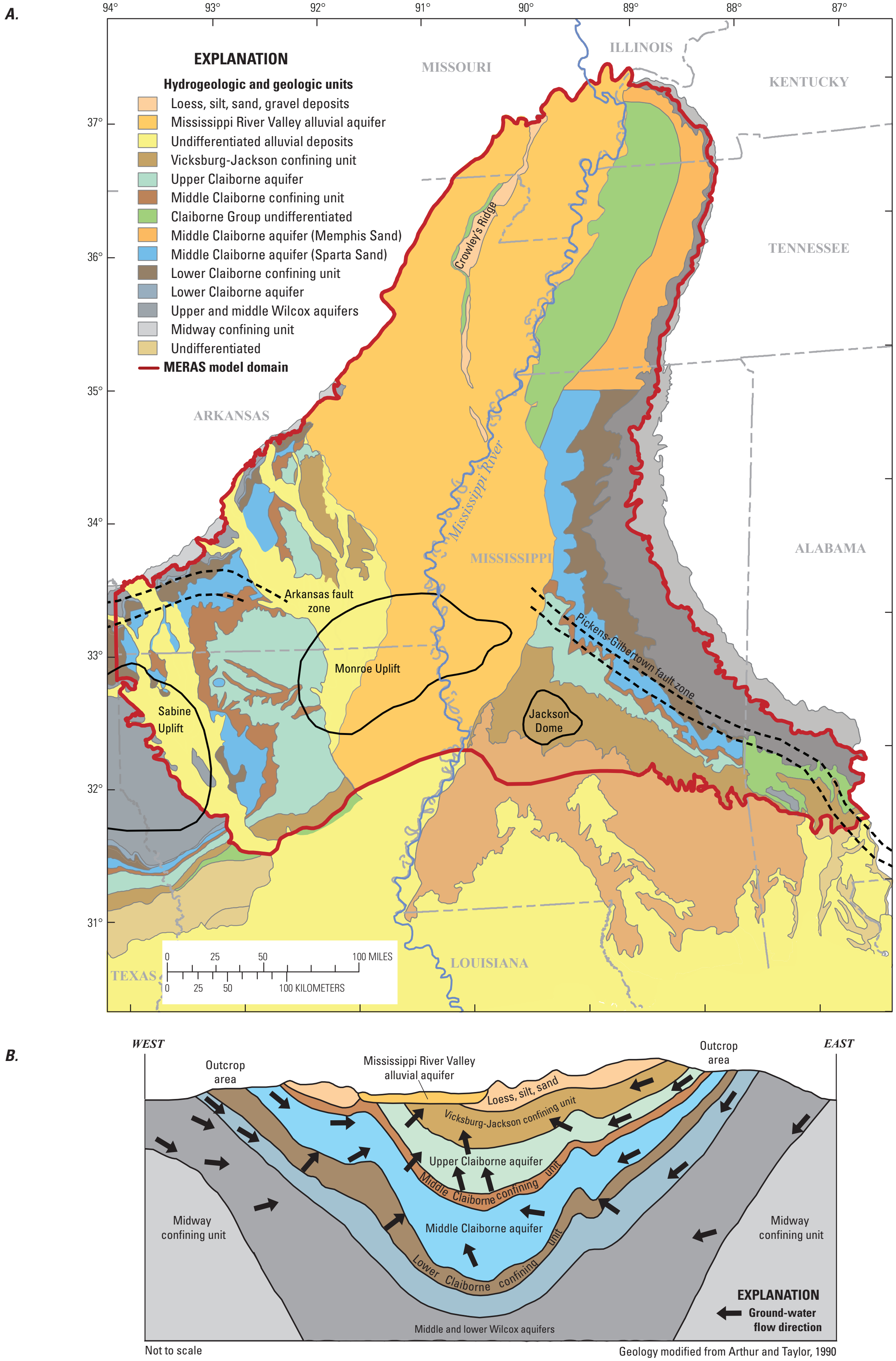


Figure 6. (*A*) Mississippi Embayment Regional Aquifer Study model domain and surficial geology; and (*B*) generalized section of hydrogeologic and geologic units.

of 0.18, 2.05, and 2.41 in/yr, respectively. Water use from the alluvial aquifer underlying the Delta was modified to represent varying amounts and distributions of conservation to produce the following simulation scenarios:

- **Base scenario**—Water use from existing regional model remains constant at 2007 rates throughout the simulation period.
- **5-percent Delta-wide conservation scenario**—Water use is reduced by 5 percent from the base scenario across the Delta, beginning in 2010, and then held constant throughout the simulation period.
- **5-percent cone-equivalent conservation scenario**—Water use is reduced by 11 percent from the base scenario (volume amount is equivalent to 5-percent Delta-wide conservation scenario) within the area of the cone of depression, beginning in 2010, and then held constant throughout the simulation period. Water use in the remaining part of the Delta is held at the base scenario rates.
- **25-percent Delta-wide conservation scenario—**Water use is reduced by 25 percent from the base scenario across the Delta, beginning in 2010, and then held constant throughout the simulation period.
- **25-percent cone-equivalent conservation scenario**—Water use is reduced by 55 percent from the base scenario (volume amount is equivalent to 25-percent Delta-wide conservation scenario) within the area of the cone of depression, beginning in 2010, and then held constant throughout the simulation period. Water use in the remaining part of the Delta is held at the base scenario rates.

Conservation Scenario Results

Results from each conservation scenario were compared to the results from the base scenario to determine the effectiveness of each conservation scenario. The effectiveness of each conservation scenario was measured by the changes in the depth to water and the volume of water in storage within the alluvial aquifer relative to the base scenario. Depth to water represents the thickness of the unsaturated zone, and as this value increases, the thickness of the saturated zone decreases. Storage represents the amount of water available for use within the pore spaces, fractures, and cracks beneath land surface. Water taken from storage is no longer available for future use unless recharged from another source. Groundwater overdraft, defined as annual withdrawal in excess of the amount that can safely be withdrawn without an undesirable effect (Freeze and Cherry, 1979), occurs when more water is removed from storage than is replaced each year by recharge. The base scenario, in which no conservation was employed, represents the largest overall water-level declines and loss of storage within the aquifer over the simulation period; therefore, each conservation scenario results in improvement of water level and storage within the aquifer.

Using the model output, depth to water after the 2038 stress period was determined for the base scenario and for each of the four conservation scenarios. For each conservation scenario, the percentage of change in water level relative to the percentage of change in water level for the base scenario was then determined for each model cell (fig. 7). Percentage values greater than 0 indicate that the conservation scenario water level increased. A percentage value equal to 0 indicates either that the depth to water for the conservation scenario is equal to that of the base scenario (no change), or water levels decreased between the base scenario and the conservation scenario. Typically, a decrease in water levels between the base scenario and conservation scenario occurs within a model cell when pumping from a well is reduced or shut off during the base simulation due to constraints within the model that do not let a well pump until the cell is completely dry. During the conservation scenario, the well is allowed to pump throughout the simulation (due to the conservation measures resulting in greater saturated thickness); therefore, the conservation scenario water level is lower than in the base scenario. For the entire Delta area, the Delta-wide scenarios result in greater average water-level improvements (relative to the base scenario) than the cone-equivalent scenarios. For the area of the cone of depression, the cone-equivalent scenarios result in greater water-level improvements (relative to the base scenario) than the Delta-wide scenarios because all conservation efforts are concentrated within the area of the cone of depression (table 1). In comparing average water-level improvements across the entire Delta to those within the area of the cone of depression, the greatest average improvements in water level occur within the area of the cone of depression for all conservation scenarios. This is caused by the relatively larger volume of unsaturated aquifer material within the area of the cone of depression and the hydraulic gradient, which slopes from the periphery of the Delta towards the cone of depression.

Net withdrawal from storage throughout each scenario simulation was determined using the USGS program ZONEBUDGET (Harbaugh, 1990), which uses MODFLOW cell-by-cell flow data and user-defined subregional zones to compute water budgets for each subregional zone. Five subregional zones were designated within the MERAS model (fig. 8). Water budget inflows to the alluvial aquifer include storage, recharge from precipitation, stream leakage, discharge from underlying units, leakage from the Mississippi River on the western periphery, and interflow from the Bluff Hills escarpment on the eastern periphery. Water budget outflows from the alluvial aquifer include storage, pumpage, leakage to the underlying units, leakage to the Mississippi River on the western periphery, leakage to streams, and leakage to the Bluff Hills escarpment on the eastern periphery (fig. 9). The dominant transient stress (outflow) on

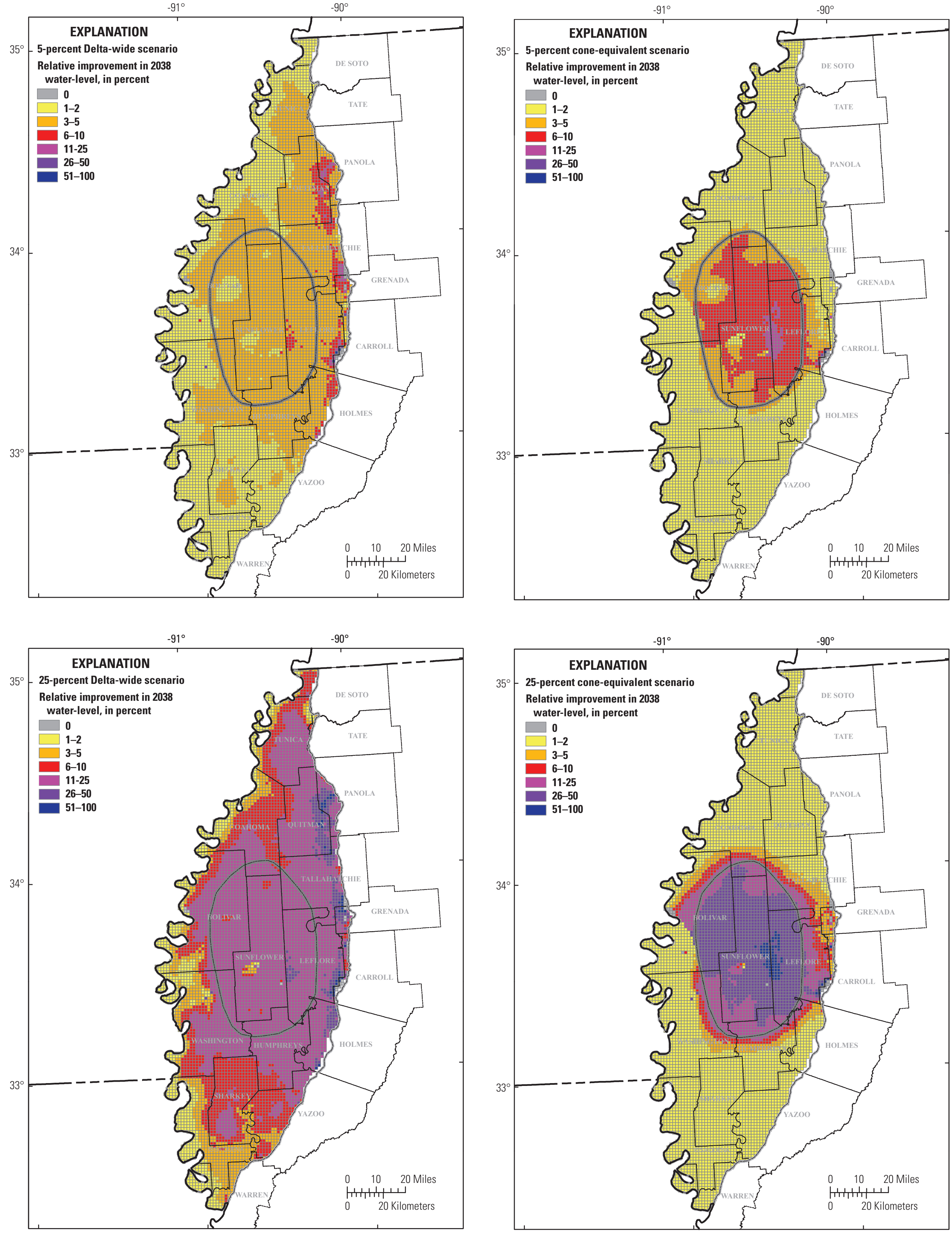


Figure 7. Percentage of change in 2038 water level for each conservation scenario relative to the base scenario.

Table 1. Average percentage of increase relative to the base scenario in alluvial aquifer water levels for each conservation scenario.

Conservation scenario	Average increase in water level relative to base scenario, in percent	
	Delta-wide	Within cone of depression
5-percent Delta-wide	2.5	3.1
5-percent cone-equivalent	2.0	6.3
25-percent Delta-wide	12.1	15.8
25-percent cone-equivalent	9.8	31.7

the alluvial aquifer is pumping, and the majority of water supplied from pumping is from storage within the alluvial aquifer.

To compare storage loss from each conservation scenario relative to the base scenario, the percentage of increase in storage within the alluvial aquifer relative to the base scenario was determined for both Delta-wide (zones 1 and 2 in fig. 8) and the area of the cone of depression only (zone 2 in fig. 8) using storage data throughout the conservation period of the simulation (2010–2038). Of the four conservation scenarios, the 25-percent cone-equivalent scenario resulted in the greatest Delta-wide increase in storage relative to results for the base scenario, with a 32-percent improvement (fig. 10). For the area of the cone of depression, the 25-percent cone-equivalent scenario also had the greatest increase in storage relative to the base scenario, with a 60-percent improvement. The 25-percent Delta-wide scenario resulted in a 29-percent improvement relative to the results for the base scenario for both the Delta-wide and cone of depression areas. Relative improvements in storage from the 5-percent Delta-wide and cone-equivalent scenarios were less than that from the 25-percent scenarios; however, they were similar to the 25-percent scenarios in that the 5-percent cone-equivalent scenario resulted in a small improvement Delta-wide relative to the 5-percent Delta-wide scenario because all conservation was focused on the area of the cone of depression. Delta-wide, the relative amount of storage increased by 1 percent between the 5-percent cone-equivalent and Delta-wide scenarios, and by 3 percent between the 25-percent cone-equivalent and Delta-wide scenarios. These results imply that focusing conservation efforts within the area of the cone of depression, rather than distributing conservation efforts uniformly across the Delta, results in greater improvements in the amount of storage within the alluvial aquifer. In addition, as the total amount of conservation increases (that is from 5 to 25 percent), the relative increase in storage between the cone-equivalent and Delta-wide scenarios also increases, resulting in greater gains in storage in the cone-equivalent scenario than in the Delta-wide scenario, for the same amount of conservation.

Model Limitations

Limitations of analysis using the MERAS model are documented in Clark and Hart (2009). The basic limitations that should be considered when interpreting model results are restated here. An understanding of model limitations is essential to effective use of simulated water-level and storage results. The accuracy of a groundwater model is limited by simplification of complexities within the flow system (conceptual model), space and time discretization effects, and assumptions made in the formulation of the governing flow equations. Model accuracy also is affected by cell size, number of layers, accuracy of boundary conditions, accuracy and availability of hydraulic property data, accuracy of withdrawal and areal recharge estimates, historical data for calibration, parameter sensitivity, and the interpolations and extrapolations that are inherent in using data in a model. Although a model might be calibrated, the calibration parameter values are not unique in yielding acceptable distributions of hydraulic head.

Information on the amount of groundwater withdrawn from the various aquifers (water use) and the amount of recharge entering the groundwater system is crucial to the MERAS model. While some site-specific information on water use exists for some areas, particularly irrigation water use in Arkansas, the period of record for this information is only about 10 to 15 years, which is a relatively small amount of time compared to the simulation calibration period of 137 years. Recharge in the MERAS model is calibrated based on water-level and streamflow observations. The range of recharge values in the MERAS model is within the range of values used by past models constructed in the study area and based on streamflow separation methods; however, field values to validate these ranges are sparse or difficult to compare. For much of the study area and simulation period, each of these datasets pertaining to water use and recharge currently has little or no information on actual values.

Another critical component of the alluvial aquifer water balance is the interaction of the many miles of rivers and streams with the alluvial aquifer in the Delta. To simulate stream leakage in the MERAS model, basic factors such as the thickness and hydraulic conductivity of the streambed were estimated because there have been very few studies to quantify these factors. The factors used in the model could change if new information becomes available.

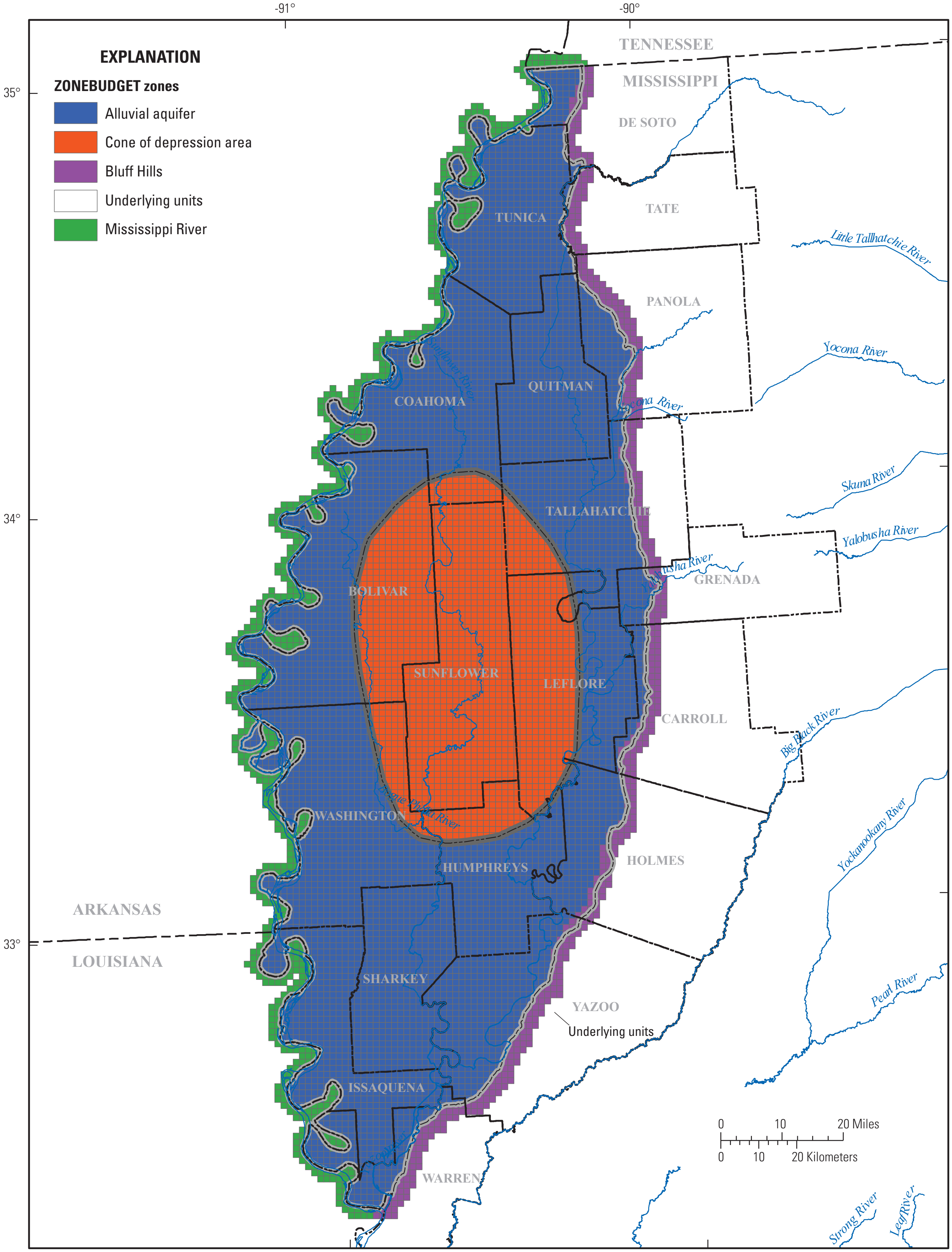


Figure 8. Subregional zones designated for ZONEBUDGET water-budget computations.

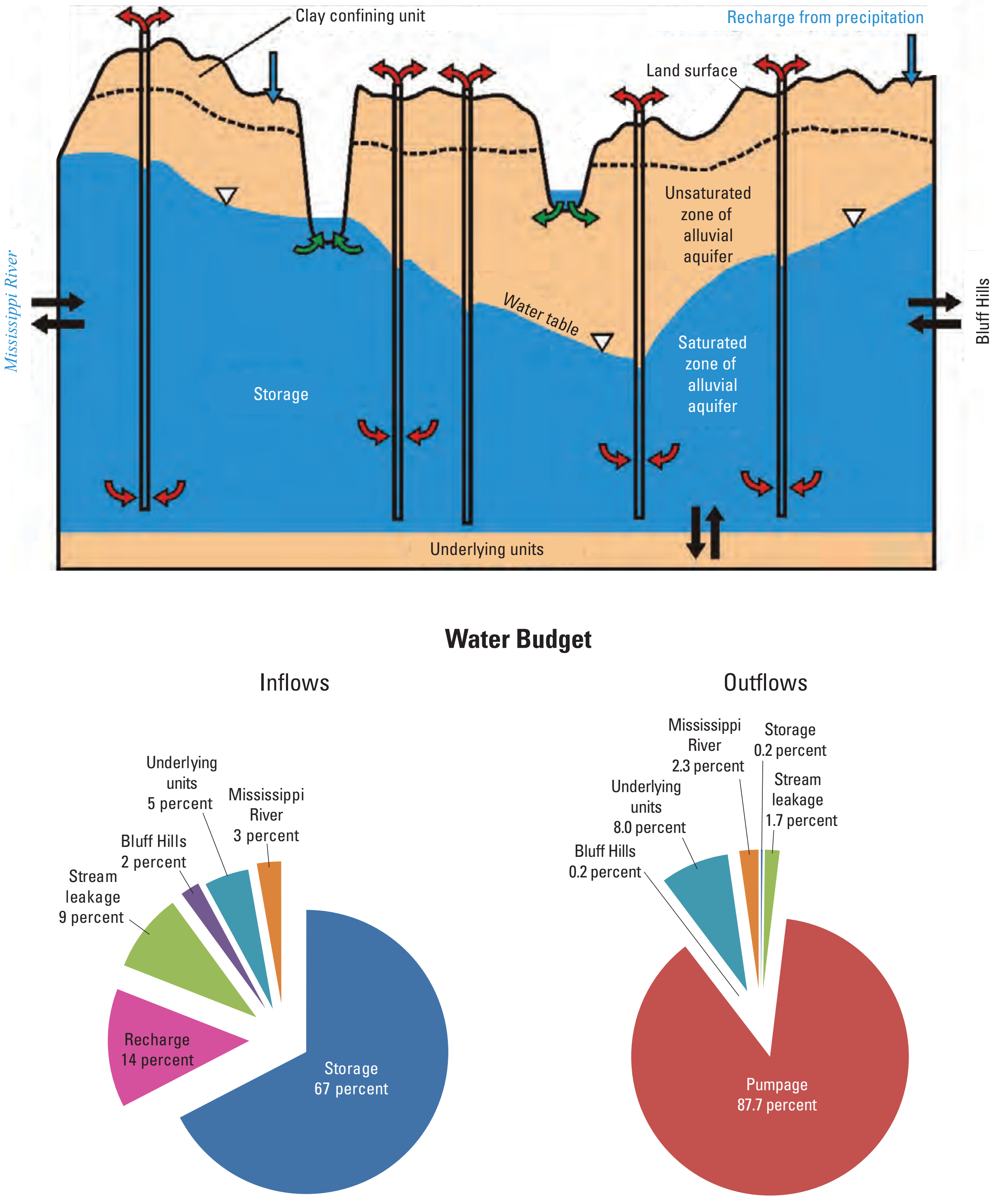


Figure 9. Water-budget inflows and outflows for base scenario simulation period (2007–2038).

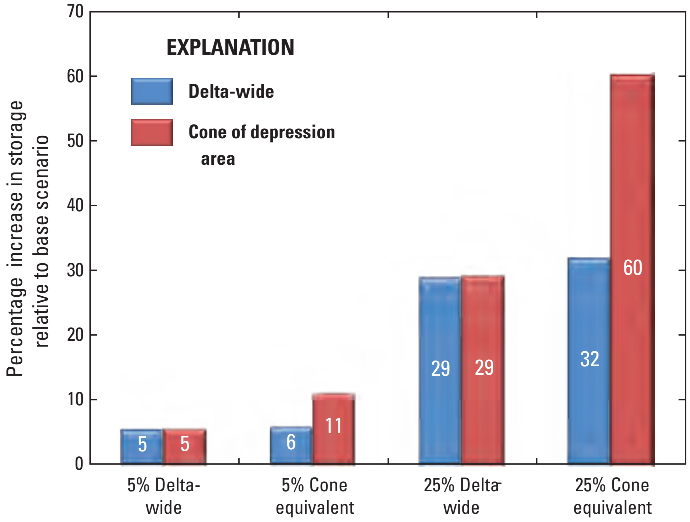


Figure 10. Percentage of increase in storage within the alluvial aquifer relative to the base scenario for each conservation scenario for the entire alluvial aquifer (Delta-wide) and the area of the cone of depression.

Summary

The Mississippi Delta, once a floodplain to the Mississippi River covered with hardwoods and marshland, is now a highly productive agricultural region of large economic importance to Mississippi. Water for irrigation is supplied primarily by the Mississippi River Valley alluvial aquifer, and although the alluvial aquifer has a large reserve, there is evidence that the current rate of water use from the alluvial aquifer is not sustainable. To sustain water resources in the Delta, the Yazoo Mississippi Delta Joint Water Management District (YMD) is currently (2010) considering several options for reducing the annual groundwater deficit including the implementation of conservation programs to use water more efficiently and stop or slow declining water levels. Recently, the U.S. Geological Survey (USGS) completed a large-scale regional model of the Mississippi embayment, extending through the primary drinking-water aquifers as part of the Mississippi Embayment Regional Aquifer Study (MERAS). Using this regional groundwater flow model, conservation scenarios were evaluated by the USGS, in cooperation with the YMD, for the alluvial aquifer underlying the Delta region in northwestern Mississippi. Conservation scenarios were developed to assess where the implementation of water-use conservation efforts would have the greatest effect on future water availability—either uniformly throughout the Delta, or focused in the area of the cone of depression in the central Delta. Five scenarios were simulated with the MERAS model: (1) a base scenario in which water use remained constant at 2007 rates throughout the entire simulation; (2) a 5-percent “Delta-wide” conservation scenario in which water use across the Delta was decreased by 5 percent; (3) a 5-percent “cone-equivalent” conservation scenario in which water use within the area of the cone of depression was decreased by 11 percent, a volume equivalent to the 5-percent Delta-wide conservation scenario; (4) a 25-percent Delta-wide conservation scenario in which water use across the Delta was decreased by 25 percent; and (5) a 25-percent cone-equivalent conservation scenario in which water use within the area of the cone of depression was decreased by 55 percent, a volume equivalent to the 25-percent Delta-wide conservation scenario.

The simulated Delta-wide scenarios resulted in greater average water-level improvements (relative to the base scenario) for the entire Delta area than the cone-equivalent scenarios. The cone-equivalent scenarios resulted in greater average water-level improvements within the cone of depression because of focused conservation efforts. Regardless of the location of conservation (Delta-wide or within the cone of depression), the greatest average improvements in water level occur within the area of the cone of depression because of the large area of unsaturated aquifer material within the area of the cone of depression and the hydraulic gradient, which slopes from the periphery of the Delta towards the area of the cone of depression.

Of the four conservation scenarios, the 25-percent cone-equivalent scenario resulted in the greatest increase in storage relative to the base scenario with a 32-percent improvement over the base scenario across the entire Delta and a 60-percent improvement within the area of the cone of depression. Although the improvements in storage for the 5-percent Delta-wide and cone-equivalent scenarios were less than for the 25-percent scenarios, they were similar to the improvements for the 25-percent scenarios in that the 5-percent cone-equivalent scenario resulted in a small improvement Delta-wide relative to the 5-percent Delta-wide scenario because all conservation was focused on the area of the cone of depression. Therefore, these results imply that focusing conservation efforts within the area of the cone of depression, rather than distributing conservation efforts uniformly across the Delta, results in greater improvements in the amount of storage within the alluvial aquifer. In addition, as the total amount of conservation increases (that is from 5 to 25 percent), the difference in storage improvement between the Delta-wide and cone-equivalent scenarios also increases, resulting in greater gains in storage in the cone-equivalent scenario over the Delta-wide scenario for the same amount of conservation.

References

Arthur, J.K., 2001, Hydrogeology, model description, and flow analysis of the Mississippi River Alluvial Aquifer in Northwestern Mississippi: U.S. Geological Survey Water-Resources Investigations Report 01–4035, 47 p.

Clark, B.R., and Hart, R.M., 2009, The Mississippi Embayment Regional Aquifer Study (MERAS)—Documentation of a groundwater flow model constructed to assess water availability in the Mississippi embayment: U.S. Geological Survey Scientific Investigations Report 2009–5172, 62 p.

Economic Research Service, U.S. Department of Agriculture, 2010, The economics of food, farming, natural resources, and rural America—State fact sheets—Mississippi, accessed January 20, 2011, at http://www.ers.usda.gov/State Facts/MS.htm.

Fisk, H.N., 1944, Geological investigation of the alluvial valley of the lower Mississippi River: U.S. Department of Army, Mississippi River Commission, 78 p.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice-Hall, 604 p.

Halford, K.J., and Hanson, R.T., 2002, User guide for the drawdown-limited, Multi-Node Well (MNW) Package for the U.S. Geological Survey's modular three-dimensional finite-difference ground-water flow model, versions MODFLOW-96 and MODFLOW-2000: U.S. Geological Survey Open-File Report 02–293, 33 p.

Harbaugh, A.W., 1990, A computer program for calculating subregional water budgets using results from the U.S. Geological Survey modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 90–392, 24 p.

Harbaugh, A.W., 2005, MODFLOW-2005, the U.S. Geological Survey modular ground-water model—The ground-water flow process: U.S. Geological Survey Techniques and Methods 6–A16, variously paged.

Hosman, R.L., 1988, Geohydrologic framework of the Gulf Coastal Plain: U.S. Geological Survey Hydrologic Investigations Atlas 695, 2 sheets.

Maupin, M.A., and Barber, N.L., 2005, Estimated withdrawals from principal aquifers in the United States, 2000: U.S. Geological Survey Circular 1279, 46 p.

Prudic, D.E., Konikow, L.F., and Banta, E.R., 2004, A new streamflow-routing (SFR1) package to simulate stream-aquifer interaction with MODFLOW-2000: U.S. Geological Survey Open-File Report 2004–1042, 95 p.

Yazoo Mississippi Delta Joint Water Management District, 2007, 2006 Annual report, accessed Febuary 1, 2009, at http://www.ymd.org/pdfs/2006annualreport.pdf.

Yazoo Mississippi Delta Joint Water Management District, 2010, 2009 Annual work summary, accessed September 10, 2010, at http://www.ymd.org/pdfs/2009annualsummary.pdf.

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