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Effects of Potential Changes in Groundwater Withdrawals from the Sparta Aquifer on Water-Level Altitudes in Jefferson County, Arkansas

Scientific Investigations Report 2009-5234

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

Cover photograph. Well within east Pine Bluff area well field, Pine Bluff, Arkansas. Photograph by John B. Czarnecki, U.S. Geological Survey.

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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
million gallons per day (Mgal/d)	0.134	cubic foot per day (ft^3/d)

Altitude, as used in this report, refers to distance above the vertical datum, and is referenced to the National Geodetic Vertical Datum of 1929 (NGVD of 1929).

Effects of Potential Changes in Groundwater Withdrawals from the Sparta Aquifer on Water-Level Altitudes in Jefferson County, Arkansas

By John B. Czarnecki

Abstract

A groundwater-flow model of the Sparta aquifer was used to evaluate changes in water-level altitudes associated with the withdrawal of groundwater at varying rates from a well field near Pine Bluff, Arkansas, in Jefferson County. Water-level altitudes at three different model cell locations from five different scenarios for varying withdrawal rates from the well field were compared for the period 1998 to 2048. The three model cells used for the comparison were located (1) near the center of the well field, (2) near the center of the city of Pine Bluff (about 5 miles west of the center of the well field), and (3) about 15 miles north of the well field. Pumping rates at the well field were varied from 7.2 million gallons per day to 27 million gallons per day for the five scenarios analyzed, and water-level hydrographs were constructed for each scenario for each of the three model cell locations. Water-level altitudes near the center of the well field changed the most of the three model cell locations analyzed. Water-level altitudes were approximately 90 feet higher for the 7.2 million gallon per day scenario in 2048 compared to the baseline scenario of 25.4 million gallons per day. Whereas, water-level altitudes at the same location were 9 feet lower for the 27 million gallon per day scenario in 2048 compared to the baseline scenario.

Introduction

The Sparta aquifer is a water-bearing assemblage of sands and interbedded clay and silt layers that underlies most of eastern Arkansas and several adjacent States. The Sparta aquifer is an important source of water for industry and municipalities. In 2005, about 170 million gallons of water per day (Mgal/d) was withdrawn from the Sparta aquifer in Arkansas, with Jefferson County having the largest amount (50 Mgal/d) (Holland, 2007). Groundwater withdrawals have caused cones of depression to develop in the aquifer water-level surface, some several hundred feet (ft) deep (Schrader, 2007). Long-term water-level measurements from the 1930's to present from wells completed in the Sparta aquifer show an average annual decline of 1 foot per year (ft/yr) or more in some areas. The expansion of the cones of depression and the consistent water-level declines indicate that groundwater withdrawals are occurring at a rate that is greater than the sustainable yield of the aquifer.

For many years, the Arkansas Natural Resources Commission (ANRC) has worked with the U.S. Geological Survey (USGS) and other agencies in the development of groundwater-flow models to be used as management tools to determine the sustainability of the water resource. A groundwater-flow model of the Sparta aquifer was developed for eastern Arkansas, and parts of northern Louisiana, western Mississippi, and western Tennessee (McKee and Clark, 2003). The flow model showed that continued groundwater withdrawals at 1997 rates for the Sparta aquifer could not be sustained indefinitely without causing water levels to decline below the top of the Sparta aquifer or decline at rates greater than 1 ft/yr (metrics that are associated with Critical Groundwater Area designation by the ANRC for certain counties in Arkansas (Arkansas Natural Resources Commission, 2009)).

For the analysis contained in this report, the groundwater-flow model of the Sparta aquifer (fig. 1) of McKee and Clark (2003) (hereafter referred to as the Sparta model) was used to simulate groundwater flow and water-level altitudes for the period 1918 to 2049. The study area includes Jefferson County, which was designated as a Critical Groundwater Area by the ANRC in 1998. Substantial changes in water use in an area located about 5 miles (mi) east of the center of Pine Bluff, Arkansas, are being considered. The USGS, in cooperation with the ANRC, has analyzed the effects of these water withdrawal changes on water-level altitudes within the Sparta aquifer.

This report compares simulated water-level altitudes (relative to the National Geodetic Vertical Datum of 1929) derived from the Sparta model for withdrawal rates of 7.2 Mgal/d (scenario 1), 12 Mgal/d (scenario 2), 24 Mgal/d (scenario 3), 25.4 Mgal/d (baseline scenario), and 27 Mgal/d (scenario 4) from the area east of the Pine Bluff well field (hereafter referred to as the east Pine Bluff area (EPBA) well field) at three model cell locations (fig. 2). The three model cell locations are: (1) model cell 1, a point near the center of the EPBA well field; (2) model cell 2, a point near the center of the city of Pine Bluff, Arkansas (about 5 mi west of the center of the well field); and (3) model cell 3, a point about 15 mi north of the EPBA well field. Simulated water-level altitudes were compared for the period 1998 to 2048.

Methods

The Sparta model was used to simulate water-level altitudes for different withdrawal rates from the EPBA well field for a 50-year period from 1998 to 2048. The 50-year period was divided into 10 transient stress periods (1998-2000; 2000-02; 2002-05; 2005-08; 2008-12; 2012-17; 2017-23; 2023-30; 2030-38; and 2038-48). Groundwater-withdrawal rates from the EPBA well field (fig. 2) totaled 25.4 Mgal/d for the simulation period 1990 to 1997, which was specified as the baseline scenario rate (the average reported water use for the period 1990-97). Because the withdrawal rate distribution was nonuniform over the well field in the Sparta model of McKee and Clark (2003), the ratio of the withdrawal rate for each model cell divided by the total EPBA well-field withdrawal rate (25.4 Mgal/d) was calculated and multiplied by the total pumping rates for each of the scenarios investigated, and assigned to each of the withdrawal model cells in the well field. Each model cell has an area of 1 square mile (mi^2).

Effects of Groundwater Withdrawals on Water-Level Altitudes

Simulated water-level altitudes vary in response to changes in withdrawal rates specified in each of the different scenarios at the EPBA well-field model cells. Hydrographs for each scenario at the three model cell locations (fig. 2) are plotted in figures 3 through 5. The general shape and relation of the different hydrographs are maintained for each of the hydrograph sets (figs. 3-5), although the magnitude of water-level altitude change decreases with distance from the EPBA well field.

The effect of reducing groundwater withdrawals from the EPBA well-field model cells can be seen in the higher water-level altitudes for scenarios 1, 2, and 3 compared to the baseline scenario (figs. 3-5; tables 1-3). The baseline scenario simulated a water-level altitude decline of approximately 20 feet (ft) from 1998 to the end of the simulation in 2048. Water-level altitude rises for scenarios 1 and 2 from 1998 until the end of the simulation in 2048 at all three model cell locations because the total withdrawal rate is reduced compared to the baseline scenario. Water-level altitudes rebounded approximately 90 and 65 ft at the center of the EPBA well field for scenarios 1 and 2, respectively, when compared to the baseline scenario. For scenario 3, however, the trend in water-level altitude continues downward (figs. 3-5) despite the slight reduction in withdrawal rate (1.4 Mgal/d) compared to the baseline scenario. The decline at each of the three model cell locations for scenario 3 is not as large as for the baseline scenario (figs. 3-5). Compared to the baseline scenario, scenario 4 produced a decline in water-level altitude of 9 ft at the center of the EPBA well field in 2048. Water-level altitudes associated with scenario 3 and 4 are similar (within about 6 and -9 ft) to the baseline scenario water-level altitude. At the city of Pine Bluff (model cell 2) simulated water-level altitudes for reduced withdrawal rates in scenarios 1 and 2 are approximately 70 and 50 ft higher, respectively, than the baseline scenario water-level altitude. Water-level altitudes associated with scenario 3 and 4 are similar (within about 5 and -7 ft) to the baseline scenario water-level altitude. At a point about 15 mi north of the EPBA well field (model cell 3), simulated water-level altitudes for reduced withdrawal rates in scenarios 1 and 2 are approximately 30 and 25 ft higher, respectively, than the baseline scenario water-level altitude. Water-level altitudes associated with scenario 3 and 4 are similar (within about 2 and -3 ft) to the baseline scenario water-level altitude. Simulated water-level altitudes at all three model cell locations for all scenarios were higher than the maximum altitude of the top of the Sparta aquifer (about -300 ft). Even with decreased withdrawals from the EPBA well-field model cells, a downward trend of water-level altitudes occurs for all scenarios (figs. 3-5), which indicates effects from withdrawals from the Sparta aquifer outside the EPBA well field.

Model Limitations

Simulated water-level altitudes resulting from withdrawals at the EPBA well field represent average conditions over the 1-mi^2 grid cells of the model. Drawdown at the actual location of the withdrawal wells will be greater.

Because the model is a simplification of a complex system, some error in simulated water-level altitude is expected, similar to the mean absolute difference between observed and simulated water-level altitudes of about 18 ft obtained by McKee and Clark (2003); however, the magnitude of the error in the simulated change in water-level altitude with time at the EPBA well field likely would be less than this amount. Local variations in hydraulic conductivity and specific storage not accounted for in the model result in additional differences between simulated and actual water-level altitudes.

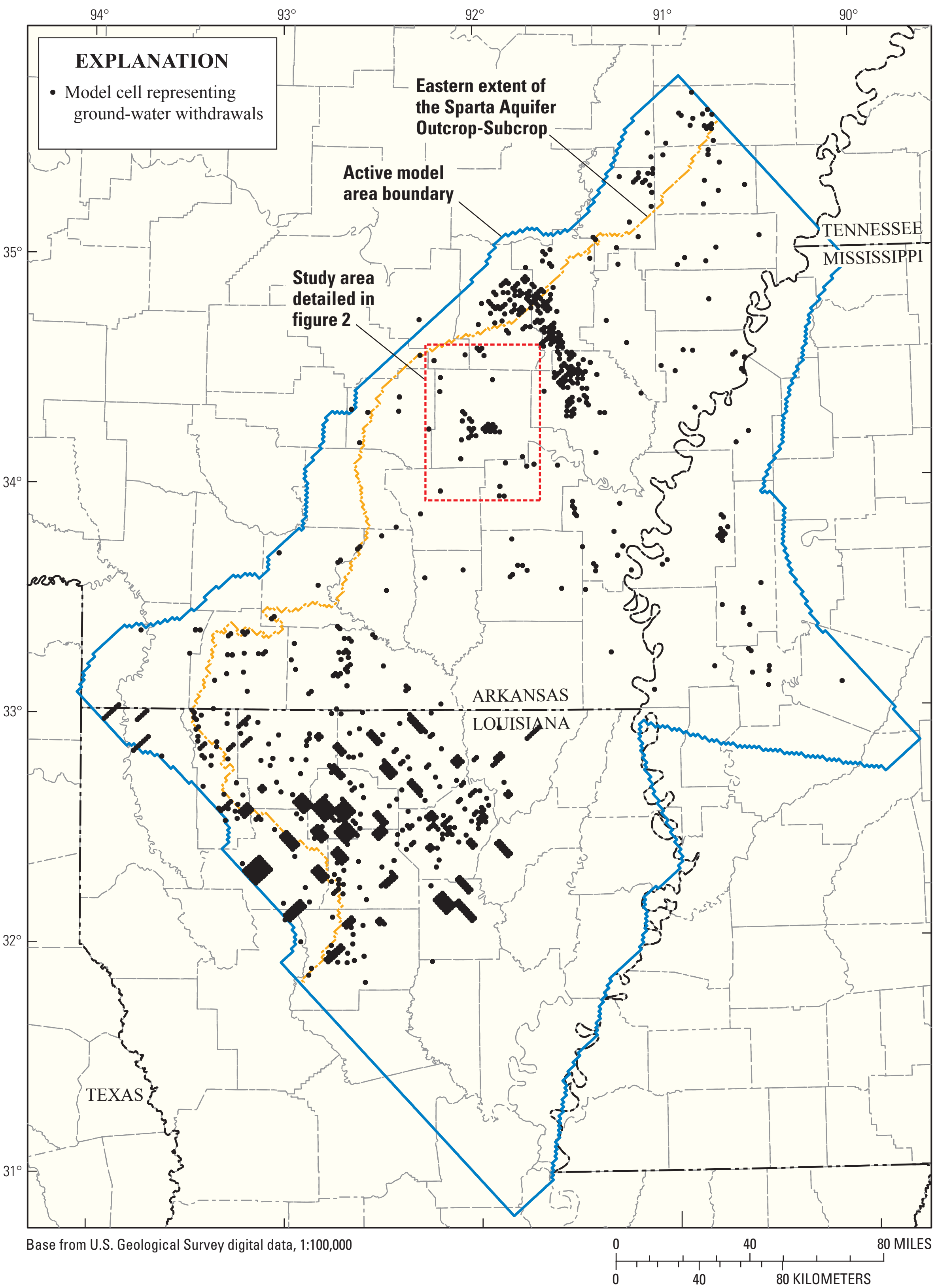

Figure 1. Location of study area, active model area, and model cell locations with groundwater withdrawals.

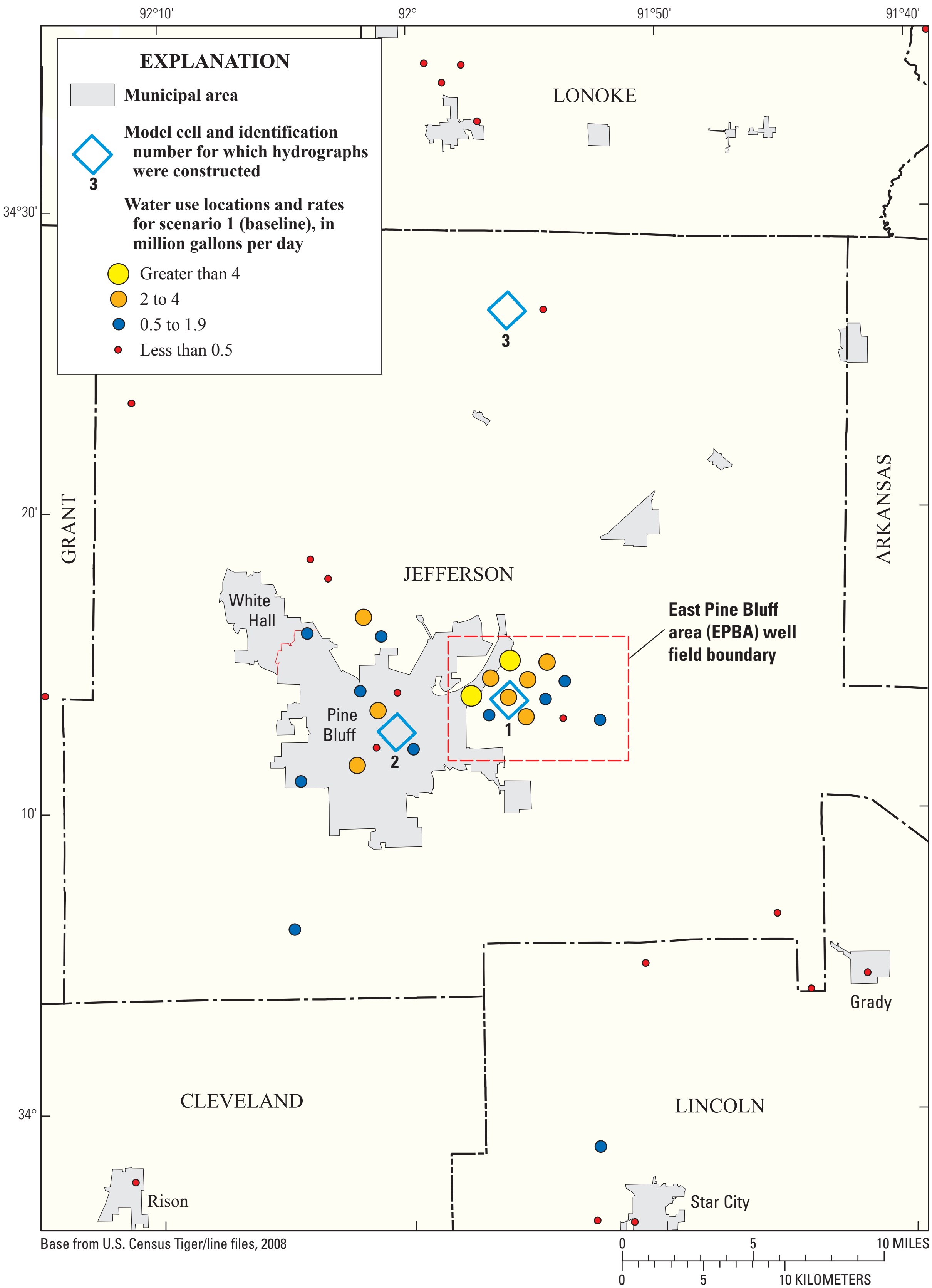

Figure 2. Model cell locations with groundwater withdrawals within study area.

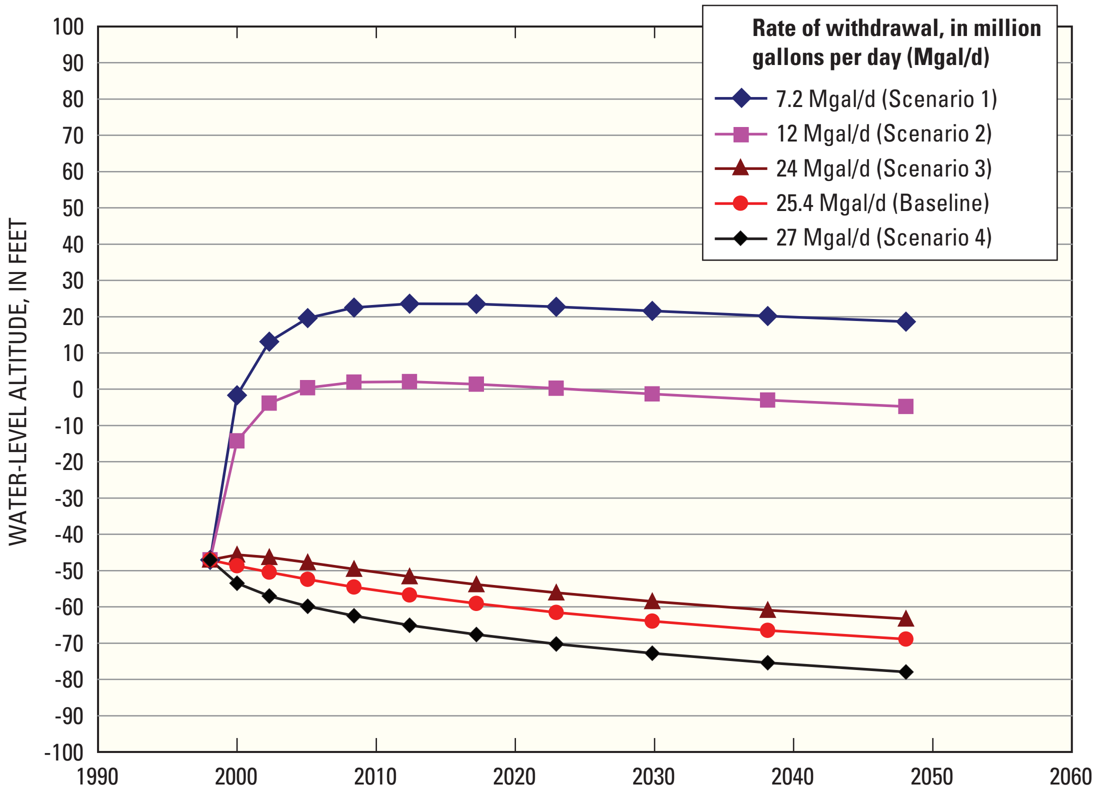

Figure 3. Simulated water-level altitudes within the Sparta aquifer at model cell 1 near the center of east Pine Bluff, Arkansas, area well field.

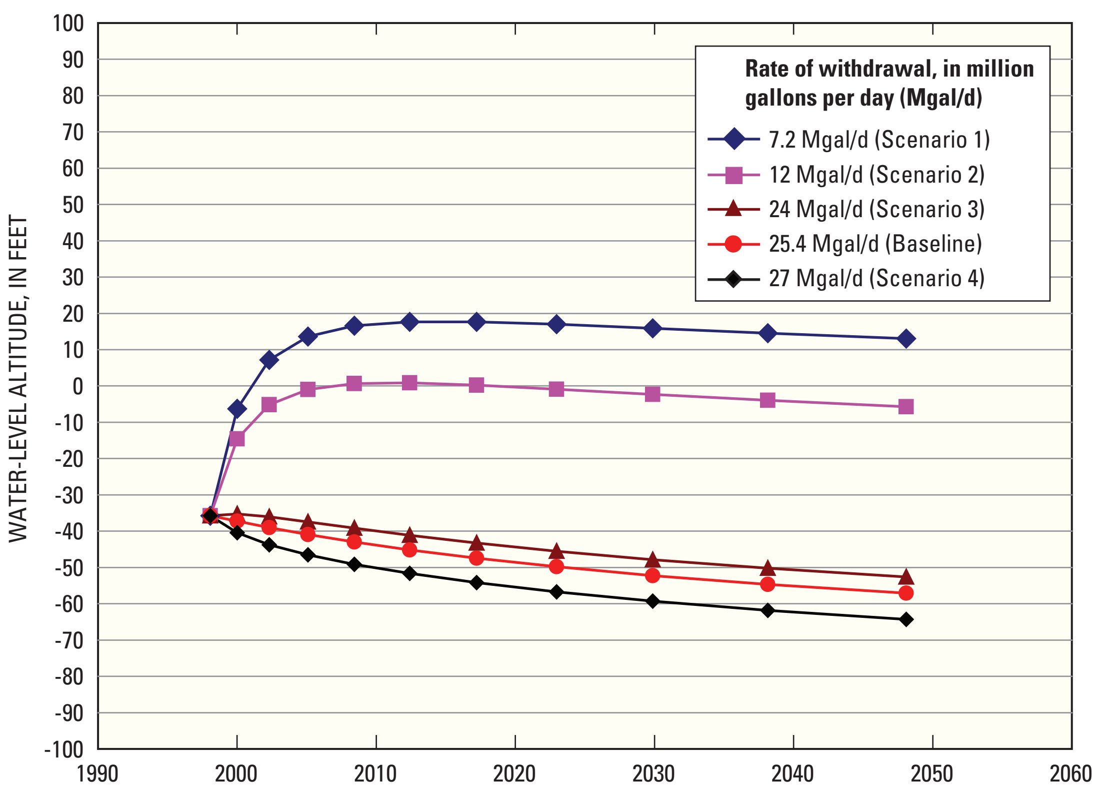

Figure 4. Simulated water-level altitudes within the Sparta aquifer at model cell 2 near the center of the city of Pine Bluff, Arkansas.

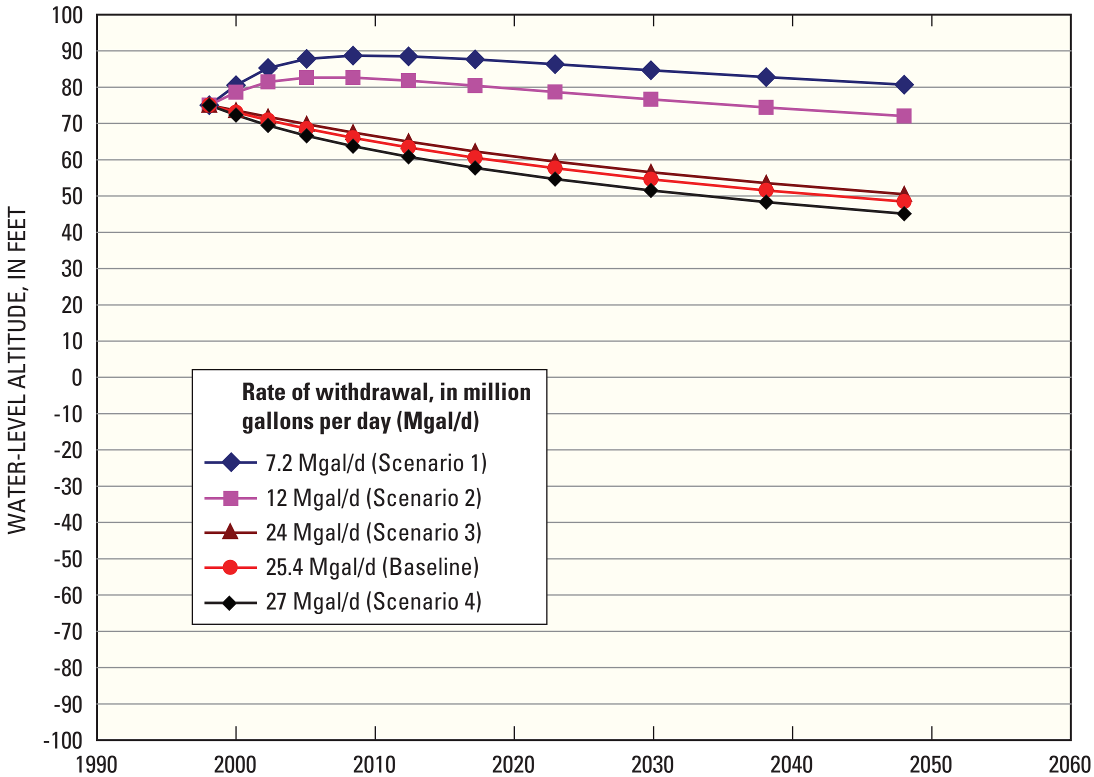

Figure 5. Simulated water-level altitudes within the Sparta aquifer at model cell 3 about 15 miles north of the east Pine Bluff, Arkansas, area well field.

Table 1. Difference between simulated water-level altitude for each scenario and the baseline scenario at model cell 1 near the center of the east Pine Bluff, Arkansas, well field.

[all values in feet; positive values indicate water-level altitudes that are higher than the baseline scenario; negative values indicate water-level altitudes that are lower than the baseline scenario. Withdrawal rates: scenario 1, 7.2 million gallons per day (Mgal/d); scenario 2, 12 Mgal/d; scenario 3, 24 Mgal/d; scenario 4, 27 Mgal/d; baseline scenario, 25.4 Mgal/d]

Year	Scenario			
	1	2	3	4
1998	0.0	0.0	0.0	0.0
2000	47.0	34.4	3.0	-4.9
2002	63.5	46.5	4.1	-6.6
2005	72.0	52.8	4.6	-7.4
2008	77.1	56.4	4.9	-8.0
2012	80.3	58.8	5.1	-8.3
2017	82.6	60.5	5.3	-8.5
2023	84.3	61.7	5.4	-8.7
2030	85.6	62.7	5.5	-8.8
2038	86.7	63.5	5.5	-8.9
2048	87.6	64.1	5.6	-9.0

Table 2. Difference between simulated water-level altitude for each scenario and the baseline scenario at model cell 2 near the center of the city of Pine Bluff, Arkansas.

[all values in feet; positive values indicate water-level altitudes that are higher than the baseline scenario; negative values indicate water-level altitudes that are lower than the baseline scenario. Withdrawal rates: scenario 1, 7.2 million gallons per day (Mgal/d); scenario 2, 12 Mgal/d; scenario 3, 24 Mgal/d; scenario 4, 27 Mgal/d; baseline scenario, 25.4 Mgal/d]

Year	Scenario			
	1	2	3	4
1998	0.0	0.0	0.0	0.0
2000	30.9	22.7	2.0	-3.2
2002	46.2	33.8	3.0	-4.8
2005	54.5	39.9	3.5	-5.6
2008	59.5	43.6	3.8	-6.1
2012	62.8	46.0	4.0	-6.5
2017	65.1	47.7	4.2	-6.7
2023	66.8	48.9	4.3	-6.9
2030	68.1	49.9	4.4	-7.0
2038	69.2	50.7	4.4	-7.1
2048	70.1	51.3	4.5	-7.2

Table 3. Difference between simulated water-level altitude for each scenario and the baseline scenario at mode cell 3 about 15 miles north of the east Pine Bluff, Arkansas, area well field.

[all values in feet; positive values indicate water-level altitudes that are higher than the baseline scenario; negative values indicate water-level altitudes that are lower than the baseline scenario. Withdrawal rates: scenario 1, 7.2 million gallons per day (Mgal/d); scenario 2, 12 Mgal/d; scenario 3, 24 Mgal/d; scenario 4, 27 Mgal/d; baseline scenario, 25.4 Mgal/d]

Year	Scenario			
	1	2	3	4
1998	0.0	0.0	0.0	0.0
2000	7.4	5.5	0.5	-0.8
2002	14.3	10.5	0.9	-1.5
2005	19.2	14.1	1.2	-2.0
2008	22.6	16.6	1.4	-2.3
2012	25.1	18.4	1.6	-2.6
2017	27.1	19.9	1.7	-2.8
2023	28.7	21.0	1.8	-3.0
2030	30.0	22.0	1.9	-3.1
2038	31.2	22.9	2.0	-3.2
2048	32.2	23.6	2.1	-3.3

Summary

A groundwater-flow model of the Sparta aquifer was used to evaluate changes in water-level altitudes associated with the withdrawal of groundwater at varying rates from a well field near Pine Bluff, Arkansas, in Jefferson County. Water-level altitudes at three model cell locations from five different scenarios for varying withdrawal rates from the well field were compared for the period 1998 to 2048. The three model cells used for the comparison were located (1) near the center of the well field, (2) near the center of the city of Pine Bluff (about 5 miles west of the center of the well field), and (3) about 15 miles north of the well field. Pumping rates at the well field were varied from 7.2 million gallons per day to 27 million gallons per day for the five scenarios analyzed. Water-level hydrographs were constructed for each scenario for each of the three model cell locations. Simulated water-level altitudes vary in response to changes in withdrawal rates specified in the scenarios and distance from the center of pumping at the EPBA well field. The general shape and relation of the different hydrographs are maintained for each of the hydrograph sets, although the magnitude of water-level altitude change decreases with distance from the EPBA well field.

Simulated differences between simulated water-level altitude for the five scenarios vary among the three model cell locations analyzed. The largest difference occurs near the center of the EPBA well field (model cell 1). By 2048, water-level altitudes simulated for reduced withdrawal rates in scenarios 1 and 2 are approximately 90 and 65 ft higher, respectively, than the baseline scenario water-level altitude. Water-level altitudes associated with scenario 3 and 4 are similar (within about 6 and -9 ft) to the baseline scenario water-level altitude. At the city of Pine Bluff (model cell 2) simulated water-level altitudes for reduced withdrawal rates in scenarios 1 and 2 are approximately 70 and 50 ft higher, respectively, than the baseline scenario water-level altitude. Water-level altitudes associated with scenario 3 and 4 are similar (within about 5 and -7 ft) to the baseline scenario water-level altitude. At a point about 15 miles north of the EPBA well field (model cell 3), simulated water-level altitudes for reduced withdrawal rates in scenarios 1 and 2 are approximately 30 and 25 ft higher, respectively, than the baseline scenario water-level altitude. Water-level altitudes associated with scenario 3 and 4 are similar (within about 2 and -3 ft) to the baseline scenario water-level altitude. Simulated water-level altitudes at all three model cell locations for all five scenarios were higher than the maximum altitude of the top of the Sparta aquifer (about -300 ft). Even with decreased withdrawals from the EPBA well-field model cells, a downward trend of water-level altitudes occurs for all scenarios, which indicates effects from withdrawals from the Sparta aquifer outside the EPBA well field.

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