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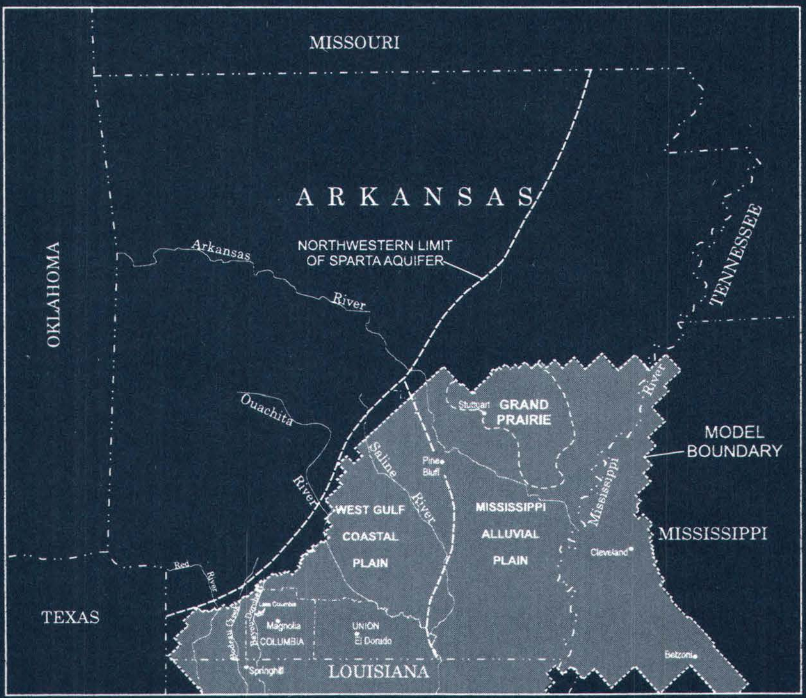
SIMULATED RESPONSE OF THE SPARTA AQUIFER TO OUTCROP AREA RECHARGE AUGMENTATION, SOUTHEASTERN ARKANSAS

Water-Resources Investigations Report 01-4039



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

SIMULATED RESPONSE OF THE SPARTA AQUIFER TO OUTCROP AREA RECHARGE AUGMENTATION, SOUTHEASTERN ARKANSAS

By Phillip D. Hays

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 01-4039

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Little Rock, Arkansas
2001

U.S. DEPARTMENT OF THE INTERIOR
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by Phillip D. Hays

ABSTRACT

Recharge augmentation by construction of infiltration impoundments is a potential means of increasing aquifer water levels and aquifer yield that is under consideration for the Sparta aquifer in southeastern Arkansas. The aquifer is a major water resource for municipal, industrial, and agricultural uses, and approximately 287 million gallons per day was pumped from the aquifer in Arkansas in 1995; this is double the amount pumped in 1975. Historically, the Sparta aquifer has provided abundant water of high quality. In recent years, however, the demand for water in some areas has resulted in withdrawals from the Sparta that significantly exceed recharge to the aquifer, and considerable declines have occurred in the potentiometric surface. To better manage the Sparta aquifer, water users in Arkansas are evaluating and implementing a variety of management practices and assessing alternative, surface-water sources to reduce stress upon the Sparta aquifer. One approach to managing and maximizing use of the Sparta aquifer is augmenting recharge to the aquifer by construction of infiltration lakes or canals within the recharge area. The basic concept of augmented recharge is simply to increase the amount of water being introduced into the aquifer so that more water will be available for use. Ground-water flow model simulations were conducted to assess the effectiveness of constructing lakes or canals to augment recharge. Results show that construction of five new lakes in the Sparta recharge area upgradient from major pumping centers or construction of a series of canals along the length of the recharge area yield notable benefit to aquifer conditions when compared with simulations entailing no augmentation of recharge.

Augmentation of recharge in the Sparta aquifer with emplacement of lakes provides slight increase to aquifer water levels. The presence of the lakes increased simulated aquifer water levels 0.5 foot or more across a broad area comprising all or a substantial part of 19 counties after the 30-year simulation period. Substantial increases of 5 feet or greater are limited to a smaller area proximal to the lakes. Increases of 5 feet or more are seen in El Dorado, Pine Bluff, and Stuttgart. The positive effect of the lakes on aquifer water levels is rapidly realized after emplacement of the lakes. For example, in the El Dorado area more than 3 feet of a total of 8 feet of water-level increase is seen in the first 5 years of the simulation; in the Pine Bluff area 9 feet of a total of 16 feet of increase occurs within 5 years. Sustainable yield from the aquifer could be expected to be increased within the zone of influence of the lakes.

Augmentation of recharge in the Sparta aquifer with emplacement of canals provides considerable increase of aquifer water levels. The zone of influence in the aquifer with canal-augmented recharge extends from the recharge area eastward to the Mississippi River. Aquifer water levels exhibit an increase of 5 feet or more across a broad area comprising all or a substantial part of 15 counties. Increases of 20 feet or more are seen in El Dorado, Pine Bluff, and Stuttgart. The amount of water moving into the aquifer is substantially increased under this scenario, and the amount of water removed from storage is decreased, thereby, increasing aquifer conditions considerably. Sustainable yield from the aquifer could be expected to be greater within the zone of influence of the canals as compared to either the scenario without recharge augmentation or recharge augmentation with lakes. The effect of the canal on aquifer water levels is rapidly realized after emplacement of the canals. For example, in the El Dorado area, 22 feet of a total of 30 feet of increase is seen in the first 5 years of the simulation; in the Pine Bluff area, 15 feet of a total of 24 feet of increase occurs within 5 years. As constructed, the model simulations imply that any lakes or canals constructed would maintain excellent hydraulic connection with

the aquifer without the existence of any permeability barriers between the canals and the aquifer.

INTRODUCTION

Recharge augmentation by construction of infiltration impoundments is a potential means of increasing aquifer water levels and aquifer yield that is under consideration for the Sparta aquifer in southeastern Arkansas. The aquifer is a major water resource for municipal, industrial, and agricultural uses, and approximately 287 million gallons per day (Mgal/d) was pumped from the aquifer in Arkansas in 1995 (Holland, 1999); this is double the amount pumped in 1975. The Sparta aquifer extends through eastern and southeastern Arkansas (fig. 1). Historically, the Sparta aquifer has provided abundant water of good quality. In recent years, however, the demand for water in some areas has resulted in withdrawals from the Sparta that substantially exceed recharge to the aquifer. Considerable declines have occurred in the potentiometric surface, and water users and managers have recognized the overextended state of the aquifer and have begun to develop management plans that will ensure the ability of the aquifer to supply water for the long term. Ground-water withdrawals have resulted in the development of large cones of depression centered beneath the cities of Pine Bluff and El Dorado in Arkansas (Joseph, 1998). Water levels in the areas of these cones have declined at rates greater than 1 foot per year (ft/yr) for more than a decade in much of southern Arkansas and are now below the top of the Sparta Sand (though not necessarily below the tops of the primary producing sand units) in parts of Union and Columbia Counties. A smaller cone of depression centered beneath Magnolia, Arkansas, diminished substantially after the completion of Lake Columbia and installation of a surface-water supply system in 1993 resulted in decreased withdrawals from the Sparta aquifer. Continuing increase of rates of withdrawal from the Sparta aquifer will result in continued expansion of the cones of depression as well as increased drilling and pumping costs, decreased aquifer yield, increased saltwater intrusion, and chemically degraded water quality.

Water users in Arkansas are evaluating and implementing a variety of water-use management practices. Industrial water users—including facilities that are major water users—are implementing water conservation measures that will decrease the amount of water used and recycle and reuse water when possible. Municipalities and water associations are implementing focused water-conservation public education programs with support and input from Federal, State, county, and local levels and are enacting more direct water reuse and conservation actions such as use of treated wastewater for irrigation purposes.

Water suppliers also are assessing and utilizing alternative, surface-water sources to reduce demand upon the Sparta aquifer. The city of Magnolia began using Lake Columbia for public water supply in 1993. The city of El Dorado is installing new wells and inactivating some existing wells, effectively moving its well field away from the current cone of depression centered beneath the town. This move will temporarily extend use of the aquifer at current rates without dropping water levels below the top of the primary producing sand unit (Hays, 2000). At the same time, the city of El Dorado and other concerned entities in Union County are building a cohesive, county-wide affiliation to evaluate and initiate use of the Ouachita River, including the building of treatment facilities and a distribution network, to supplement the water supplied by the Sparta aquifer.

Another approach to managing and maximizing use of the Sparta aquifer is augmenting recharge to the aquifer by construction of infiltration lakes or canals within the Sparta aquifer recharge area—that is the outcrop area where the aquifer receives recharge by infiltration of precipitation and surface water (fig. 1). While this approach to aquifer management previously has not been applied in Arkansas (nor is it common in the region), the approach has been effectively applied in other States and countries (Detay and Bersillon, 1998; Fennemore and others, 2001; Khepar and others, 2000; Koehler, 1983; Lee and others, 1992; Ma and Spalding, 1997).

Constructing a series of lakes or canals to augment Sparta aquifer recharge is one of the means that is being considered in southeastern Arkansas for increasing water levels and use of the aquifer. The potential effects of recharge augmentation on water availability are of prime interest to water managers and users as well as the general public. Assessing the potential benefit to be realized by the aquifer is a critical initial step in attempting to augment aquifer recharge. Evaluating the potential response of the aquifer to these means of augmenting recharge allows the effects to be evaluated prior to expending resources towards other activities

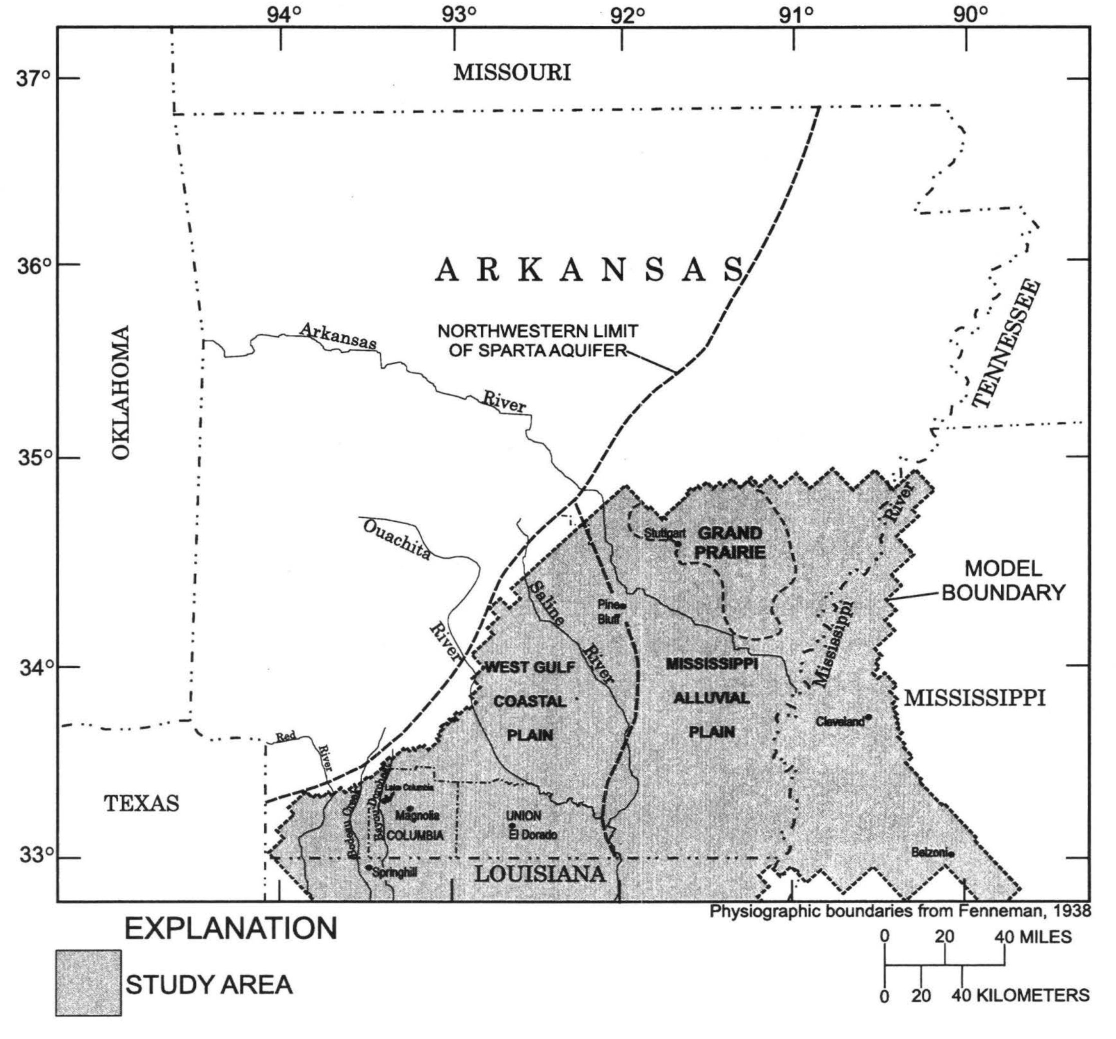

Figure 1. Location of study and model areas.

required, such as engineering design, siting and land-acquisition study, and cost-benefit analysis.

Therefore, the U.S. Geological Survey (USGS) conducted a study, in cooperation with the Arkansas Soil and Water Conservation Commission (ASWCC) to simulate potential response of the Sparta aquifer to outcrop area recharge augmentation in southeastern Arkansas. The simulation was done using a previously constructed digital ground-water flow model of the Sparta aquifer, hereinafter referred to as the Sparta model. The Sparta model provides a tool that is capable of testing the potential efficacy of constructing such recharge-augmentation lakes or canals. The Sparta model is a calibrated digital computer simulation of the Sparta aquifer that can be used to test the response of the aquifer to management options that change stresses on the aquifer.

Purpose and Scope

This report describes the simulated response of the Sparta aquifer to augmented recharge from simulated infiltration lakes and canals placed in the aquifer outcrop area. The existing calibrated and reverified ground-water flow model (Hays and others, 1998) is used for this simulation. The report compares the results of the two scenarios—infiltration of water from (1) five simulated lakes and (2) a simulated infiltration canal along the length of the recharge area (fig. 1) through Arkansas—with results from a scenario in which no new lakes or canals are present (Scenario 2 in Hays and others, 1998). The area included in the model includes most of southeastern Arkansas, northern Louisiana, and parts of northwestern Mississippi. The focus of this study was response of the aquifer in Arkansas. The two scenarios were designed to evaluate the effects of augmented recharge on water levels in the aquifer during a 30-year period. Information on the simulations of the lakes and canals and a comparison of simulated (30-year time period) potentiometric surfaces are presented using maps that show the difference in simulated hydraulic head between the potentiometric surfaces with and without augmented recharge.

Study Area Description

The study area encompasses southeastern Arkansas, a subarea of the larger model area that was analyzed for simulated effects of recharge augmentation. The model area, however, also includes portions of northern Louisiana and northwestern Mississippi (fig. 1). The model area lies within the Mississippi Alluvial Plain and West Gulf Coastal Plain sections of the Coastal Plain Physiographic Province (Fenneman, 1938). Land-surface altitudes range from more than 500 feet (ft) above sea level[1] along the northwestern Sparta aquifer limit and outcrop recharge area to less than 100 ft along the Mississippi River. The principal drainages are the Mississippi, Arkansas, Saline, Ouachita, and Red Rivers. Mean annual precipitation is approximately 50 inches (Freiwald, 1985). Water use from the Sparta aquifer in the study area reflects the predominant land uses; ground water is intensively used for municipal supply, plant- and animal-based agriculture, aquaculture, and manufacturing of forest products, chemicals, and other industrial products. Detailed discussion of the history of Sparta aquifer water use, model area hydrogeologic setting, and a description of the aquifer also are included in the two reports and are not repeated here. In 1991, the model was verified (Kilpatrick, 1992) by the USGS in cooperation with the ASWCC and selected scenarios of future ground-water withdrawals in Union County, Arkansas, were simulated. The model was reverified with updated pumpage and potentiometric surface data in 1997, and various pumping scenarios were simulated (Hays and others, 1998).

Previous Studies

In 1985, the USGS, in cooperation with the ASWCC and the Louisiana Department of Transportation and Development (LaDOTD), began a study of the hydrogeologic characteristics of the Sparta aquifer and the regional effects of increased pumpage on water levels in the aquifer. The primary product of the study was the Sparta model (Fitzpatrick and others, 1990; McWreath and others, 1991). Model construction, calibration, and first application are fully described in Fitzpatrick and others (1990) and McWreath and others (1991). These reports define the initial goals of the model and describe model testing and simulation results for selected pumping scenarios.

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[1]In this report, sea level refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly call Sea Level Datum of 1929.

GROUND-WATER FLOW MODEL DESCRIPTION

The digital code used by Fitzpatrick and others (1990) and McWreath and others (1991) for development of the Sparta model was the modular finite-difference ground-water flow model (MODFLOW) developed by McDonald and Harbaugh (1988). MODFLOW simulates ground-water flow in three dimensions using a block-centered, finite-difference equation approach to the solution of the partial-differential equation for ground-water flow. Details of model development, construction, and calibration are presented in Fitzpatrick and others (1990) and McWreath and others (1991). Details on pumpage data updating, assimilation and input, model reverification and error analysis are given in Kilpatrick (1992) and Hays and others (1998). For this study, as for the modeling work described in Hays and others (1998), the Sparta model was converted to run in MODFLOWARC, a MODFLOW pre- and post-processor that allows interface with a geographic information system (Orzol and McGrath, 1992). The model was re-run after conversion (Hays and others, 1998) to ensure that functionality and output were unchanged from originally reported results.

For the recharge-augmentation modeling, described in this report, no basic model or calibration parameters were changed and no changes in input that would violate model assumptions were applied. Pumping stress was the same as tested in Hays and others (1998) in Scenario 2. Recharge augmentation was simulated by designating river cells (MODFLOW terminology) in discrete areas.

SIMULATED RESPONSE TO RECHARGE AUGMENTATION

The basic concept of augmented recharge is simply to increase the amount of water being introduced into the aquifer so that more water will be available for use. There are two basic approaches to increasing recharge. The first, and perhaps most direct, approach is to install wells in the aquifer and inject water into areas where large amounts of drawdown have occurred. Major drawbacks associated with this approach are the high cost of pumping water into the aquifer (typically greater than the cost of pumping water out) and the necessity of injecting very clean water (free of sediment and biological material). Injection of untreated water can progressively occlude porosity near the well bore, decrease permeability, and decrease the ability of the aquifer to accept injection water at rates needed to achieve a reasonable level of recharge. The second approach is to increase the amount of water introduced into the aquifer in the aquifer outcrop area (recharge area) by constructing lakes or canals. This approach is less direct— many of the major pumping centers are well removed from the recharge area and an actual parcel of water introduced in the outcrop area might take hundreds of years to travel to a point of discharge (based on simple Darcy equation calculation). However, water that is introduced in the recharge area can have a near-immediate effect on ground-water levels across a broad area because the Sparta aquifer is a confined aquifer. The Sparta aquifer is confined through most of its extent, and the aquifer is under pressure, thus changes in hydraulic head (water-level) in the unconfined outcrop area are rapidly communicated as changes in pressure head—in a near instantaneous fashion—across the confined portion of the aquifer.

The Sparta model was used to predict the effects of two different augmented-recharge mechanisms on water levels over a 30-year simulation period. Total pumpage stress in the model was the same for each scenario. The pumpage was increased from 33.1 million cubic feet per day (ft^3/d) to a maximum of 52.9 million ft^3/d (tables 1 and 2) over the 30-year simulation to reflect projected pumping increases by ground-water users. To determine this pumpage stress as used in the flow model, a simple regression model projecting total water use was constructed for each county and parish in the active flow-model area using water-use data available since 1980. The trend in change of observed water-use rates over the period 1980-1997 was used to project water use for each county or parish for the 30-year simulation period (representing 1998-2027). The simulation period was segmented into six stress periods of 5 years each. The percentage contribution (1997) of each well to total pumpage within a county or parish in model pumpage data was determined, and pumpage at each well was increased according to the regression-derived county/parish total multiplied by the well percentage for each stress period. Projected future withdrawals based on declining water use in some Arkansas counties indicated that withdrawals from the Sparta aquifer would cease prior to the end of the 30-year simulation. Because this is probably unrealistic, water use in these counties was held constant at 1997 rates.

Table 1. Volumetric budget comparison for 2027 for Sparta model infiltration scenarios

Scenario 2—No lakes or canals		Scenario 2a—Lakes		Scenario 2b—Canals	
In budget component	**Rate (cubic feet per day)**	**In budget component**	**Rate (cubic feet per day)**	**In budget component**	**Rate (cubic feet per day)**
Storage	7,687,000	Storage	4,072,000	Storage	3,443,000
Constant head	38,678,000	Constant head	35,485,000	Constant head	33,555,000
Wells	0	Wells	0	Wells	0
Recharge	13,298,000	Recharge	13,298,000	Recharge	13,298,000
River leakage	2,450,000	River leakage	12,094,000	River leakage	29,991,000
Total in	62,113,000	Total in	64,949,000	Total in	80,287,000
Out budget component	**Rate (cubic feet per day)**	**Out budget component**	**Rate (cubic feet per day)**	**Out budget component**	**Rate (cubic feet per day)**
Storage	6,000	Storage	645,000	Storage	2,306,000
Constant head	2,064,000	Constant head	2,100,000	Constant head	3,067,000
Wells	52,867,000	Wells	52,867,000	Wells	52,867,000
Recharge	0	Recharge	0	Recharge	0
River leakage	7,177,000	River leakage	9,337,000	River leakage	22,047,000
Total out	62,114,000	Total out	64,949,000	Total out	80,287,000

Table 2. Selected water-level-altitude data from model cells representative of pumping centers at year 0 (start, all scenarios) and year 30 (listed for Scenarios 2, 2a, and 2b) for the model simulations

[Final pumpage =52.9 million cubic feet per day]

		Water-level altitude (feet above sea level)			
			Year 30		
Location	Row, column	Year 0 (start)	Scenario 2 (nonaugmented)	Scenario 2a (lake-augmented)	Scenario 2b (canal-augmented)
Lonoke County, Ark.	3,321	72	-25	-2	8
Pine Bluff, Ark.	4,928	-58	-277	-261	-253
El Dorado, Ark.	8,253	-307	-438	-430	-408
Magnolia, Ark.	9,833	-102	-115	-110	-73
Monroe, La.	8,982	-202	-225	-224	-221

Development of the scenarios was based on construction of five lakes located upgradient from major pumping centers (Scenario 2a—Lakes Scenario, plate 1) or construction of a series of canals extending the length of the recharge area through Arkansas (Scenario 2b— Canals Scenario, plate 2). Predicted hydraulic head distribution and volumetric budget of the two augmented recharge scenarios were compared with Scenario 2, from Hays and others (1998), which is a model simulation having no augmentation of recharge but otherwise is identical to Scenarios 2a and 2b. Scenario 2 provides simulated conditions if the current rate of change in water withdrawal rates continues and provides a reasonable basis of comparison for testing the effects of lakes and canals on conditions in the aquifer.

Lakes Scenario (2a)

Lakes were simulated upgradient from major pumping centers, such as Pine Bluff and El Dorado, near rivers that could be impounded. Lakes were simulated using the MODFLOW river package. Factors in model construction were stage, surface area, and bottom-sediment characteristics. Lake stages were formulated from digital elevation model data; the lowest cell center elevation in each lake area was determined, and the lake stage across all cells in a specific lake was determined by arbitrarily adding 60 ft to this value. The resultant stage was not checked against topography, projected lake size, or potential dam locations; thus, in terms of depth, location, and extents, simulated lakes give a very rough approximation of any actual lake that might be constructed for recharge augmentation in the area. Lake surface areas were designated to be in the range of 10,000 to 20,000 acres with the areas of the individual lakes being partially controlled by model cell size in the target areas and the location of man-made and natural features such as towns, major roads, and rivers. Sediments that collect on the bottoms of lakes and the low hydrodynamic energy portion of many rivers are often silt and clay rich. Silt and clay sediments typically exhibit low hydraulic conductivity and can act as a barrier to flow to and from aquifers that are in connection with rivers or lakes. The potential for such sediments to affect the exchange of water between lake and aquifer was treated in the model by the use of riverbed conductance values in lake cells. Riverbed conductance values were formulated using lake-cell dimensions, a bottom-sediment thickness of 1.0 ft, and a river-bottom hydraulic conductivity of 0.1 ft/d (table 3). These values were held constant, in concurrence with an assumption that the lakes would be dredged intermittently to maintain an average bottom-sediment thickness of 1.0 ft. Thus, the model representation implies that any lakes constructed must maintain excellent hydraulic connection with the aquifer without the existence of a significant permeability barrier between the lakes and the aquifer.

Table 3. Hypothetical lake information

	Source river	Area (acres)	Stage (feet above sea level)
Lake 1	Bayou Meto	16,000	276
Lake 2	Hurricane Creek	13,000	367
Lake 3	Saline River	19,000	275
Lake 4	Little Bayou	12,000	263
Lake 5	Two Bayou	10,000	165
Total		70,000	
Bottom-sediment thickness	1.0 foot		
Bottom-sediment hydraulic conductivity	0.1 foot per day		
Average total infiltration rate	110 cubic feet per second		

Analysis of simulated flow shows that total flow through the Sparta aquifer is greater with the presence of lakes—about 65 million ft^3/d with the lakes compared to about 62 million ft^3/d without lakes after 30 years (fig. 2, table 1). During the 30-year simulation, water removed by wells was increased from 33.1 million ft^3/d to 52.9 million ft^3/d. The presence of the lakes increased the amount of water moving into the aquifer through river cells (which include lake cells) from about 2.5 million ft^3/d without lakes to about 12.1 million ft^3/d with lakes present. These data indicate that about 9.6 million ft^3/d (110 ft^3/s) would have to be added to the lakes to maintain lake stage, based on the volume rate moving into the aquifer. This figure does not include water—a substantial amount— that would be lost from the lakes due to evaporation. The net amount of additional water moving into the aquifer (when increased losses to other river cells are considered) is 7.5 million ft^3/d. The net amount lost from aquifer storage (comparison of the difference in "Storage IN" minus "Storage OUT" between scenarios 2 and 2a, table 1) is 4.2 million ft^3/d less with the presence of lakes. In general, the amount of water moving into the aquifer is increased under this scenario, and the amount of water removed from storage is decreased, thereby increasing aquifer conditions. Assuming that lake stages could be maintained over the long term, sustainable yield from the aquifer could be expected to be increased within the zone of influence of the lakes.

The presence of the lakes increased simulated aquifer water levels 0.5 ft or more across a broad area comprising all or a substantial part of 19 counties in Arkansas (plate 1). Substantial increase of 5 ft or more is limited to relatively small areas near the lakes. Increases of 5 ft or more are seen near El Dorado, Pine Bluff (table 2), and Stuttgart (plate 1). This increase is relative to ground-water levels simulated for 2027 if no recharge augmentation is implemented. The simulation shows smaller, but continuing, declines even with lake recharge augmentation.

The simulated effect of the lakes on aquifer water levels is rapidly realized after emplacement of the lakes. For example, in the El Dorado area more than 3 ft of a total of 8 ft of increase is seen in the first 5 years of the simulation (fig. 3); in the Pine Bluff area, 9 ft of a total of 16 ft of increase occurs within 5 years (fig. 3).

Lake-augmented recharge yields an increase in water levels when compared with water levels simulated without augmentation, but augmentation by lakes does not stabilize water levels across a broad area. Water levels continue to decline through the 30-year simulation (fig. 4), indicating that water is being removed at a rate greater than the aquifer can supply for the long term, even with lake-augmented recharge.

Canals Scenario (2b)

Canals near the southeastern limit of the recharge area were simulated using the MODFLOW river package. Factors in model representation were stage, canal dimensions, and bottom-sediment characteristics. Stage was determined using digital elevation models; 10 ft (the target canal depth) to the elevation value at each cell center. Topography was not considered in canal placement. A canal width of 60 ft was input to the model; a total canal length of approximately 220 miles was input. Riverbed conductance values were formulated using cell length (relative to canal traverse), a canal width of 60 ft, a bottom-sediment thickness of 0.5 ft, and a river-bottom hydraulic conductivity of 0.1 ft/d (table 4). These values were held constant in the model in concurrence with the assumption that the canals would be dredged intermittently to maintain an average bottom-sediment thickness of 0.5 ft. Thus, the model representation implies that any canals constructed would maintain excellent hydraulic connection with the aquifer without the existence of any permeability barrier between the canals and the aquifer.

Table 4. Hypothetical canal information

Total length	198 miles
Width	60 feet
Total canal area	1,440 acres
Depth	10 feet
Bottom-sediment thickness	0.5 feet
Bottom-sediment hydraulic conductivity	0.1 foot per day
Average infiltration rate	320 cubic feet per second

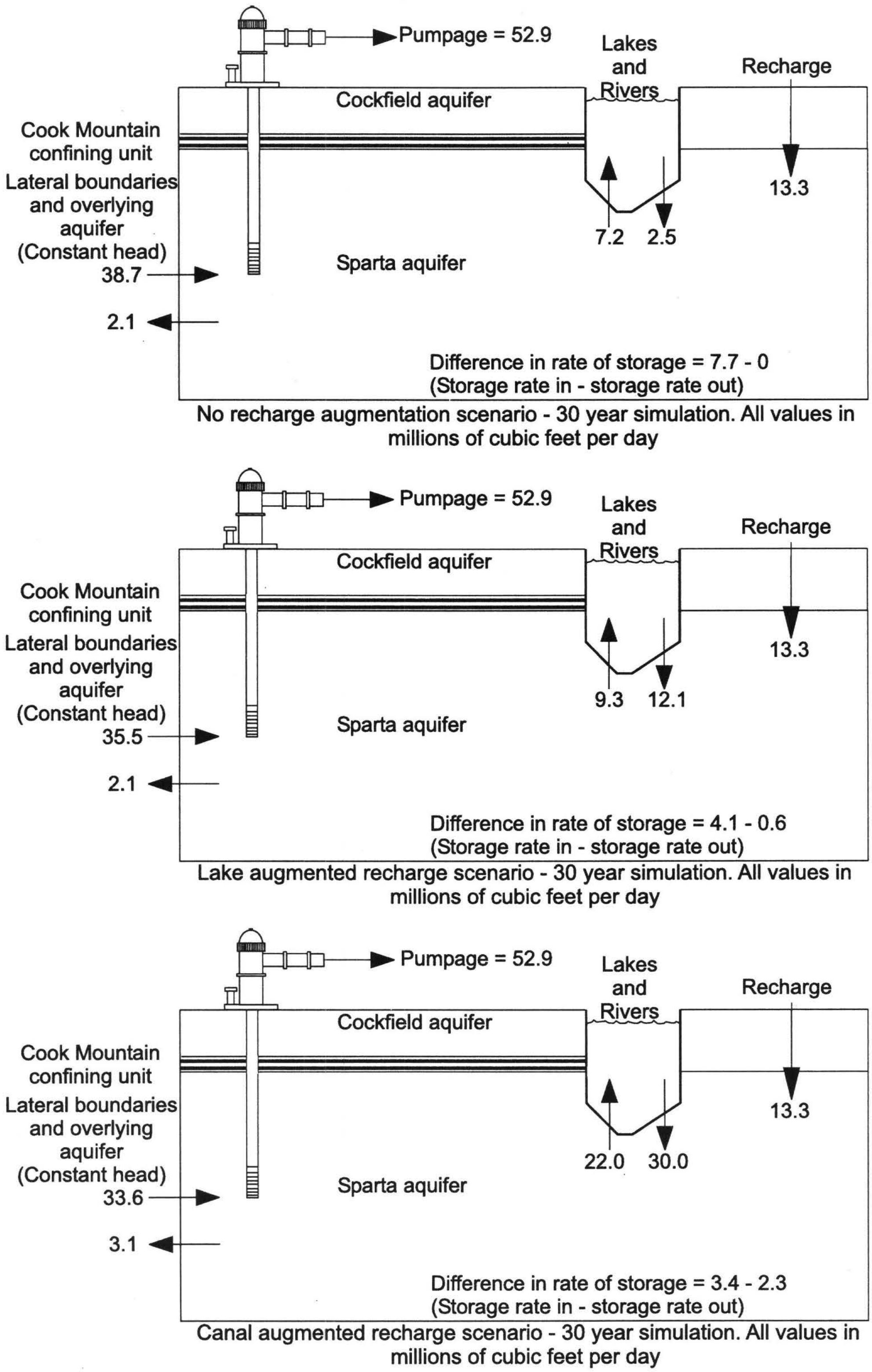

Figure 2. Volumetric budget components for nonaugmented recharge, lake-augmented recharge, and canal-augmented recharge scenarios for 2027.

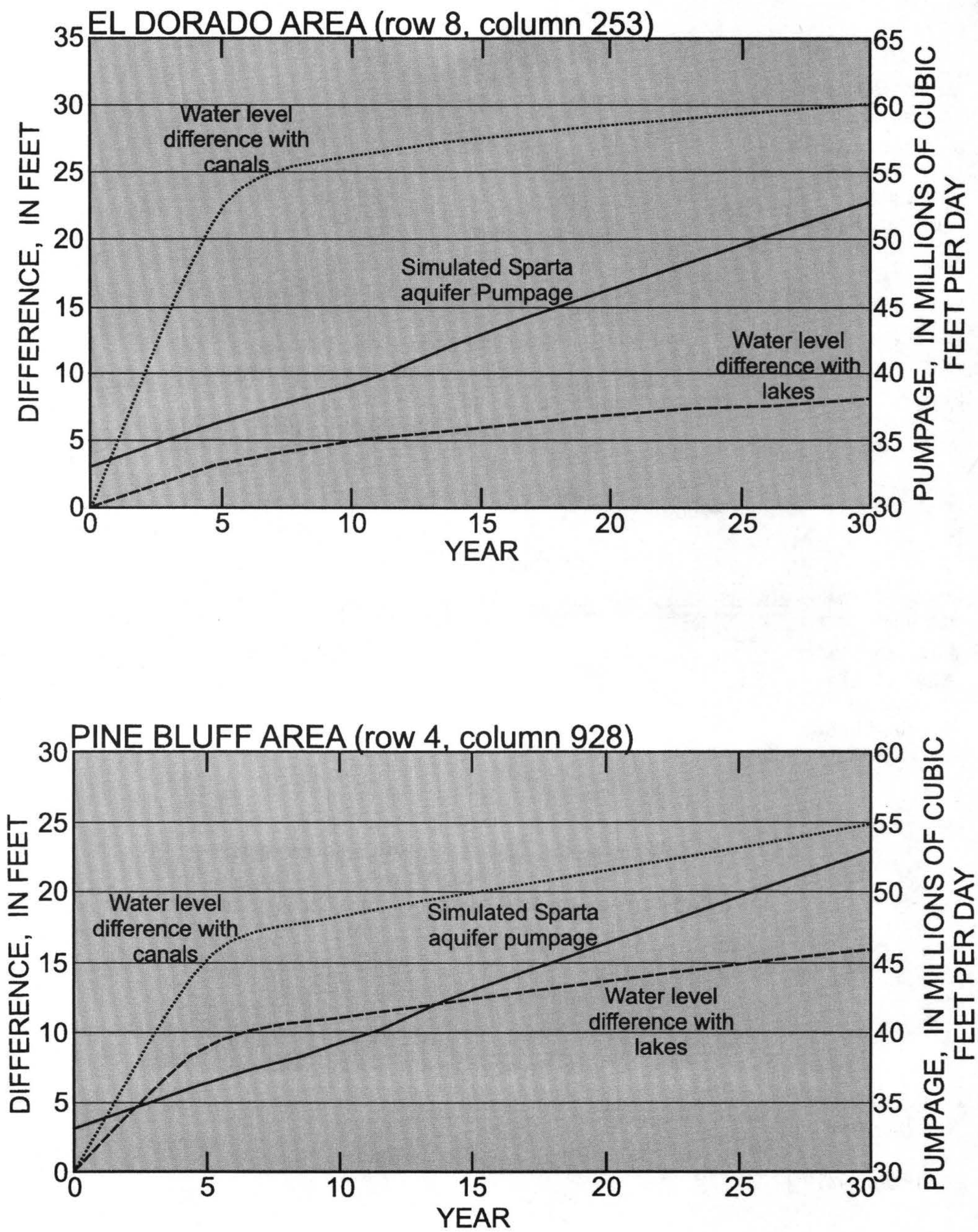

Figure 3. Simulated total pumpage, and differences in Sparta aquifer water levels between augmented (lakes or canals) and nonaugmented recharge conditions at selected model cells in the El Dorado and Pine Bluff areas.

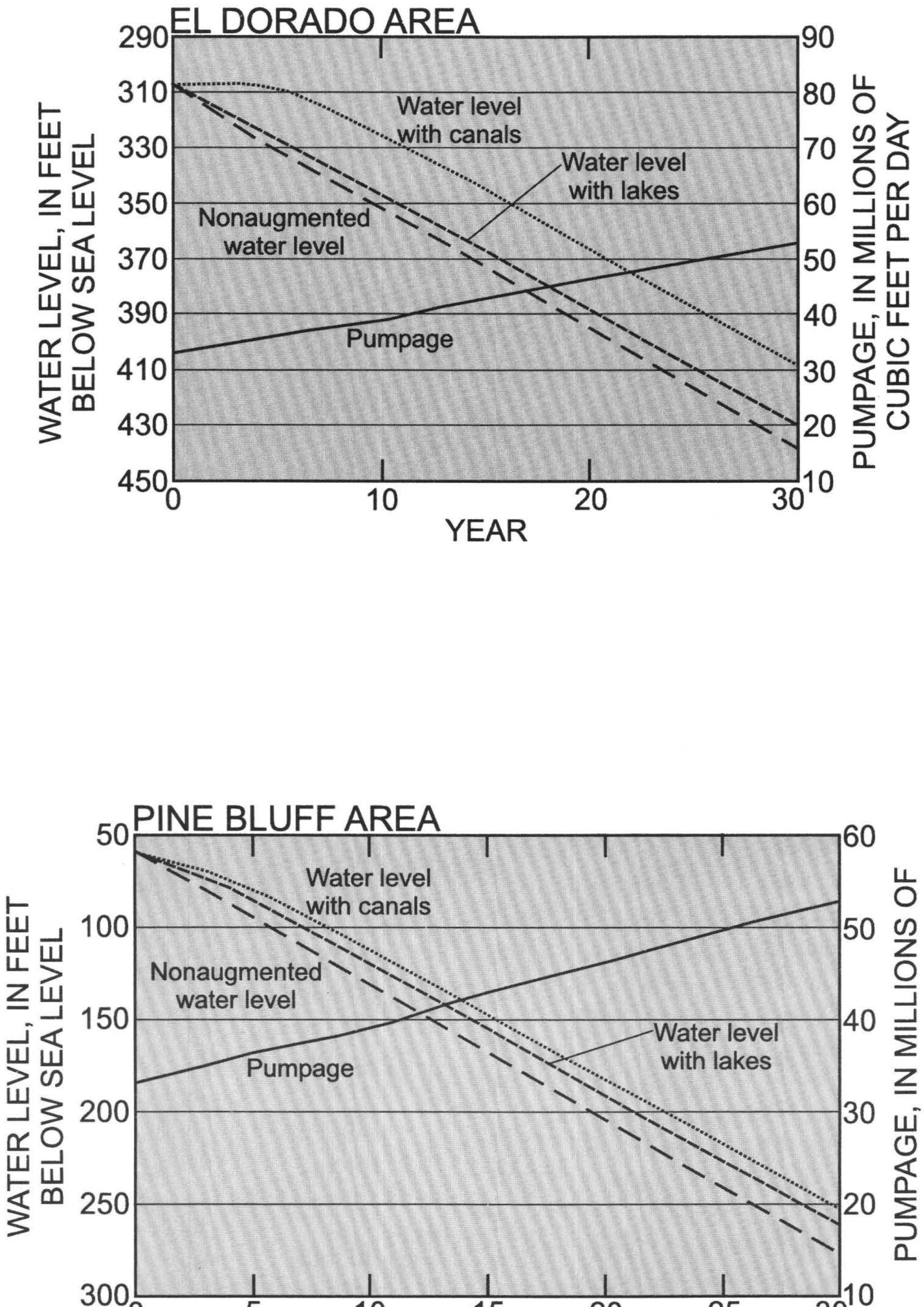

Figure 4. Simulated total pumpage and Sparta aquifer water levels for augmented (lakes or canals) and nonaugmented recharge conditions at selected model cells in the El Dorado and Pine Bluff areas.

Analysis of simulated flow shows that total flow through the Sparta aquifer is greater with the presence of canals—about 80 million (ft^3/d) with the canals compared to about 62 million ft^3/d without canals (fig. 2, table 1). During the 30-year simulation, water removed by wells increased from 33.1 million ft^3/d to 52.9 million ft^3/d. The presence of the canals increased the amount of water moving into the aquifer through river cells (which include the canal cells) from 2.5 million ft^3/d without canals to 30.0 million ft^3/d with canals present. These data indicate that about 27.5 million ft^3/d (320 ft^3/sec) would have to be added to the canals to maintain canal stage, based on the volume rate moving into the aquifer. This figures does not include a substantial amount of water that would be lost to evaporation. The net amount of additional water moving into the aquifer (when increased losses to other river cells are considered) is 12.7 million ft^3/d. The net amount lost from aquifer storage is 6.6 million ft^3/d less with the presence of canals. In general, the amount of water moving into the aquifer is substantially increased under this scenario, and the amount of water removed from storage is decreased, thereby increasing aquifer conditions considerably. Assuming that canal stages could be maintained over the long term, sustainable yield from the aquifer could be expected to be greater within the zone of influence of the canals as compared to either the scenario without recharge augmentation or recharge augmentation with lakes.

Considerable differences in simulated water-level distributions are evident between the nonaugmented recharge and canal augmented recharge scenarios (scenarios 2 and 2b) after the 30-year simulation period (plate 2). The canal zone of influence in the aquifer extends from the recharge area eastward to the Mississippi River. Simulated aquifer water levels increased 5 ft or more across a broad area comprising all or a substantial part of 15 counties in Arkansas. This increase is relative to water levels predicted for 2027 if no recharge augmentation is implemented; smaller, but continued declines, are simulated even with recharge augmentation. Increases of 20 ft or more are seen near El Dorado and Pine Bluff (table 2); 5 to 20 ft of increase is seen near Stuttgart (plate 2).

The simulated effect of the canal on aquifer water levels is rapidly realized after emplacement of the canals. For example, in the El Dorado area 22 ft of a total of 30 ft of increase is seen in the first 5 years of the simulation (fig. 3); in the Pine Bluff area 15 ft of a total of 25 ft of increase occurs within 5 years (fig. 3).

Water levels in the Sparta aquifer increase substantially with canal-augmented recharge (relative to no recharge augmentation) across a broad area of southeastern Arkansas. However, water levels continue to decline through the 30-year simulation (fig. 4), indicating that water is being removed at a rate greater than the aquifer can supply for the long term, even with canal-augmented recharge.

It should be noted that the northern extent of the canal, as simulated in the model, is adjacent to the northern boundary of the model. Because of this, a part of the water from the canal is being modeled as moving quickly to the constant head boundary that constitutes the northern model boundary. This may result in less accuracy in simulated results in the area of the model boundary proximal to canal cells (with less water recharging the aquifer and raising water levels) and a higher apparent volume rate of water required to maintain canal water level.

SUMMARY

Recharge augmentation by construction of infiltration impoundments is a potential means of increasing aquifer water levels and aquifer yield that is under consideration for the Sparta aquifer in southeastern Arkansas. The aquifer is a major water resource for municipal, industrial, and agricultural uses, and approximately 287 million gallons per day (Mgal/d) was pumped from the aquifer in Arkansas in 1995 (Holland, 1999); this is double the amount pumped in 1975. Historically, the Sparta aquifer has provided abundant water of high quality. In recent years, however, the demand for water in some areas has resulted in withdrawals from the Sparta that substantially exceed recharge to the aquifer, and considerable declines have occurred in the potentiometric surface. Water managers and water users in Arkansas are evaluating and implementing a variety of management practices and assessing alternative, surface-water sources to reduce stress upon the Sparta aquifer. One approach to managing and maximizing use of the Sparta aquifer is augmenting recharge to the aquifer by construction of infiltration lakes or canals within the recharge area. The basic concept of augmented recharge is simply to increase the amount of water being introduced into the aquifer so that more water will be available for use. Ground-water flow model simulations were conducted to assess the effectiveness of constructing lakes or canals to augment recharge.

Results show that construction of five new lakes upgradient from major pumping centers or construction of a series of canals along the length of the recharge areas yields notable benefit to aquifer conditions when compared with simulations entailing no augmentation of recharge.

Analysis of simulated flow shows that total flow through the Sparta aquifer is greater with lake-augmented recharge as compared with nonaugmented recharge. The amount of water moving into the aquifer is increased under this scenario, and the amount of water removed from storage is decreased, thereby increasing aquifer conditions. Sustainable yield from the aquifer could be expected to be increased within the zone of influence of the lakes. The presence of the lakes increased simulated aquifer water levels 0.5 ft or more across a broad area comprising all or a substantial part of 19 counties after the 30-year simulation period. Increases of 5 ft or more are limited to a smaller area proximal to the lakes. Increases of 5 ft or more are seen in El Dorado, Pine Bluff, and Stuttgart. The effect of the lakes on aquifer water levels is rapidly realized after emplacement of the lakes. For example, in the El Dorado area more than 3 ft of a total of 8 ft of increase is seen in the first 5 years of the simulation; in the Pine Bluff area 9 ft of a total of 16 ft of increase occurs within 5 years. Although water levels in the Sparta aquifer increase with lake-augmented recharge (relative to no recharge augmentation), water levels do continue to decline through the 30-year simulation indicating that water is being removed at a rate greater than the aquifer can supply for the long term, even with lake augmented recharge.

Analysis of simulated flow shows that total flow through the Sparta aquifer is greater with the presence of canals—80 million cubic feet per day (ft^3/d) with the canals compared to about 62 million ft^3/d without canals. The amount of water moving into the aquifer is substantially increased under this scenario, and the amount of water removed from storage is decreased, thereby increasing aquifer conditions considerably. Sustainable yield from the aquifer could be expected to be greater within the zone of influence of the canals as compared to either the scenario without recharge augmentation or recharge augmentation with lakes.

Considerable differences in simulated water-level distributions are evident between the nonaugmented recharge and canal augmented recharge scenarios (scenarios 2 and 2b) after the 30-year simulation period. The canal zone of influence in the aquifer extends from the recharge area eastward to the Mississippi River. Aquifer water levels increased 5 ft or more across a broad area comprising all or a substantial part of 15 counties. Increases of 20 ft or more are seen in El Dorado, Pine Bluff, and Stuttgart.

The effect of the canal on aquifer water levels is rapidly realized after emplacement of the canals. For example, in the El Dorado area, 22 ft of a total of 30 ft of water-level increase is seen in the first 5 years of the simulation; in the Pine Bluff area, 15 ft of a total of 24 ft of increase occurs within 5 years. Although water levels in the Sparta aquifer increase substantially with canal-augmented recharge (relative to no recharge augmentation), water levels do continue to decline through the 30-year simulation indicating that water is being removed at a rate greater than the aquifer can supply for the long term. As constructed, the model simulations imply that any lakes or canals constructed must maintain excellent hydraulic connection with the aquifer without the existence of any permeability barrier between the canals and the aquifer.

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