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Evaluation of Effects of Groundwater Withdrawals at the Proposed Allen Combined-Cycle Combustion Turbine Plant, Shelby County, Tennessee

Scientific Investigations Report 2016–5072

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

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)

Datum

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

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By Connor J. Haugh

Abstract

The Mississippi Embayment Regional Aquifer Study groundwater-flow model was used to simulate the potential effects of future groundwater withdrawals at the proposed Allen combined-cycle combustion turbine plant in Shelby County, Tennessee. The scenario used in the simulation consisted of a 30-year average withdrawal period followed by a 30-day maximum withdrawal period. Effects of withdrawals at the Allen plant site on the Mississippi embayment aquifer system were evaluated by comparing the difference in simulated water levels in the aquifers at the end of the 30-year average withdrawal period and at the end of the scenario to a base case without the Allen combined-cycle combustion turbine plant withdrawals. Simulated potentiometric surface declines in the Memphis aquifer at the Allen plant site were about 7 feet at the end of the 30-year average withdrawal period and 11 feet at the end of the scenario. The affected area of the Memphis aquifer at the Allen plant site as delineated by the 4-foot potentiometric surface-decline contour was 2,590 acres at the end of the 30-year average withdrawal period and 11,380 acres at the end of the scenario. Simulated declines in the underlying Fort Pillow aquifer and overlying shallow aquifer were both less than 1 foot at the end of the 30-year average withdrawal period and the end of the scenario.

Introduction

The Tennessee Valley Authority (TVA) proposes to reduce sulfur dioxide emissions at its Allen Fossil Plant (ALF) in Shelby County, Tennessee, by retiring the coal units and constructing a natural gas power plant. The existing coal-fired units at the ALF provide real and reactive power for the Memphis, Tennessee, area. To continue to reliably serve the area, generation resources must be located at or near the ALF. The proposed plant will be a two-on-one natural gas plant that can run in either simple- or combined-cycle mode. The simple-cycle mode uses very little water, whereas the combined-cycle mode is projected to use an annual average of 2,500 gallons per minute (gal/min) and a maximum of 5,000 gal/min from wells screened in the Memphis aquifer (table 1).

In 2016, the U.S. Geological Survey (USGS), in cooperation with the TVA, conducted an investigation to define the potential effects of groundwater withdrawals associated with the proposed Allen combined-cycle combustion turbine plant (hereafter referred to as the Allen plant site) on water levels in the Mississippi embayment aquifer system. Groundwater from the Memphis and Fort Pillow aquifers, which are in the Mississippi embayment aquifer system, is used to supply municipal and industrial water needs in West Tennessee (Parks and Carmichael, 1989, 1990). Self-supplied domestic groundwater withdrawals are usually from shallower zones including the alluvium or the fluvial deposits, which constitute the shallow aquifer at many locations.

The Mississippi Embayment Regional Aquifer Study (MERAS) was completed as part of the USGS Groundwater Resources Program to assess groundwater availability within the Mississippi embayment. The primary tool used in the assessment of groundwater availability is the MERAS groundwater-flow model (Clark and Hart, 2009). In the study described in this report, the effects of groundwater withdrawals associated with operation of the proposed Allen plant site were estimated by using the MERAS groundwater-flow model.

Purpose and Scope

This report presents an analysis of the potential effects of groundwater withdrawals associated with operation of the proposed Allen combined-cycle combustion turbine plant in Shelby County, Tennessee (fig. 1). The effects of groundwater withdrawals at the Allen plant site, in conjunction with existing withdrawals, were analyzed using the MERAS groundwater-flow model (Clark and Hart, 2009). This analysis will help further the understanding and evaluation of the effects of increased water use on an important multistate aquifer. This report does not address the potential effects of water leakage from the shallow aquifer on groundwater quality in the Memphis aquifer.

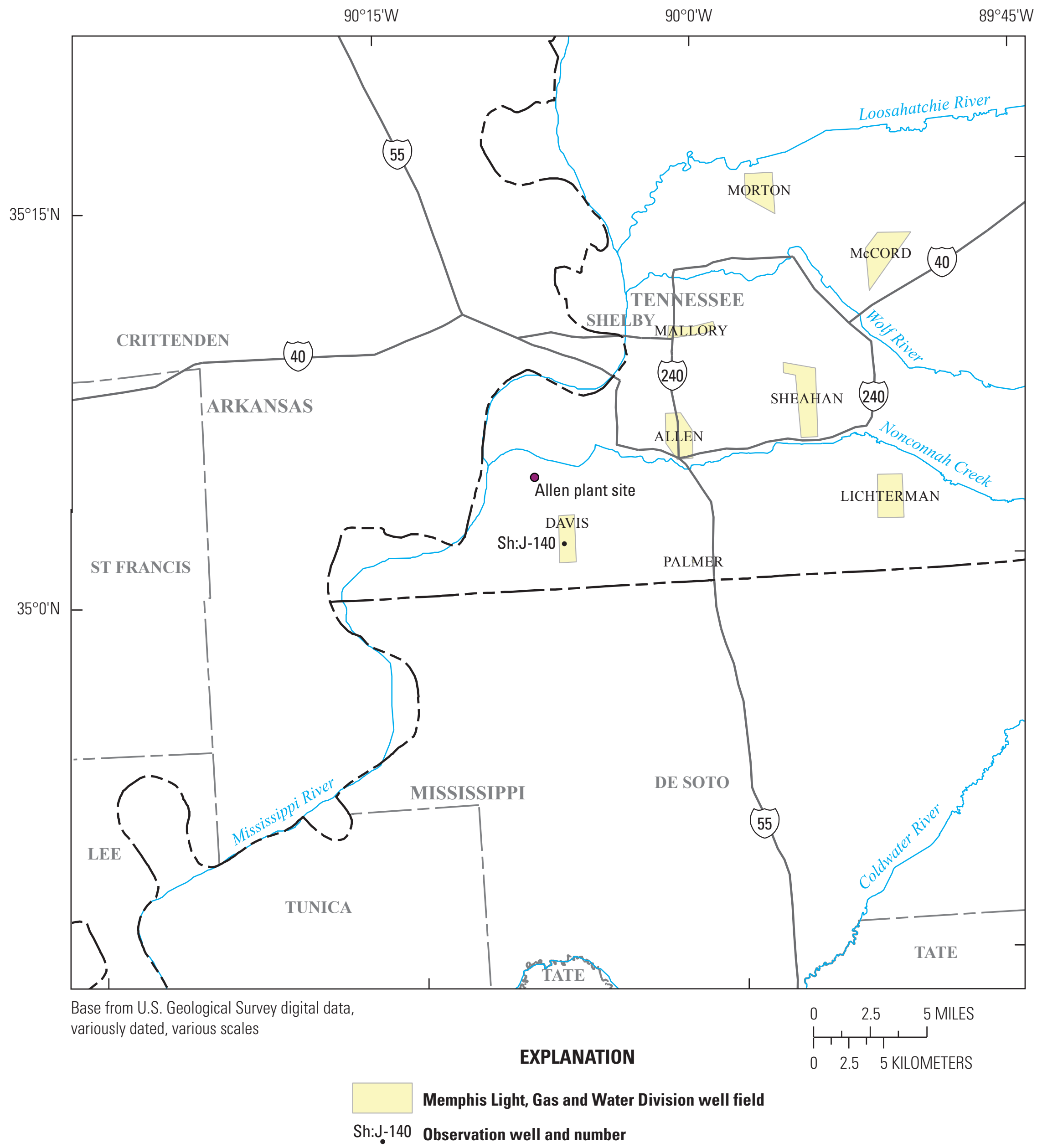

Figure 1. Location of the proposed Allen combined-cycle combustion turbine plant, Shelby County, Tennessee.

Approach

The effects on water levels in the aquifer system from the Allen plant site withdrawals were evaluated by comparing the difference in simulated water levels in the aquifers at the end of the 30-year average withdrawal period and at the end of the scenario (30-year average plus 30-day maximum withdrawal, hereafter referred to as the TVA withdrawal scenario) to a base case with no withdrawals at the Allen plant site. The differences in water levels between the simulations with and without the Allen plant withdrawals were contoured to provide an overall measure of withdrawal effects. The areas encompassed by the –4-ft potentiometric surface change contour were used to compare the affected areas (Haugh, 2012).

The Allen plant site (fig. 1) is simulated to have an annual average groundwater withdrawal of 2,500 gal/min and a 30-day maximum groundwater withdrawal of 5,000 gal/min. The wells at the proposed site would pump water from the Memphis aquifer (table 1). The rate of groundwater withdrawal by the proposed Allen combined-cycle combustion plant was assumed to be constant at the annual average rate over the 30-year period. This same approach was used during an investigation by the USGS, in cooperation with the TVA, conducted during 2008–2009 to define the potential effects of

Table 1. Generalized correlation chart of units of Tertiary age of the Claiborne and Wilcox Groups in West Tennessee and northern Mississippi.

[Fm, formation]

<table>
<tr><th>System</th><th>Series</th><th>Group</th><th>West Tennessee</th><th>Northern Mississippi</th><th>Regional hydrogeologic unit</th></tr>
<tr><td>Quaternary</td><td>Holocene and Pleistocene</td><td></td><td>Alluvium</td><td>Alluvium</td><td rowspan="2">Shallow aquifer</td></tr>
<tr><td>Quaternary</td><td>Pleistocene</td><td></td><td>Fluvial Deposits (terrace deposits)</td><td>Fluvial Deposits (terrace deposits)</td></tr>
<tr><td rowspan="11">Tertiary</td><td rowspan="6">Eocene</td><td rowspan="5">Claiborne</td><td>Cockfield Fm</td><td>Cockfield Fm</td><td>Upper Claiborne aquifer</td></tr>
<tr><td>Cook Mountain Fm</td><td>Cook Mountain Fm</td><td>Middle Claiborne confining unit</td></tr>
<tr><td rowspan="3">Memphis Sand (Memphis aquifer)</td><td>Sparta Sand (Sparta aquifer)</td><td>Middle Claiborne aquifer</td></tr>
<tr><td>Zilpha Clay</td><td>Lower Claiborne confining unit</td></tr>
<tr><td>Lower sands in the Claiborne Group</td><td rowspan="2">Lower Claiborne-Upper Wilcox aquifer</td></tr>
<tr><td rowspan="4">Wilcox</td><td>Flour Island Fm</td><td rowspan="2">Upper sands in the Wilcox Group</td></tr>
<tr><td rowspan="5">Paleocene</td><td rowspan="2">Fort Pillow Sand (Fort Pillow aquifer)</td><td rowspan="2">Middle Wilcox aquifer</td></tr>
<tr><td rowspan="2">Lower sands in the Wilcox Group</td></tr>
<tr><td>Old Breastworks Fm</td><td>Lower Wilcox aquifer</td></tr>
<tr><td rowspan="2">Midway</td><td>Porters Creek Clay</td><td>Porters Creek Clay</td><td rowspan="2">Midway confining unit</td></tr>
<tr><td>Clayton Fm</td><td>Clayton Fm</td></tr>
</table>

Modified from Hosman and Weiss, 1991.

groundwater withdrawals associated with the operation of five proposed combined-cycle combustion turbine plants on the Mississippi embayment aquifer system in West Tennessee and northern Mississippi (Haugh, 2012).

Regional Model

The MERAS model covers 97,000 square miles (mi^2) and consists of 13 model layers with grid cells of 1 mi^2 (Clark and Hart, 2009). The modeling code used for the MERAS model is MODFLOW-2005 (Harbaugh, 2005). Model layers correspond to aquifers and confining units from land surface down to the top of the Midway Group (table 1). In Shelby County, these include the following aquifers: the “shallow aquifer” (alluvium and fluvial deposits), the Memphis aquifer, and the Fort Pillow aquifer (table 1). In Shelby County, the Memphis aquifer is confined by the overlying Cook Mountain Formation. Recharge to the Memphis aquifer is primarily from the infiltration of rainfall in the outcrop area (east of Shelby County). The Memphis aquifer also receives some water as vertical leakage from the shallow aquifer where the confining unit is thin, sandy, or absent. The MERAS model simulations spanned more than 130 years from 1870 to 2007 and incorporated the most current water withdrawal data available (Clark and Hart, 2009).

Effects of Groundwater Withdrawals

The differences in water levels between simulations with and without pumping at the Allen plant site were contoured to provide an overall measure of the effects of pumping at the Allen plant site. At the end of the 30-year average withdrawal period, the simulated potentiometric surface of the Memphis aquifer in the model cell containing the Allen plant site declined by about 7 feet (ft; fig. 2). Simulated declines in the underlying Fort Pillow aquifer and overlying alluvial aquifer did not exceed 1 ft. The area encompassed by the –4-ft potentiometric surface change contour at the end of the 30-year average withdrawal period is 2,590 acres. At the end of the TVA withdrawal scenario (30-year average plus 30-day maximum withdrawal), the simulated potentiometric surfaces of the Memphis aquifer in the model cell containing the Allen plant site declined by 11 ft (fig. 3). Simulated declines in the underlying Fort Pillow aquifer and overlying shallow aquifer did not exceed 1 ft. The area encompassed by the –4-ft potentiometric surface change contour (affected area) at the end of the TVA withdrawal scenario is 11,380 acres.

The simulated potentiometric surface decline of about 7 ft in response to the estimated average groundwater withdrawal at the Allen plant site can be compared to measured water levels from well Sh:J-140 (http://dx.doi.org/10.5066/F7P55KJN, USGS station no. 350124090072200), an observation well completed in the Memphis aquifer and located in the Davis well field (about 3 miles [mi] to the southeast) (fig. 1). The Davis well field began withdrawals in August 1971 with average withdrawals of about 8,300 gal/min from 1972 through 2000 (Parks and others, 1995). In the early 2000s, withdrawals at the Davis well field increased and averaged about 12,900 gal/min from 2006 through 2014. Periodic water-level measurements from well Sh:J-140 show an initial decline during 1971–72 of about 20 ft due to withdrawals at the Davis well field (fig. 4). Annual water-level variations in subsequent years (1973–2015) in well Sh:J-140 average about 10 ft. Seasonal water-level fluctuations in the Memphis aquifer in the Davis well field area are related to variations in withdrawals at the well field or in the Memphis area (Parks and others, 1995). The simulated potentiometric surface declines at the Allen plant site of about 7 ft in response to average withdrawals at the Allen plant site would be less than the typical seasonal variations in water levels observed in observation well Sh:J-140 at the Davis well field.

The simulated potentiometric surface decline of 11 ft at the end of the TVA withdrawal scenario at the Allen plant site is notably less than the simulated declines (20 to 56 ft) in source aquifers from the five sites previously analyzed by Haugh (2012). The affected area at the Allen site (11,380 acres) is near the minimum area from the five sites previously analyzed where affected areas ranged from 11,362 to 535,143 acres (Haugh, 2012). Pumping rates at the Allen site were similar to those at the previously studied sites where four of the five sites had annual average water withdrawals of 2,460 gal/min and 30-day maximum water withdrawals of 3,473 gal/min. The magnitude of change at all the sites and the spatial extent of affected areas varied depending on the transmissivity and storativity of the aquifers, the amount of confinement from above and below, the withdrawal rates, and the effects of nearby boundary conditions (Haugh, 2012). At the Allen plant site, the simulated decline is smaller than the decline at any of the previously studied sites, most likely due to the greater thickness and transmissivity of the Memphis aquifer at the Allen plant site.

The simulations show less than a 1-ft decline in the overlying shallow aquifer; however, the potential effect of the withdrawals on water levels in the shallow aquifer as well as the potential for water-quality changes due to the leakage of water from the shallow aquifer near the Allen plant site cannot be fully evaluated with the available data and the scope of the current investigation. Water-quality changes in the Memphis aquifer due to the leakage of water from the shallow aquifer have been noted in nearby Memphis Light, Gas and Water Division well fields at Davis (about 3 mi to the southeast) (Parks and others, 1995) and at Allen (about 6 mi to the west) (Parks, 1990). The simulated declines in the potentiometric surface of the Memphis aquifer as a result of simulated withdrawals at the Allen plant site were localized and similar in magnitude and extent to declines associated with other users over the simulation period.

Model Limitations

Models are simplifications of natural systems. Factors that affect how well a model represents a given natural system include the model scale, the accuracy and availability of hydraulic property data, the accuracy of withdrawal, water-level, and streamflow data, and appropriately defined boundary conditions. The MERAS model, used for the analysis presented in this report, is consistent with the conceptual model and hydrologic data of the MERAS study area. The MERAS model uses a grid-cell size of 1 mi^2, and a model will not provide accurate prediction on a scale smaller than the grid resolution. The hydraulic-conductivity zones used in the MERAS model represent large-scale variation in hydraulic properties; the actual spatial variations of hydraulic properties of the aquifer system occur on a much smaller scale and are poorly defined. Further discussion of the limitations of the MERAS model are reported by Clark and Hart (2009, p. 56).

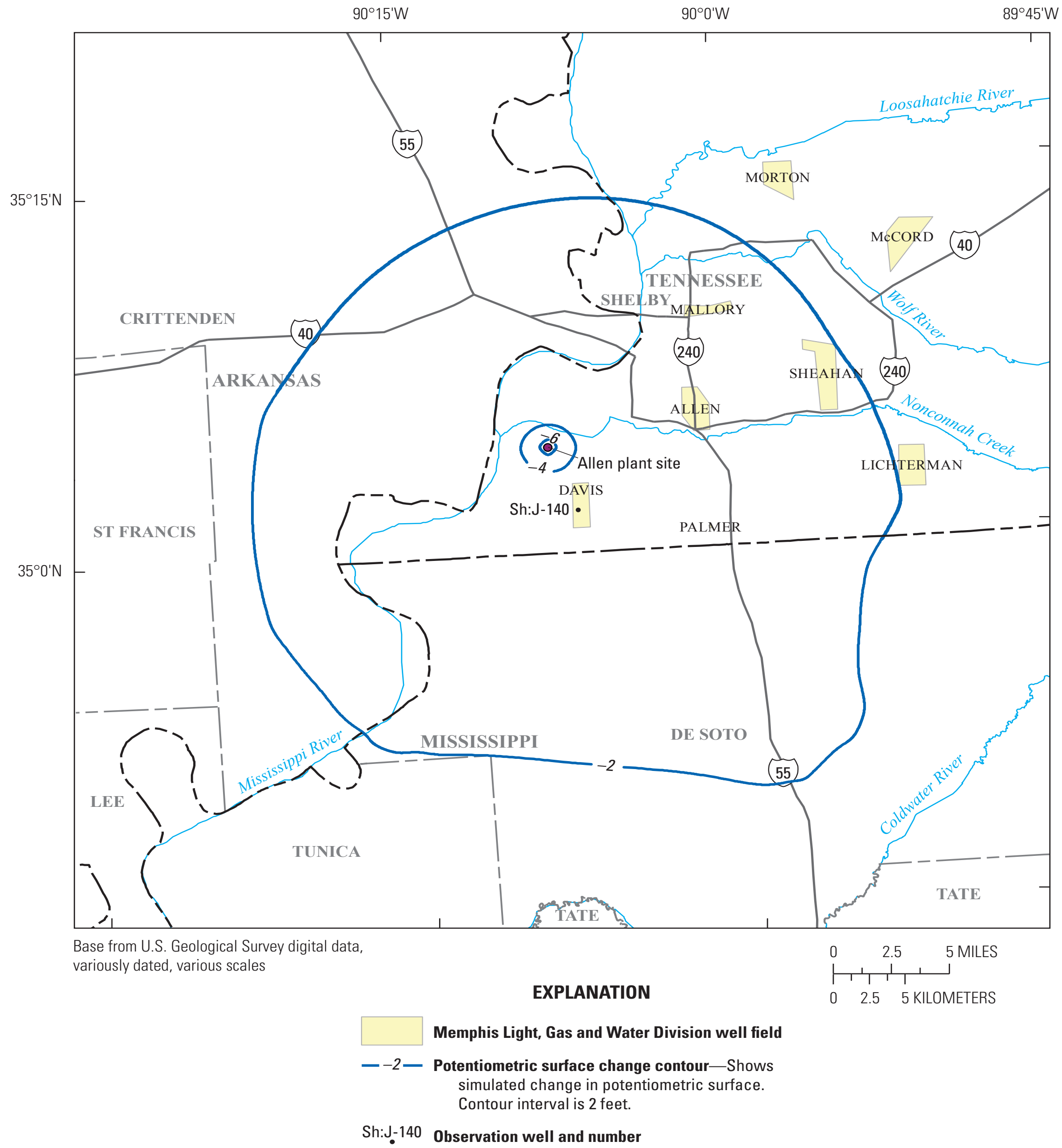

Figure 2. Simulated potentiometric surface change in the Memphis aquifer at the end of the 30-year average withdrawal period at the proposed Allen combined-cycle combustion turbine plant, Shelby County, Tennessee.

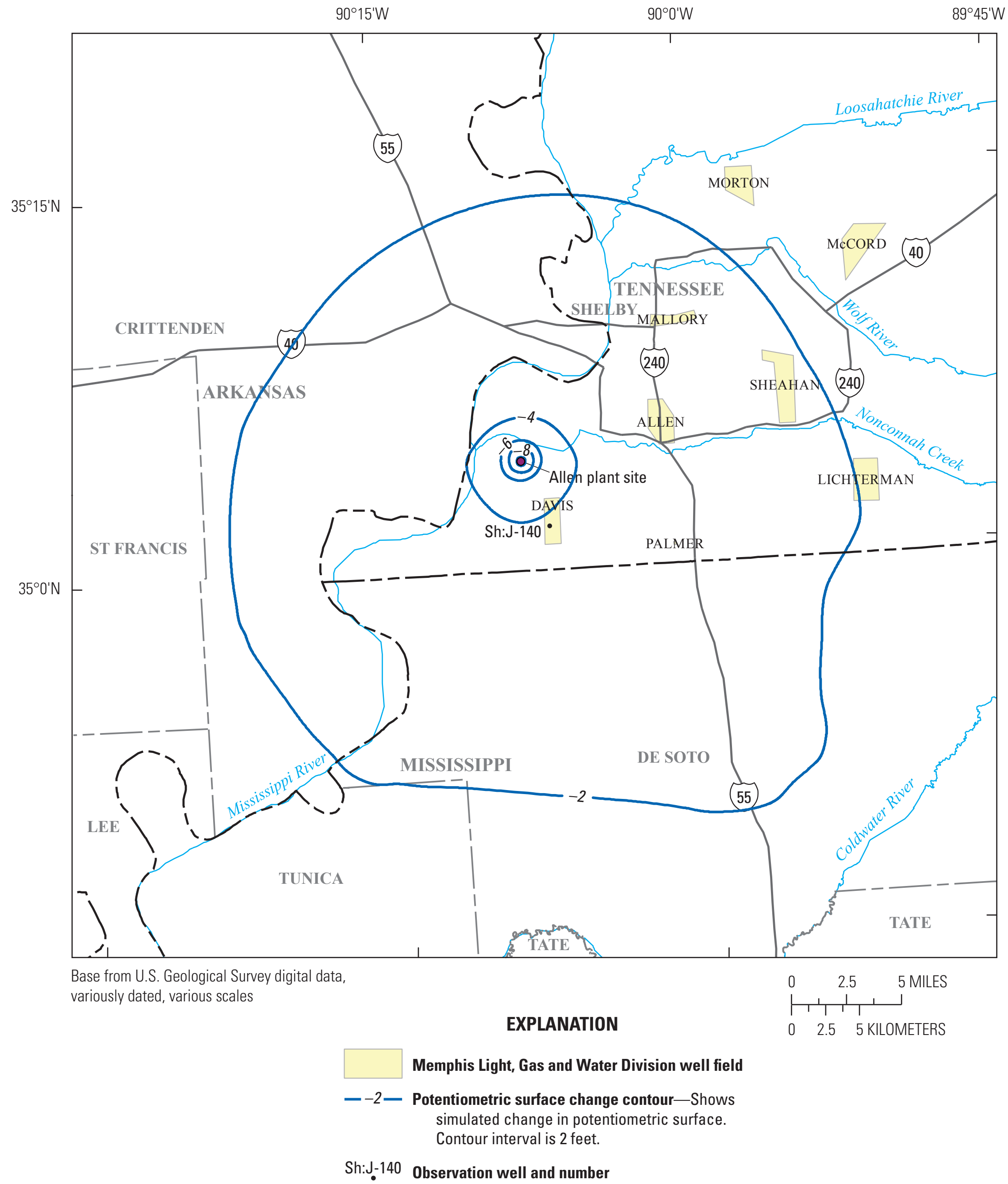

Figure 3. Simulated potentiometric surface change in the Memphis aquifer at the end of the Tennessee Valley Authority withdrawal scenario at the proposed Allen combined-cycle combustion turbine plant, Shelby County, Tennessee.

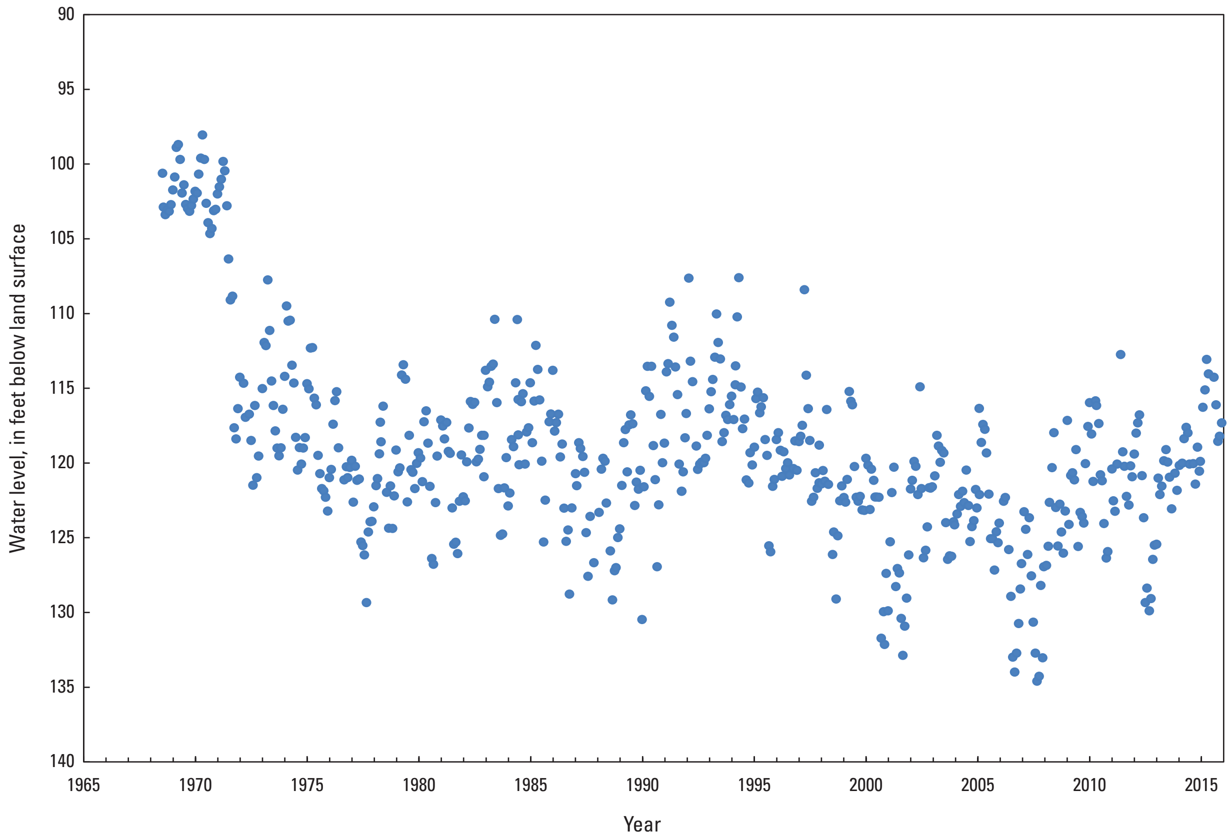

Figure 4. Periodic water levels in well Sh:J-140 from 1968 to 2015, Davis well field, Shelby County, Tennessee.

Summary

The Tennessee Valley Authority (TVA) proposes to reduce sulfur dioxide emissions at its Allen Fossil Plant (ALF) in Shelby County, Tennessee, by retiring the coal units and constructing a natural gas power plant. The proposed plant (the Allen combined-cycle combustion turbine plant, referred to as the Allen plant site) will be a two-on-one natural gas plant that can run in either simple- or combined-cycle mode. The combined-cycle mode is projected to use an annual average of 2,500 gallons per minute (gal/min) and a maximum of 5,000 gal/min. Therefore, the effects of groundwater withdrawal at the proposed Allen plant site on the aquifers and on groundwater levels were evaluated.

Model results indicate potentiometric surface declines at the Allen plant site of about 7 feet (ft) at the end of a 30-year period of average groundwater withdrawal and 11 ft at the end of the TVA withdrawal scenario (30 years average withdrawal plus 30 days maximum withdrawal). The change at the Allen plant site is smaller than the declines at any of the five sites studied during 2008–2009, which ranged from 20 to 56 ft. The simulated decline of 7 ft in response to average groundwater withdrawal is also smaller than seasonal variations of about 10 ft observed in Sh:J-140, an observation well completed in the Memphis aquifer at the Davis well field (about 3 miles to the southeast). Simulated declines in the potentiometric surface of the Memphis aquifer from simulated withdrawals at the Allen plant site were localized and similar in magnitude and extent to declines associated with other users of the Memphis aquifer.

The potential effect of the withdrawals at the Allen plant site on water levels in the shallow aquifer as well as the potential for water-quality changes due to the leakage of water from the shallow aquifer near the Allen plant site cannot be fully evaluated with the available data. Simulated declines in the overlying shallow aquifer at the Allen site were less than 1 ft; however, water-quality changes in the Memphis aquifer due to the leakage of water from the shallow aquifer have been noted in nearby Memphis Light, Gas and Water Division well fields at Davis and Allen.

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