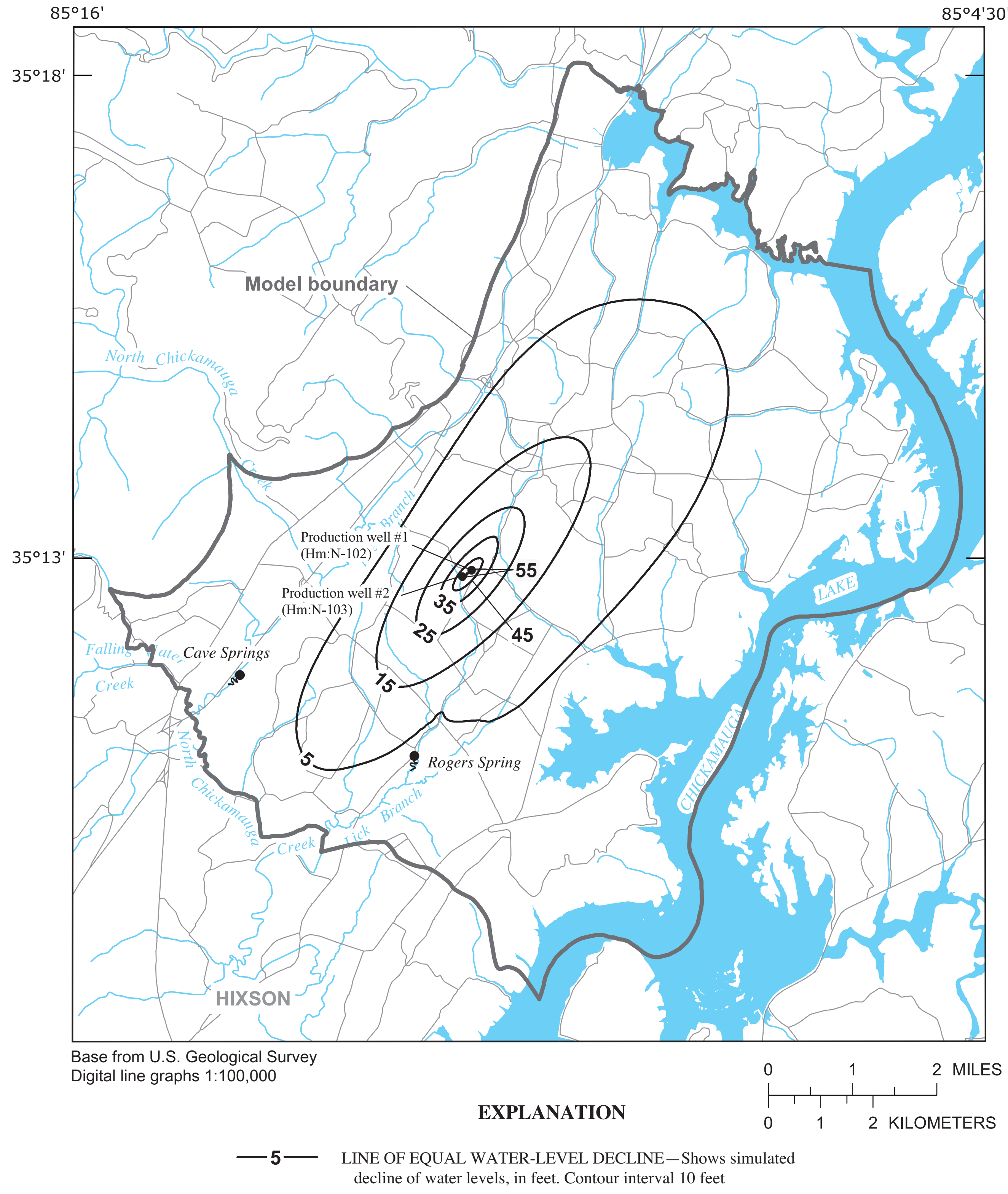
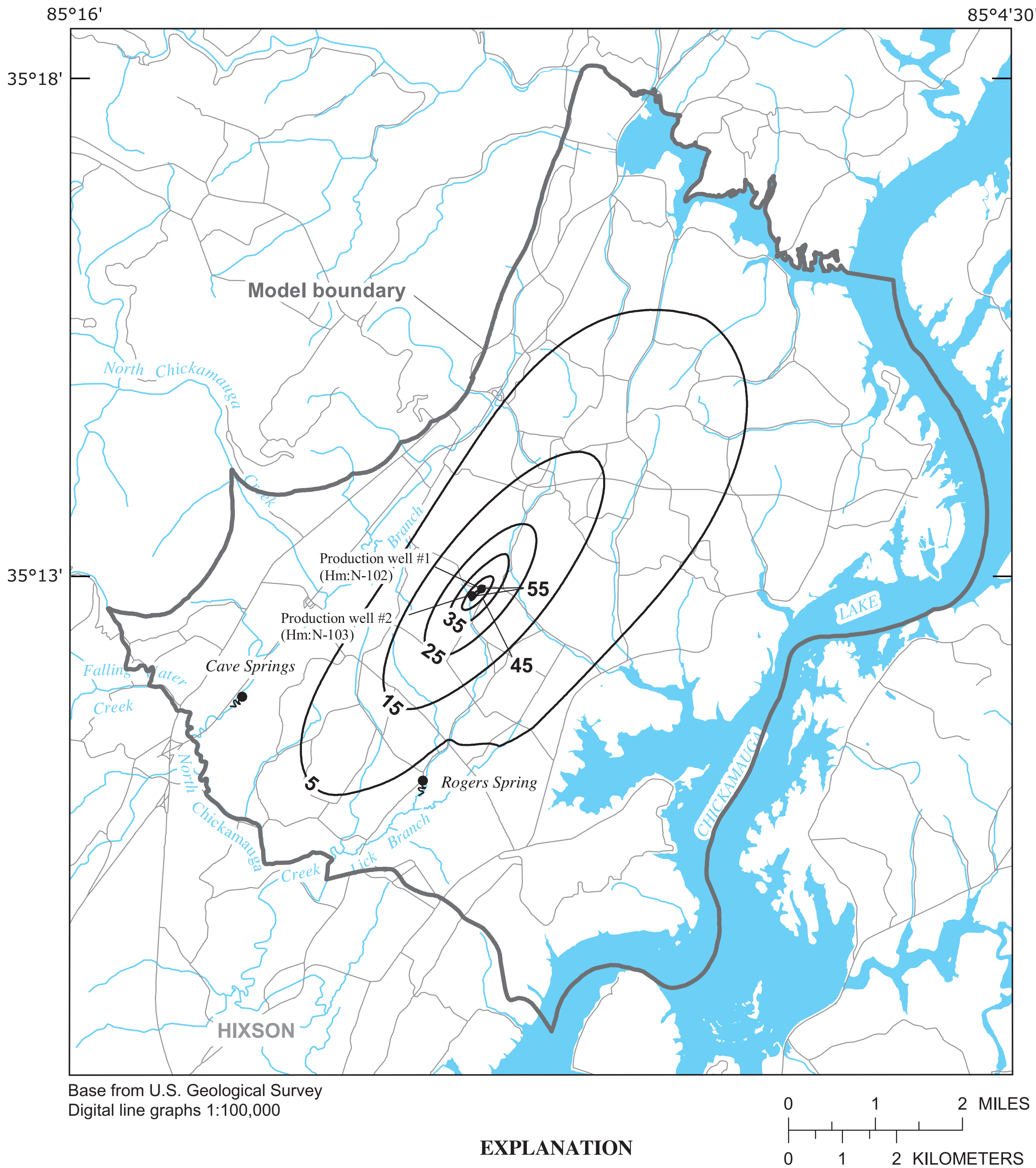


Figure 29. Model-simulated steady-state water-level decline with Walkers Corner production wells #1 and #2 in use, layer 1.



EXPLANATION

—5— LINE OF EQUAL WATER-LEVEL DECLINE—Shows simulated decline of water levels, in feet. Contour interval 10 feet

Figure 30. Model-simulated steady-state water-level decline with Walkers Corner production wells #1 and #2 in use, layer 2.

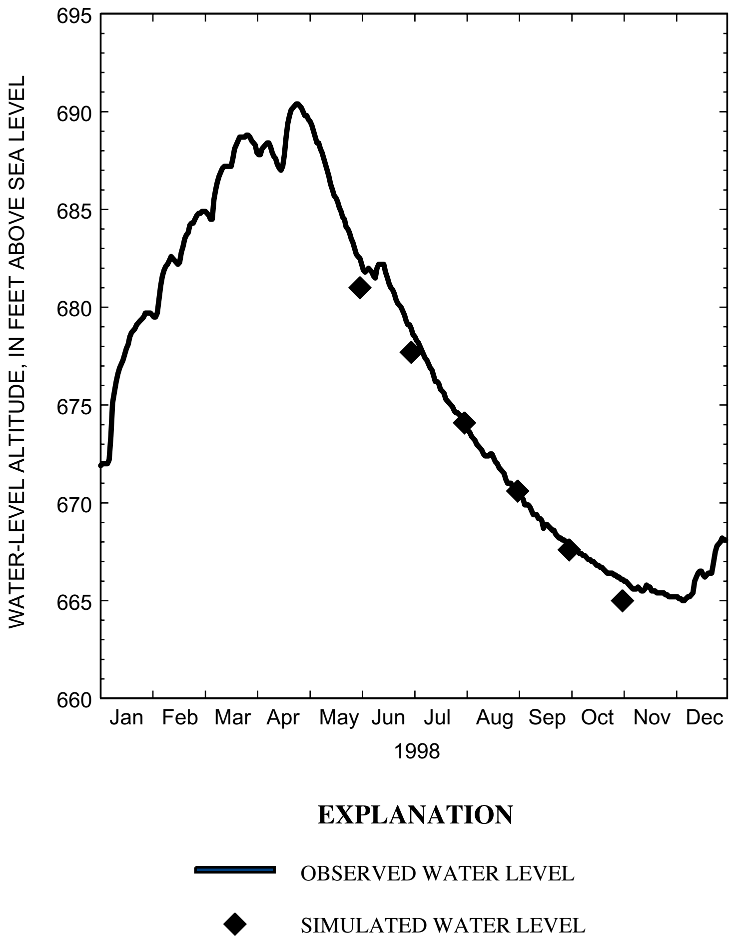


Figure 31. Observed and simulated water-level recession in well Hm:N-051.

case of no recharge from infiltrating precipitation or recharge from losing streams along the Cumberland Plateau escarpment. Recharge from these losing streams is an important source of recharge for Cave Springs, and this flux of water would continue for a period of time in the absence of precipitation as the aquifers on the Cumberland Plateau supply base flow to streams draining the plateau. Field observations confirm that North Chickamauga Creek has sustained base flow in the North Chickamauga Creek Gulch during summer months when rainfall is limited.

Sensitivity Analysis

Composite scaled sensitivities were calculated for the steady-state calibration model using the sensitivity process in MODFLOW-2000 for all the hydraulic conductivity and recharge parameters (fig. 35). Hill and others (2000) describe how sensitivities can be calculated for any of the model parameters discussed by Harbaugh and others (2000). Composite scaled sensitivities can be used to compare the importance of different parameters to the calculation of model-simulated water levels and flows (Hill, 1998). Parameters with greater composite sensitivities have greater importance and greater influence on the model solution. The most sensitive model parameter is the layer 2 hydraulic conductivity for the average zone (HK2_average). The next most sensitive parameter is the recharge rate for the ridge area (RCH_ridge). The model is least sensitive to the parameters HK1_high, HK2_low, HK2_walkers, and HK1_walkers.

Model Limitations

Models, by their very nature, are simplifications of the natural system. Factors that affect how well a model represents the natural system include the model scale, inaccuracies in estimating hydraulic properties, inaccurate or poorly defined boundary conditions, and the accuracy of pumping, water-level, and streamflow data. The model presented in this report is consistent with the conceptual model and hydrologic data of the area. The model uses a variably spaced grid so the model resolution is greatest near the pumping centers. The model will not provide accurate predictions on a scale smaller than the grid resolution.

The hydraulic-conductivity zones used in the model represent large-scale variations in hydraulic properties; the actual spatial variations of hydraulic properties of the aquifer occur on a much smaller scale and are poorly defined. Additionally, the aquifer, being karst in nature, has a wide range of measured transmissivity. Finally, evidence suggests that the aquifer behaves anisotropically, but no measured values of the degree of anisotropy exist.

The boundary conditions for the model correspond to natural features throughout most of the study area. The greatest uncertainty in boundary conditions is the recharge flux along the Cumberland Plateau escarpment. Water draining from the Cumberland Plateau is an important source of recharge to the study area, but the quantity and distribution of this recharge flux is uncertain.

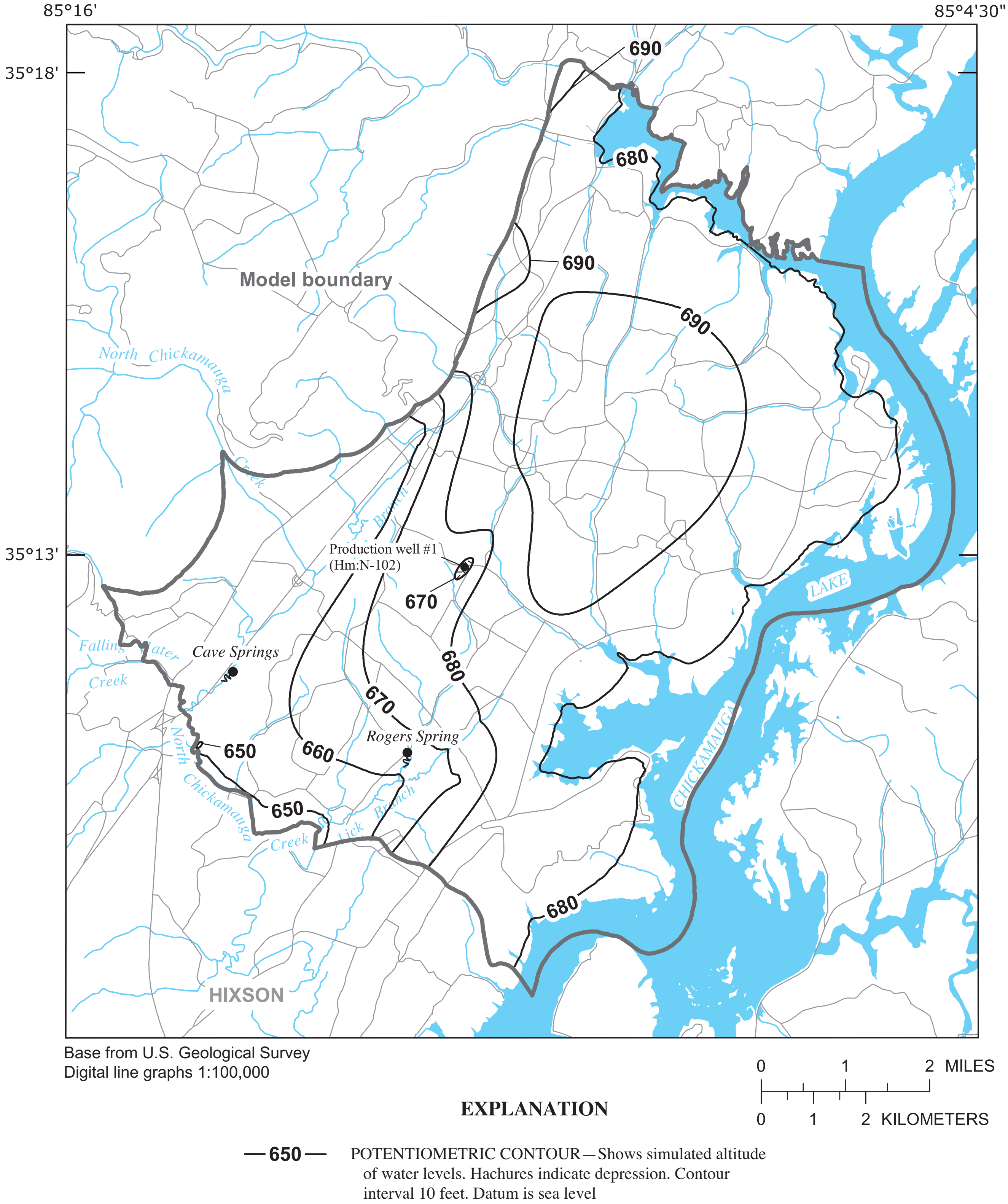
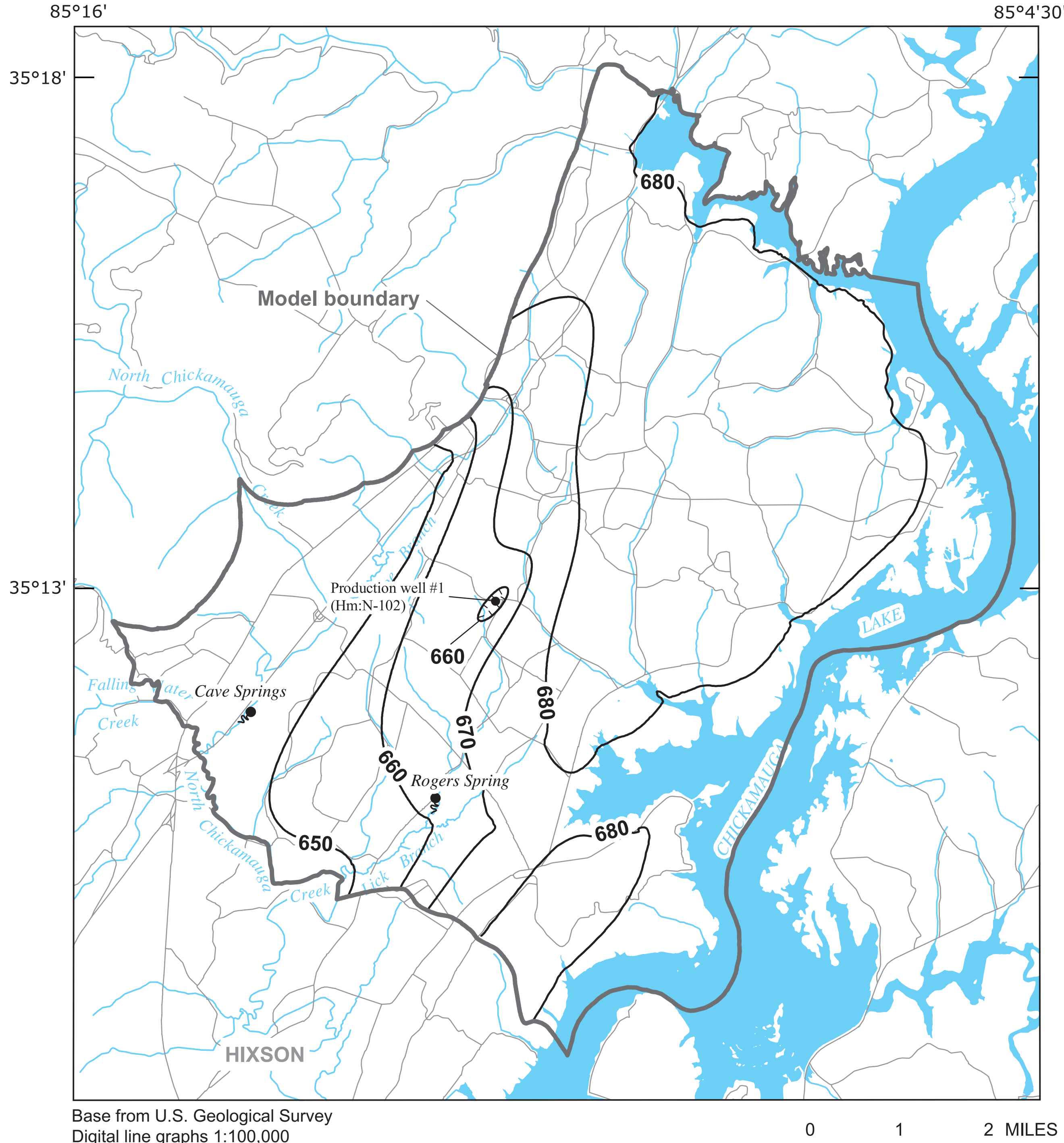


Figure 32. Model-simulated water levels after 4 months without recharge, layer 1.



EXPLANATION

— 650 — POTENTIOMETRIC CONTOUR—Shows simulated altitude of water levels. Hachures indicate depression. Contour interval 10 feet. Datum is sea level

Figure 33. Model-simulated water levels after 8 months without recharge, layer 1.

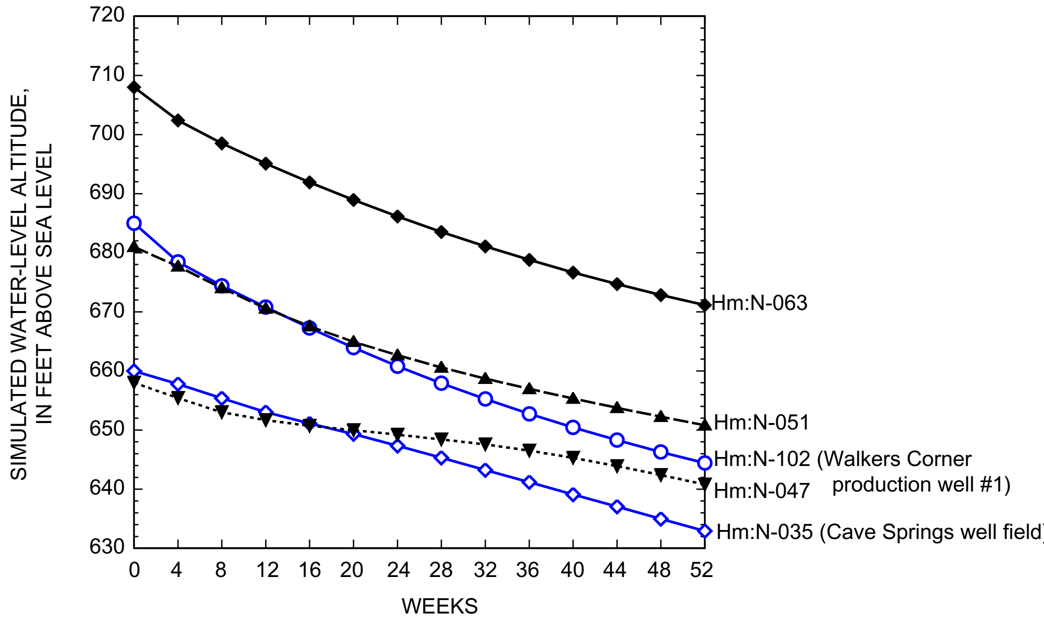


Figure 34. Simulated water-level recessions from a period with no recharge for selected wells.

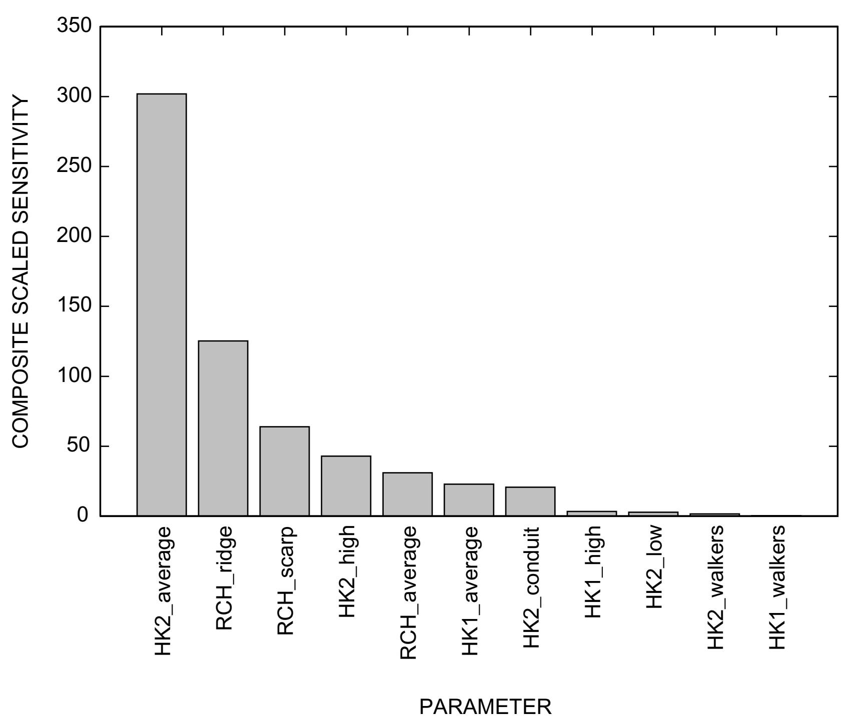


Figure 35. Composite scaled sensitivities for model perameters.

The ground-water model provides a reasonable match to observed water-levels for both pre- and post-pumping at Walkers Corner production well #1 (figs. 20 and 23). The observed water levels provide a fairly complete and accurate data set for the model. Simulated stream base flows are within expected ranges, but the data set to determine stream base flow is limited. Continuous streamflow information in the study area is sparse. Cave Springs has the most complete flow record in the study area with 5 years of continuous discharge data and accounts for 18 percent of the calibration model water budget. Ground-water discharge to Chickamauga Lake cannot be measured in the field, but this discharge accounts for 23 percent of the calibration model water budget. The larger uncertainty with measured fluxes (as opposed to measured water levels) makes defining the best model for the system difficult because the same water-level surface can be supported by different flows as long as the ratio of flows to hydraulic conductivity remains constant. Therefore, the model solution is not unique, which means that other combinations of model parameters can result in the same water-level distribution.

The model simulates the change in water levels from pumping at Walkers Corner production well #1 reasonably well (fig. 25). The predicted changes in water levels from additional pumping at Walkers Corner production well #2 assume that production well #2 behaves similarly to production well #1. Preliminary data suggest that Walkers Corner production well #2 has a greater specific capacity than production well #1. If this is true, then the model will overpredict the water-level declines from the additional pumping at production well #2.

This report presents potentiometric-surface data and water-budget data from a numerical flow model of the study area. The aquifer in the study area contains fractured bedrock and dissolution openings common in karst aquifers. For modeling purposes, the aquifer is treated as an equivalent porous media. Using this approach, potentiometric-surface data and water-budget data can be satisfactorily simulated at a regional scale. However, this report presents no model-simulated time-of-travel data because no information about the effective porosity of the aquifer was developed as part of this study.

SUMMARY

The ground-water resource in the Cave Springs area is used by the Hixson Utility District (HUD) as a water supply and is one of the more heavily stressed in the Valley and Ridge Physiographic Province. In 1999, ground-water withdrawals by the HUD averaged about 6.4 Mgal/d from two pumping centers. Historically, the HUD has withdrawn about 5.8 Mgal/d from wells at Cave Springs, one of the larger springs in Tennessee. In 1995 to meet increasing demand, an additional well field was developed at Walkers Corner, located about 3 miles northeast of Cave Springs. From 1995 through 2000, pumping from the first production well at Walkers Corner has averaged about 1.8 Mgal/d. A second production well at Walkers Corner has now increased the capacity of the well field by an additional 2 Mgal/d.

Ground water in the study area is present in both regolith and bedrock. A thick mantle of regolith, composed of insoluble chert and clay residuum formed from the weathering of carbonate bedrock, covers most of the study area. Regolith thickness varies from less than 1 to 298 feet and is thickest on Cave Springs Ridge. The thick clay-rich regolith acts as a leaky confining unit and provides a large ground-water storage reservoir for recharge to the underlying bedrock. In the valley of North Chickamauga Creek, the regolith also contains coarse-grained alluvium, consisting of gravel, cobbles, and boulders eroded from the sandstones of the Cumberland Plateau. The coarse-grained alluvium provides a highly permeable pathway for surface water in streams flowing off the plateau to recharge the underlying Newman Limestone.

Most of the bedrock in the study area has low primary porosity and permeability; however, fracturing and dissolution have produced substantial secondary porosity and permeability. Ground-water flow through the bedrock occurs as both diffuse and conduit flow. Most of the flow in the bedrock occurs in dissolutionally enlarged fractures, joints, and bedding planes. Secondary permeability is the most developed in the Newman Limestone.

Recharge to the ground-water system in the study area is from two distinct sources: direct infiltration of precipitation and losing streams. Estimates of recharge rates using hydrograph separation for two nearby basins range from 10.6 to 12.5 inches per year. Using a Thornwaite water-budget method, an average annual recharge rate of 15 inches per year was determined, with most of the recharge occurring during the winter and spring months. Recharge from losses of streamflow is most significant along parts of North Chickamauga Creek. Streamflow discharge measurements show flow losses of 24 and 11 ft^3/s from a reach of North Chickamauga Creek upstream of the mouth of Poe Branch. This losing reach of North Chickamauga Creek is an important source of concentrated recharge to the Cave Springs ground-water system. The losing reach most likely extends from the mouth of Poe Branch upstream to where North Chickamauga Creek first contacts the Newman Limestone.

Potentiometric-surface maps show that ground-water levels are highest along the ridge near the center of the study area and ground water flows radially outward towards Chickamauga Lake, Lick Branch, Poe Branch, and North Chickamauga Creek. The North Chickamauga Creek and Poe Branch valley is clearly evident in the potentiometric surfaces with low gradients along much of the axis of the valley. Potentiometric-surface maps constructed since 1995 show a depression at the Walkers Corner well field. Water-level declines from May 1993 to May 1999 are about 30 feet in Walkers Corner production well #1, 20 feet or less outside the immediate area of the well field, and more pronounced along strike.

A numerical ground-water-flow model of the aquifer system was constructed and calibrated using MODFLOW-2000. Results of the modeling effort confirm that losing streams along the base of the Cumberland Plateau escarpment at the western edge of the study area are an important source of recharge to the Cave Springs ground-water system, supplying about 50 percent of the recharge to the study area. The other source of recharge, direct infiltration of precipitation, accounts for the remaining recharge to the study area. The model water budget shows that in 1999, ground-water withdrawals of 9.9 ft^3/s (6.4 Mgal/d) equal about 11 percent of the total ground-water recharge with the remaining 89 percent of recharge discharging to North Chickamauga Creek and Cave Springs (58 percent, 50.4 ft^3/s), Chickamauga Lake (22 percent, 19.0 ft^3/s), Poe Branch (5 percent, 4.1 ft^3/s), and Lick Branch and Rogers Spring (4 percent, 3.4 ft^3/s). The model simulates the regional water-level surface and the current drawdown at the Walkers Corner well field reasonably well.

Ground-water withdrawals at Walkers Corner averaged about 2.8 ft^3/s (1.8 Mgal/d) in 2000. If additional pumping at Walkers Corner increases withdrawals by 3 ft^3/s (2 Mgal/d) for a total withdrawal at Walkers Corner of about 5.8 ft^3/s (3.8 Mgal/d), the model-simulated drawdown at Walkers Corner well field increases to about 60 feet. Preliminary field observations suggest Walkers Corner production well #2 may have a greater specific capacity than production well #1. If this is true, then production well #2 would produce less drawdown than the model currently estimates. The model water budget indicates that additional ground-water withdrawal at Walkers Corner from production well #2 would result in decreases in simulated ground-water discharge of 1.0 ft^3/s to Chickamauga Lake, 0.8 ft^3/s to North Chickamauga Creek, 0.5 ft^3/s to Lick Branch-Rogers Spring drainage, 0.5 ft^3/s to Poe Branch, and 0.2 ft^3/s to Cave Springs.

The effects of a drought were analyzed by using the model to simulate a 12-month period without recharge. Results show that water levels decline as the ground-water system drains. While a 12-month period with no recharge may not be realistic, the results from this simulation can be used to estimate the effects on water levels in the study area if no recharge occurs for several months, given observations of the current conditions at any point in time. Hydrographs of simulated water-level recessions in the study area show that water levels recede quickest in the center of the study area, farthest from the natural discharge areas. Additionally, water levels recede quicker at the pumping centers. This drought scenario simulation would overestimate the water-level decline at the Cave Springs well field because the model simulates an extreme case of no recharge from infiltrating precipitation or recharge from losing streams along the Cumberland Plateau escarpment. Recharge from these losing streams is an important source of recharge for Cave Springs, and this flux of water would continue for a period of time in the absence of precipitation as the aquifers on the plateau supply base flow to streams draining the plateau.

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