SIMULATION OF GROUND-WATER FLOW IN THE ALBUQUERQUE BASIN, CENTRAL NEW MEXICO, 1901-95, WITH PROJECTIONS TO 2020

(Supplement Two to U.S. Geological Survey Water-Resources Investigations Report 94-4251)

By John Michael Kernodle

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
foot	0.3048	meter
mile	1.609	kilometer
square mile	2.590	square kilometer
acre-foot	0.001233	cubic hectometer
	43,560	cubic foot
acre-foot per year	0.001233	cubic hectometer per year
	0.0013803	cubic foot per second
foot per day	0.3048	meter per day

Sea level: 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 called Sea Level Datum of 1929.

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Abstract

The ground-water-flow model of the Albuquerque Basin (Kernodle, J.M., McAda, D.P., and Thorn, C.R., 1995, Simulation of ground-water flow in the Albuquerque Basin, central New Mexico, 1901-1994, with projections to 2020: U.S. Geological Survey Water-Resources Investigations Report 94-4251, 114 p.) was updated to include new information on the hydrogeologic framework (Hawley, J.W., Haase, C.S., and Lozinsky, R.P., 1995, An underground view of the Albuquerque Basin: Proceedings of the 39th Annual New Mexico Water Conference, November 3-4, 1994, p. 37-55). An additional year of ground-water-withdrawal data was appended to the simulation of the historical period and incorporated into the base for future projections to the year 2020. The revised model projects the simulated ground-water levels associated with an areally enlarged occurrence of the relatively high hydraulic conductivity in the upper part of the Santa Fe Group east and west of the Rio Grande in the Albuquerque area and north to Bernalillo. Although the differences between the two model versions are substantial, the revised model does not contradict any previous conclusions about the effect of City of Albuquerque ground-water withdrawals on flow in the Rio Grande or the net benefits of an effort to conserve ground water. Recent revisions to the hydrogeologic model (Hawley, J.W., Haneberg, W.C., and Whitworth, P.M., in press, Hydrogeologic investigations in the Albuquerque Basin, central New Mexico, 1992-1995: Socorro, New Mexico Bureau of Mines and Mineral Resources Open-File Report 402) of the Albuquerque Basin eventually will require that this model version also be revised and updated.

INTRODUCTION

Hawley and Haase (1992), in a study by the New Mexico Bureau of Mines and Mineral Resources, described the hydrogeologic framework of the Albuquerque Basin. Their description differed significantly from the previous commonly accepted conceptual model of the tectonic history, structure, and hydrogeology of the basin (Bjorklund and Maxwell, 1961; Kelley, 1977; Kernodle and others, 1987). In addition, they presented detailed information on the geohydrologic properties of the Santa Fe Group basin-fill deposits, which constitute the sole source of drinking water for all municipalities in the basin. In response to this new information the U.S. Geological Survey (USGS) in cooperation with the City of Albuquerque conducted a two-part investigation of the geohydrology of the basin. The first of two reports resulting from the investigation (Thorn and others, 1993) described the geohydrologic framework and hydrologic conditions in the Albuquerque Basin. The second report (Kernodle and others, 1995) described a detailed ground-water-flow model of the Albuquerque Basin that was constructed on the basis of the hydrogeology as described by Hawley and Haase (1992), the geohydrology as described by Thorn and others (1993), and information obtained from numerous other sources (Kernodle and others, 1995, p. 10, 22-23).

Since the publication of the description of the first version of the ground-water-flow model (Kernodle and others, 1995), Hawley and others (1995) have significantly revised the conceptual model of the hydrogeologic framework of the basin. The ground-water-flow model has been changed to include most, but not all, of these and other revisions and to make corrections and updates. This report updates some of the previous hydrologic information in Thorn and others (1993) and describes the changes to the ground-water-flow model, projections, and conclusions of Kernodle and others (1995). Readers are encouraged to familiarize themselves with the sequence of reports by

Hawley and Haase (1992), Thorn and others (1993), and Kernodle and others (1995). A review of Bjorklund and Maxwell (1961), Reeder and others (1967), Kelley (1977), and Kernodle (1992) would be useful for historical perspective.

This report is not intended to be an exhaustive review of information and compilation of interpretations from the previous two USGS reports but rather a presentation of the recent structural modifications to the model and the major consequences, in terms of the predictive capability of the model, of those changes. The discussion of interpretation is limited primarily because the changes to the model have relatively little effect on the conclusions that may be drawn about the water resources of the Albuquerque area.

Keeping the ground-water-flow model current with the constantly evolving hydrogeologic conceptual model and additional information has been and will continue to be a challenging process. As knowledge of the surface- and ground-water-flow systems of the Albuquerque Basin increases and improves, the model needs to be revised accordingly. The ground-water-flow model described in this report is but one in a probable long series of efforts to numerically quantify the overall water resources of the basin. An unquantifiable benefit of this process of evolution in numerical modeling, in combination with data collection and interpretation, is that one process guides and improves the other.

The USGS acknowledges the provision of information, in addition to that already mentioned, from the City of Albuquerque, the City of Rio Rancho, the Office of the State Engineer, the Pueblo of Cochiti, the Pueblo of Isleta, the Pueblo of Jemez, the Pueblo of San Felipe, the Pueblo of Santa Ana, the Pueblo of Santo Domingo, the Pueblo of Zia, the Bureau of Indian Affairs, and the Bureau of Reclamation.

GROUND-WATER-FLOW MODEL REVISIONS, CORRECTIONS, AND UPDATES

As mentioned in the introduction, this second version of the ground-water-flow model of the Albuquerque Basin (fig. 1) significantly differs from the first version. Although the differences between the two model versions are substantial, the revised model does not contradict any previous conclusions about the effect of City of Albuquerque ground-water withdrawals on flow in the Rio Grande or about the net benefits of an effort to conserve ground water. The most substantial changes in model revisions and simulation results were outside the Albuquerque metropolitan area. In the following sections, the term *revision* indicates a change that was made because of enhanced understanding of the flow systems; the term *correction* refers to the correction of an error in the first version; and the term *update* refers to the inclusion of additional historical or spatial data not available for the previous version. Most of these changes were made simultaneously so no absolutely quantifiable responses for each change can be described. Without exception, however, the changes proposed by Kernodle and others (1995, p. 99-108) that were applied to the revised model produced the expected results as discussed in Kernodle and others (1995).

Revisions

Three revisions were made, the effects of which are discussed later. The first revision was a major redefinition of the distribution of aquifer units, especially the extent of the high-hydraulic-conductivity axial-channel deposits in the upper part of the Santa Fe Group. The second was a repositioning of a number of major faults within the Albuquerque area (Hawley and others, 1995). The third revision was an increase in the simulated horizontal and vertical hydraulic conductivity of the clay layer within the Rio Grande alluvial fill in the Albuquerque area.

The hydrogeologic interpretations upon which this model version are based have been superseded by Hawley and others (in press). Nevertheless, the mapped redistribution of aquifer units and repositioning of faults used in this study were based on additional field investigations, drillers' logs of new wells, and numerous new interpretations of existing geophysical logs. The distributions of aquifer hydraulic conductivities are presented for each model layer in figures 2 through 12 and can be compared with figures 7 through 17 in Kernodle and others (1995).

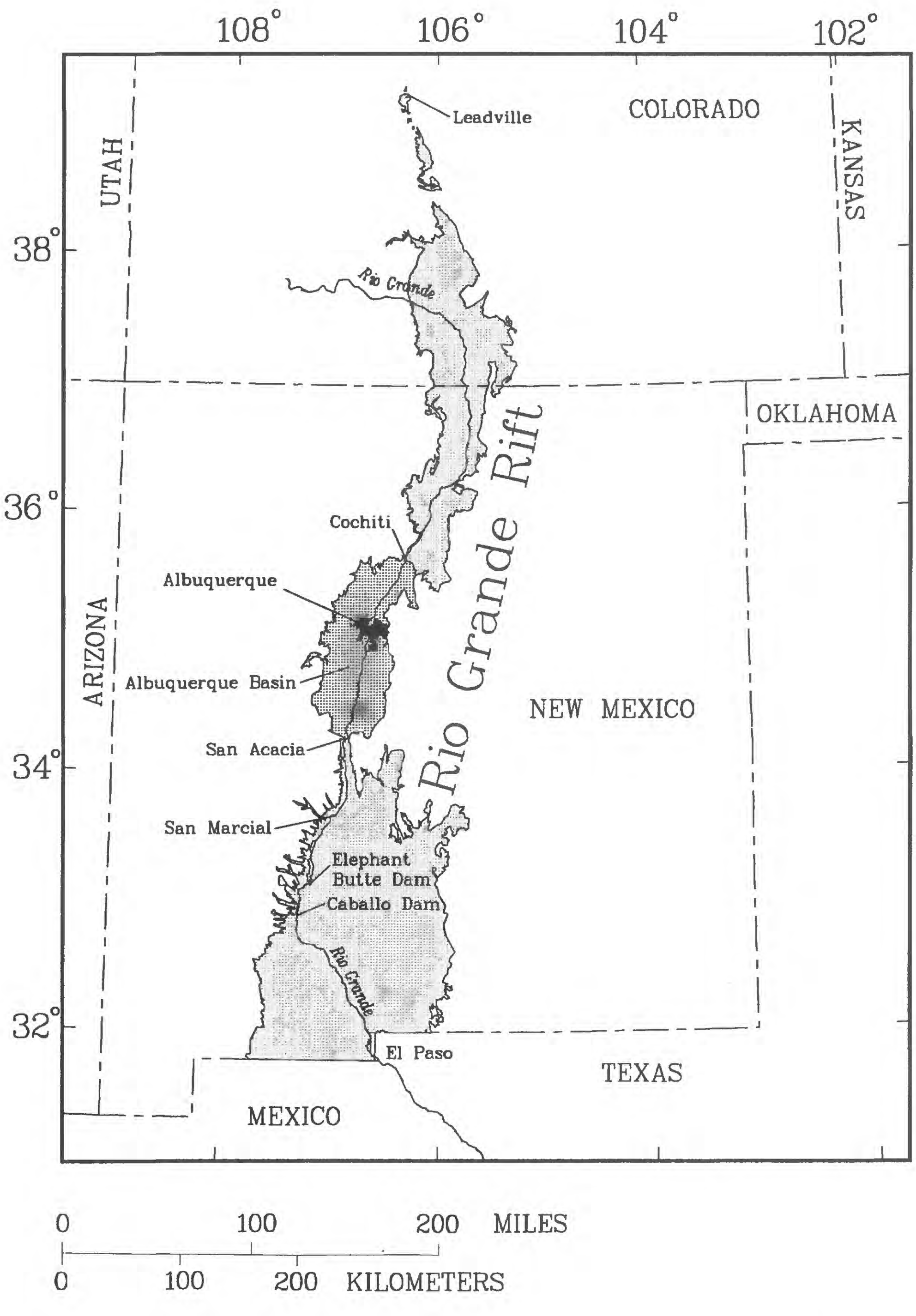


Figure 1.—Location of the Albuquerque Basin and the Rio Grande Rift, central New Mexico (modified from Thorn and others, 1993, fig. 1).

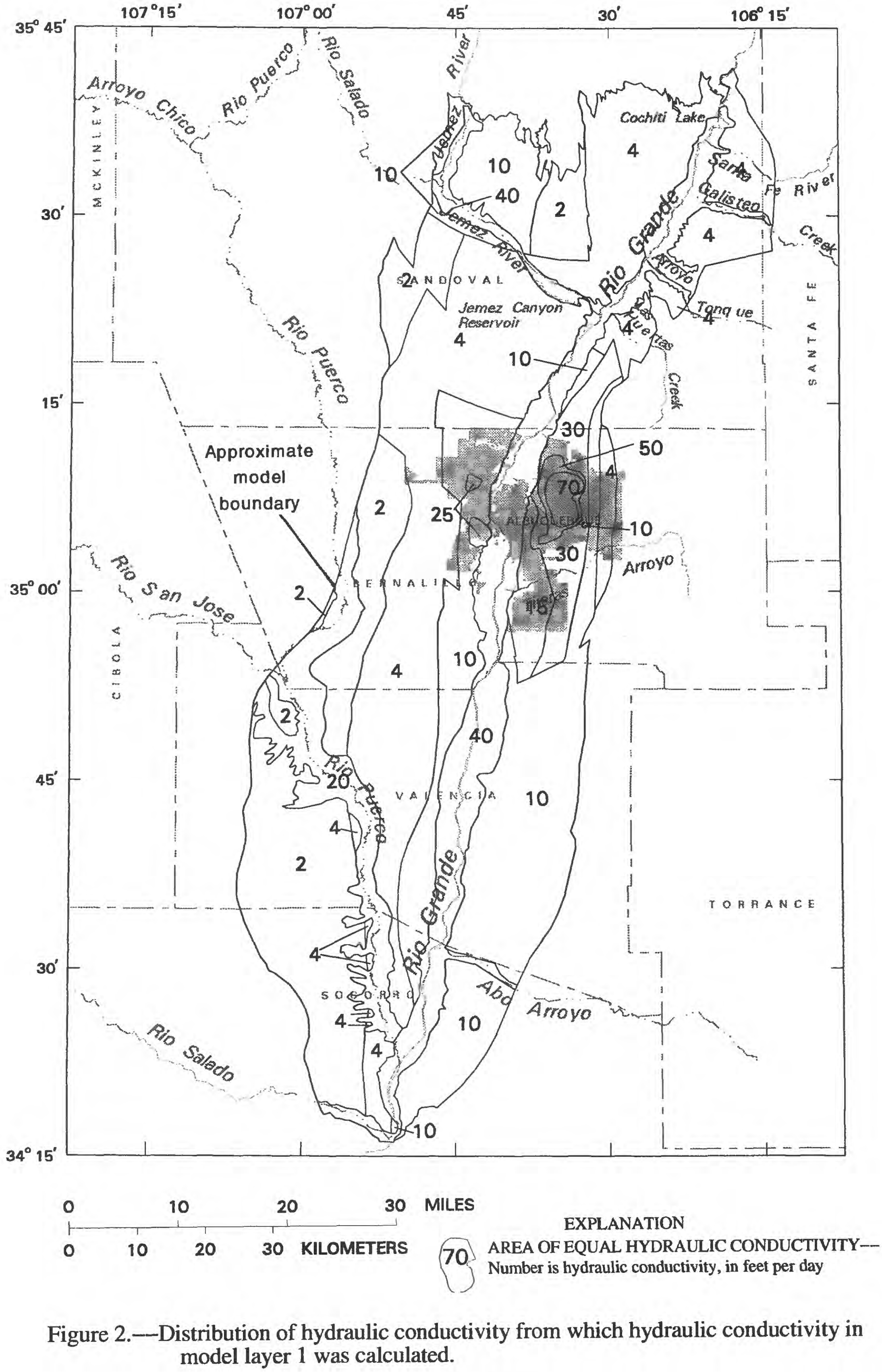


Figure 2.—Distribution of hydraulic conductivity from which hydraulic conductivity in model layer 1 was calculated.

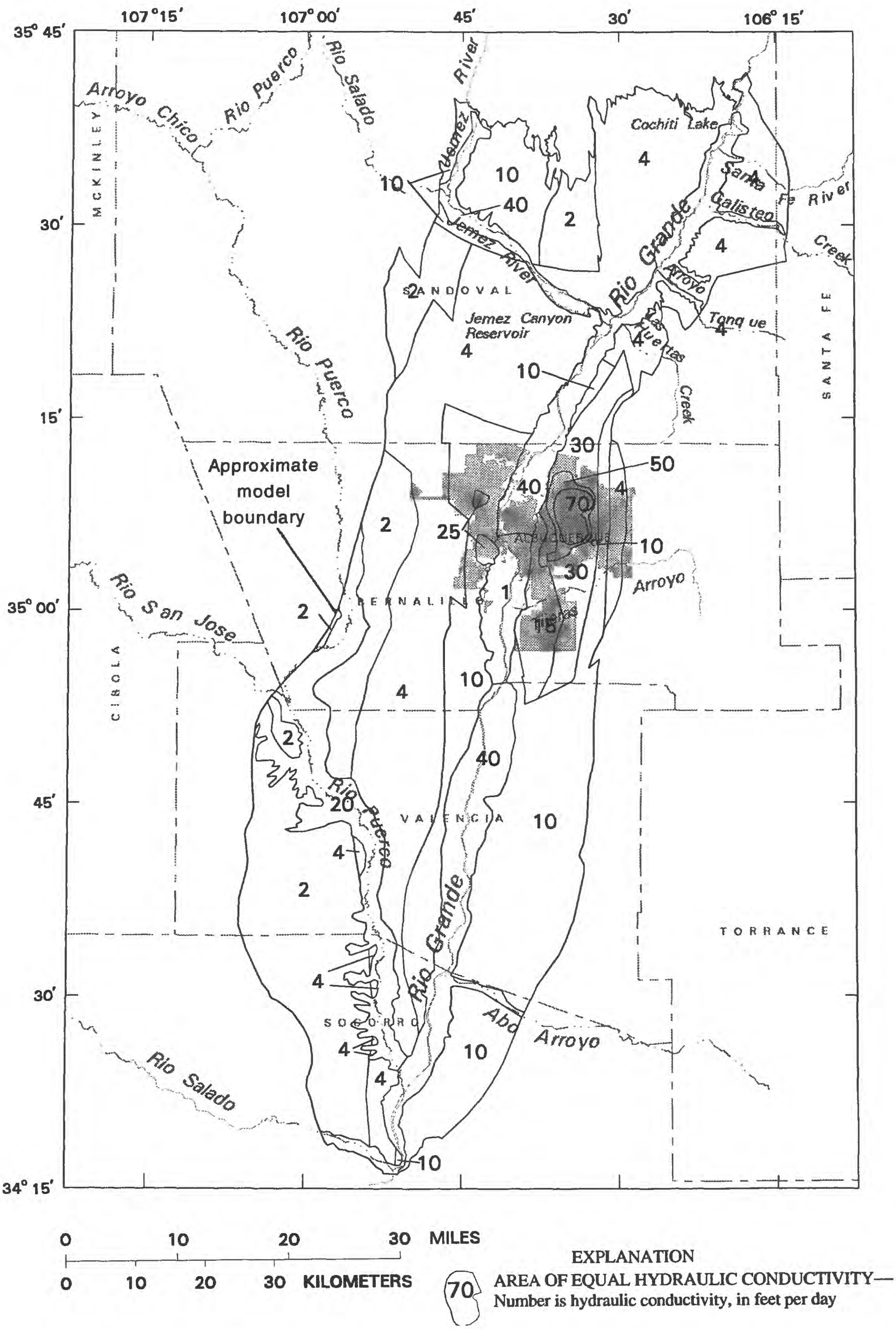


Figure 3.—Distribution of hydraulic conductivity from which hydraulic conductivity in model layer 2 was calculated.

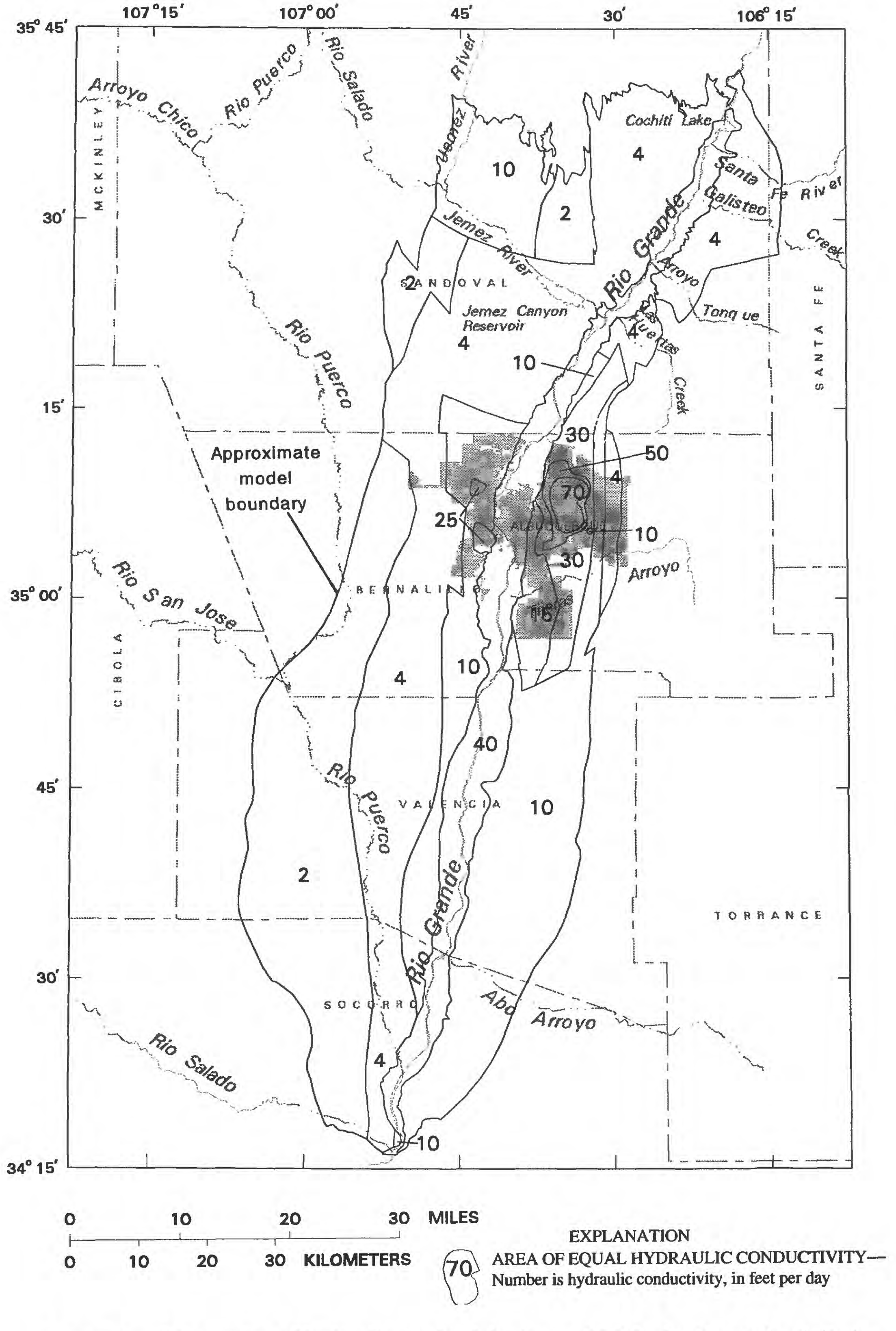


Figure 4.—Distribution of hydraulic conductivity from which hydraulic conductivity in model layer 3 was calculated.

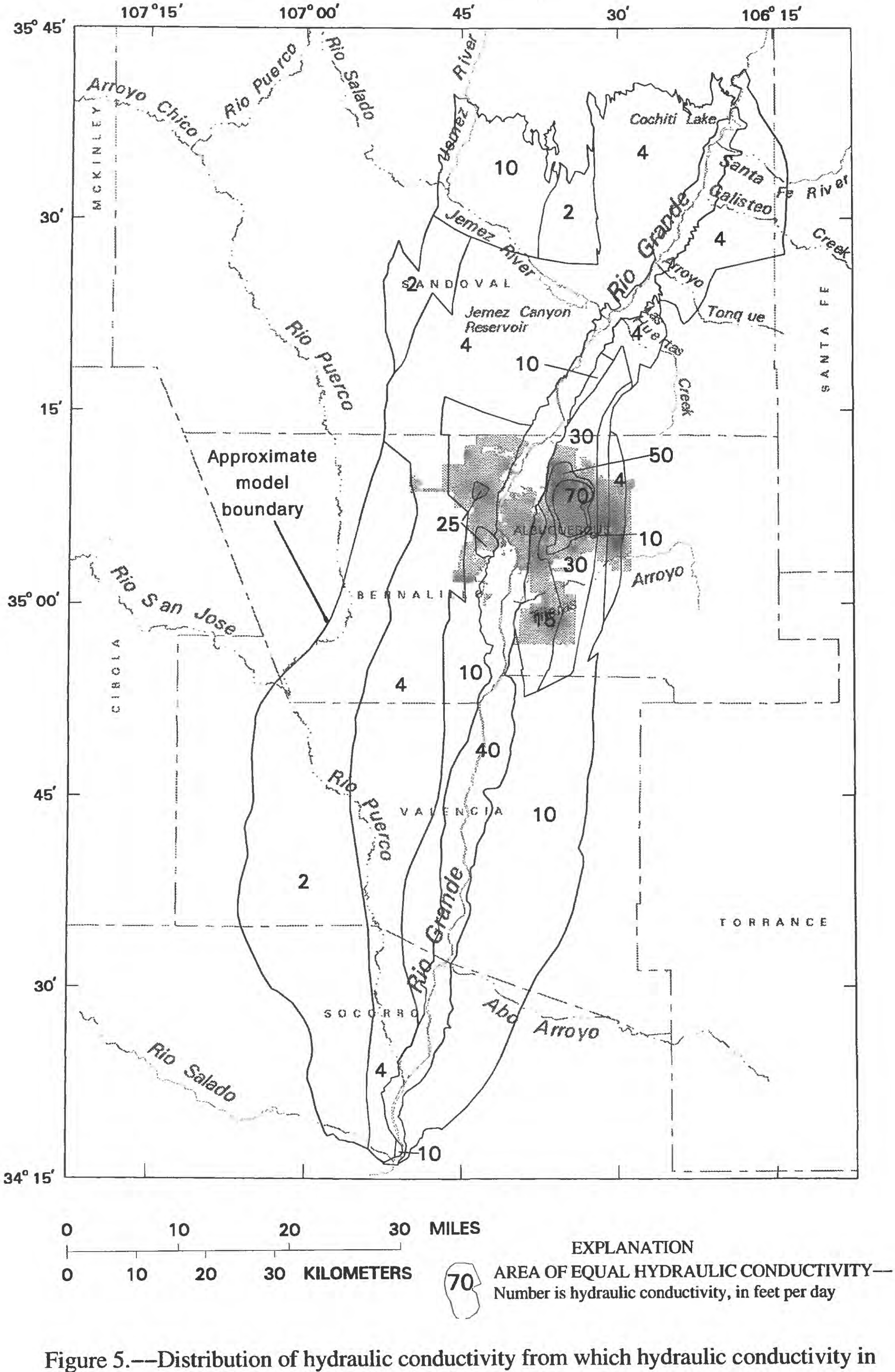


Figure 5.—Distribution of hydraulic conductivity from which hydraulic conductivity in model layer 4 was calculated.

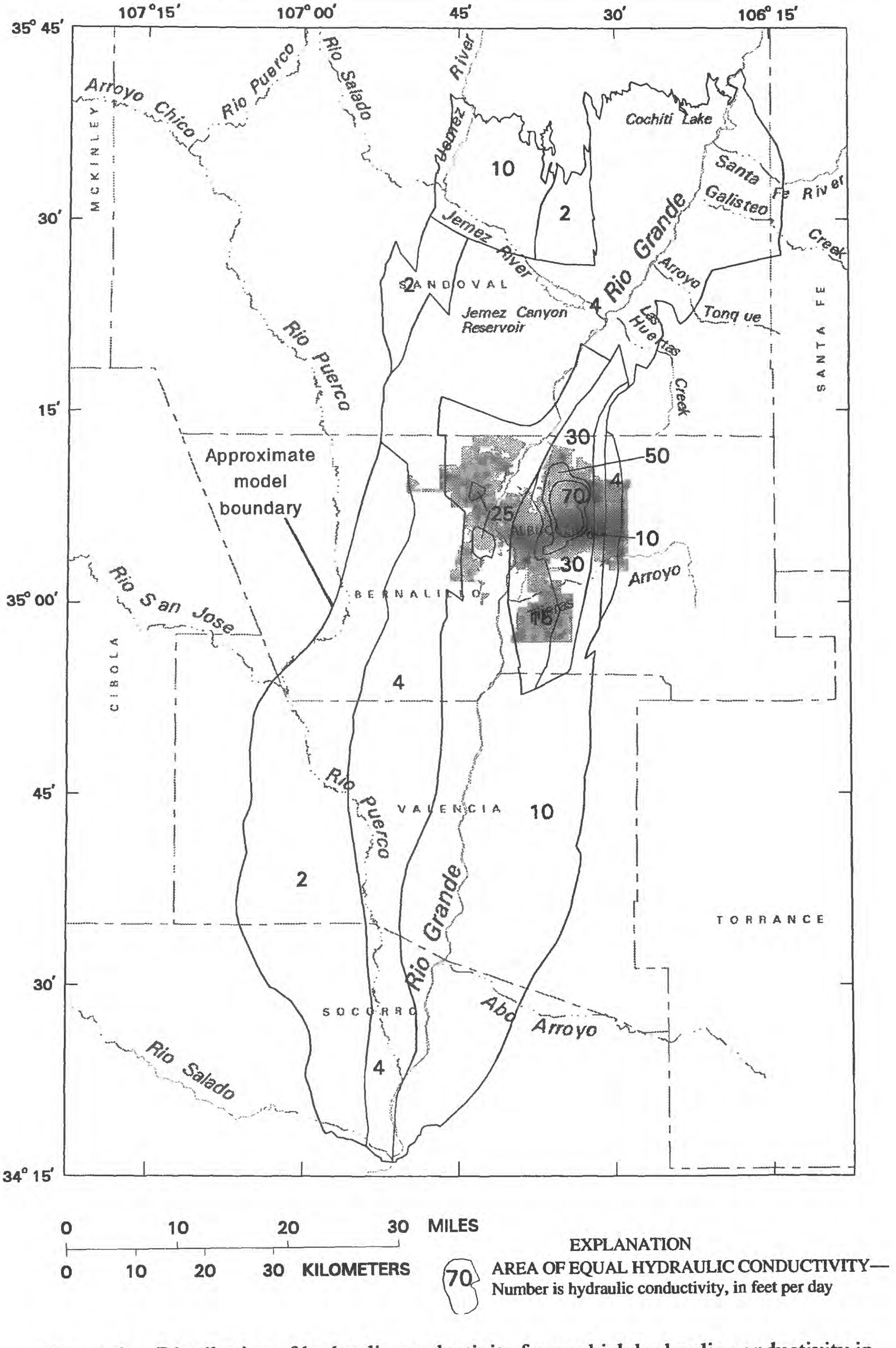


Figure 6.—Distribution of hydraulic conductivity from which hydraulic conductivity in model layer 5 was calculated.

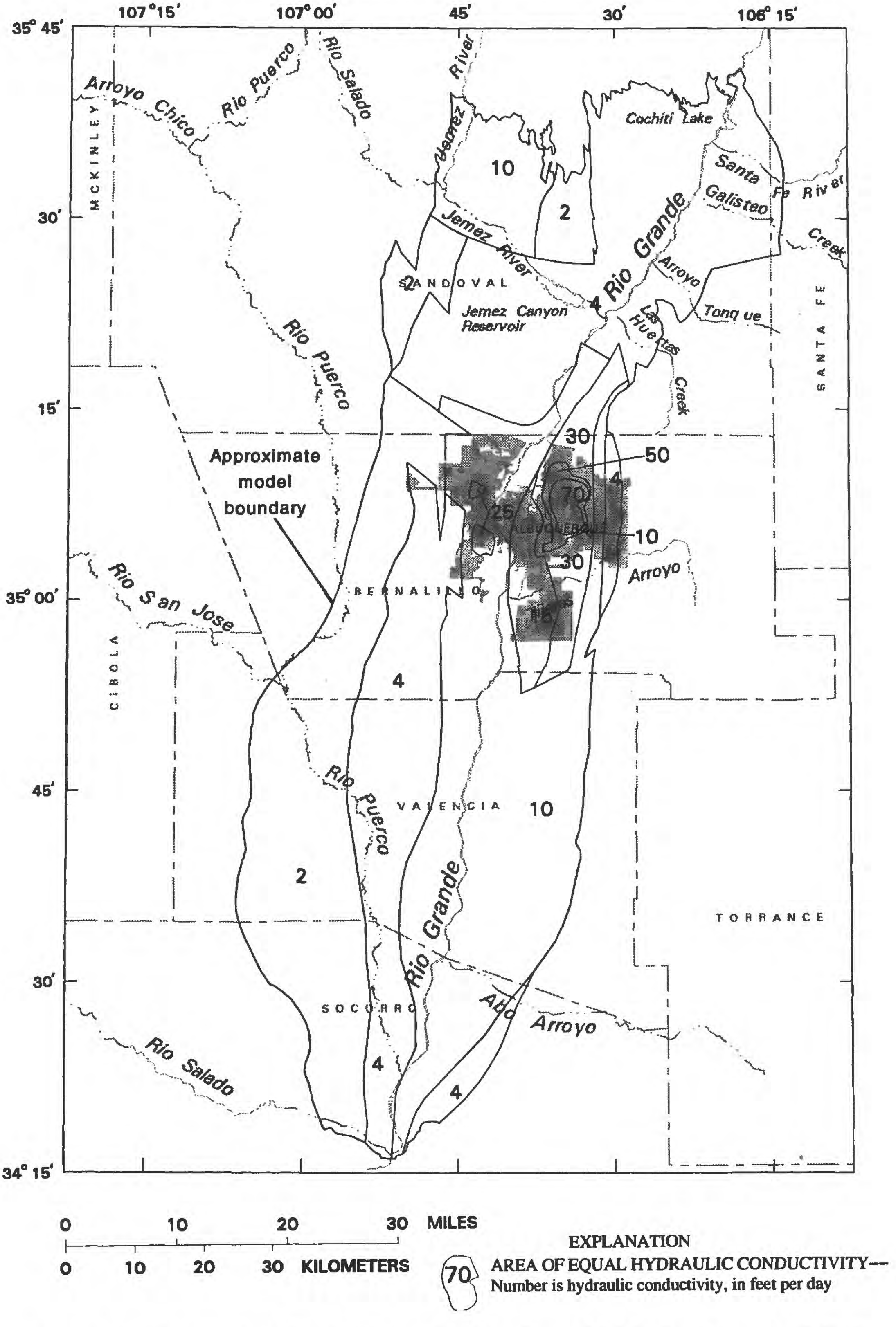


Figure 7.—Distribution of hydraulic conductivity from which hydraulic conductivity in model layer 6 was calculated.

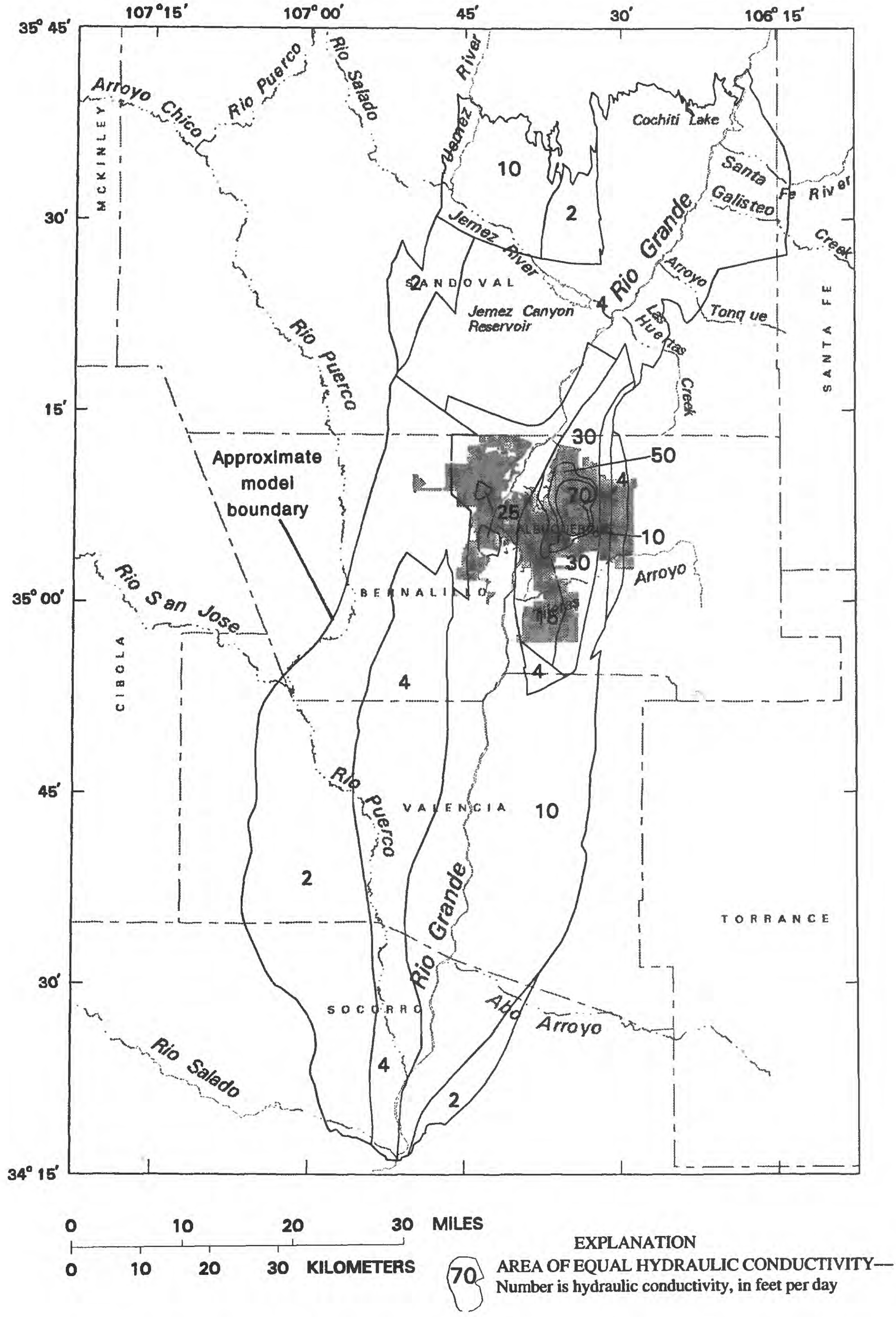


Figure 8.—Distribution of hydraulic conductivity from which hydraulic conductivity in model layer 7 was calculated.

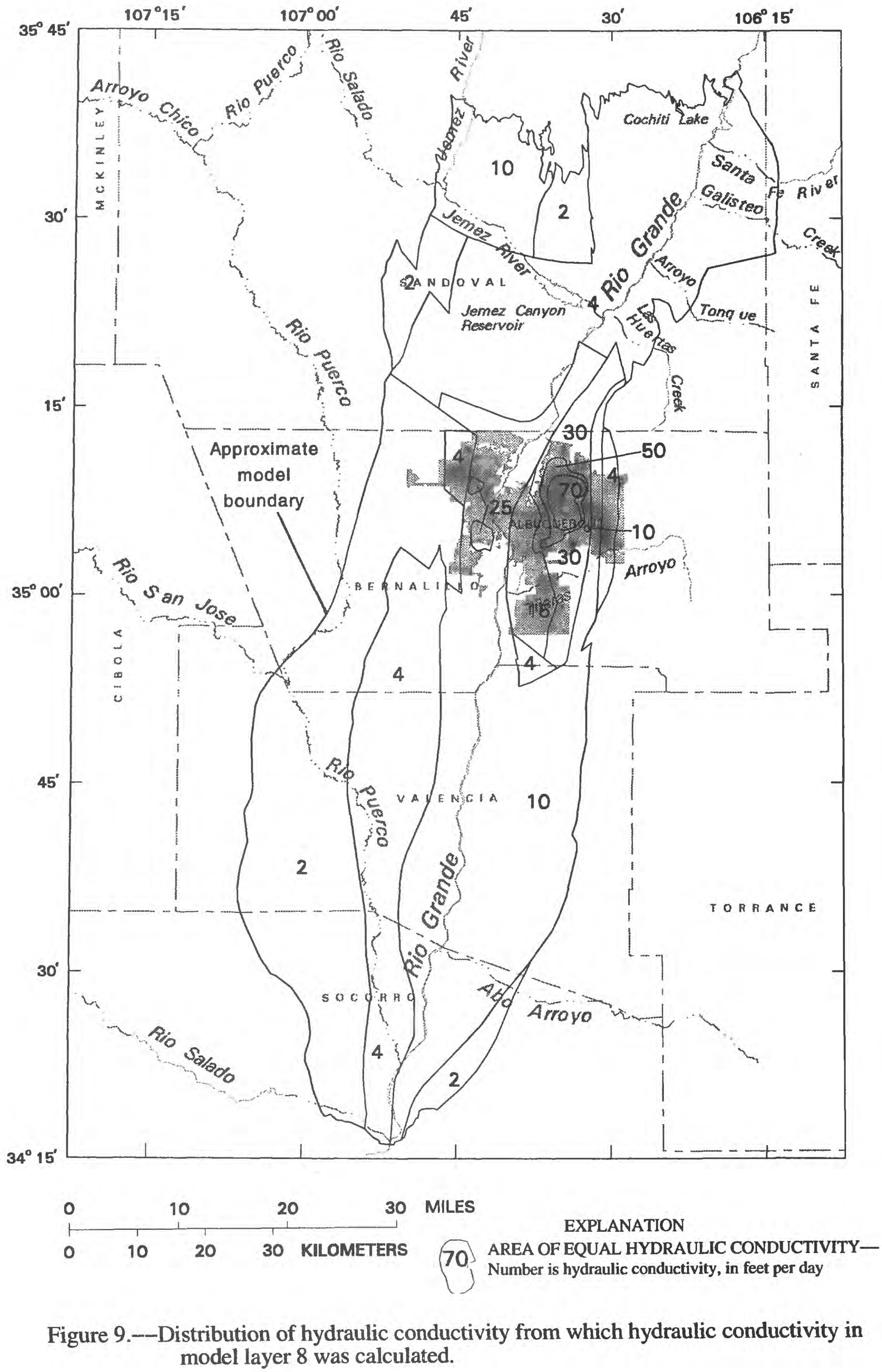


Figure 9.—Distribution of hydraulic conductivity from which hydraulic conductivity in model layer 8 was calculated.

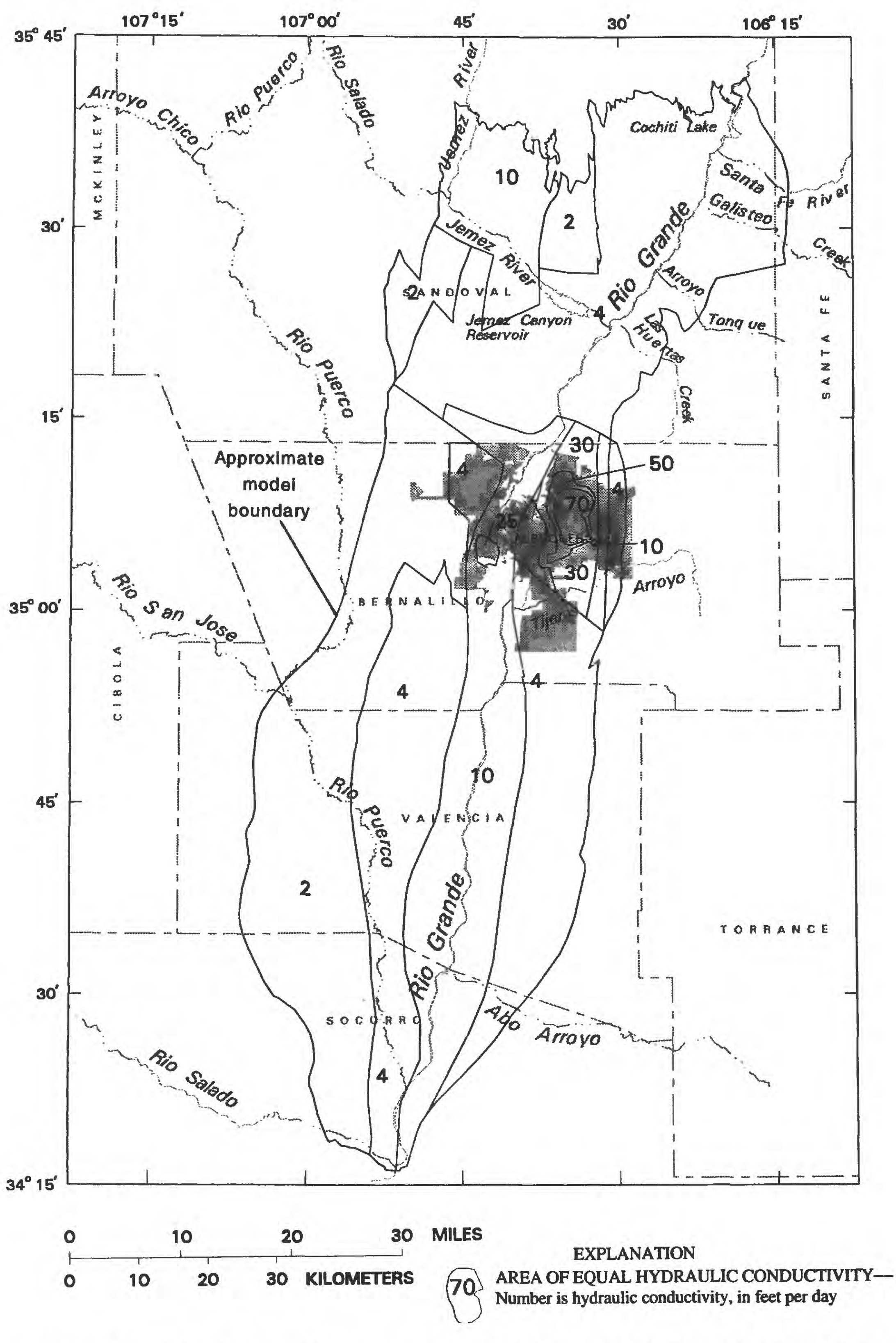


Figure 10.—Distribution of hydraulic conductivity from which hydraulic conductivity in model layer 9 was calculated.

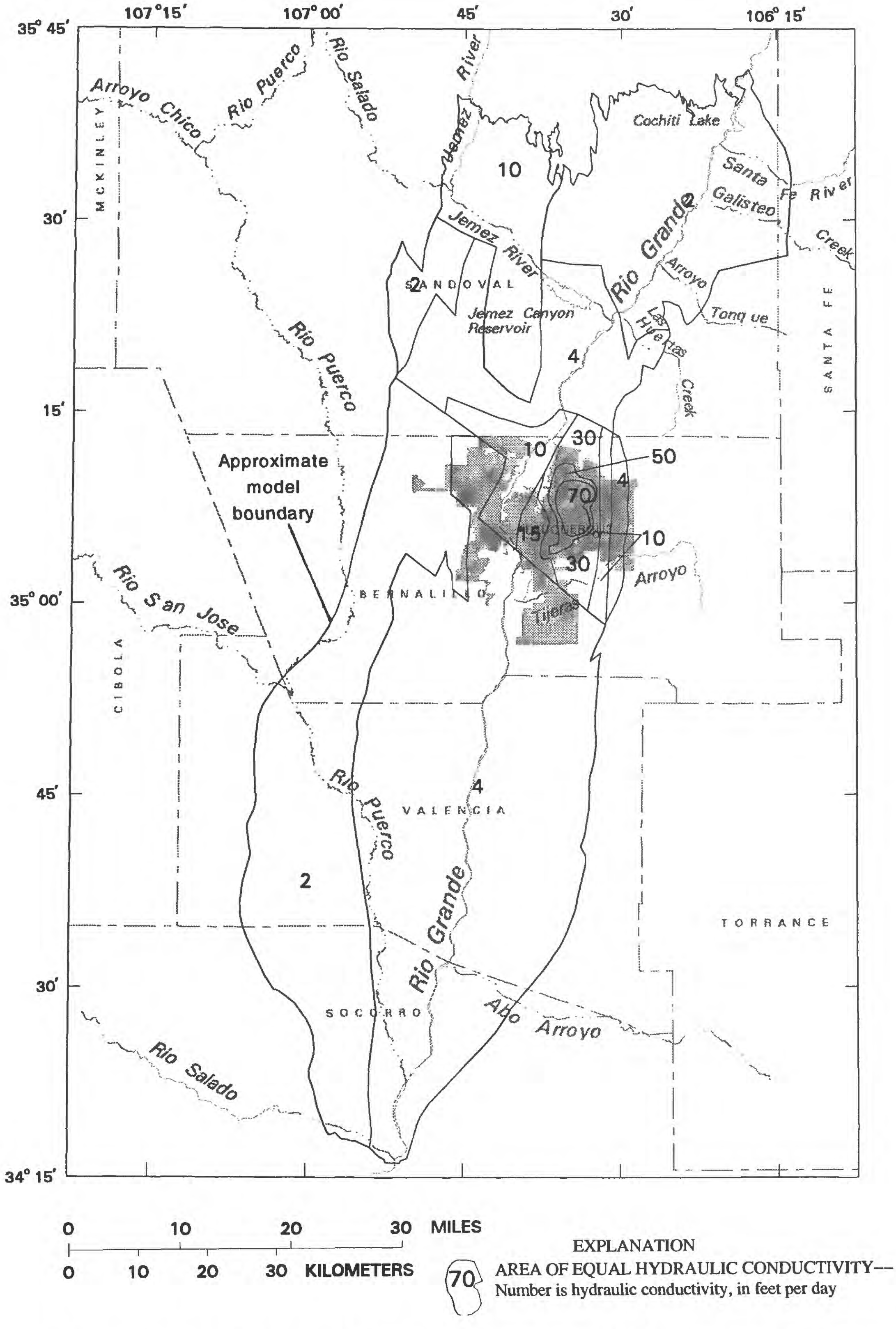


Figure 11.—Distribution of hydraulic conductivity from which hydraulic conductivity in model layer 10 was calculated.

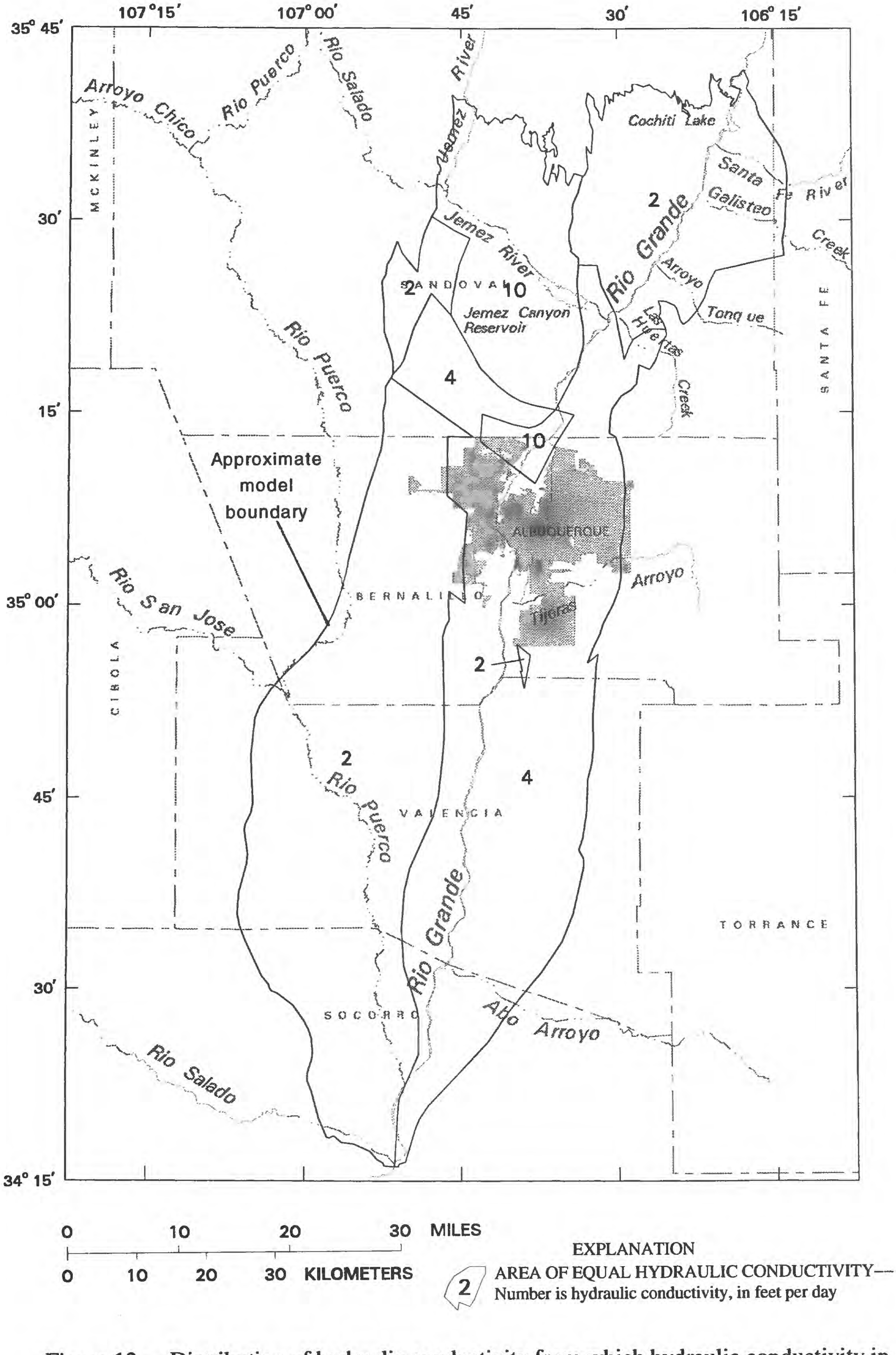


Figure 12.—Distribution of hydraulic conductivity from which hydraulic conductivity in model layer 11 was calculated.

The first revision actually consists of four distinct changes affecting aquifer-unit distribution. Recent investigations (Connell, 1995) revealed that the upper part of the Santa Fe Group extends well north of Albuquerque (fig. 6; Kernodle and others, 1995, fig. 10). This reinterpretation allowed a higher hydraulic conductivity to be simulated several miles farther north than done in Kernodle and others (1995). Secondly, analyses of geophysical logs (Hawley and others, 1995; Hawley and others, in press) indicated that the eastern limit of the axial-channel deposits in northeast Albuquerque is farther east than indicated in Thorn and others (1993). Thirdly, new production wells drilled in the vicinity of southern Rio Rancho (see fig. 17) show a westward branch and thickening of the upper part of the Santa Fe Group. Lastly, the axial-channel deposits in the upper part of the Santa Fe Group were thought at the time of preparation of this model version to be faulted and to ramp upward and out of the zone of saturation south of about the Bernalillo-Valencia County line. The previous model version extended these high-conductivity deposits to the southern end of the basin. Although a structure exists that raises the upper part of the Santa Fe Group to shallow depths for a short distance, the previous model version (Kernodle and others, 1995) is more likely to be consistent with the revised conceptual model south of Isleta Pueblo (see fig. 17; Hawley and others, in press).

In the second revision the positions of two major faults were remapped in the Albuquerque area (figs. 13-15; Thorn and others, 1993, fig. 16). The Rio Grande Fault was mapped farther east and the Isleta Fault was mapped farther west to connect with a fault previously mapped by Kelley (1977). The positions of many of these faults are based on inference and, although the repositions are based on new and more narrowing data, the actual positions of most are still not exactly known.

The third revision was an increase in hydraulic conductivity from 0.5 to 1 foot per day of a clay layer in a reach of alluvial-fill aquifer downstream from central Albuquerque (fig. 3; Kernodle and others, 1995, fig. 8). This was the most easily implemented approach for improving the vertical connection between the surface-water and ground-water systems (Kernodle and others, 1995, p. 104-105). As described later, this change had little apparent effect on the net simulated effect of City of Albuquerque pumpage on surface-water flow.

Corrections

Four errors in the first model version were identified and subsequently corrected. First, because of a coding error, about 10,000 acre-feet of mountain-front recharge was eliminated from the predevelopment portion of the previous model version (Kernodle and others, 1995, fig. 5 and table 5). Recharge was intended to be applied to the uppermost *active* layer. However, the coding error caused the recharge to be applied only to the top layer. Obtaining convergence of the predevelopment hydraulic heads and thicknesses of the top four layers was an iterative process and at each iteration some areas of the uppermost layers would go dry. In effect, the coding error led to the permanent removal of some recharge in predevelopment runs from the affected columns of cells, all of which were in the vicinity of the Sandia Mountains (fig. 16). This error initially escaped detection because a few model cells in the uppermost model layer at the basin edge remained saturated, and the contouring program that was used for preliminary interpolation of hydraulic heads constructed a reasonable water-table surface. The error was detected when a review showed that the expected recharge amount disagreed with the simulated amount. The error was not present in the transient historical and future simulations. The previous model appears to have quickly adjusted to the correct recharge amounts, with no major effect on simulations of recent or projected heads and water budgets.

A second correction dealt with the way that mapped faults previously were erroneously simulated to cross and impede flow in the alluvial-fill aquifers. In the recent model version (figs. 13-15) faults were not simulated to affect the alluvial systems. As might be expected, this change, which affected only 40 to 80 feet of the +1,700-foot column of aquifer, had little effect on the simulations.

A third minor correction was the relocation of some ground-water-withdrawal wells to more accurate simulated locations. In general, the relocation distance was small or the amount of withdrawal was small; in a few instances, however, the changes affected the simulation as much as 200 acre-feet per year with relocation distances of several miles. Only minor local effects were noted for these corrections.

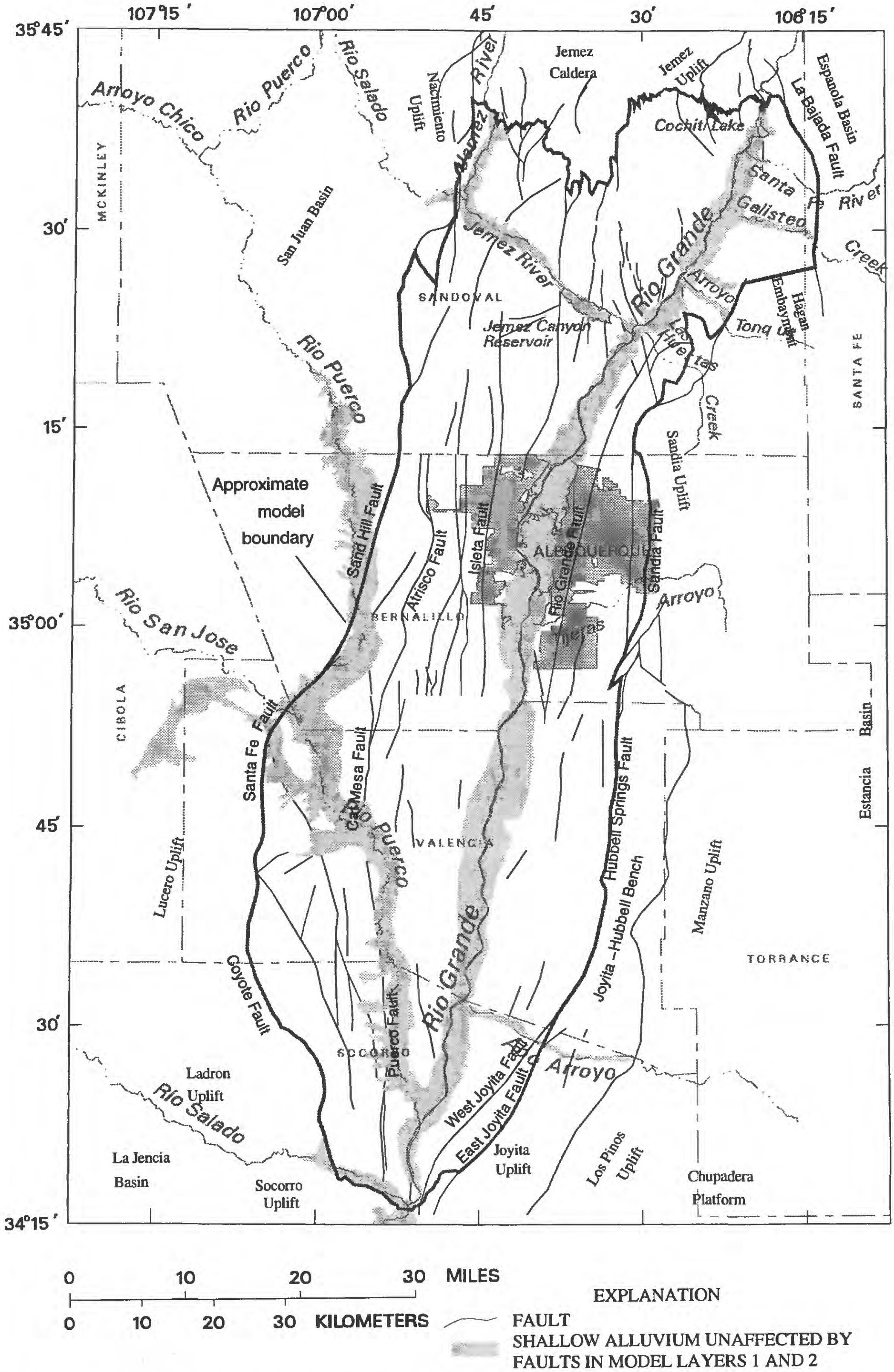


Figure 13.--Location of faults in model layers 1 and 2 and other faults in the vicinity of the Albuquerque Basin (modified from Kelley, 1977; Hawley and Haase, 1992; and Hawley and others, in press).

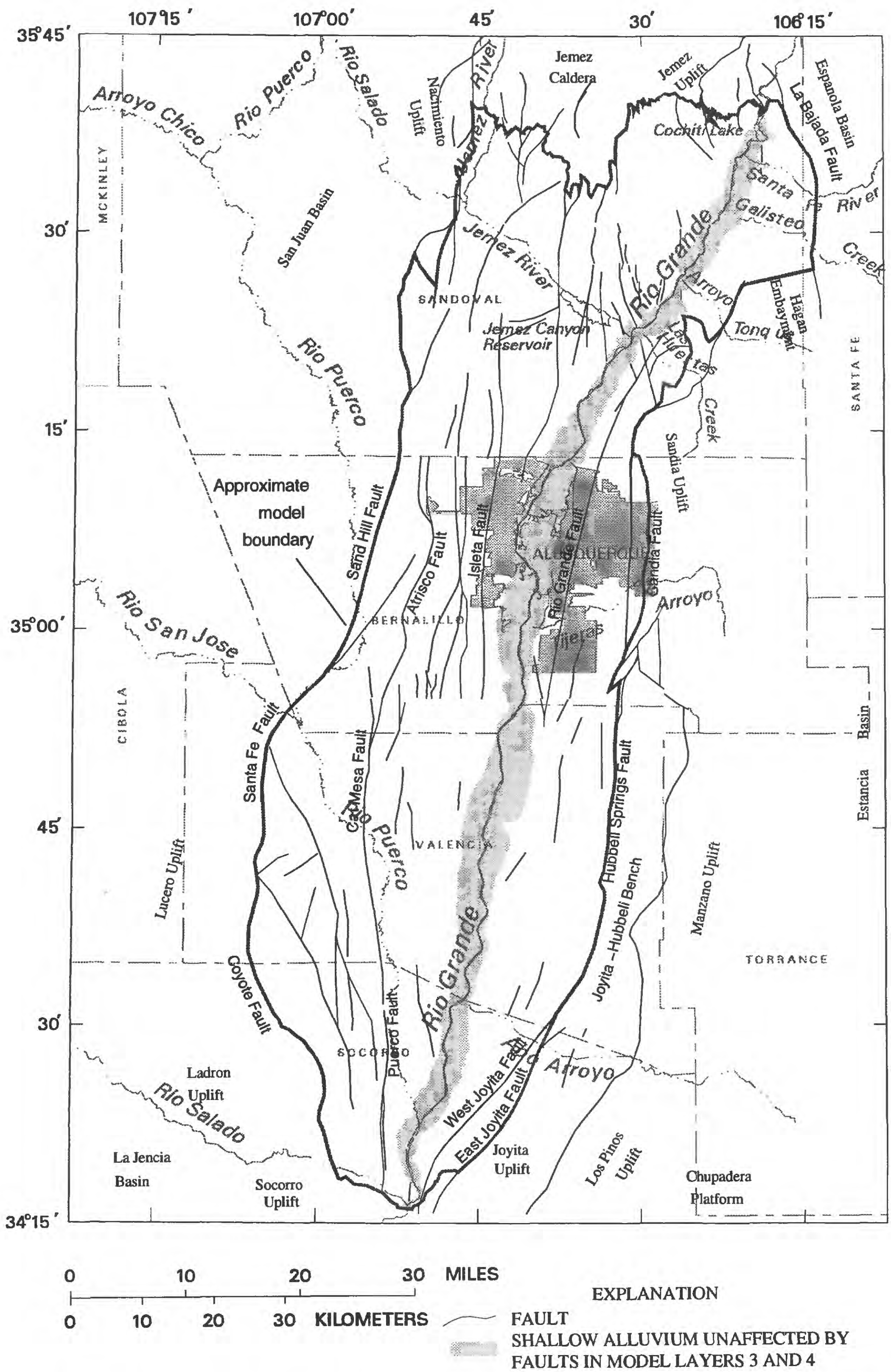


Figure 14.—Location of faults in model layers 3 and 4 and other faults in the vicinity of the Albuquerque Basin (modified from Kelley, 1977; Hawley and Haase, 1992; and Hawley and others, in press).

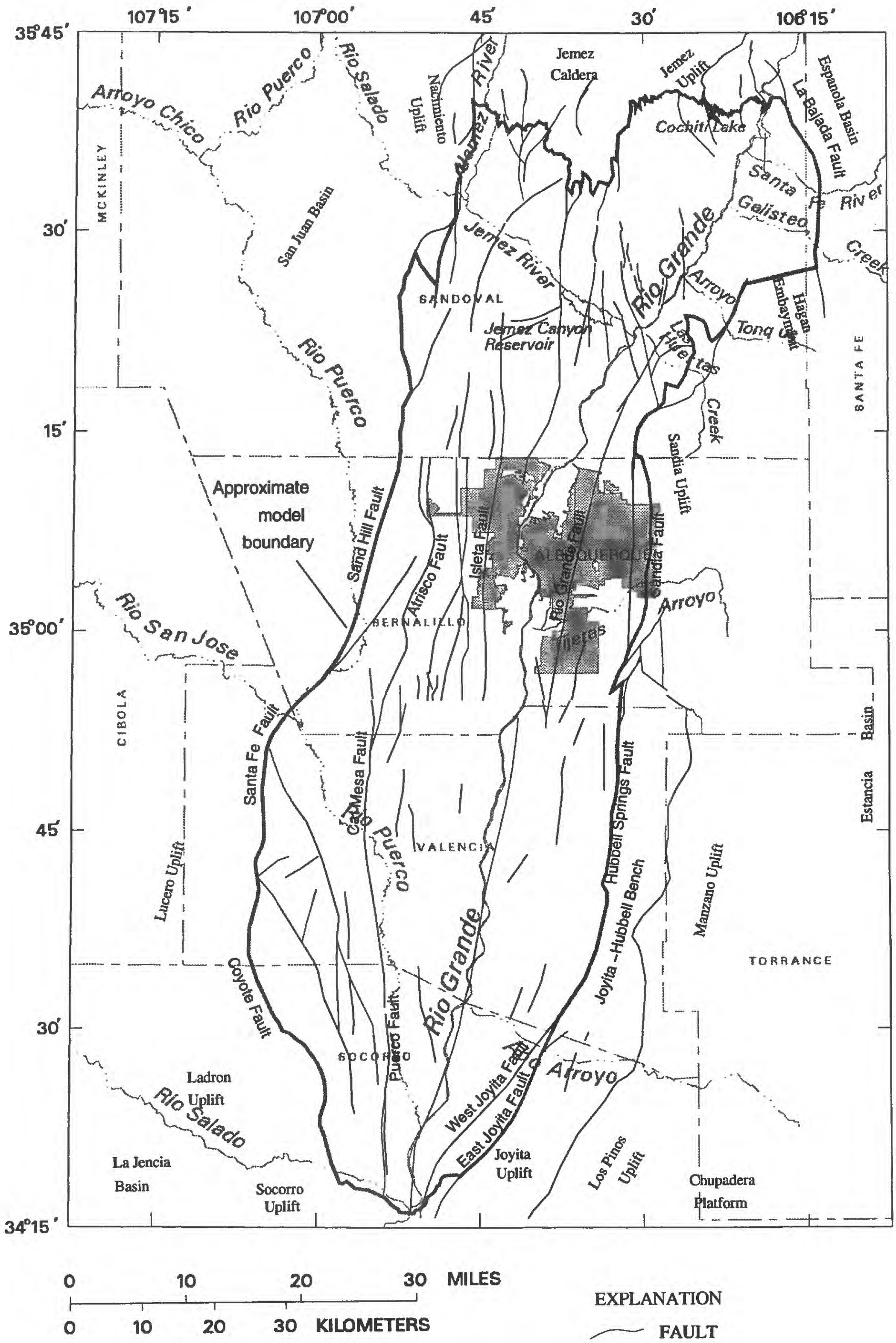


Figure 15.--Location of faults in model layers 5 through 11 and other faults in the vicinity of the Albuquerque Basin (modified from Kelley, 1977; Hawley and Haase, 1992; and Hawley and others, in press).

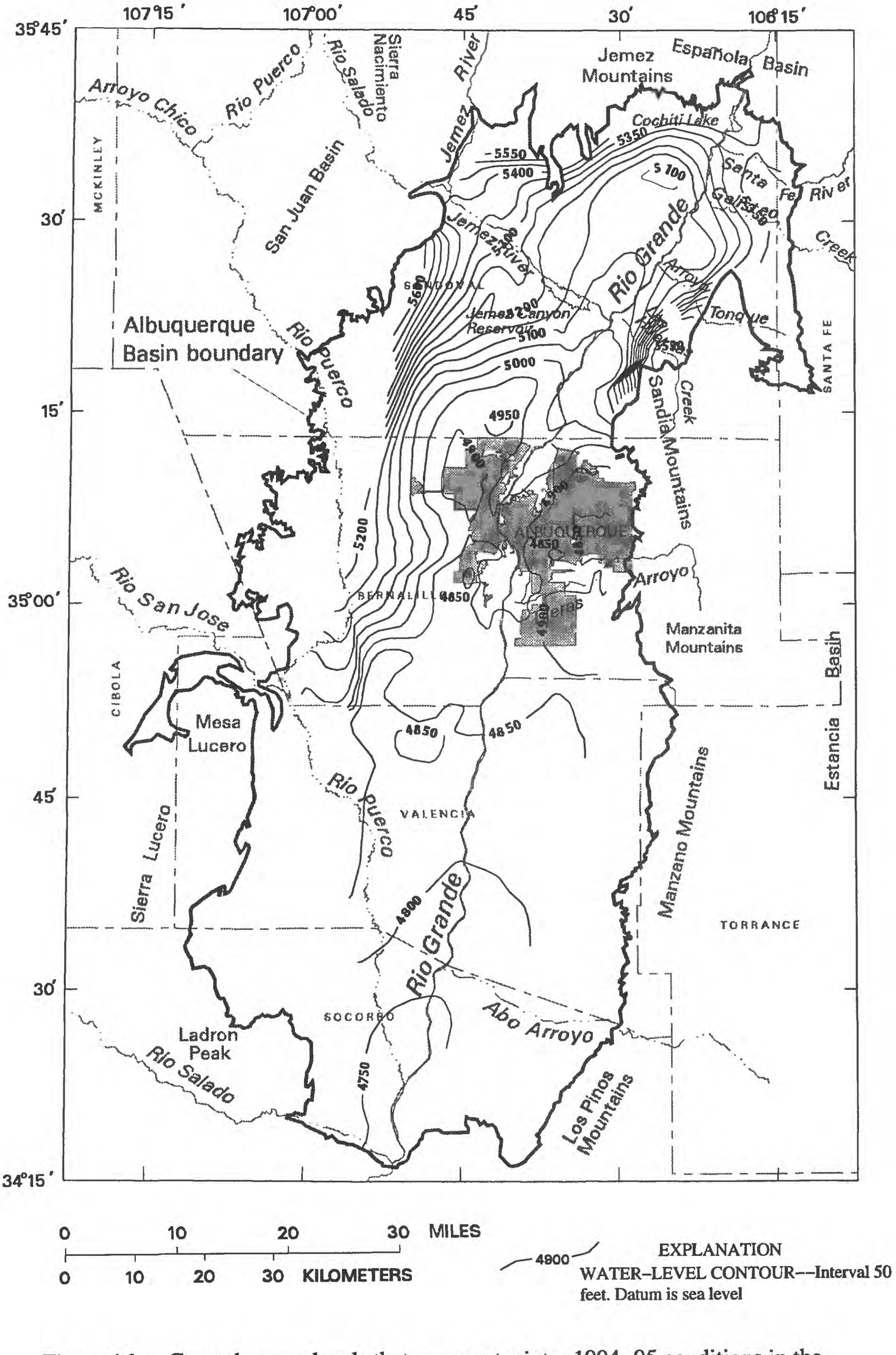


Figure 16.---Ground-water levels that represent winter 1994–95 conditions in the Santa Fe Group aquifer system in the Albuquerque Basin.

Finally, in the previous model version two small areas of elevated (25 feet per day) horizontal hydraulic conductivity were inadvertently deleted from model layers 5 through 9, although one of these areas is shown in figures 11-14 in Kernodle and others (1995). When these areas were included in this new model version, simulated local drawdown that was centered around several City of Albuquerque production wells was dramatically reduced.

Updates

Three updates to the previous model were performed. The first update was to incorporate mid-1950's land-use/land-cover data in the simulation. These data were used to represent the period 1955-60 in the revised simulation. This was a period of major change in population growth and water-supply infrastructure for the City of Albuquerque that was coincident with major changes in the irrigation-supply and drain systems implemented by the Bureau of Reclamation for the Middle Rio Grande Conservancy District. The abrupt change in sources of water for Albuquerque withdrawals (Kernodle and others, 1995, fig. 38) is due to all these major changes taking place at once within the context of historical records of spatial data. The additional mid-1950's data from the Bureau of Reclamation serve to better define the time of the radical change but do not significantly reduce the simulated and actual abrupt changes in the water budget.

The second update replaced the 1:500,000-scale data on the location of the Rio Grande and lower Jemez River inner valleys with 1:24,000-scale data. This information was used to determine the area where riparian evapotranspiration can take place and therefore the amount of possible evapotranspiration. The change and especially its effects on the simulation were minor.

The final and most important update extended the historical simulation to the spring of 1995 by including recorded ground-water withdrawals through March 1995. During compilation of these data several commercial and public-supply users reported significant reductions in ground-water withdrawal, accounting for a basinwide reduction in ground-water withdrawal from an estimated 171,000 acre-feet for the year ending in March 1994 to about 167,000 acre-feet for the year ending in March 1995.

As part of this model update, the projections to 2020 were begun in the spring of 1995, a year later than in Kernodle and others (1995), and the zoned projections (Kernodle and others, 1995, fig. 42) for growth rates were moved ahead accordingly to begin in 1996. Also, the initial withdrawal rates in the projections for the City of Albuquerque were based on an average of the rates for 1993 and 1994 instead of 1992 and 1993. The projected commercial, industrial, and private-domestic withdrawal rates remained unchanged for 1996 through 2020.

This last collective update of historical and projected withdrawals warrants further discussion because of its major effect on the interpretation of the simulations to 2020. First, all the projections in Kernodle and others (1995) and in this report are based on antecedent conditions. Those conditions differ for the two model versions and, therefore, the projections can be expected to differ for this reason alone. The additional year of ground-water-withdrawal data (to spring 1995) follows most closely the medium-growth-rate projections of Kernodle and others (1995). Therefore, the projections to 2020 for these and the "current" growth rates do not differ significantly between the two model versions because the base values are nearly identical. However, the simulated implementation of the City of Albuquerque's conservation program was moved ahead 1 year and into the range of historical data in the revised model. These historical data do not fully reflect the anticipated conservation production rates. In this transition period between continued trends of increased water use and the implementation of an effective conservation program, projections based on recent trends are very uncertain.

COMPARISONS OF HISTORICAL AND SIMULATED WATER LEVELS

Water levels measured from November 1994 through February 1995 were compiled to construct water-level contour maps for a large part of the Albuquerque Basin (fig. 16) and, at a smaller contour interval, for the metropolitan Albuquerque area (fig. 17). The location and generalized production capacity of the wells in which water levels were measured are shown in figures 18 and 19. The majority of these measurements, including virtually all measurements in municipal wells and wells on Indian pueblo lands, are owner reported.

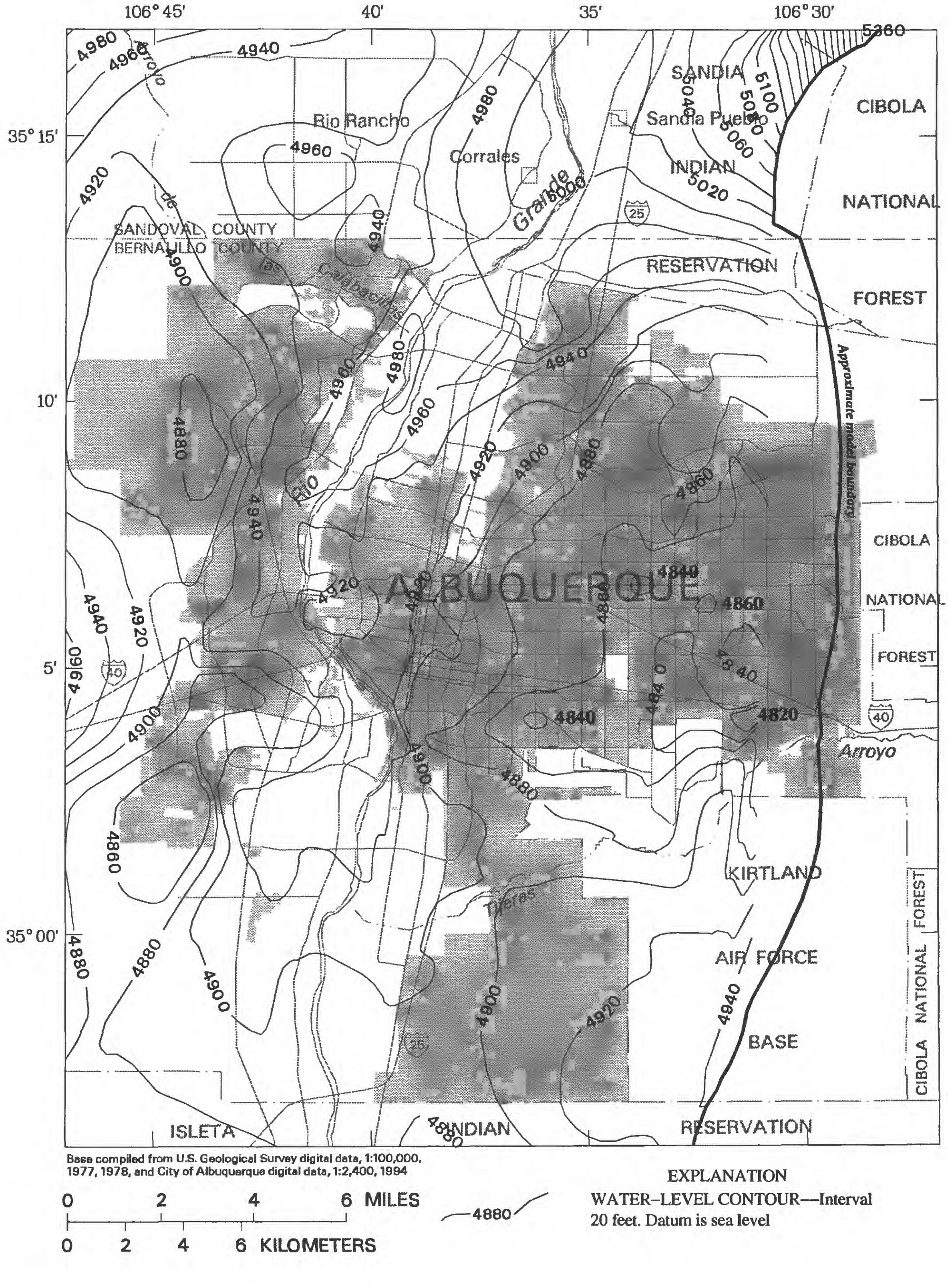


Figure 17.—Ground–water levels that represent winter 1994–95 conditions in the Santa Fe Group aquifer system in the Albuquerque area.

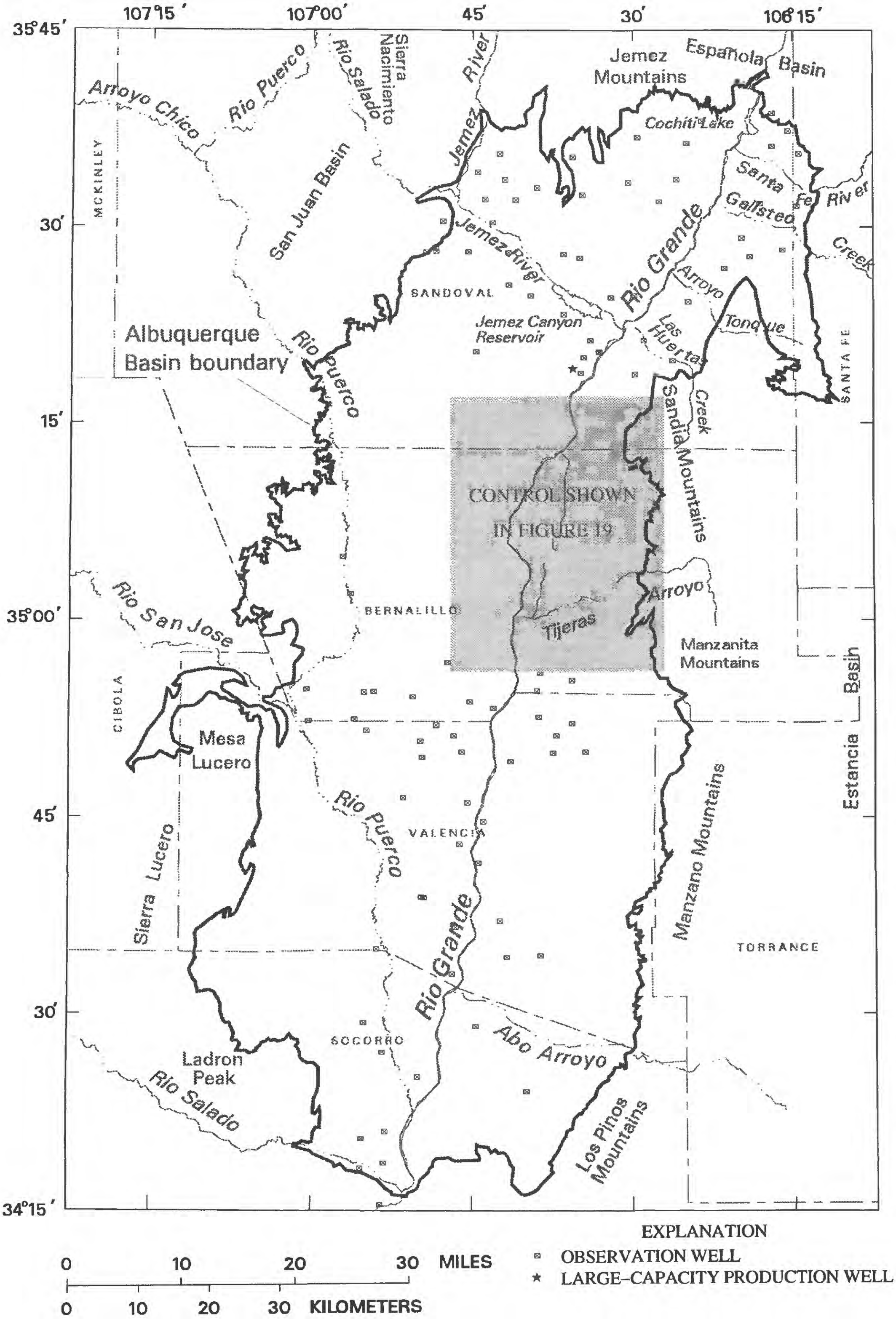


Figure 18.—Location of wells in the Albuquerque Basin that were used to construct the winter 1994–95 water-level contour maps.

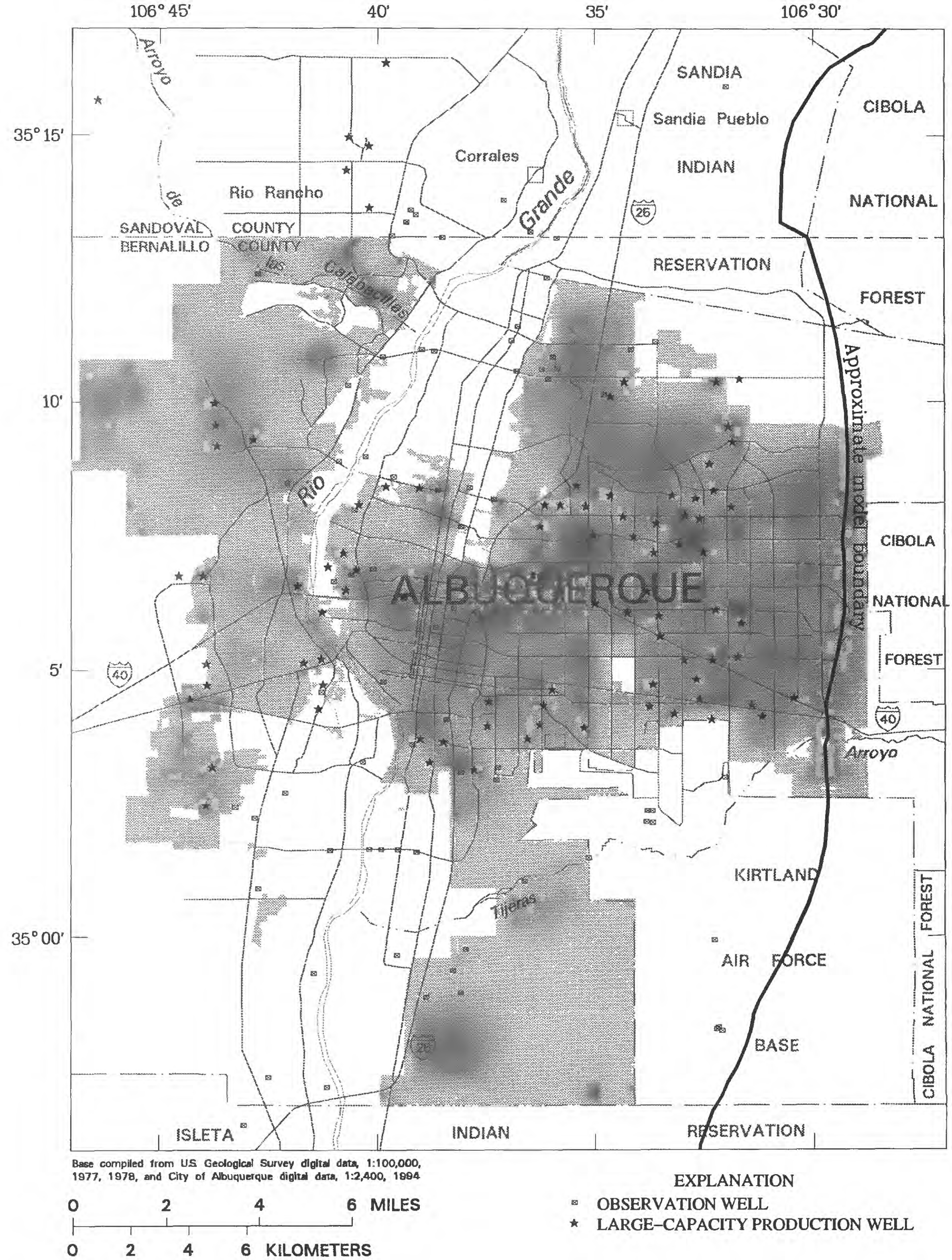


Figure 19.--Location of wells in the Albuquerque area that were used to construct the winter 1994-95 water-level contour maps.

Although water-table measurements in observation wells or wells completed in the upper part of the saturation zone were preferred, they were not always obtainable. Large-capacity production wells, which typically have long screened intervals, are emphasized in figures 18 and 19 because water levels measured in them are strongly affected by vertical ground-water gradients and intraborehole flow and by ground-water withdrawals from other nearby large-capacity wells. Therefore, even though a well may have been out of production for several days or more, its measured water level may be unrepresentative of a truly static water table.

Figures 20 and 21 show simulated spring 1995 water levels in model layer 9 for the basin and the metropolitan Albuquerque area, respectively. These water levels best represent deep, regional water-level trends. However, within Albuquerque's main production area east of the Rio Grande the simulated water levels appear to be about 20 feet higher than the contoured measured water levels. This difference is similar to the results in Kernodle and others (1995) and probably is due, at least in part, to the errors introduced by the use of water-level measurements in large-capacity production wells to construct figures 16 and 17. Also, the updated model simulates stresses and responses at no less than a 6-month period, and only randomly timed head data for winter 1994-95 were available for areal comparison between calculated and measured heads.

Figures 22 and 23 show the water-level altitude in the highest saturated layer for each vertical column of hydraulically connected model cells. The advantage of these shallow-aquifer water-level maps is that they closely resemble water-table maps and emphasize the shallow-aquifer effects of recharge from the Rio Grande and its tributaries and along the mountain fronts. The disadvantage is that deep, regional water levels often are poorly represented. These maps include perched areas that are still simulated to be in hydraulic connection with the main aquifer body. With the exception of the immediate vicinity of the Rio Grande, perched water-table areas connected to the main aquifer were simulated to occur throughout the metropolitan Albuquerque area by 1995. Perched zones create a situation of multiple water tables, each one contributing water from unconfined storage with a specific yield of 0.15 for each unconfined layer. Whether this is realistic and reasonable in the simulations depends on the occurrence of actual perched zones in the aquifer. If perched water-table zones are present then the increased yield from storage in the simulations could be thought of as representing delayed yield from storage in the aquifer. Recently drilled test holes located on Kirtland Air Force Base indicated that perched zones are fairly common on the base and may be assumed to be common elsewhere as well.

Perched water-table areas that were simulated to have become vertically disconnected from the main aquifer body across completely dewatered and inactive model cells are not included in figures 20 and 21. Less than 10 model cells totaling 0.15 square mile were perched and hydraulically disconnected in the simulation to spring 1995. Perched zones hydraulically disconnected from the main aquifer are not treated realistically in the simulations. A dewatered cell becomes inactive and does not allow water to pass vertically between two simulated water tables, whereas under actual field conditions, downward unsaturated flow would still take place. The overall effect on the simulation to spring 1995 is minimal. The effect becomes significant, however, in the projections to 2020.

Both basinwide maps of simulated water levels (figs. 20 and 22) show a large disagreement with the contour map (fig. 16) of measured water levels near the area where the Jemez River enters the Albuquerque Basin. Because this area has not been subjected to large transient stresses that would affect water levels, the difference could be due to simulation of too little local recharge, too large simulated hydraulic conductivities, or a combination of both. Another possibility might be that the effects of faulting on regional flow have been underestimated. This last possibility is given further support by comparing the contoured measured and simulated heads across the Cat Mesa Fault (figs. 13-15) southwest of Albuquerque. The measured gradient across that fault is significantly greater than the simulated gradient, indicating that the fault is impeding horizontal flow more than is being simulated. Although water-level control (fig. 18) in the area of the Jemez River is dense, it is not dense enough to clearly define the local effect of faults on water levels and water-level gradients.

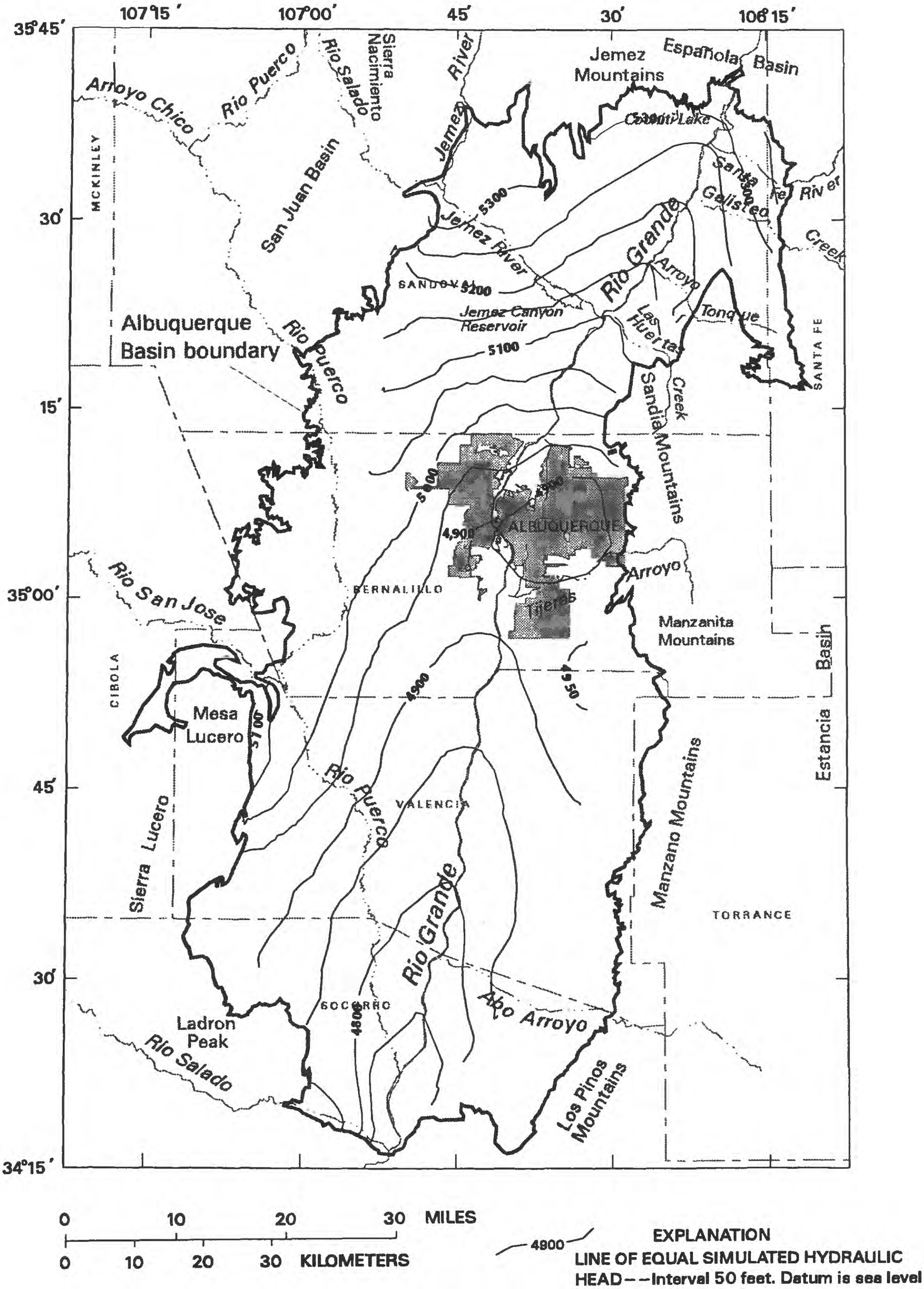


Figure 20.--Simulated spring 1995 hydraulic head in model layer 9 in the Albuquerque Basin.

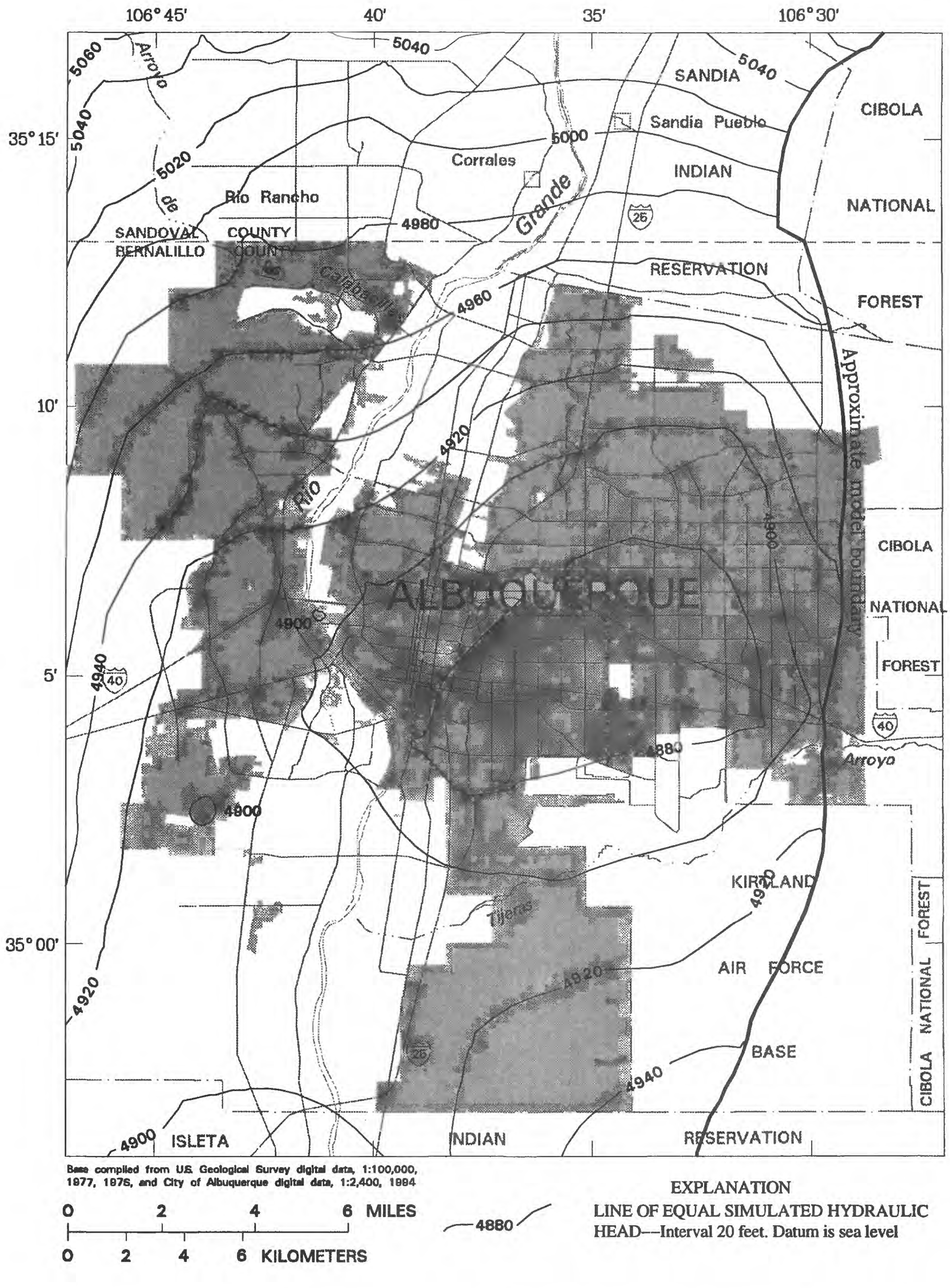


Figure 21.—Simulated spring 1995 hydraulic head in model layer 9 in the Albuquerque area.

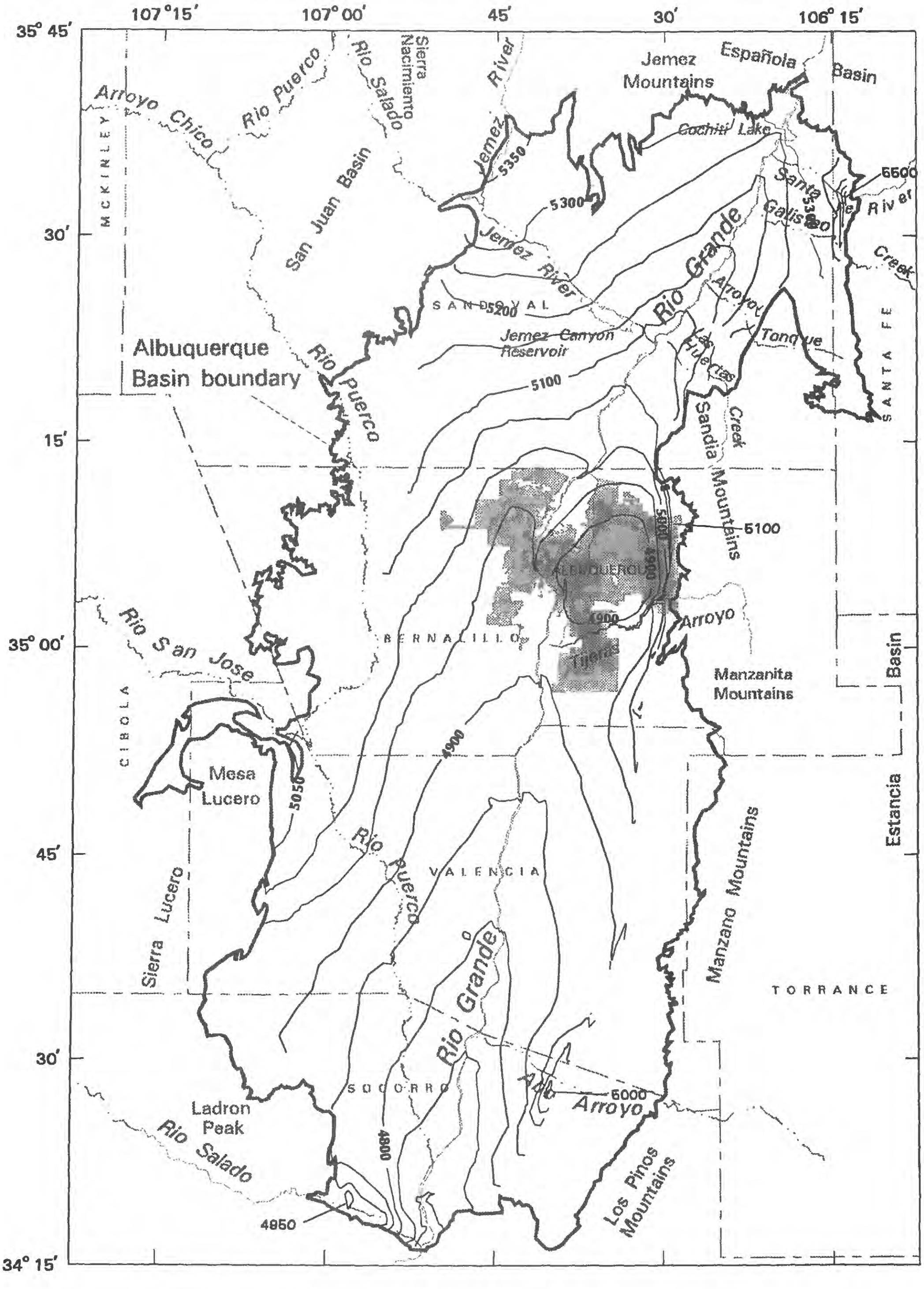


Figure 22.—Simulated spring 1995 hydraulic head that approximates the water table in the Albuquerque Basin.

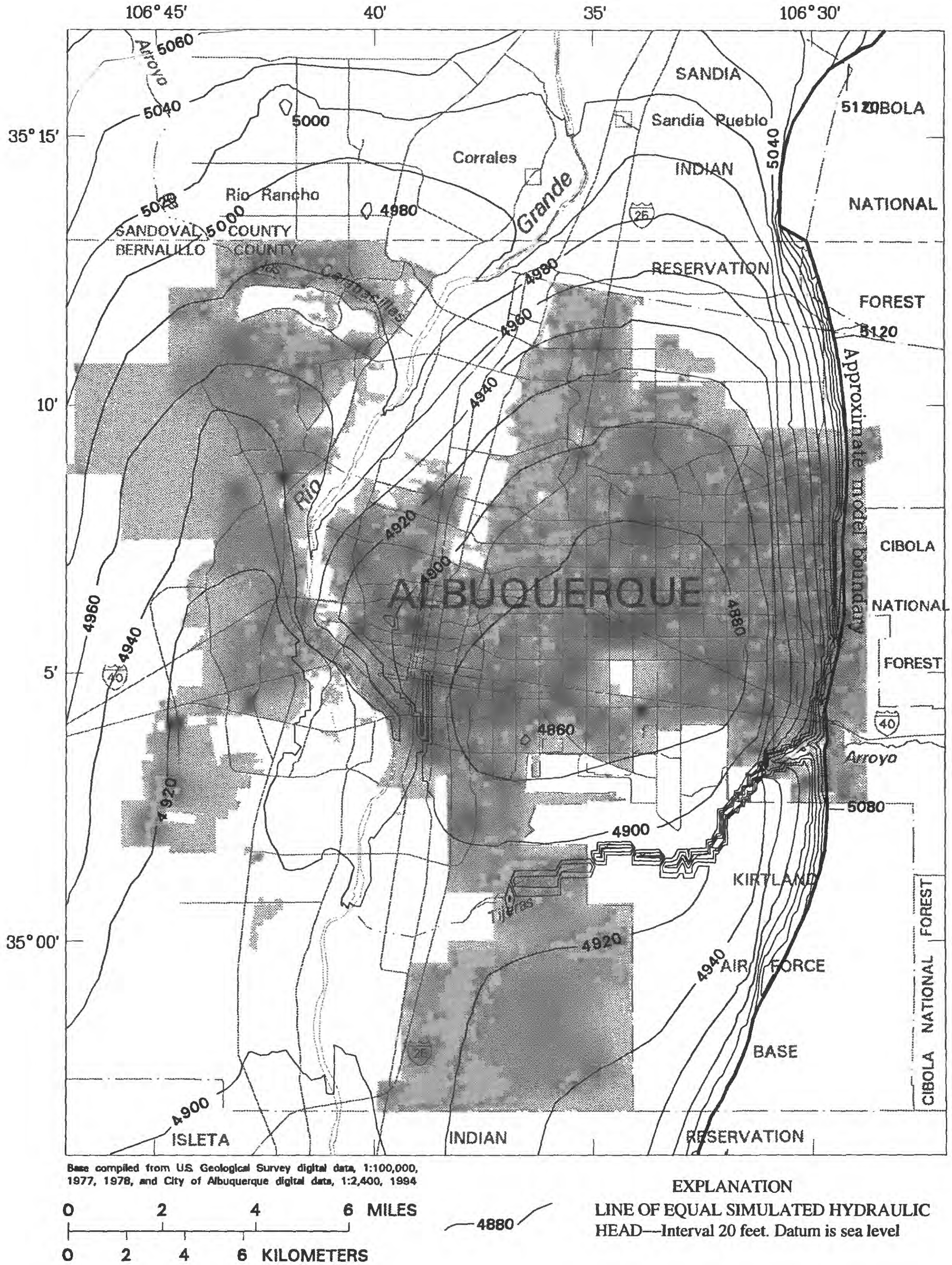


Figure 23.—Simulated spring 1995 hydraulic head that approximates the water table in the Albuquerque area.

Historical ground-water-level hydrographs for selected wells in the Albuquerque Basin are shown in figure 24 (the locations of these wells are shown in fig. 25). The hydrographs show that hydraulic heads may change rapidly with time and that the overall trend of simulated heads in the Albuquerque area closely matches the observed trend, generally to within 20 feet. The hydrographs may be compared with those in Kernodle and others (1995, fig. 26). In general, when compared with those for the previous model version, the new hydrographs show no change or an improved match in the northern part of the basin, an improved to worsened match in the Albuquerque area, and worsened matches in the southern-central part of the basin. The changes were expected to result from the recent revisions to the hydrogeologic conceptual model. The worsened matches in the southern-central part of the basin may be due to the removal in the simulations of a zone of aquifer material of high hydraulic conductivity in the upper part of the Santa Fe Group. Recent hydrogeologic work by Hawley and others (in press) does show that the highly conductive axial-channel deposits in the upper part of the Santa Fe Group are uplifted above the water table south of the boundary between Kirtland Air Force Base and Isleta Pueblo (fig. 23). However, the deposits quickly drop back into the saturated zone at the northern end of the southern subbasin (the Belen-Bernardo subbasin of Hawley and others, in press). Reinclusion of the simulated highly conductive deposits in the southern subbasin probably would restore the acceptable hydrograph matches south of Albuquerque.

SIMULATED WATER BUDGETS

The simulated Albuquerque Basin water budgets for predevelopment (steady state), 1960, and the years ending in the springs of 1994 and 1995 are shown in table 1 (compare with Kernodle and others, 1995, table 5). The simulated historical water budgets for this version and the previous version of the model show substantial differences in specific details yet still retain remarkable similarities overall. As mentioned earlier, the predevelopment water budget for the previous model version, which is assumed to represent conditions in 1901, mistakenly deleted about 10,000 acre-feet per year of mountain-front recharge from the Sandia Mountains. Other simulated budget components were adjusted but the most notable change was an increase of about 12,000 acre-feet per year in evapotranspiration accompanied by an increase of about 2,000 acre-feet per year in inflow from surface-water sources. These model results confirm that virtually all recharge around the perimeter of the basin before ground-water development supported riparian evapotranspiration. From another perspective, mountain-front recharge prevented the river from losing flow of water to support the riparian vegetation.

Differences in the 1960 water budgets for the two model versions result from the combined effects of the current inclusion of 1955-60 land-cover data from the Bureau of Reclamation in the simulations and any residual effects of the corrected predevelopment recharge estimates. Because of the substantial irrigation-supply and drain infrastructure improvements that the Bureau of Reclamation and Middle Rio Grande Conservancy District made in the mid-1950's, irrigation application (and return to ground water) increased, which was the intended purpose of the irrigation-improvement project. Although simulated net river and canal loss increased slightly, this cannot be clearly attributed to the increased density of the irrigation network or to the simulated, locally improved surface-water / Santa Fe Group aquifer connection across the alluvial aquifer in south-central Albuquerque.

Three changes in historical trends are apparent in the water budget for the revised simulation from the spring of 1994 to the spring of 1995. The changes result from (1) significant changes (corrections?) in withdrawal rates and known withdrawal points for commercial and other non-municipal large users of ground water in the basin; (2) a slightly less than anticipated conservation-effort reduction of ground-water pumpage by the City of Albuquerque; and (3) an upset in routine operation of Albuquerque's production and supply system caused by a long-term aquifer test, jointly funded by the City of Albuquerque and USGS, that was conducted to determine the effect of City pumpage on flow in the Rio Grande. The 1994-95 year was anomalous for production from City wells east of the Rio Grande, so low base-value productions for wells in the aquifer-test area in Albuquerque's north valley and correspondingly high base-value productions in the heights east of the valley were used in the 1994-95 simulation and in the projections of City pumpage to 2020. Simulated basinwide pumpage decreased about 3,000 acre-feet per year from 1994 to 1995 and depletion of aquifer storage decreased about 6,000 acre-feet per year. Net surface-water loss

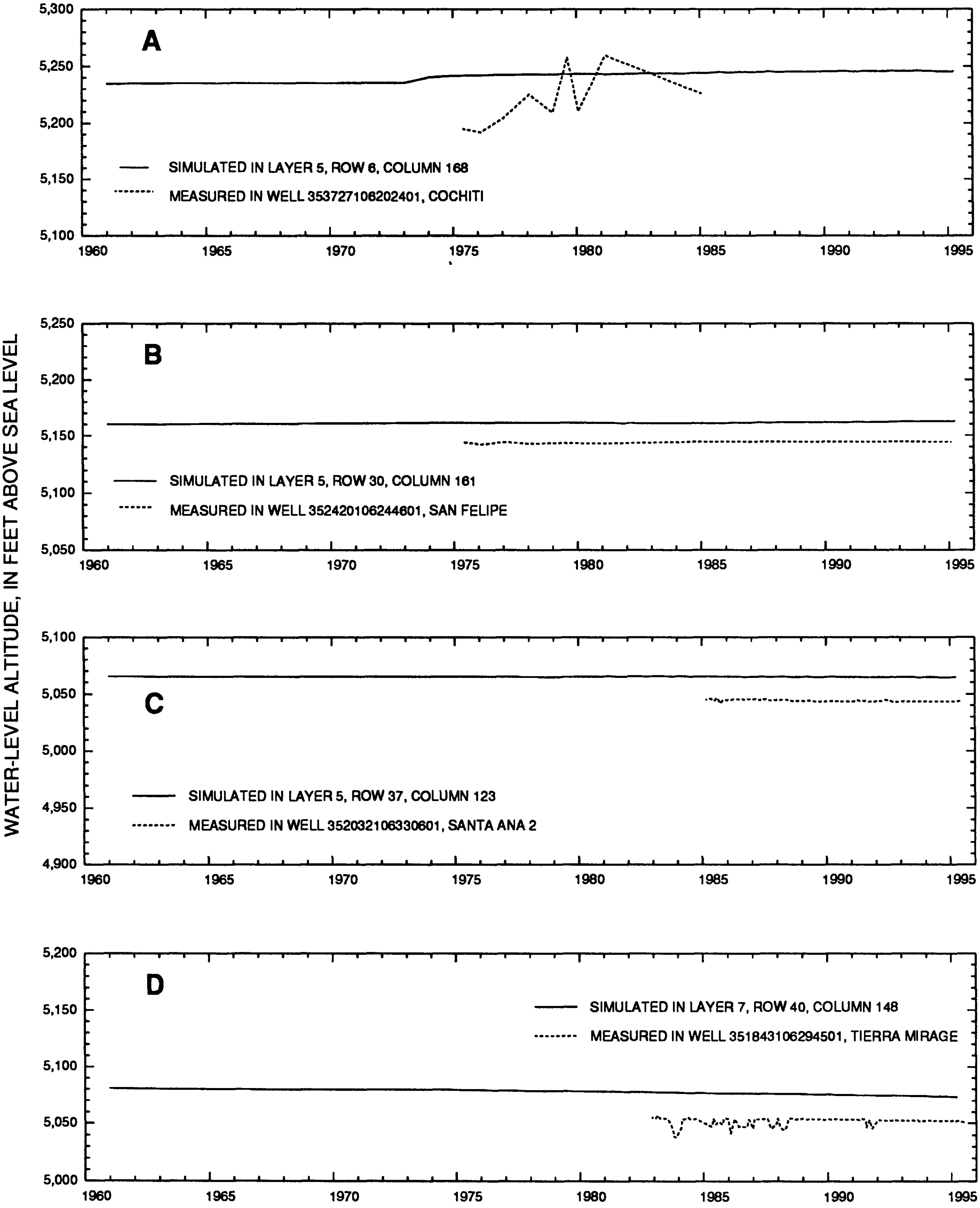


Figure 24.--Water levels measured in selected wells in the Albuquerque Basin and those simulated in corresponding model cells (location of wells shown in fig. 25).

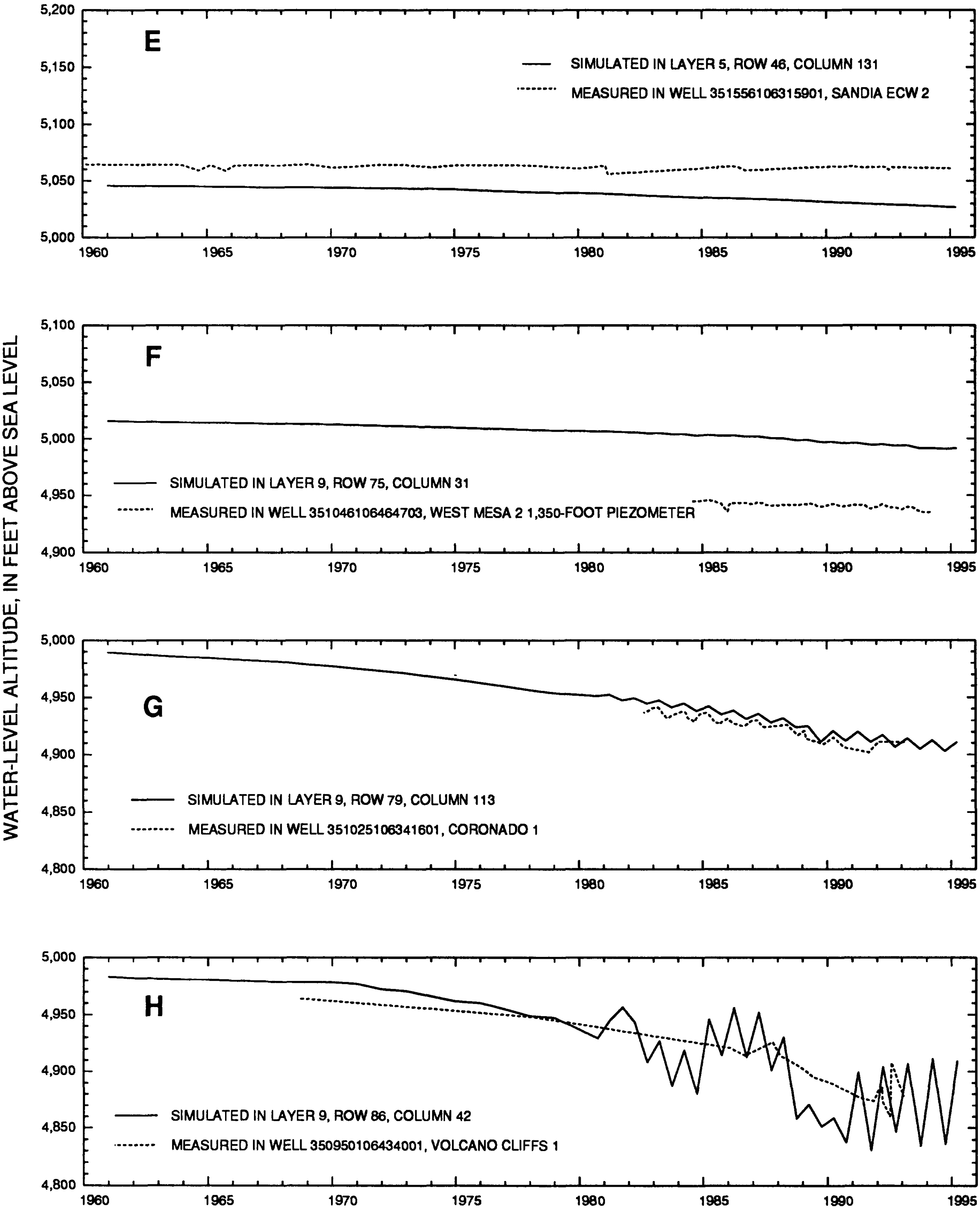


Figure 24.--Water levels measured in selected wells in the Albuquerque Basin and those simulated in corresponding model cells (location of wells shown in fig. 25)--Continued.

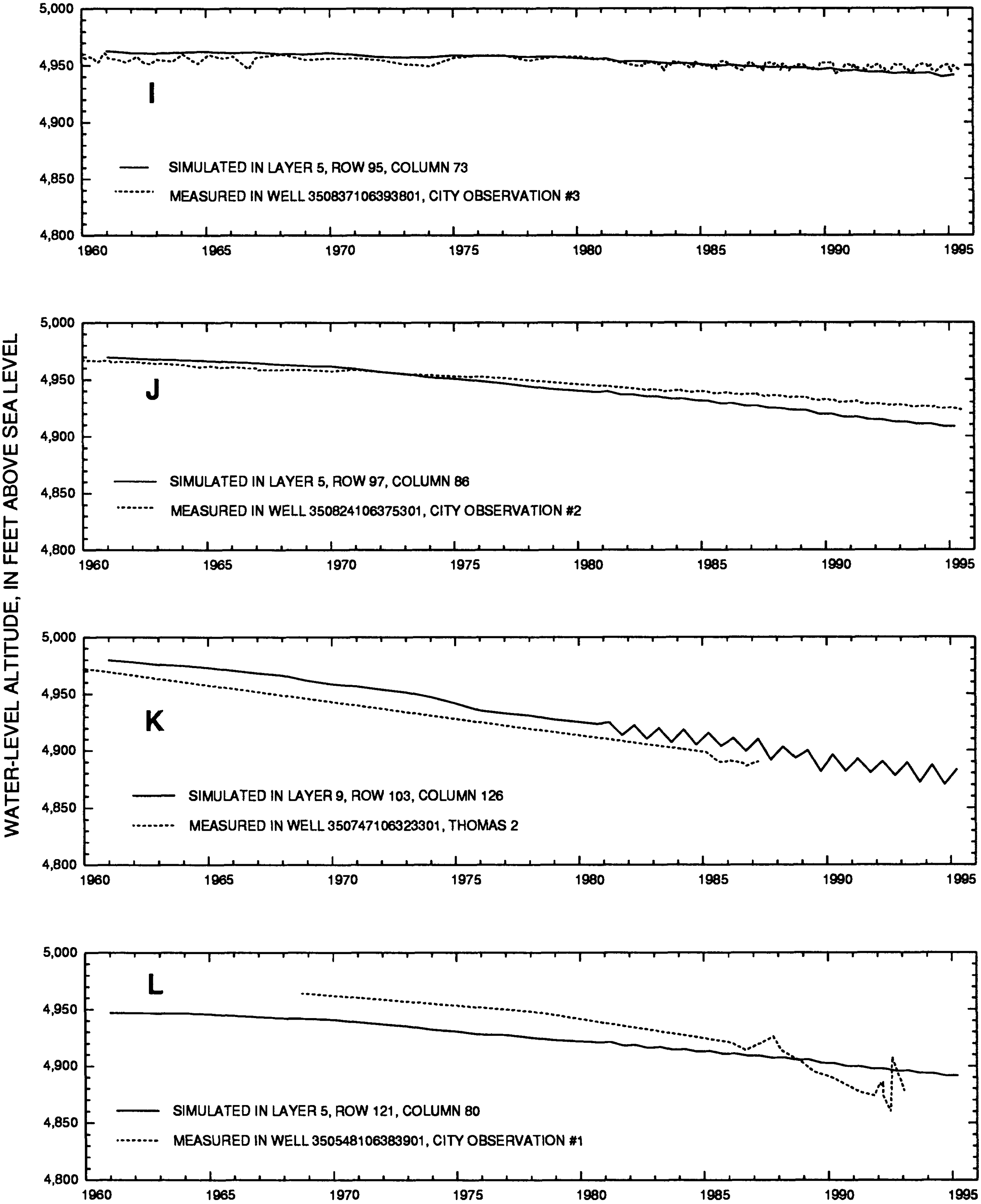


Figure 24.--Water levels measured in selected wells in the Albuquerque Basin and those simulated in corresponding model cells (location of wells shown in fig. 25)--Continued.

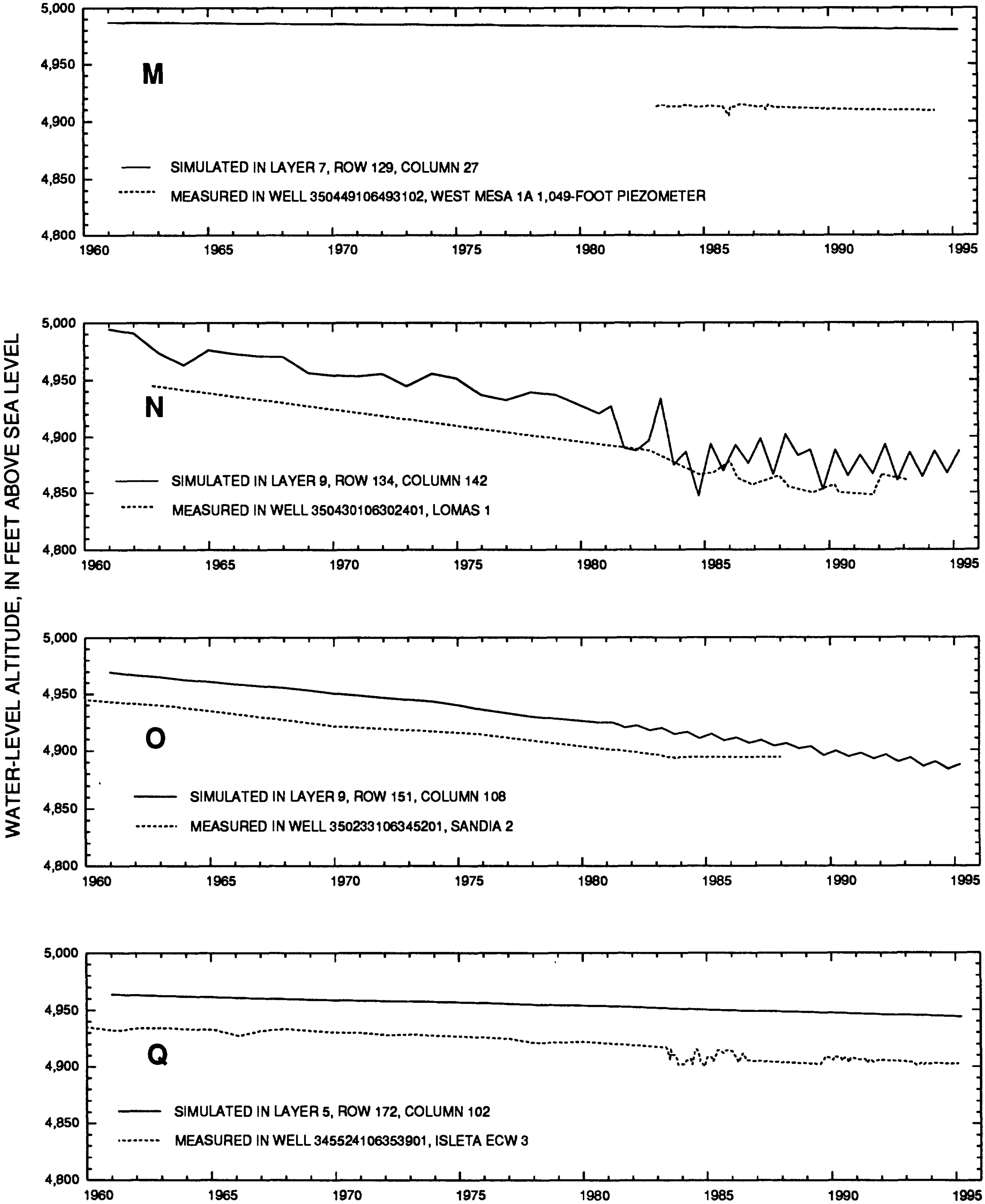


Figure 24.--Water levels measured in selected wells in the Albuquerque Basin and those simulated in corresponding model cells (location of wells shown in fig. 25)--Continued.

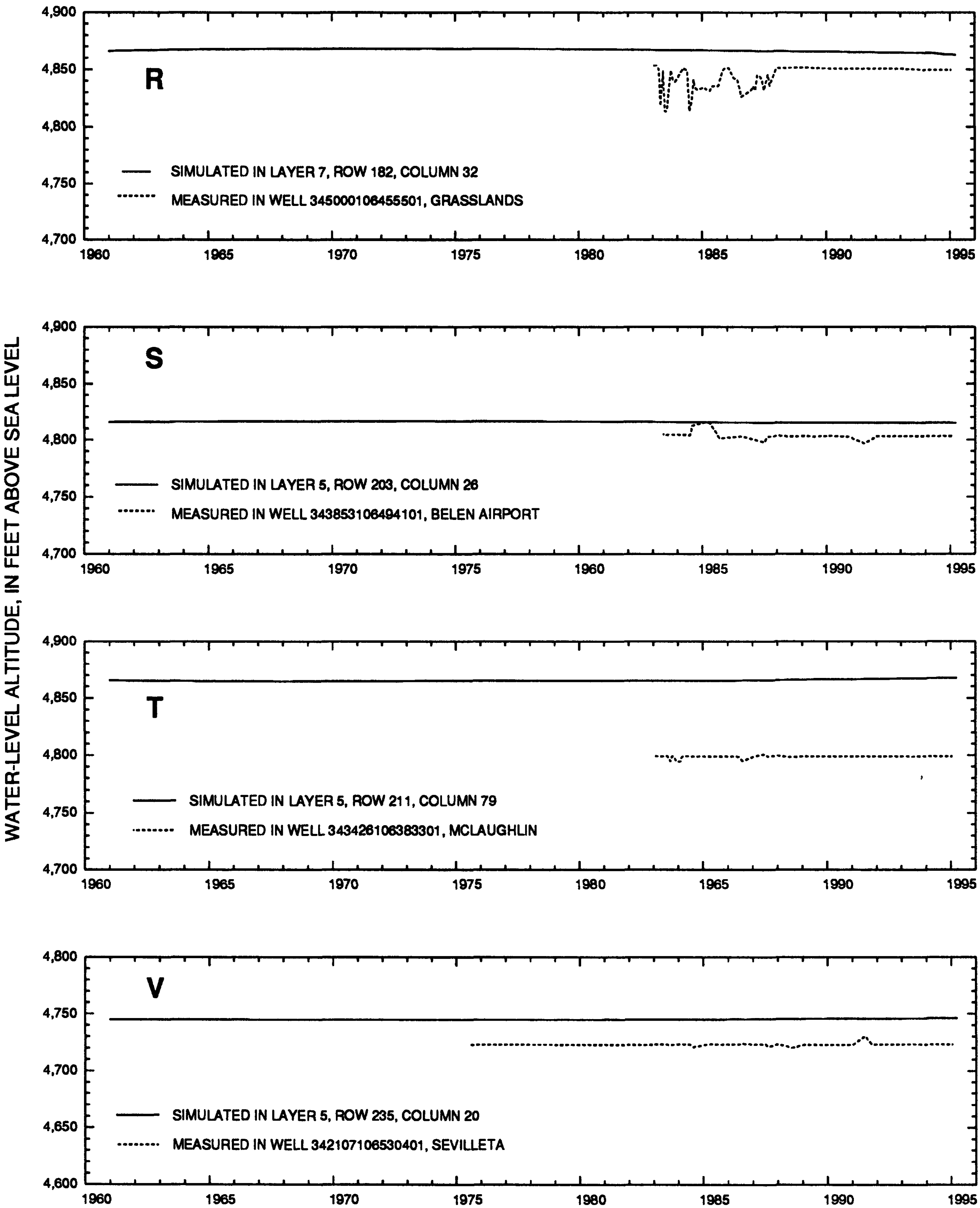


Figure 24.--Water levels measured in selected wells in the Albuquerque Basin and those simulated in corresponding model cells (location of wells shown in fig. 25)--Continued.

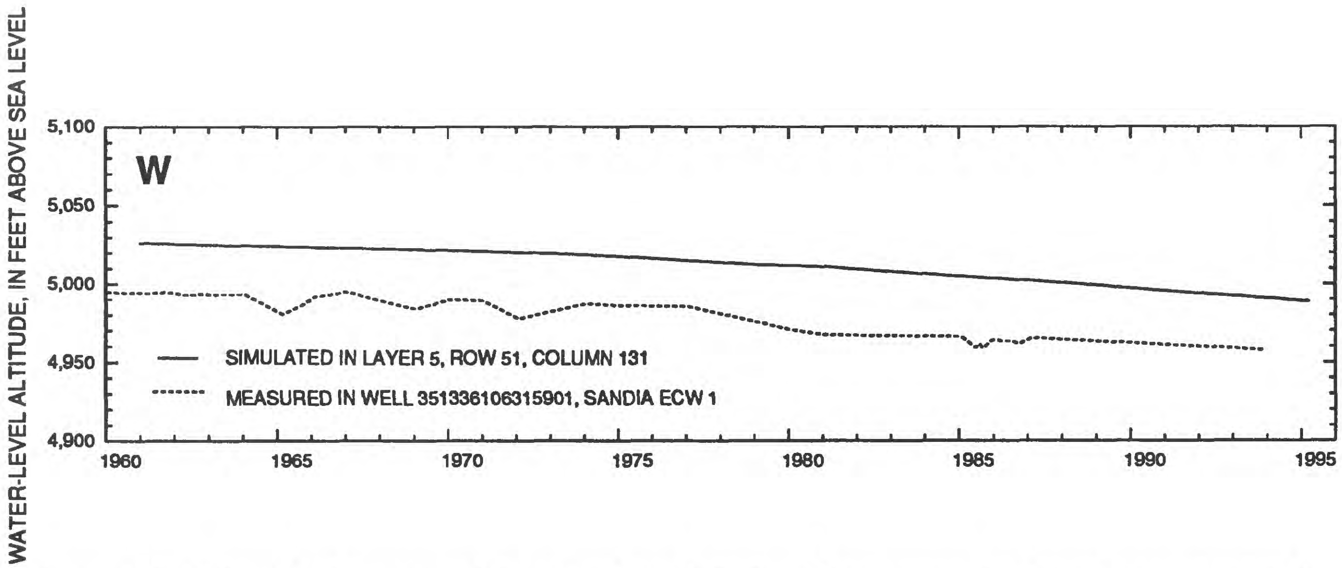


Figure 24.--Water levels measured in selected wells in the Albuquerque Basin and those simulated in corresponding model cells (location of wells shown in fig. 25)--Concluded.

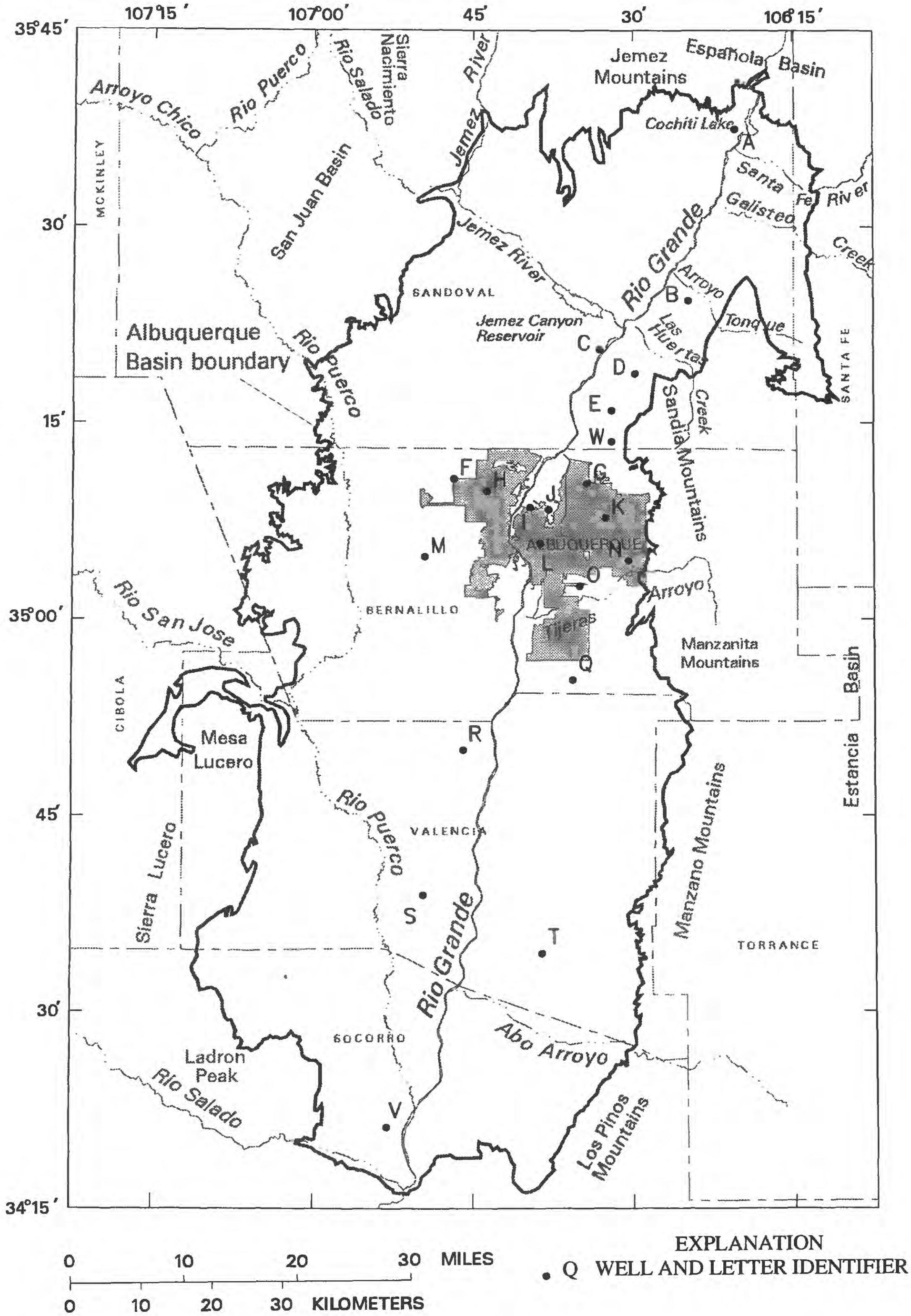


Figure 25.--Location of selected wells in the Albuquerque Basin (modified from Thorn and others, 1993).

Table 1.--Simulated annual water budgets for the Albuquerque Basin: steady state, 1960, 1994, and 1995

[All values in acre-feet per year]

	Steady state (predevelopment)			1960			Year ending spring 1994			Year ending spring 1995		
Mechanism	Inflow	Outflow	Net	Inflow	Outflow	Net	Inflow	Outflow	Net	Inflow	Outflow	Net
Mountain-front and tributary recharge	109,667	0	109,667	107,471	0	107,471	109,664	0	109,664	109,664	0	109,664
Ground-water inflow from adjacent basins	28,400	0	28,400	28,400	0	28,400	28,400	0	28,400	28,400	0	28,400
River, canal, and reservoir leakage	142,200	6,981	135,219	234,611	5,871	228,740	250,872	43,794	207,078	253,331	43,695	209,636
Drain seepage	0	0	0	0	101,575	-101,575	0	219,359	-219,359	0	218,168	-218,168
Riparian and wetland evapotranspiration	0	273,283	-273,283	0	276,729	-276,729	0	89,020	-89,020	0	89,206	-89,206
Irrigation seepage	0	0	0	48,899	0	48,899	48,645	0	48,645	48,645	0	48,645
Ground-water withdrawal	0	0	0	0	61,512	-61,512	0	170,966	-170,966	0	167,892	-167,892
Septic-field return flow	0	0	0	0	0	0	9,527	0	9,527	9,527	0	9,527
Aquifer storage	0	0	0	30,864	4,643	26,221	103,617	27,640	75,977	96,062	25,904	70,158
Error			3			-45			-54			764

(river loss and canal loss minus drain-return flow) increased about 3,000 acre-feet per year. All other differences were masked in minor adjustments within other components of the surface-water and riparian systems and in an increase in the net error from 54 acre-feet per year in 1994 to 764 acre-feet per year in 1995.

Table 5 in Kernodle and others (1995) contains some substantial bookkeeping errors for 1994 that affect reported rates of mountain-front recharge and return flows from irrigated agriculture and private-domestic septic leach fields. The rates were correctly simulated but were incorrectly reported. Therefore, the results of the two model versions and in particular the projections to 2020 were unaffected by the reporting error. Table 1 in this report contains the correct recharge rates.

Two balancing changes are evident for the two model versions that end in the spring of 1994: loss from the surface-water system (excluding drains) increased by about 4,000 acre-feet per year, and depletion of aquifer storage decreased by about 3,000 acre-feet per year. Apparently in both model versions the overall 1994 simulated water-budget results are nearly independent of the new model adjustments to the simulated aquifer properties, predevelopment recharge rates, and slight transitional smoothing brought about by inclusion of the mid-1950's land-cover data. However, the projections to 2020 do appear to have some dependency on these revisions and especially on recent, and consequently projected, changes in ground-water-withdrawal rates.

Table 2 shows sources of water for City of Albuquerque ground-water withdrawals for 1960, 1994, and 1995 (compare with Kernodle and others, 1995, table 6). Differences for 1960 between the two model versions reflect residual effects of the corrected predevelopment mountain-front recharge rates and simulated changes in irrigation-return flow and evapotranspiration resulting from the addition of the mid-1950's land-cover data.

Although all budget components of the two model versions except ground-water withdrawal showed some change for 1994, the most notable changes were a decrease in simulated aquifer-storage depletion of about 6,000 acre-feet per year and an increase in net surface-water loss of about 4,000 acre-feet per year (from 53,000 to 56,700 acre-feet). The shift probably is attributable primarily to the increase in simulated hydraulic conductivity of the clay zone in the valley-fill alluvium (fig. 3) in the Albuquerque area.

The sources of water for Albuquerque pumpage from 1901 to spring 1995 (compare with Kernodle and others, 1995, fig. 38) are shown in figure 26. At the scale of the figure the only obvious difference is the change in water-budget proportions simulated to take place in 1961. Most of the rapid change between 1960 and 1961 results from a change in simulated capture of drain-return flow; the remainder results from a sharp reduction in salvaged evapotranspiration. The changes were brought about by modifications in drain and canal infrastructure that actually took place over several years rather than in an instant in time in 1961 as was simulated by the model. It is doubtful that data will ever be acquired that are needed to simulate a smooth transition in the infrastructure for this period.

PROJECTIONS TO 2020

Figures 27 through 29 show simulated projected hydraulic heads in model layer 9 (approximately the main production interval for most City of Albuquerque wells) for 2020 under assumed conditions of the current growth trend, medium growth, and medium growth with 30-percent conservation. The base period for the projections was spring 1993 through spring 1995, as described earlier. Also, the projection time span was from spring 1995 to spring 2020, a year shorter than that in the previous model version.

Changes to the revised model appear to have the greatest effect on the projected water levels resulting from continuing the current growth trend and have essentially no effect on the projected water levels for medium growth with an additional 30-percent conservation. In all scenarios the water-level altitudes are higher than those reported in Kernodle and others (1995). For the current growth-rate projection, the simulated increase in water-level altitude is locally as much as 70 feet west of the river and 30 feet east of the river. Outside these local areas the change generally is 10 feet or less. It is important to emphasize that these areas of large difference between the two model versions are localized to a few areas of 1 square mile or less (fig. 27; Kernodle and others, 1995, fig. 52). By comparison, the differences between the two model versions for the medium growth rate with 30-percent conservation are 10 feet or less virtually everywhere (fig. 29; Kernodle and others, 1995, fig. 49).

Table 2.--Simulated water budget without and with City of Albuquerque ground-water withdrawals: 1960, 1994, and 1995

[All values in acre-feet per year]

	1960			1994			1995		
	Simulation without City withdrawal	Simulation with City withdrawal	Difference	Simulation without City withdrawal	Simulation with City withdrawal	Difference	Simulation without City withdrawal	Simulation with City withdrawal	Difference
Net storage	12,503	26,211	13,708	12,558	75,977	63,419	8,762	70,158	61,396
River, canal, and reservoir leakage	220,341	228,790	8,449	184,658	207,078	22,420	185,115	209,636	24,521
Drain seepage	-106,707	-101,575	5,132	-253,599	-219,359	34,240	-252,962	-218,168	34,794
Riparian and wetland evapotranspiration	-283,689	-276,729	6,960	-92,348	-89,020	3,328	-92,298	-89,206	3,092
Recharge[1]	184,772	184,770	0	196,237	196,235	0	196,237	196,235	0
Ground-water withdrawal	-27,247	-61,512	-34,265	-47,515	-170,966	-123,451	-44,810	-167,892	-123,082
Net surface-water loss[2]			13,581			56,660			59,315

[1]Mountain-front and tributary recharge, ground-water inflow from adjacent basins, irrigation seepage, and septic-field return flow.
[2]Increased river, canal, and reservoir seepage plus decreased drain seepage.

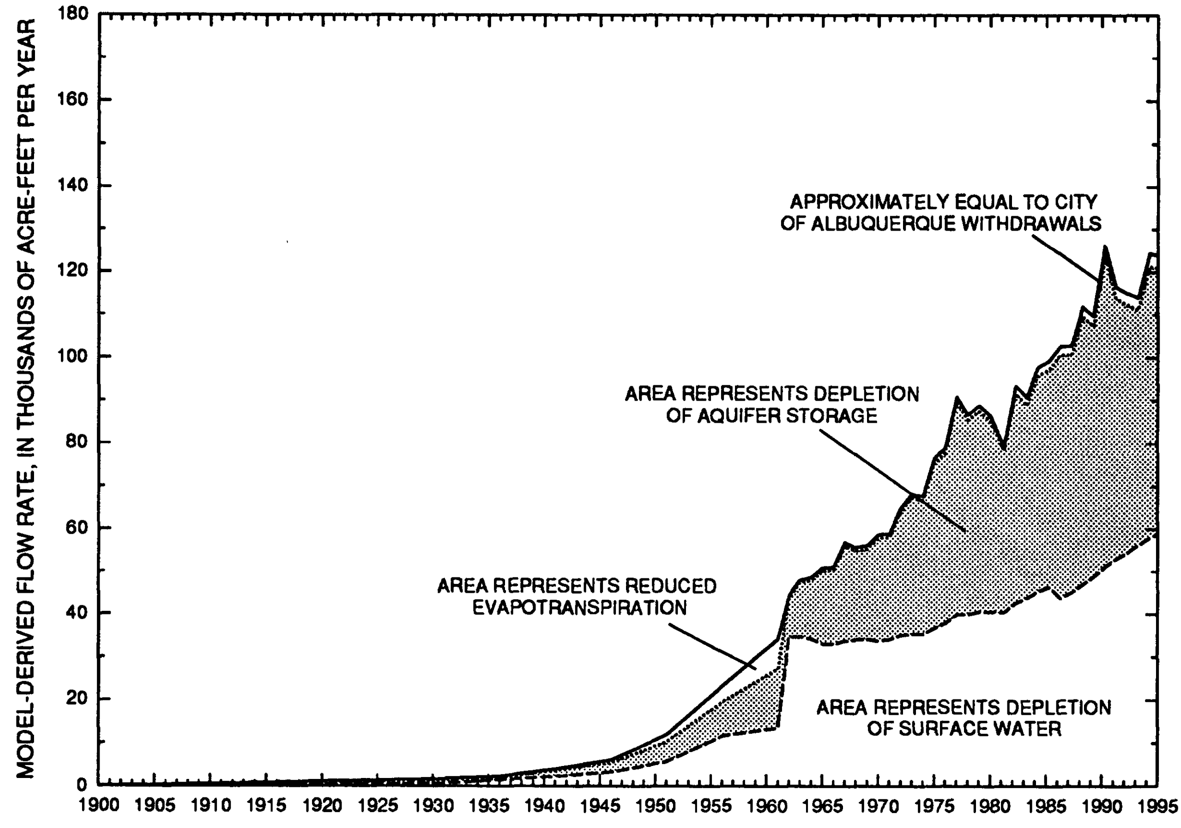


Figure 26.--Sources of City of Albuquerque withdrawals, 1901-95.

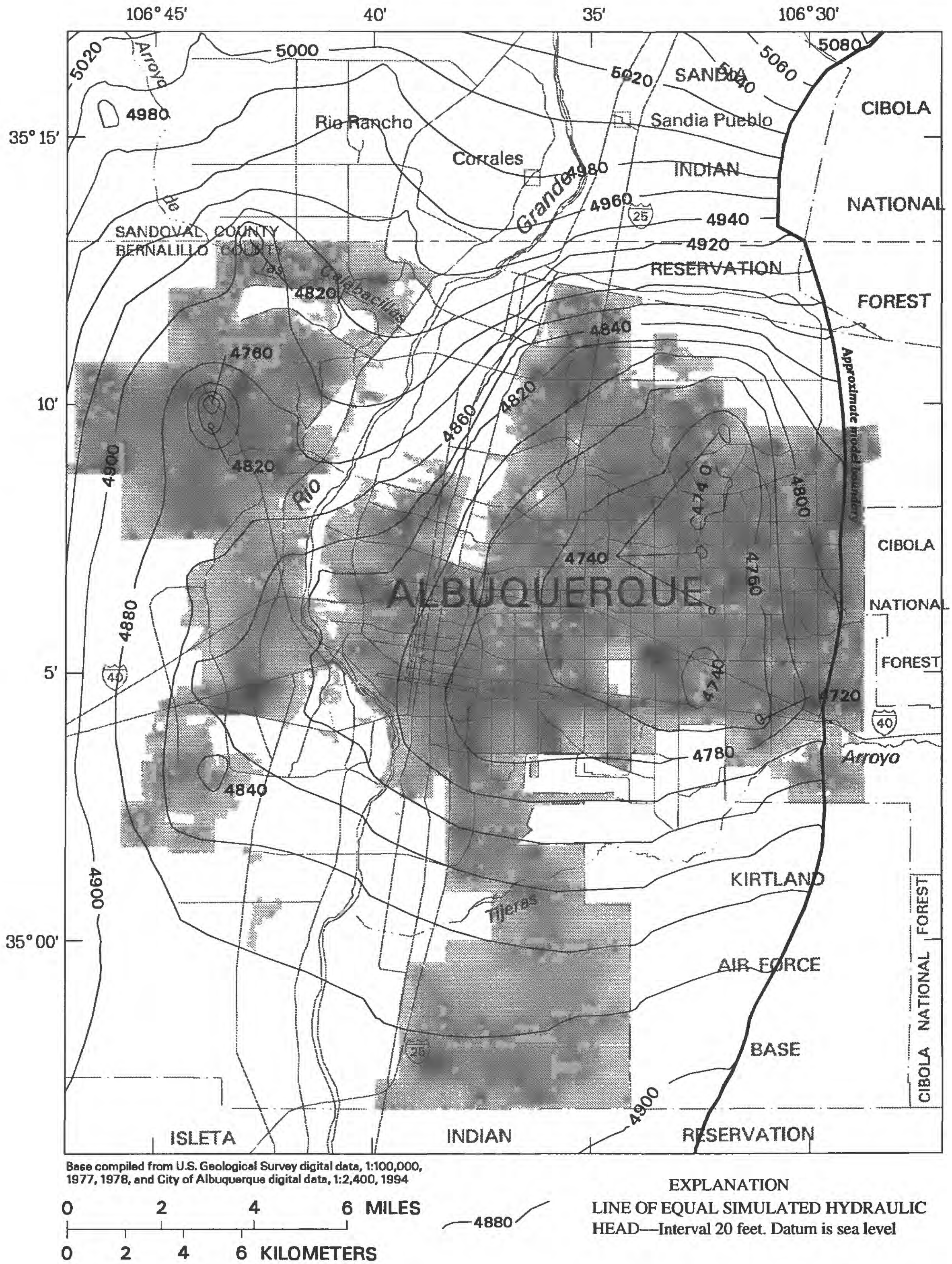


Figure 27.—Simulated 2020 hydraulic head in model layer 9 in the Albuquerque area assuming the current growth trend.

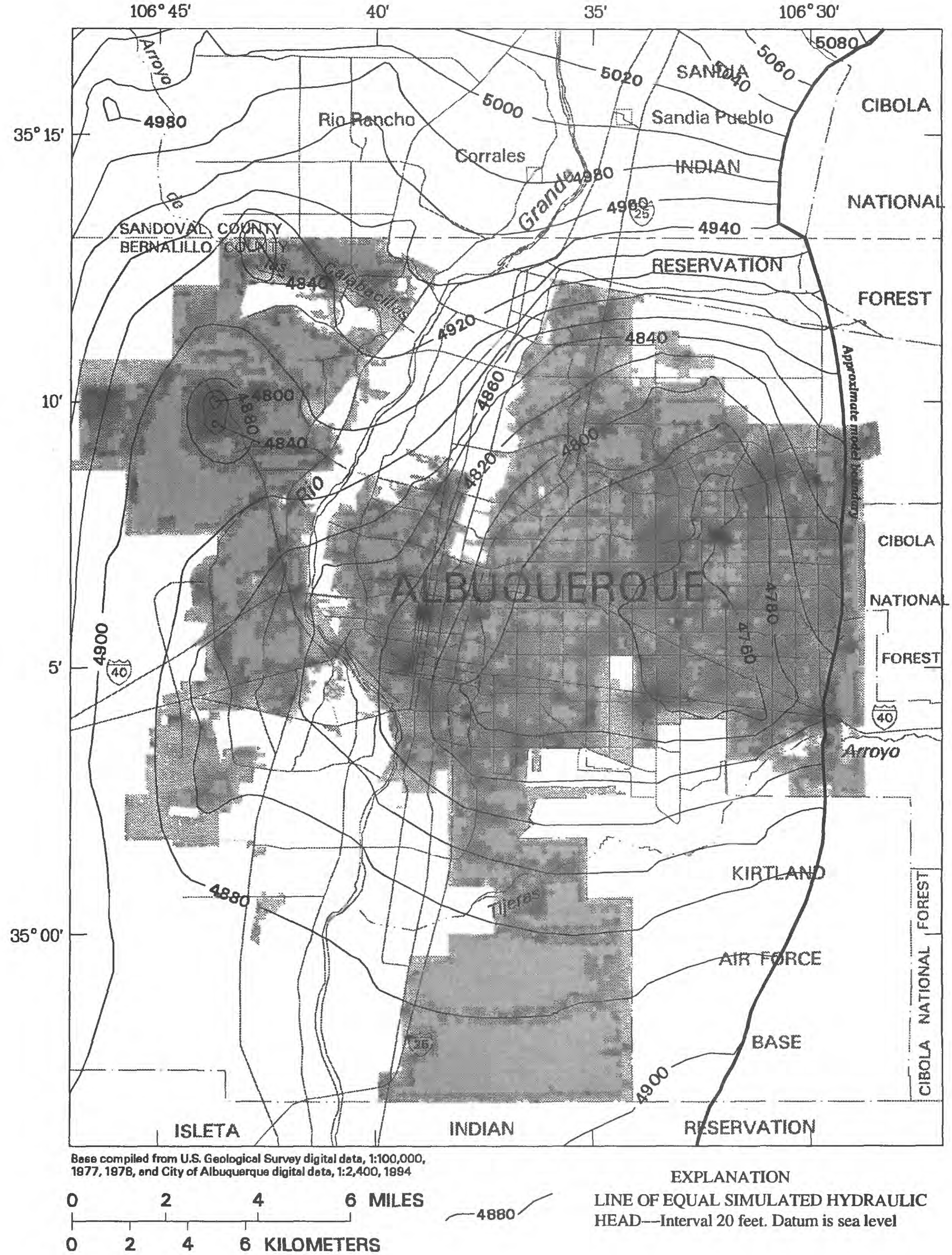


Figure 28.—Simulated 2020 hydraulic head in model layer 9 in the Albuquerque area assuming medium growth.

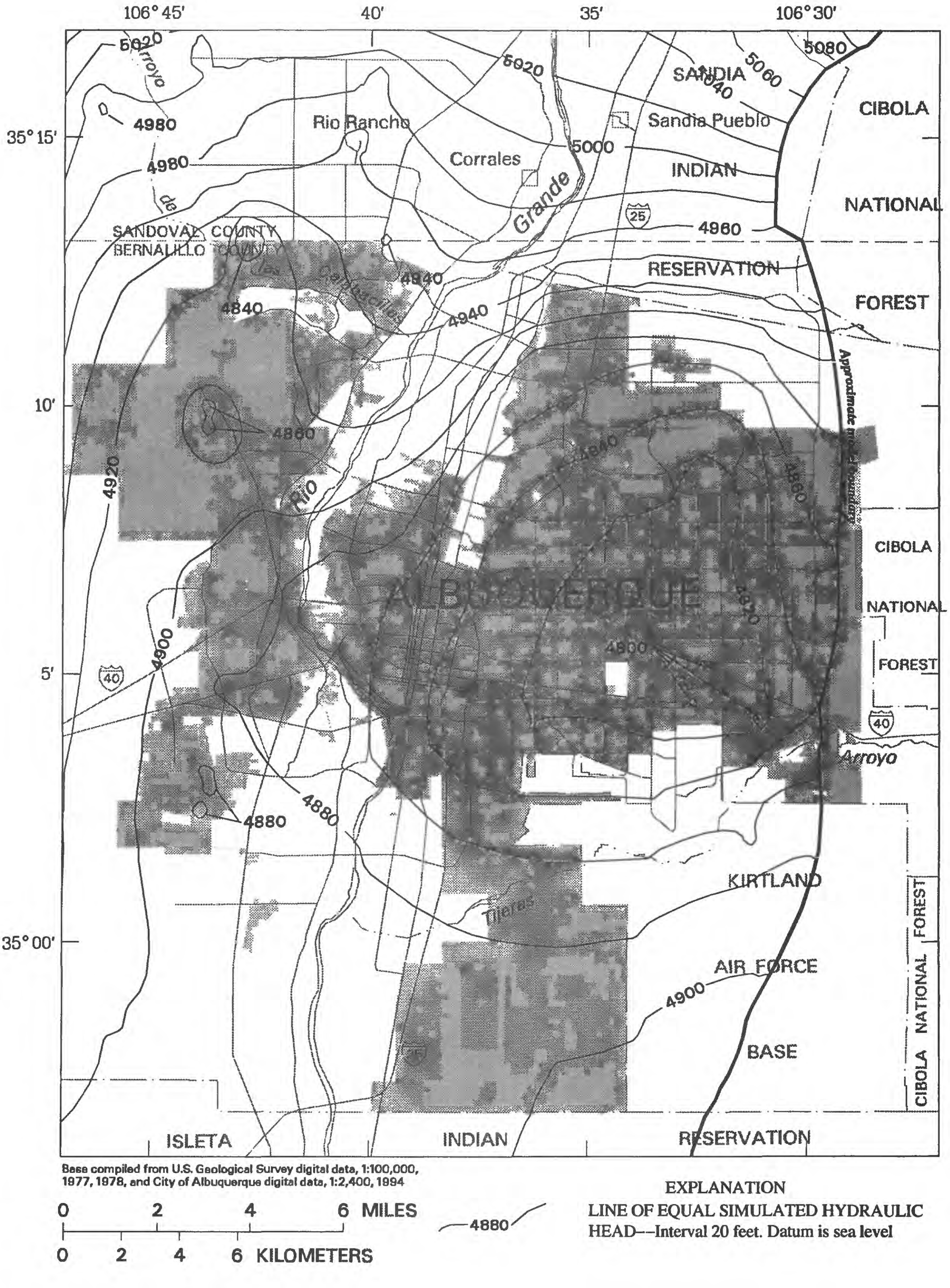
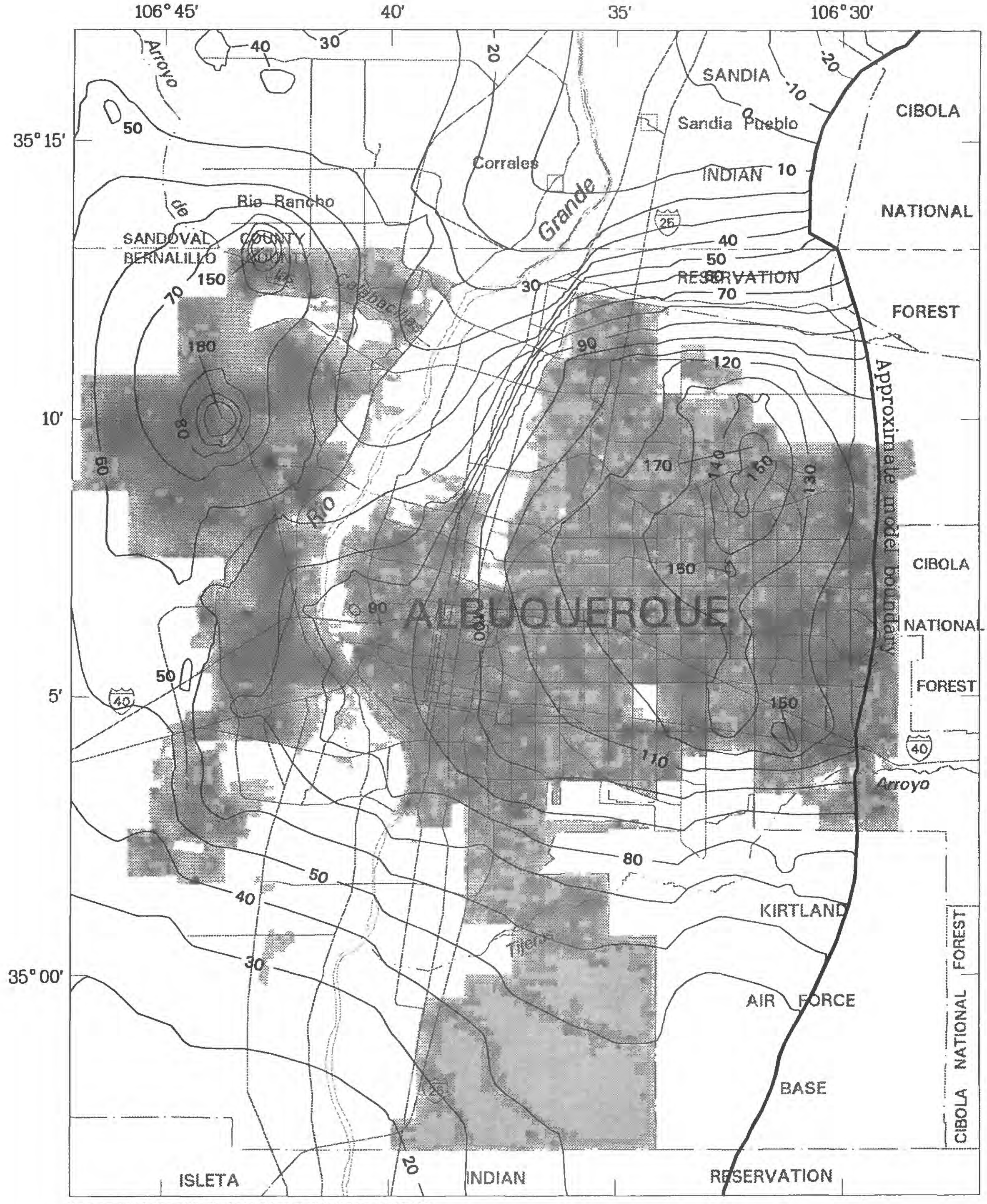


Figure 29.--Simulated 2020 hydraulic head in model layer 9 in the Albuquerque area assuming medium growth and 30-percent conservation.

Numerous factors are incorporated in these projections that involve changes in simulated aquifer properties as well as significant revision of the base level of ground-water withdrawals upon which the projections depend. The revised projected water levels under the current growth scenario appear to be most greatly affected by the eastward shift in the simulated position of the axial-channel deposits in northeast Albuquerque and by corrections and revisions of the simulated hydraulic conductivities west of the Rio Grande. These corrections and revisions have the effect of locally improving the simulated specific capacity (production rate divided by drawdown) of the City wells.

Projected 25-year water-level declines in model layer 9 to the year 2020 for the same projection scenarios are shown in figures 30 through 32. Figure 33 shows the increased water-level decline that would result from the current growth trend compared to medium growth with 30-percent conservation.

The projected effects that City of Albuquerque ground-water withdrawals might have in the future on sources of water for the three growth scenarios by 2020 are shown in table 3 (see Kernodle and others, 1995, table 8). Figures 34 through 36 (see Kernodle and others, 1995, figs. 62-64) illustrate those effects over time. Table 4 compares the net storage depletion and streamflow depletion caused by City of Albuquerque ground-water withdrawals as simulated by the two model versions. Of the three scenarios, the medium growth rate with 30-percent conservation shows the greatest difference between model versions, primarily because the projected ground-water withdrawal is greater in the revised version.



Base compiled from U.S. Geological Survey digital data, 1:100,000, 1977, 1978, and City of Albuquerque digital data, 1:2,400, 1994

0 2 4 6 MILES

0 2 4 6 KILOMETERS

EXPLANATION

60 LINE OF EQUAL SIMULATED DECLINE IN HYDRAULIC HEAD--Interval 10 feet

Figure 30.--Simulated decline in hydraulic head in model layer 9 in the Albuquerque area assuming the current growth trend, 1995–2020.

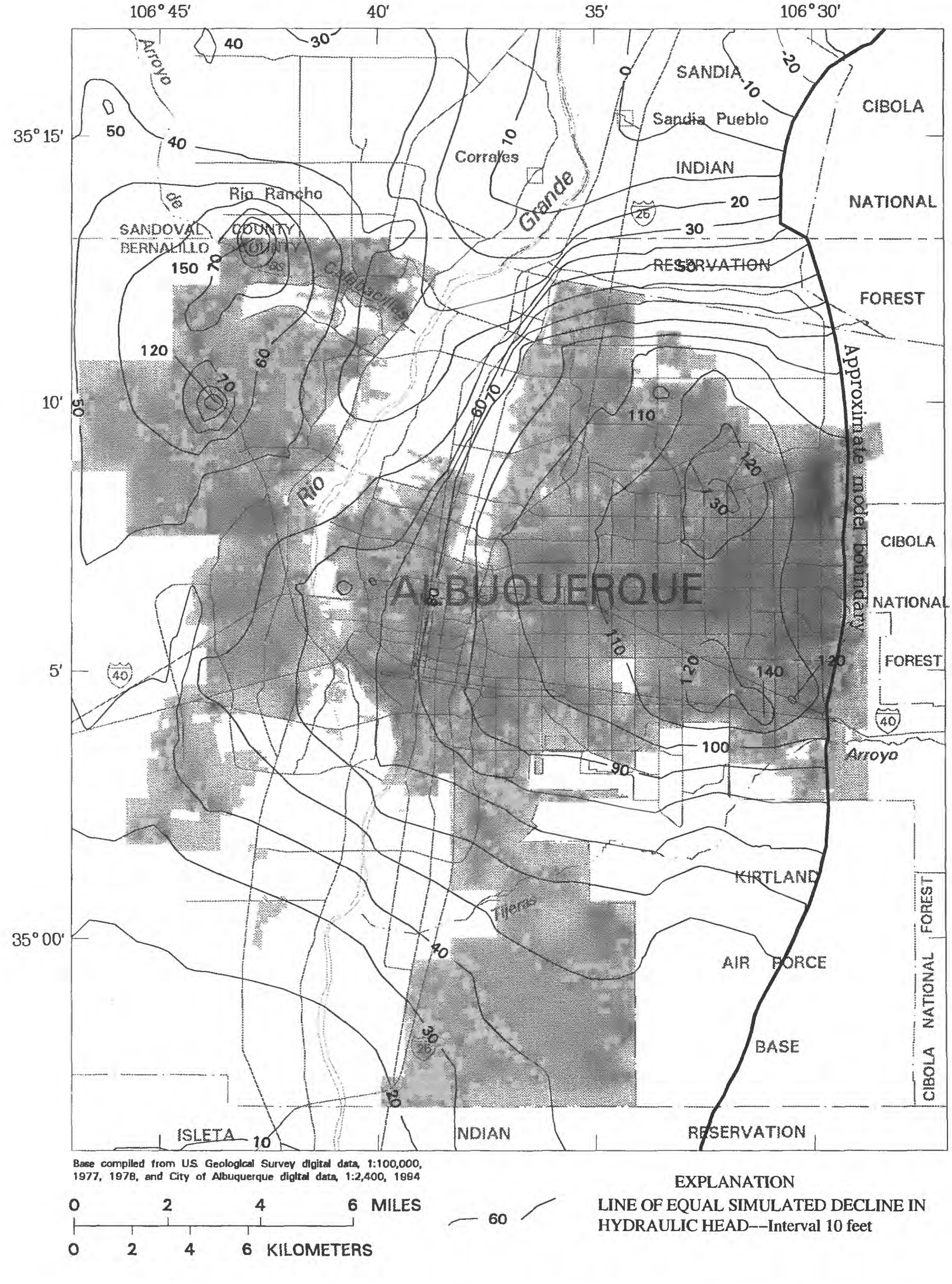


Figure 31.--Simulated decline in hydraulic head in model layer 9 in the Albuquerque area assuming medium growth, 1995–2020.

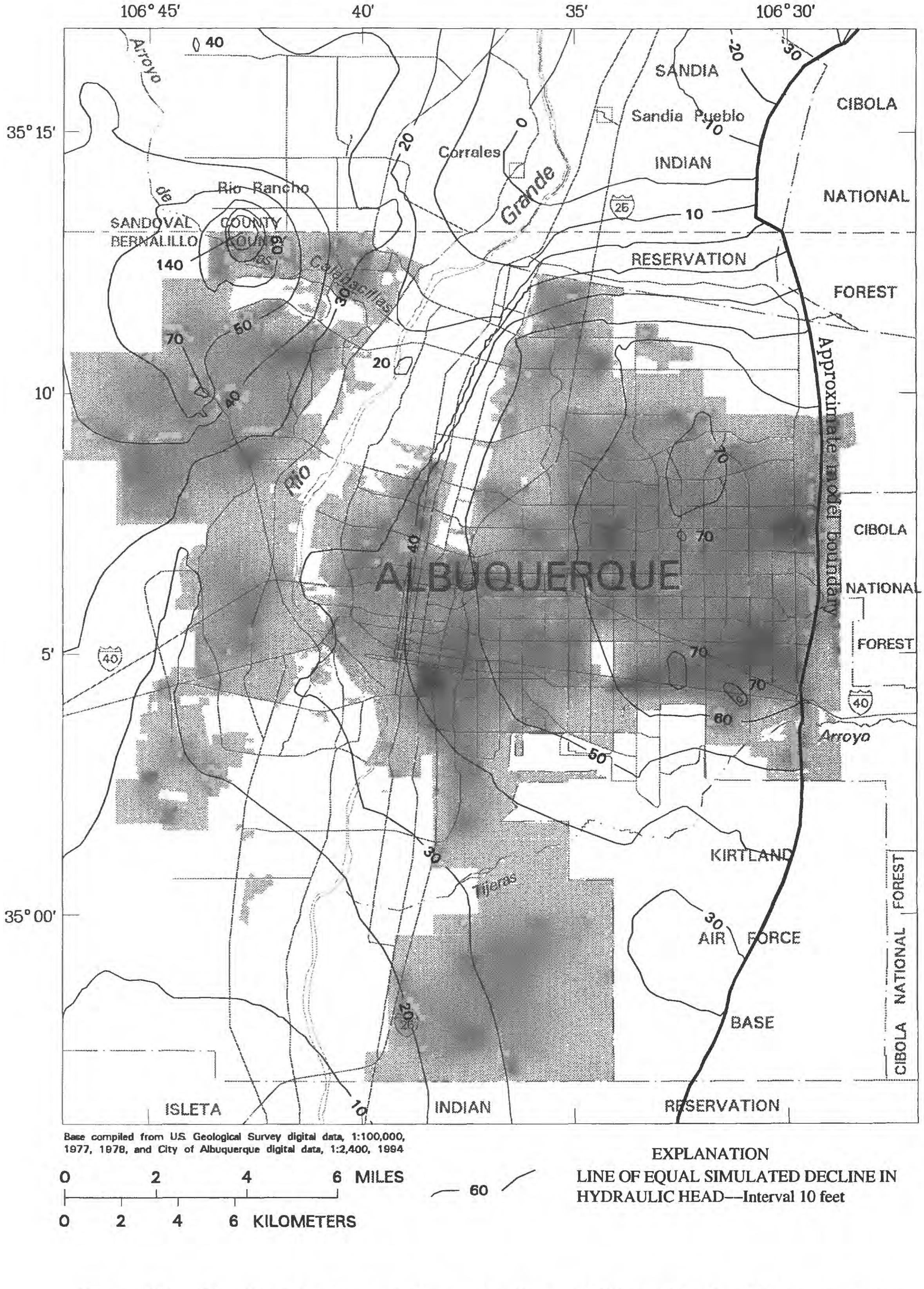


Figure 32.—Simulated decline in hydraulic head in model layer 9 in the Albuquerque area assuming medium growth and 30-percent conservation, 1995–2020.

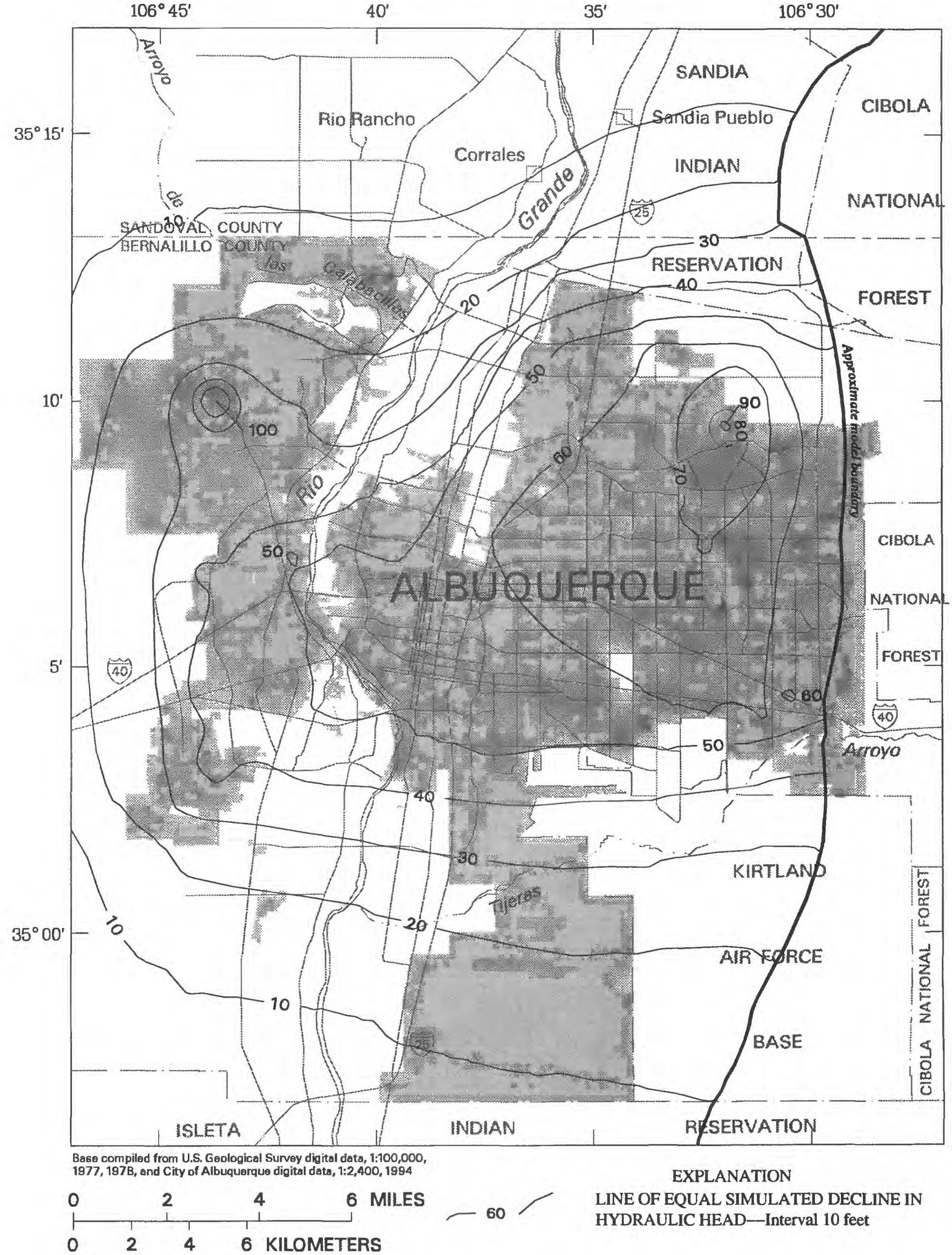


Figure 33.--Simulated increased decline in hydraulic head in model layer 9 in the Albuquerque area that would result from the continued growth trend instead of medium growth and 30-percent conservation, 1995–2020.

Table 3.--Simulated water budget without and with City of Albuquerque ground-water withdrawals with City of Albuquerque withdrawals for current growth, medium growth, and 30-percent conservation scenarios, 2020

[All values in acre-feet per year]

		Current growth		Medium growth		30-percent conservation	
	Simulation without City withdrawal	Simulation with City withdrawal	Difference	Simulation with City withdrawal	Difference	Simulation with City withdrawal	Difference
Net storage	54,189	152,752	98,563	127,828	73,639	95,658	41,469
Recharge[1]	196,133	196,133	0	196,133	0	196,133	0
River, canal, and reservoir leakage	173,820	219,340	45,520	216,332	42,512	207,864	34,044
Ground-water--withdrawal	74,761	-251,466	-176,705	-227,249	-152,488	-186,121	-111,360
Drain seepage	-254,425	-221,116	33,309	-221,891	32,534	-222,420	32,005
Riparian and wetland evapotranspiration	-94,959	-89,986	4,973	-90,323	4,636	-90,708	4,251
Net surface-water loss[2]			78,829		75,046		66,049

[1]Mountain-front and tributary recharge, ground-water inflow from adjacent basins, irrigation seepage, and septic-field return flow.
[2]Increased river, canal, and reservoir seepage plus decreased drain seepage.

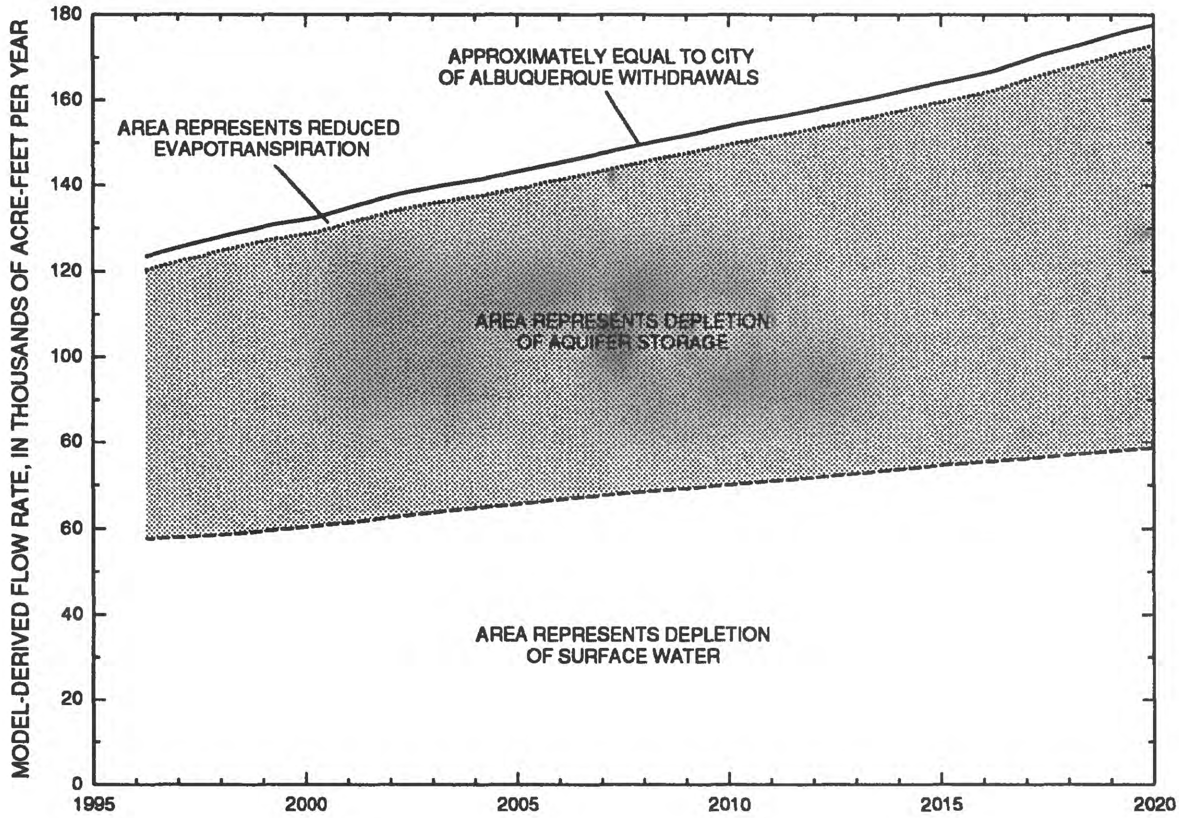


Figure 34.--Sources of City of Albuquerque withdrawals assuming the current growth trend, 1996-2020.

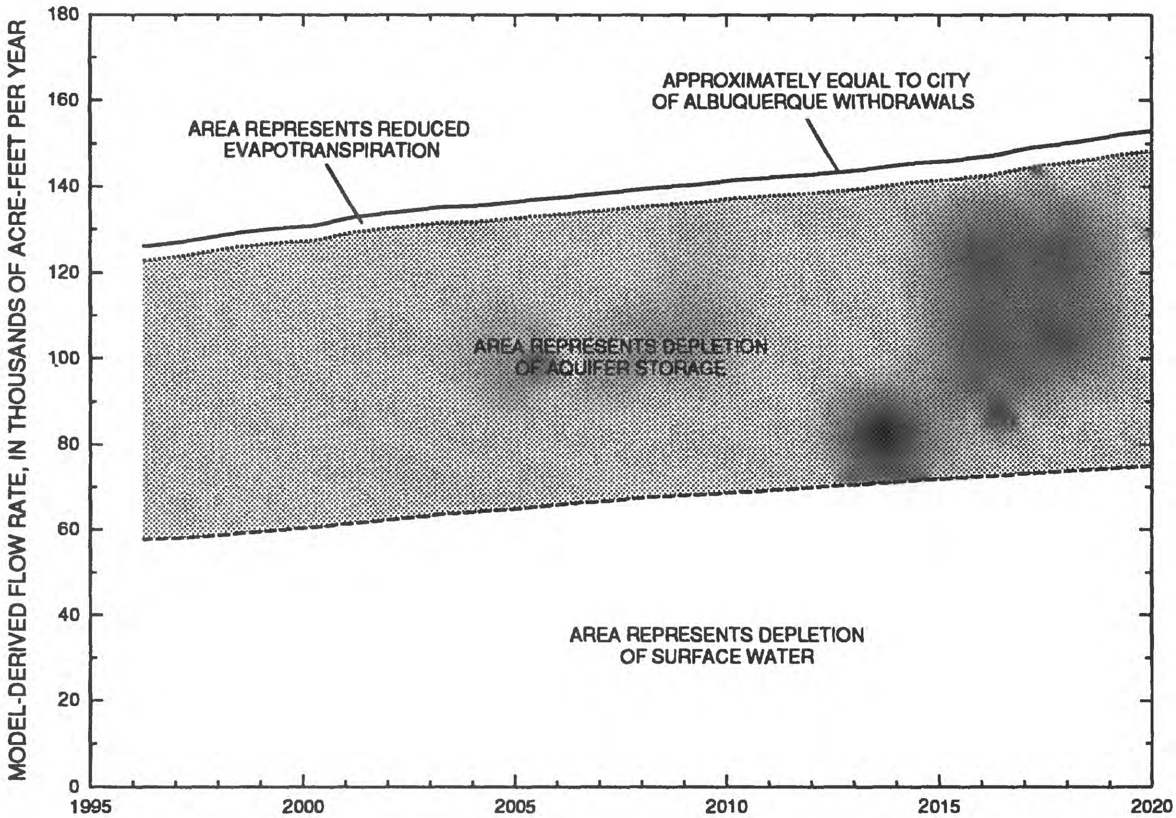


Figure 35.--Sources of City of Albuquerque withdrawals assuming medium growth, 1996-2020.

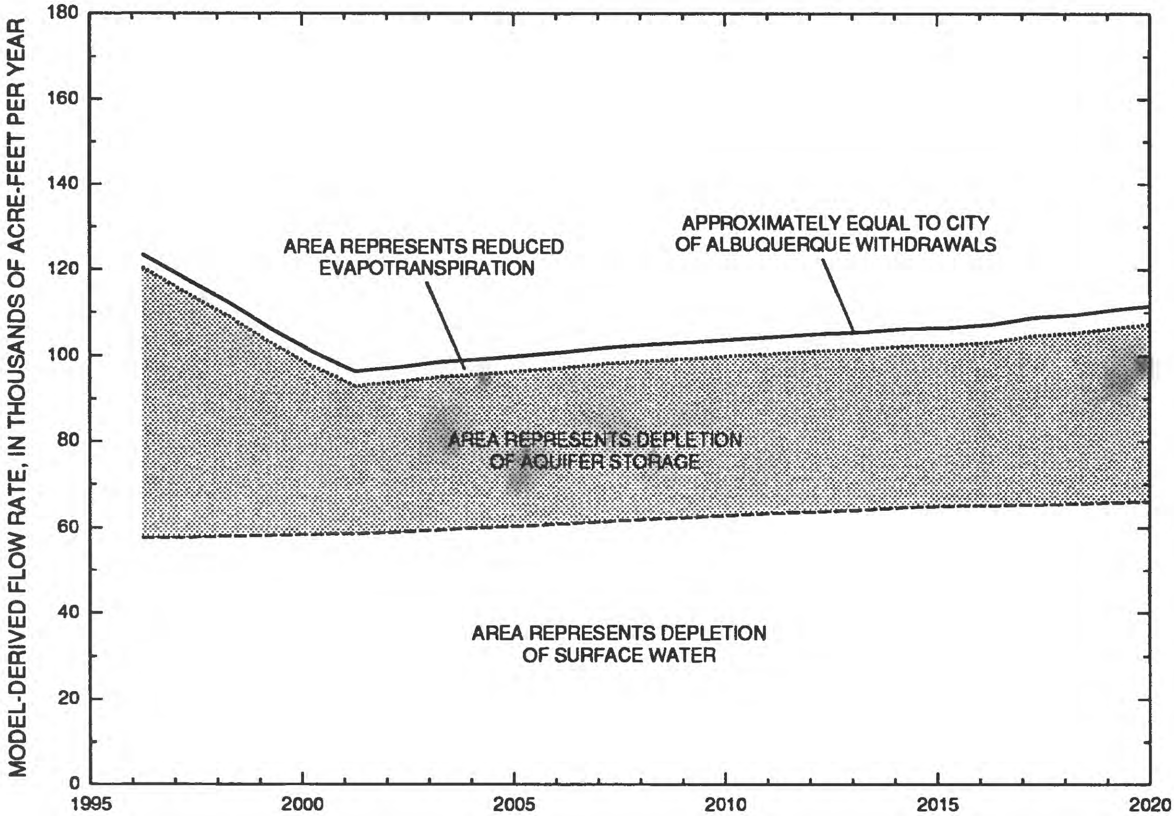


Figure 36.--Sources of City of Albuquerque withdrawals assuming medium growth and 30-percent conservation, 1996-2020.

Table 4.--Comparison of simulated aquifer storage and streamflow depletions due to City of Albuquerque withdrawals for the two model versions, 2020

	Depletion rates, in acre-feet per year					
	Current growth		Medium growth		30-percent conservation	
	1995[1] model	Current model	1995[1] model	Current model	1995[1] model	Current model
Storage depletion	95,900	98,600	72,700	73,600	33,400	41,500
Streamflow depletion	77,000	78,800	73,000	75,000	62,000	66,000

[1]Kernodle and others (1995)

SUMMARY

The 1995 USGS three-dimensional ground-water-flow model of the Albuquerque Basin, central New Mexico, was revised to include a more recent version of the conceptual model of the basin's geohydrologic framework. In addition, several significant corrections were made to the model, including the restoration of about 10,000 acre-feet per year that had been inadvertently omitted from the predevelopment simulation. Finally, an additional year of ground-water-withdrawal data was added to the historical simulations and also used to revise the base-level withdrawal rates for simulations to 2020.

The historical simulations showed no change or improved historical matches in the northern part of the basin, improved and worsened matches in the urban Albuquerque area, and often a worsened match in the southern-central part of the basin. The worsened match in the southern-central part of the basin may be due to the removal in the simulations of a zone of aquifer material of high hydraulic conductivity in the upper part of the Santa Fe Group. The improvements in the Albuquerque area and northward probably are in response to a fuller understanding of the tectonic framework of the basin and of the occurrence of upper Santa Fe Group deposits.

The water budgets of the two model versions are very similar. Differences were expected because simulated historical stresses were revised; in most instances, however, the differences are minor. For example, the simulated effect of City of Albuquerque withdrawals on the Rio Grande surface-water system rose from about 53,000 to about 56,700 acre-feet per year for 1994, a relatively minor change considering the magnitude of some of the model revisions and corrections.

Three scenarios were analyzed in the projections to 2020: continued growth in ground-water withdrawals at the current rate, medium growth, and, medium growth with 30-percent conservation. These three scenarios are documented in the 1995 USGS model. Because the base period was revised to be from spring 1995 instead of spring 1994, the projections were 1 year shorter than in the previous model version. The water budgets for current and medium growth projections were only slightly affected by the shift because the 1994-95 withdrawal data are in line with a slightly less than medium growth rate. However, the water budget for the projection that included 30-percent conservation showed substantial response to the shift probably because 1994-95 withdrawal data partly replaced some of the initial conservation estimates. The high-stress scenarios of current and medium growth rates differ little between the two model versions. In contrast, the much lower stress scenario of medium growth with 30-percent conservation departs significantly from the previous model version probably because the newly included 1994-95 withdrawals by the City of Albuquerque were greater than anticipated conservation goals.

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