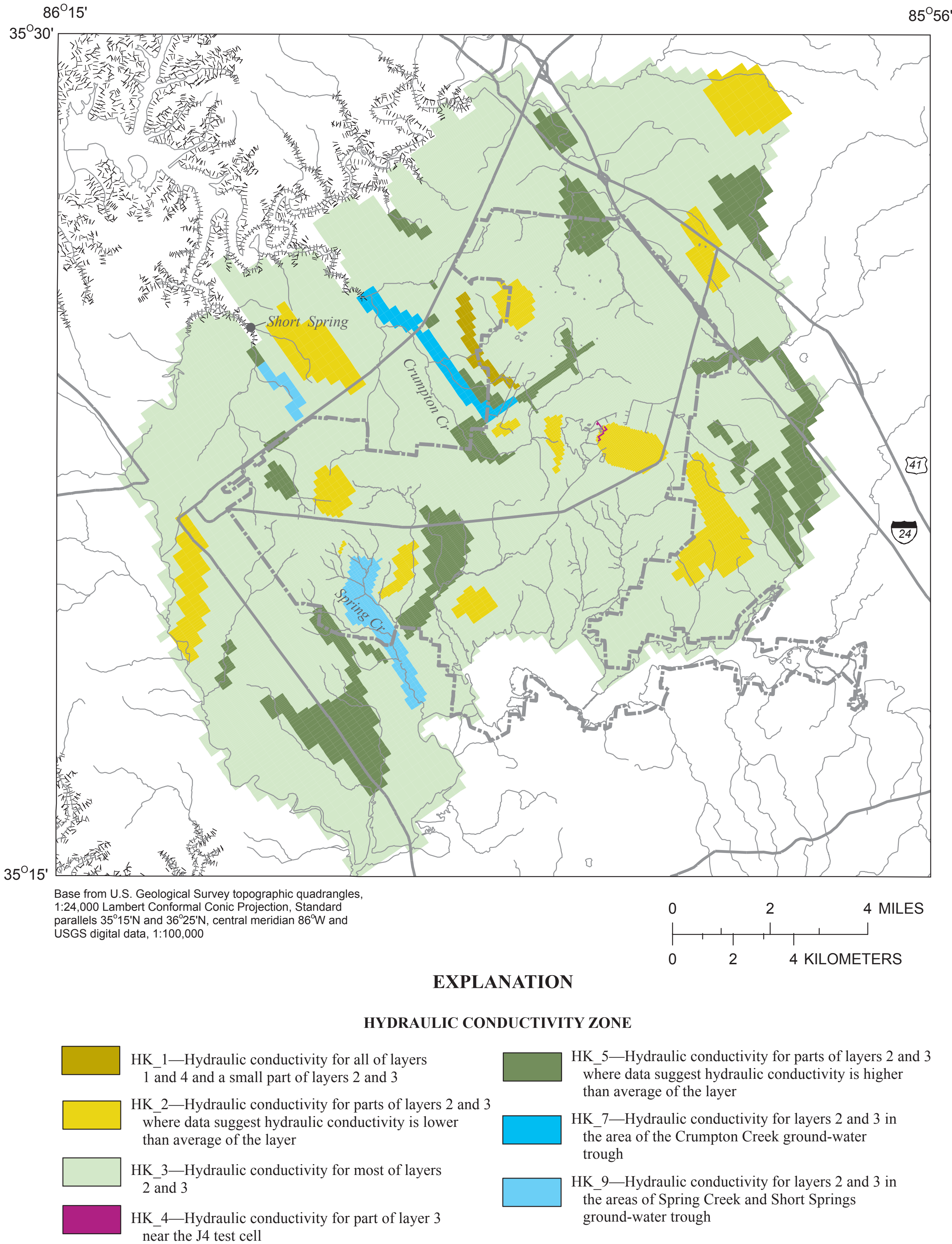


Figure 20. Hydraulic-conductivity zones for model layer 3 of the Arnold Air Force Base area.

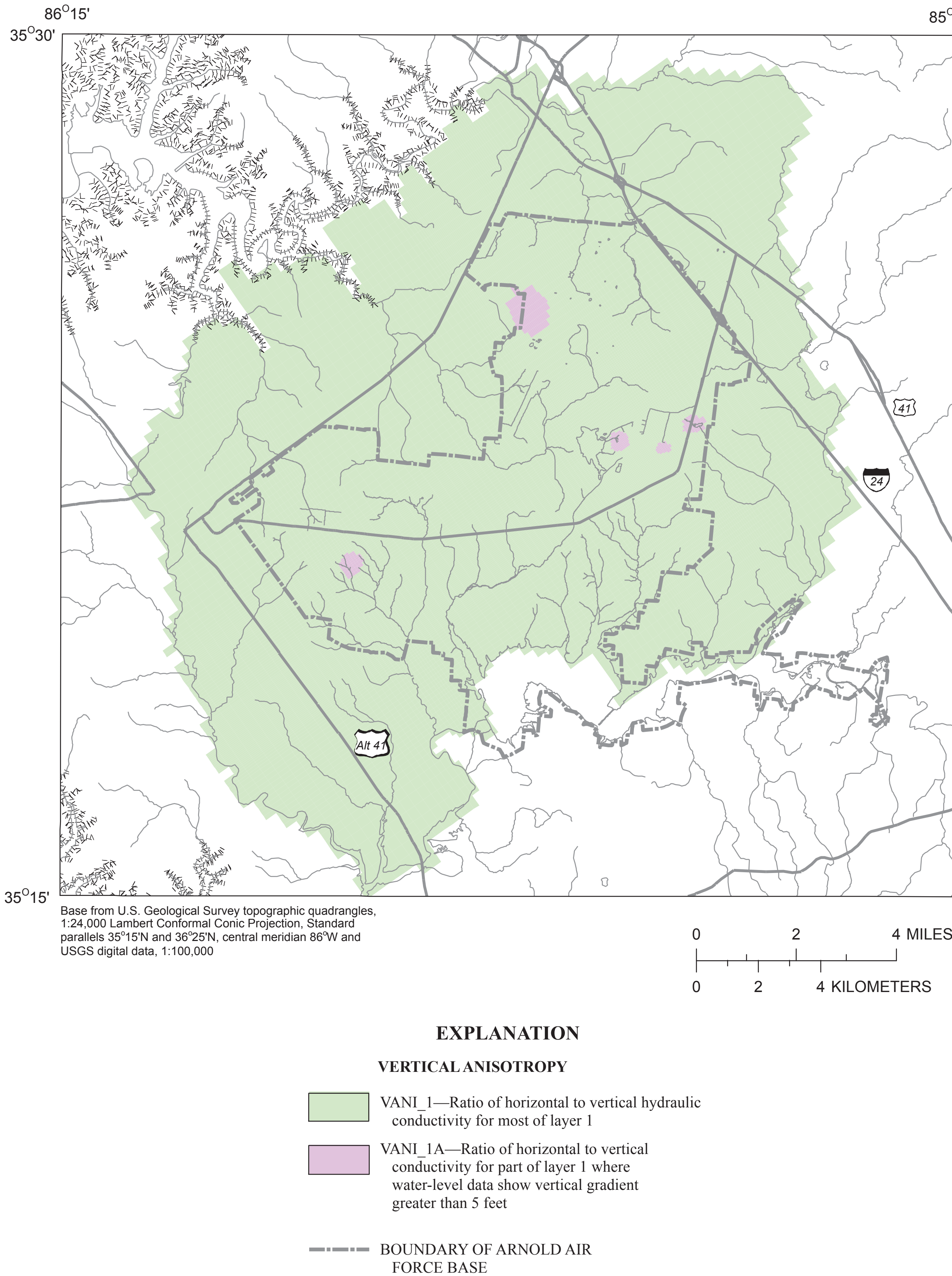
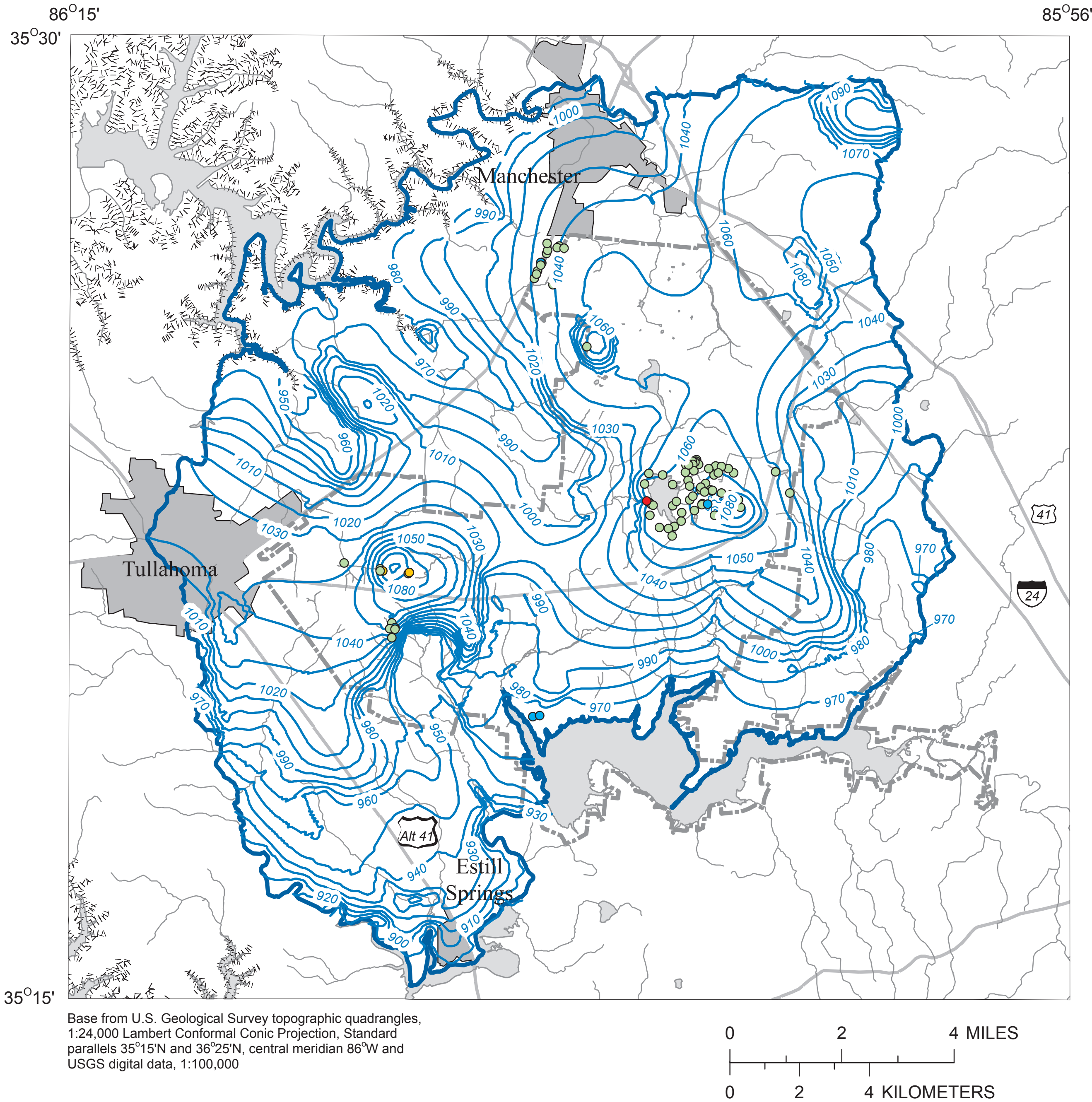


Figure 21. Vertical anisotropy zones for model layer 1 of the Arnold Air Force Base area.



EXPLANATION

900 — POTENTIOMETRIC CONTOUR—Shows simulated altitude of water level. Hachures indicate depression. Contour interval 10 feet. Datum is NGVD 29

HYDROLOGIC BOUNDARY—Delineation of regional ground-water flow system underlying Arnold Air Force Base

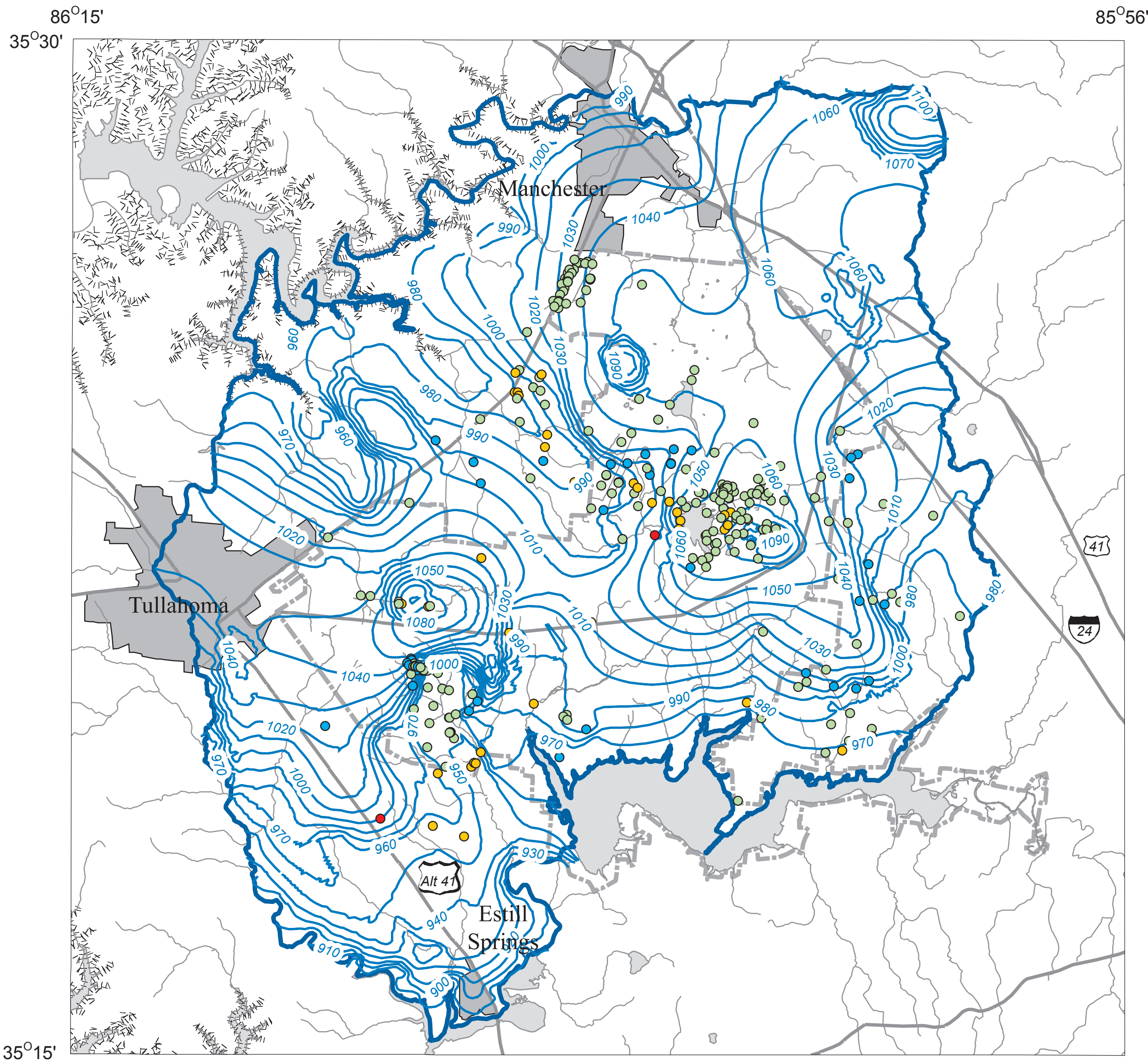
HIGHLAND RIM ESCARPMENT

BOUNDARY OF ARNOLD AIR FORCE BASE

RESIDUAL, IN FEET

- LESS THAN –20
- –20 to –10
- –10 to 10
- 10 to 20
- GREATER THAN 20

Figure 22. Simulated steady-state water levels for layer 1 of the Arnold Air Force Base area ground-water flow model.



Base from U.S. Geological Survey topographic quadrangles, 1:24,000 Lambert Conformal Conic Projection, Standard parallels 35°15'N and 36°25'N, central meridian 86°W and USGS digital data, 1:100,000

0 2 4 MILES

0 2 4 KILOMETERS

EXPLANATION

— 900 — POTENTIOMETRIC CONTOUR—Shows simulated altitude of water level. Hachures indicate depression. Contour interval 10 feet. Datum is NGVD 29

HYDROLOGIC BOUNDARY—Delineation of regional ground-water flow system underlying Arnold Air Force Base

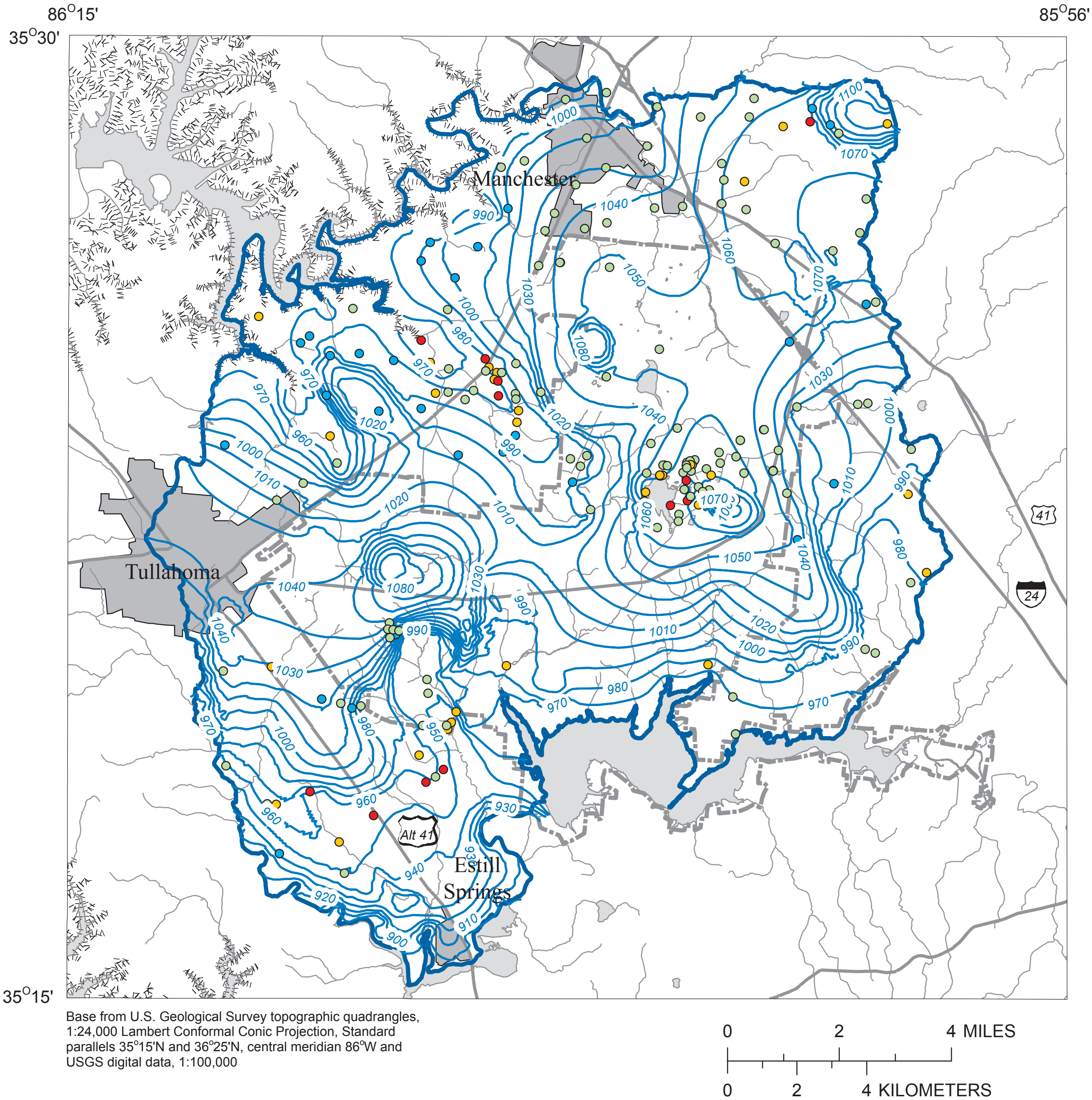
HIGHLAND RIM ESCARPMENT

BOUNDARY OF ARNOLD AIR FORCE BASE

RESIDUAL, IN FEET

- LESS THAN –20
- –20 TO –10
- –10 TO 10
- 10 TO 20
- GREATER THAN 20

Figure 23. Simulated steady-state water levels for layer 2 of the Arnold Air Force Base area ground-water flow model.



Base from U.S. Geological Survey topographic quadrangles, 1:24,000 Lambert Conformal Conic Projection, Standard parallels 35°15'N and 36°25'N, central meridian 86°W and USGS digital data, 1:100,000

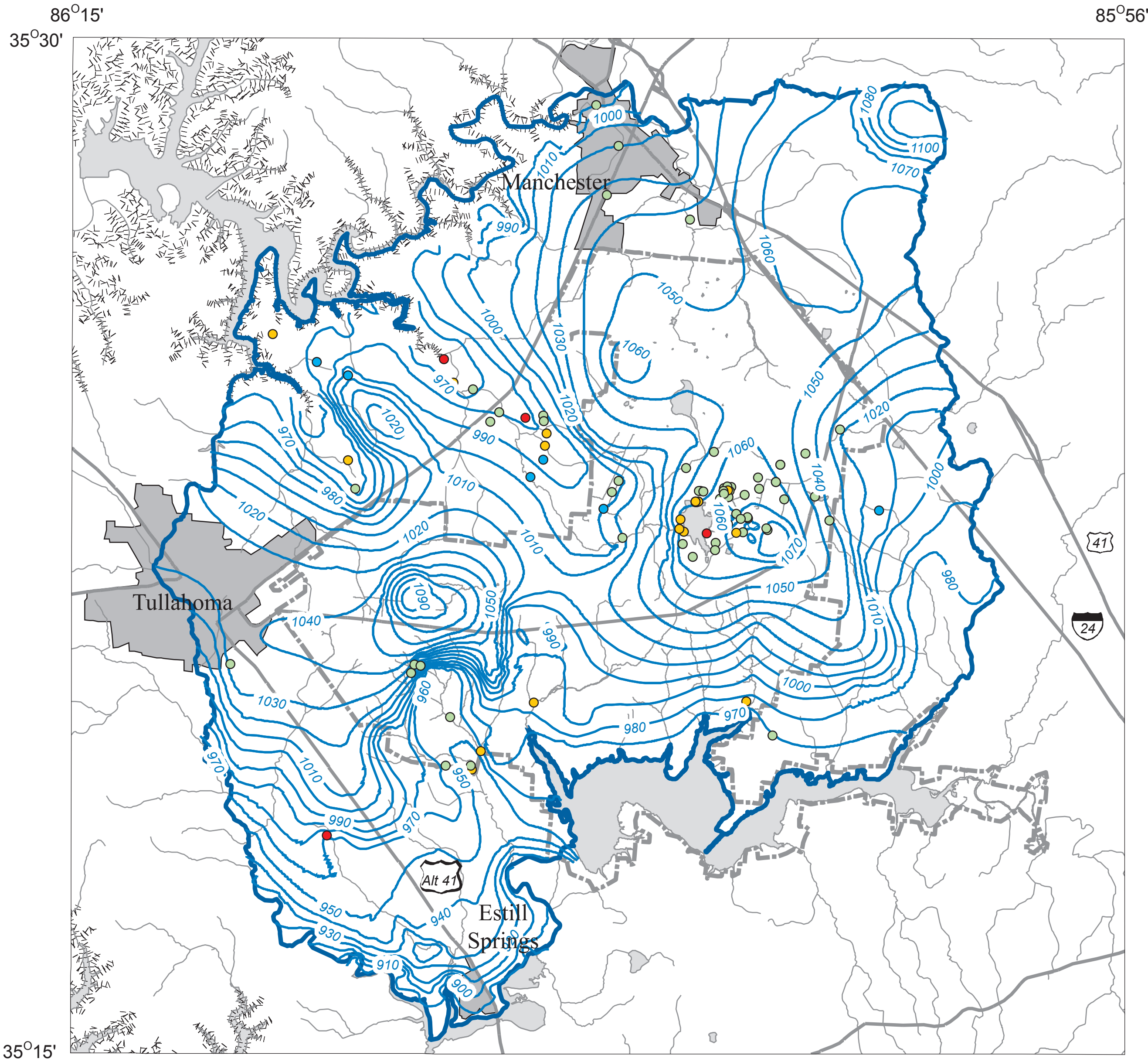
EXPLANATION

- 900 — POTENTIOMETRIC CONTOUR—Shows simulated altitude of water level. Hachures indicate depression. Contour interval 10 feet. Datum is NGVD 29
- HYDROLOGIC BOUNDARY—Delineation of regional ground-water flow system underlying Arnold Air Force Base
- HIGHLAND RIM ESCARPMENT
- BOUNDARY OF ARNOLD AIR FORCE BASE

RESIDUAL, IN FEET

- LESS THAN –20
- –20 TO –10
- –10 TO 10
- 10 TO 20
- GREATER THAN 20

Figure 24. Simulated steady-state water levels for layer 3 of the Arnold Air Force Base area ground-water flow model.



Base from U.S. Geological Survey topographic quadrangles, 1:24,000 Lambert Conformal Conic Projection, Standard parallels 35°15'N and 36°25'N, central meridian 86°W and USGS digital data, 1:100,000

0 2 4 MILES
0 2 4 KILOMETERS

EXPLANATION

900 POTENTIOMETRIC CONTOUR—Shows simulated altitude of water level. Hachures indicate depression. Contour interval 10 feet. Datum is NGVD 29

HYDROLOGIC BOUNDARY—Delineation of regional ground-water flow system underlying Arnold Air Force Base

HIGHLAND RIM ESCARPMENT

BOUNDARY OF ARNOLD AIR FORCE BASE

RESIDUAL, IN FEET

- LESS THAN –20
- –20 TO –10
- –10 TO 10
- 10 TO 20
- GREATER THAN 20

Figure 25. Simulated steady-state water levels for layer 4 of the Arnold Air Force Base area ground-water flow model.

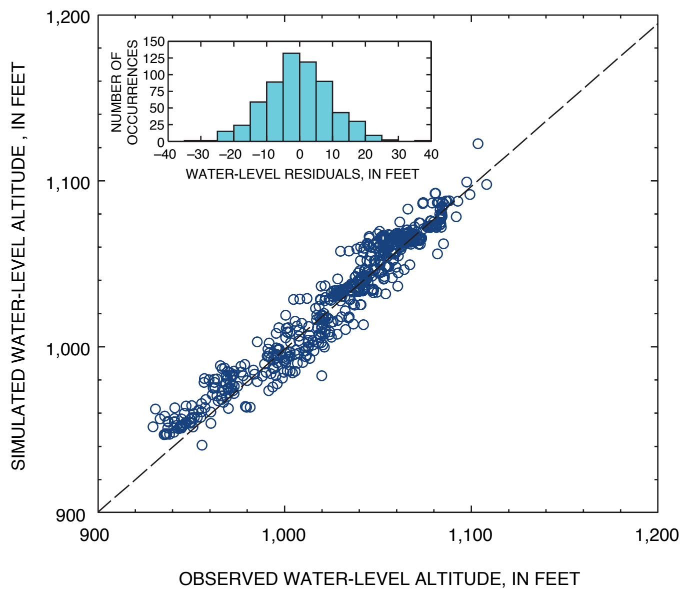


Figure 26. Simulated and observed water levels and distribution of residuals for the Arnold Air Force Base area ground-water flow model.

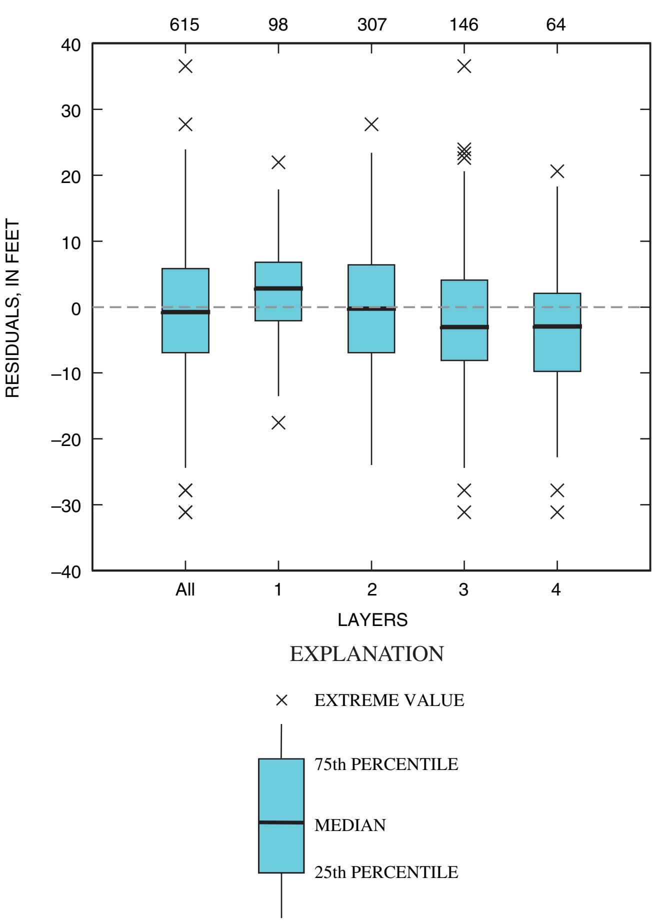


Figure 27. Distribution of residuals by layer for the Arnold Air Force Base area ground-water flow model.

The final values of hydraulic-conductivity parameters generally were within the range of initial estimates with the exception of parameters HK_7 and HK_9 where the calibrated values were slightly higher than the upper range of the initial estimates (table 3). The calibrated recharge rates generally were within the range of initial estimates. The calibrated recharge rates correspond to an average recharge rate over the entire model area of 7.6 in/yr.

Some of the estimated parameters for the calibrated flow model show high correlation coefficients (table 5). When parameters are correlated, the parameter-estimation process may not have enough information to estimate parameters individually and may estimate only the ratio or sums of parameters (Hill, 1998). To determine if the parameters were uniquely estimated, the parameter estimation was run from several different sets of starting parameter values. In each case, the regression converged to the same final values, indicating that the final values probably were estimated individually.

Components of the steady-state water budget of the simulated system are shown in figure 28. The primary source of water to the ground-water system is recharge (79.4 ft^3/s) to layer 1. Most of the water (70.0 ft^3/s) discharges from the ground-water system as seepage to rivers and drains. The remaining amount discharges to constant-head cells at Woods Reservoir and Tims Ford Lake (8.87 ft^3/s) or ground-water withdrawal wells and dewatering facilities (0.55 ft^3/s). Of the water entering layer 1, approximately 92 percent reaches layers 2 and 3, whereas only 5 percent reaches layer 4.

Sensitivity Analysis

Composite-scaled sensitivities were calculated for the calibrated model using the sensitivity process in MODFLOW-2000 for all the hydraulic-conductivity and recharge parameters (fig. 29) (Hill 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 larger composite sensitivities have greater importance and greater influence on the model solution than parameters with smaller composite sensitivities. The most sensitive model parameter is RCH_divide, the recharge rate in The Barrens area. The next most sensitive parameter is HK_3. Three of the four most sensitive parameters were for recharge. The model is least sensitive to the parameters VANI_4, VANI_3, HK_4, and VANI_2.

Advective Flow Particle Tracking

A particle-tracking program, MODPATH (Pollock, 1994), used results from the flow model to depict ground-water flow paths under several different conditions to assess the effects of ground-water withdrawal wells and dewatering facilities. The only changes made to the model for the particle-tracking simulations were adding or removing ground-water withdrawals as

Table 5. Correlation coefficients between estimated parameters of the Arnold Air Force Base area ground-water flow model.

[See table 3 for parameter descriptions]

Estimated parameters	Correlation coefficients										
	HK_1	RCH_divide	VANI_1	HK_3	RCH_base	RCH_spcr	HK_9	HK_2	HK_7	HK_5	VANI_1a
HK_1	1.00										
RCH_divide	0.75	1.00									
VANI_1	0.03	–0.28	1.00								
HK_3	0.57	0.89	–0.28	1.00							
RCH_base	0.57	0.83	–0.47	0.90	1.00						
RCH_spcr	0.75	0.93	–0.21	0.92	0.81	1.00					
HK_9	0.58	0.58	0.23	0.58	0.43	0.73	1.00				
HK_2	–0.28	0.12	–0.18	0.18	0.15	0.07	–0.02	1.00			
HK_7	0.41	0.41	0.54	0.48	0.37	0.45	0.56	0.02	1.00		
HK_5	0.28	0.34	0.00	0.01	0.07	0.14	0.06	0.02	–0.09	1.00	
VANI_1a	0.24	0.02	0.09	–0.05	0.01	–0.04	0.02	–0.21	0.03	0.06	1.00

needed. In each simulation, particles were evenly distributed within each model cell in the appropriate starting locations. MODPATH is based on advective transport only and cannot be used to compute solute concentrations in ground water. In order to determine time-of-travel for the particles, porosities of 0.10 for layer 1, 0.20 for layers 2 and 3, and 0.05 for layer 4 were used. These porosity values are consistent with typical values for the lithologies of the layers (Freeze and Cherry, 1979; Heath, 1989).

Pre-Ground-Water Withdrawal Wells Particle Tracking

Particle-tracking analysis was done first under conditions before any ground-water withdrawal wells at SWMUs were operational. For these simulations, all dewatering at test facilities were active. Particles were tracked forward from four sites: SWMU 1&2, SWMU 5, SWMU 8, and SWMU 10 (fig. 30). These path lines should represent the historic flow paths from these sites. The flow paths indicated by the particle-tracking simulations agree reasonably well with maps of interpreted contaminant plumes (fig. 2).

From SWMU 1&2, most of the particles (70 percent) move to the northwest under the retention pond, then move west under the air field, then follow a prominent trough in the ground-water surface to discharge to Big Spring at Rutledge Falls. The estimate of travel times for ground water leaving SWMU 1&2 to reach the discharge point at Rutledge Falls ranges from 16 to 362 years with a mean travel time of 46 years and a median travel time of 43 years. Some of the particles (30 percent) from SWMU 1&2 curl around to the northeast to discharge to the J4 test cell. The estimate of travel times for ground water from SWMU 1&2 that is captured by dewatering operations at J4 ranges from 4 to 17 years with a mean travel time of 8 years and a median travel time of 7 years.

Pathlines from SWMU 5 show that particles generally move west and northwest to discharge to Cat Creek, Bates Spring Branch, or seeps and springs along the Highland Rim escarpment. The estimate of travel times for ground water from SWMU 5 to discharge locations ranges from 11 to 45 years with a mean travel time of 21 years and a median travel time of 20 years.

Pathlines from SWMU 8 show that particles move to the southeast to discharge along Spring Creek. The estimate of travel times for ground water from SWMU 8 to discharge locations along Spring Creek ranges from 1 to 8 years with a mean travel time of 3 years and a median travel time of 2 years.

Pathlines from SWMU 10 show that particles move to the northeast before turning south to discharge to springs along the lower reach of Bradley Creek. The estimate of travel times for ground water from SWMU 10 to discharge locations along Bradley Creek ranges from 33 to 244 years with a mean travel time of 78 years and a median travel time of 40 years.

Pathlines from SWMU 10 are sensitive to the extent of hydraulic-conductivity zone HK_5 in the Bradley Creek Basin. Under an alternate calibration of the flow model with a slight modification of the HK_5 zone, particles from SWMU 10 diverged to show two flow paths that both discharged to springs along the lower reach of Bradley Creek (fig. 31). Based on a detailed review of local water levels and water-quality data, these alternate flowpaths are believed to be less likely than the first scenario presented here, but may occur periodically or seasonally. SWMU 10 is located in an area near the regional divide where the horizontal ground-water gradients are flat and may vary locally in response to individual recharge events. Also, seasonal water levels vary over a greater range to the north of SWMU 10 when compared to areas south of SWMU 10. The flat gradient and greater range in water levels cause some additional uncertainty in modeling flow paths from SWMU 10.