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Analysis of Potential Water-Supply Management Options, 2010–60, and Documentation of Revisions to the Model of the Irwin Basin Aquifer System, Fort Irwin National Training Center, California

Scientific Investigations Report 2014–5081

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

Cover. Aerial view of Fort Irwin Military Reservation, Fort Irwin, California. Photo taken by Bobak Ha'Eri, on July 27, 2009.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm^3/yr)
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
acre-feet per month (acre-ft/mo)	0.000469	cubic meters per second (m^3/s)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

ASL	above sea level
CIMIS	California Irrigation Management Information System
GMG	Geometric Multigrid Solver
MODFLOW-88	USGS Modular Three-Dimensional Finite-Difference Groundwater Flow-Model
NAVD 88	North American Vertical Datum of 1988
NTC	Fort Irwin National Training Center
USGS	U.S. Geological Survey

Acknowledgments

The authors thank the following personnel at Fort Irwin NTC: Justine Dishart, Muhammed Bari, and Chris Woodruff for providing groundwater withdrawal data.

Analysis of Potential Water-Supply Management Options, 2010–60, and Documentation of Revisions to the Model of the Irwin Basin Aquifer System, Fort Irwin National Training Center, California

By Lois M. Voronin, Jill N. Densmore, and Peter Martin

Abstract

The Fort Irwin National Training Center is considering several alternatives to manage their limited water-supply sources in the Irwin Basin. An existing three-dimensional, finite-difference groundwater-flow model—the U.S. Geological Survey's MODFLOW—of the aquifer system in the basin was updated and the initial input dataset was supplemented with groundwater withdrawal data for the period 2000–10. The updated model was then used to simulate four combinations, or scenarios, of groundwater withdrawal and recharge over the next 50 years (January 2011 through December 2060). The scenarios included combinations of continuing withdrawals from currently active production wells, supplementing any increases in demand with withdrawals from an inactive production well, reducing withdrawal amounts and rates, and reducing the discharge of treated wastewater to infiltration ponds that provide a recharge source to the underlying aquifer. Results of the simulations indicated that, depending on the scenario implemented, groundwater levels would rise (over the next 50 years) from 40 feet to as much as 65 feet in the northwestern part of the Irwin Basin, and from 5 feet to 10 feet in the southeastern part.

Introduction

Fort Irwin National Training Center (Fort Irwin NTC) in the Mojave Desert of California has been used as a military training facility almost continuously since August 1940. The training center currently (2012) obtains its potable water supply by pumping from wells in the Irwin, Bicycle, and Langford Basins. Groundwater development began in the Irwin Basin in 1941. From 1941 to 1996, most of the groundwater pumpage was from the Irwin Basin which resulted in water-level declines of about 30 ft in the basin during this period. Pumping from the Bicycle and Langford Basins began in 1967 and 1992, respectively, and pumping from these basins has resulted in a decrease in the groundwater demand from the Irwin Basin. Since 1991, the combined pumping from the adjacent Bicycle and the Langford Basins has exceeded that in the Irwin Basin. Since the 1990's, reduced pumping and artificial recharge of wastewater and irrigation in the Irwin Basin has caused water levels to stabilize or rise throughout the basin. Although water levels are currently rising in the Irwin Basin, treated wastewater that percolates through evaporate deposits underlying the wastewater-treatment facility and infiltration/holding ponds has resulted in high concentrations of dissolved solids in groundwater that is migrating toward the pumping-caused depression in water levels near the center of the basin (Densmore and Londquist, 1997). Water-quality concerns have led to the abandonment or destruction of several production wells in the Irwin Basin.

To effectively manage the water resources and plan for future water needs at the Fort Irwin NTC, it is important to have a complete understanding of the hydrogeologic and geochemical framework of the Irwin, Langford, and Bicycle Basins. To provide the information needed to develop that understanding, the U.S. Geological Survey (USGS), in cooperation with the Fort Irwin NTC, conducted a series of studies to evaluate the hydrogeologic system and conditions at the training center. This report describes the results of one of those studies.

Purpose and Scope

This report describes the results of the simulation of groundwater flow in the aquifer system in the Irwin Basin at the Fort Irwin NTC, California, using an existing groundwater-flow model developed by Densmore (2003) that was updated to run with MODFLOW 2005, the most current version of the USGS three-dimensional, finite-difference groundwater model, and to use groundwater withdrawal data for the period 2000–10. The original model simulated the hydrologic conditions of the Irwin Basin for the period 1941–99. This report describes the hydrogeology of the Irwin Basin, the updates made to the existing model, and the results of the simulation of four scenarios of hypothetical combinations of groundwater recharge and withdrawal over the next 50 years. The updated groundwater-flow model is a useful tool to help estimate the long-term availability of groundwater from the basin by evaluating differences in groundwater-level altitudes (or water levels) among scenarios simulating different withdrawal and recharge rates. The updated model was used to evaluate the potential spatial effects on groundwater levels as a consequence of 1) continued withdrawals at the 2010 average rate of pumping, 2) supplementing water-supply needs with withdrawals from an inactive production well, 3) a reduction in groundwater recharge from treated wastewater.

Location and Description of Study Area

The Fort Irwin NTC is about 130 miles (mi) northeast of Los Angeles and 35 mi northeast of Barstow in southern California (fig. 1). The training center covers about 970 mi^2 (square miles) of the northern part of the Mojave Desert and encompasses several ground-water basins. Wells in the Irwin, Bicycle, and Langford Basins currently supply water to the base (fig. 1).

The Irwin Basin has a fairly flat floor bordered to the east by Beacon Hill, to the north-northwest by Northwest Ridge, to the west by Southwest Ridge, and to the south by low-lying hills that separate the Irwin Basin from the Langford Basin (fig. 2). The surface-water drainage area of the basin is about 30 mi^2 and the floor of the basin is about 7 mi^2. There are no perennial streams in the basin but several dry washes convey surface flow during, or immediately after, large storms. Surface-water flow out of the basin, when it occurs, is to the southeast into the Langford Basin, through an unnamed ephemeral wash near Garlic Spring (fig. 2).

The basin climate is typical of the Mojave Desert, with scant precipitation, hot summers, and cool winters. There are no official weather records for the Irwin Basin itself, but at Goldstone, about 15 mi northwest of the basin (fig. 1), 1973– 2006 average annual precipitation is about 5.8 in. (inches), most of which falls during the winter, with a few isolated thunderstorms during the summer. At Barstow, 35 mi southwest of the basin, 1997–2011 average annual precipitation is about 5.1 in. Between 1973 and 2011, the annual precipitation at Barstow ranged from about 2.0 in. in 1975 to about 13.2 in. in 2005. Between 1940 and 2013, temperatures at Barstow ranged from 3 °F to 116 °F and averaged about 64 °F. The 1997–2011 average annual potential evaporation at Barstow is about 72 in., (National Oceanic and Atmospheric Administration, 1994; EarthInfo, Inc., 1995, 2000; David Inouye, California Department of Water Resources, written commun., 1996; California Irrigation Management Information System, 2013).

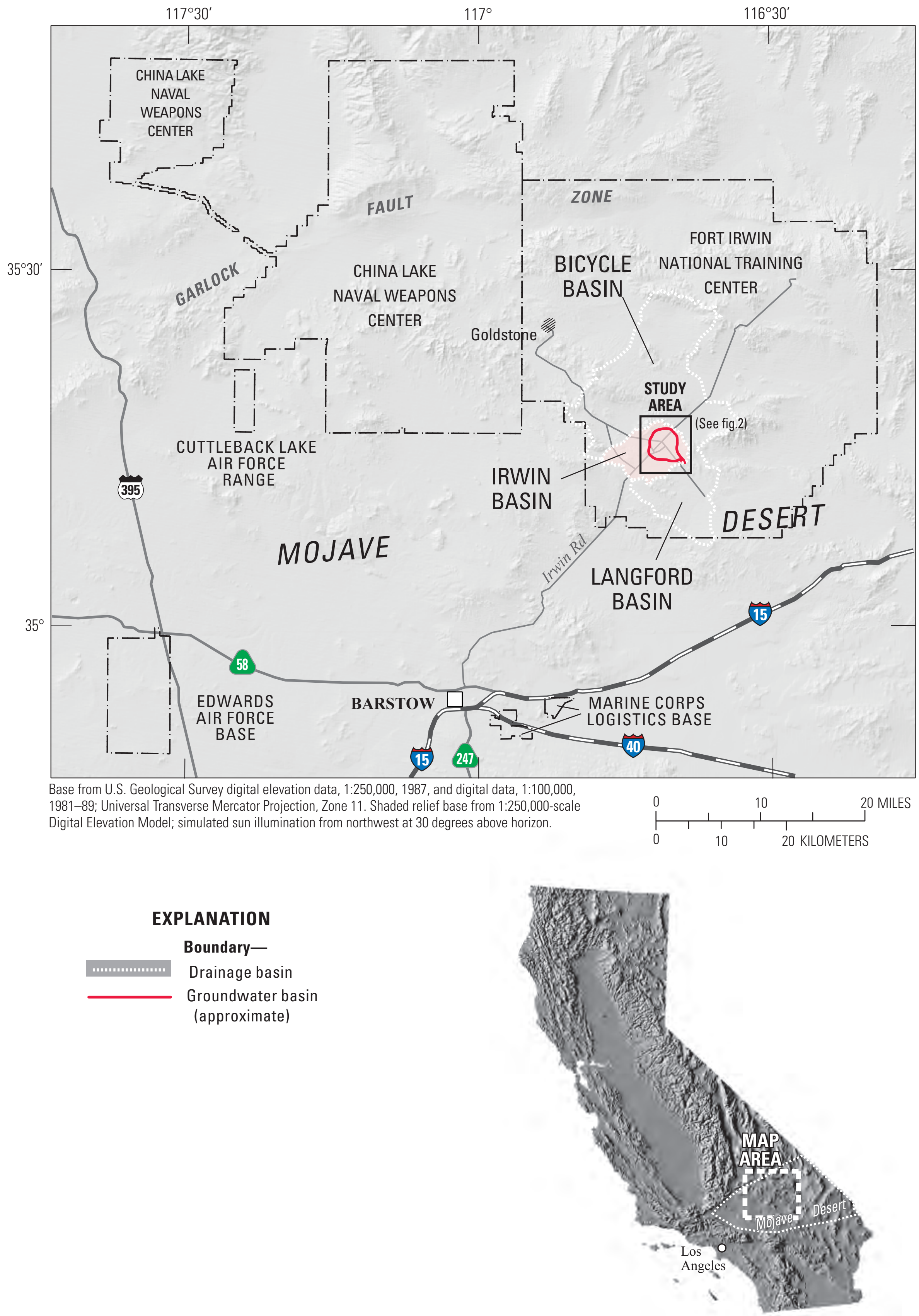
Hydrogeologic Setting

The Irwin Basin is filled with as much as 950 ft of unconsolidated deposits that consist of younger alluvium of Quaternary age and older alluvium of late Tertiary to Quaternary age (Densmore, 2003, fig. 3). The deposits are unconsolidated at land surface and become partly consolidated with depth. The unconsolidated deposits are the only water-bearing material in the basin from which appreciable amounts of groundwater can be obtained. These deposits are underlain by a basement complex of volcanic rocks of Tertiary age and igneous and metamorphic rocks of pre-Tertiary age, which convey insignificant amounts of groundwater except in areas where they are jointed, weathered or fractured.

The older alluvium (fig. 3, QTa and Tl) consists of sand, gravel, and clay derived predominantly from granitic material, except in the northern part of the basin, where volcanic material dominates. Where the older alluvium consists predominantly of sand and gravel, it yields moderate amounts of water to wells. In the southeastern part of the basin, however, the older alluvium consists almost entirely of low-permeability lacustrine deposits (fig. 3, B-B’, Tl) of silt and clay. These low-permeability deposits extend from well 14N/3E-33N1 near the center of the basin to well 13N/3E-10E1-3 in the unnamed wash that leads to Garlic Spring, and are bounded by the Garlic Spring Fault on the northeast and an unnamed fault on the southwest.

The younger alluvium (fig. 3, Qa) consists primarily of loose coarse sand and gravel with small amounts of clay. Some thin, discontinuous clay lenses overlie the lacustrine deposits within the older alluvium in the area beneath the former sprinkler-pivot field in the southeastern part of the basin (fig. 2) and may result in a perched water table in this area. Most of the younger alluvium lies above the water table; however, in areas where it is saturated, primarily in the center of the basin, it yields large quantities of water to wells (as much as 1,000 gal/min). Wellbore-flow tests of selected base supply wells indicate that most of the water pumped comes from the younger alluvium (Densmore and Londquist, 1997).

The aquifer system in the Irwin Basin consists of an upper aquifer and a lower aquifer. The upper aquifer is unconfined and is contained within the saturated part of the younger alluvium. This aquifer reaches a maximum thickness of about 200 ft in the west-central part of the basin (fig. 3). The lower aquifer is composed of older alluvium and is confined throughout most of the basin. This aquifer reaches a maximum thickness of about 600 ft in the central part of the basin (fig. 3). Although some water is contained in the underlying basement complex, the effective base of the groundwater system is at the top of basement complex. The altitude of the surface of the basement complex in the Irwin Basin is shown in figure 4.



Base from U.S. Geological Survey digital elevation data, 1:250,000, 1987, and digital data, 1:100,000, 1981–89; Universal Transverse Mercator Projection, Zone 11. Shaded relief base from 1:250,000-scale Digital Elevation Model; simulated sun illumination from northwest at 30 degrees above horizon.

Figure 1. Location of study area at Fort Irwin National Training Center, California

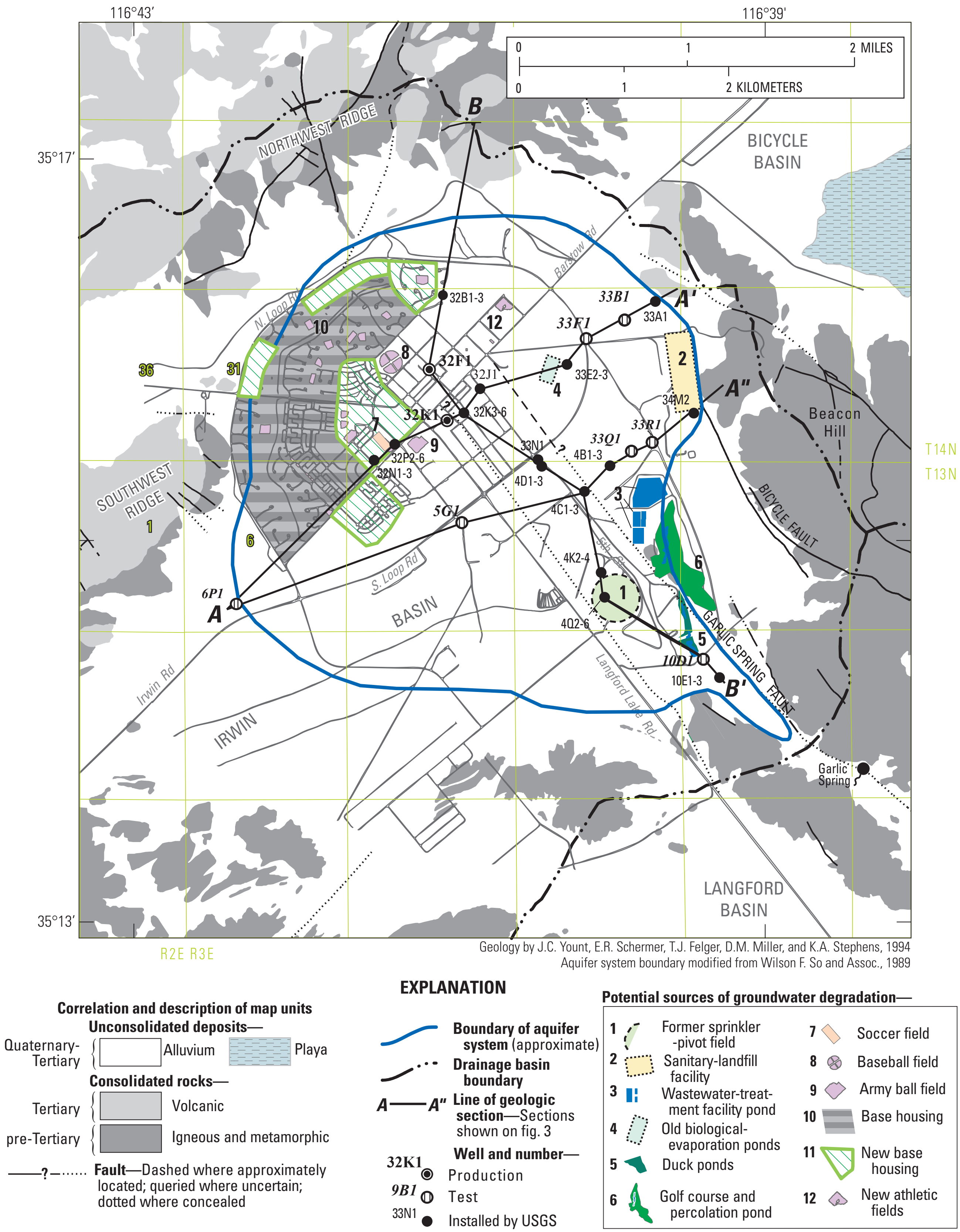


Figure 2. Generalized map of the Irwin Basin, Fort Irwin National Training Center, California.

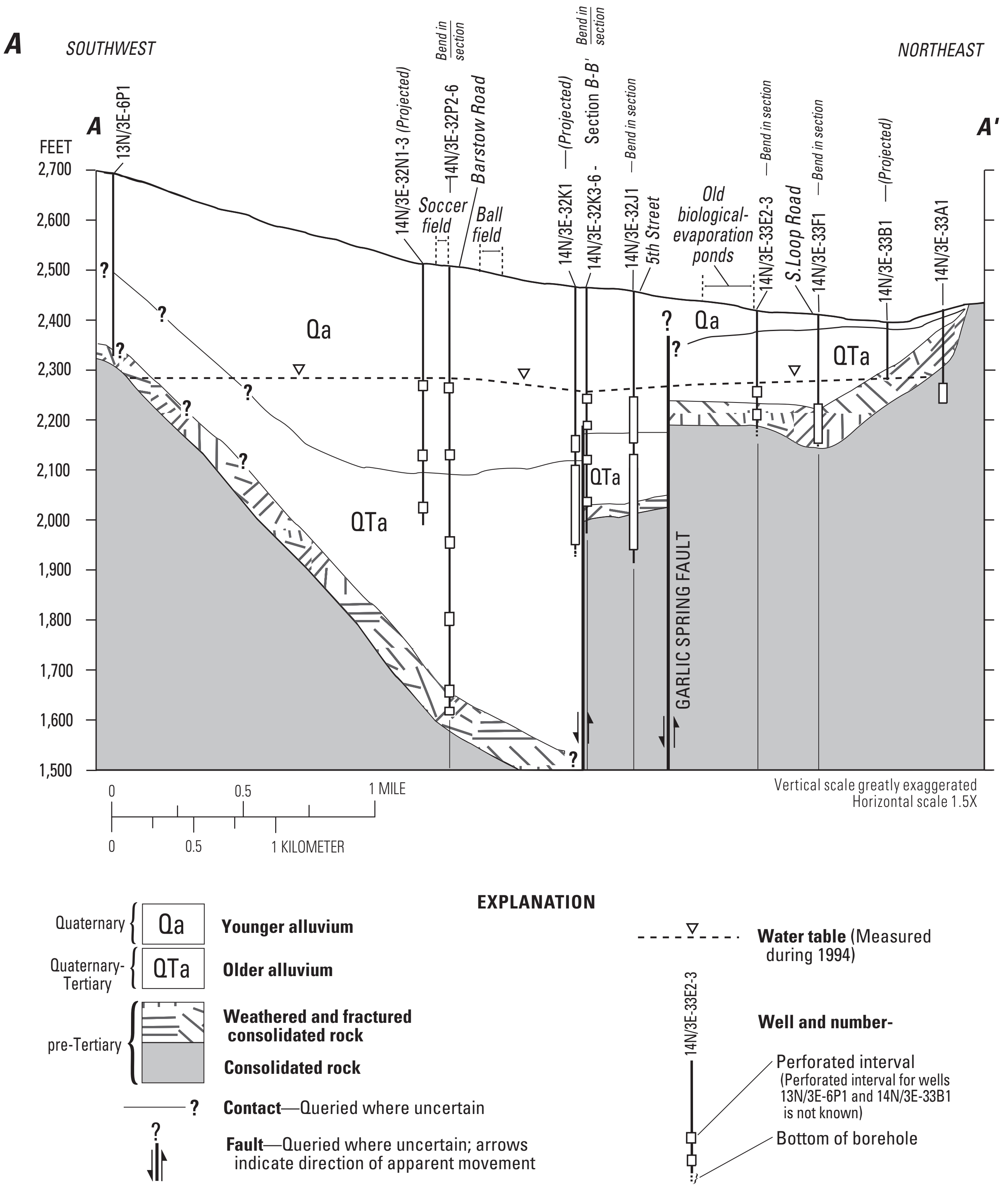


Figure 3. Generalized geology of the Irwin Basin, Fort Irwin National Training Center, California (Densmore, 2003). [Section locations shown in fig. 2]

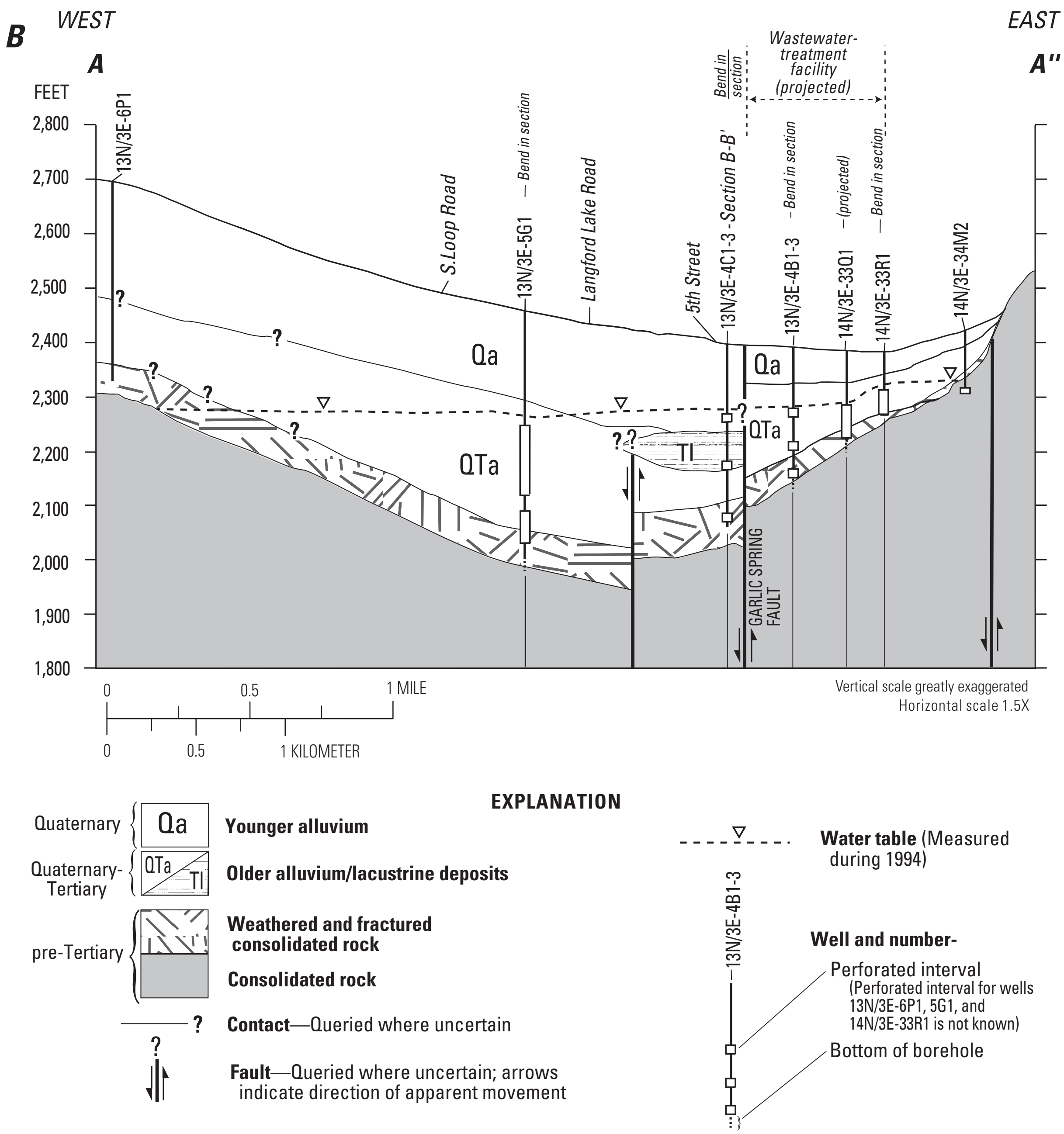


Figure 3. —Continued

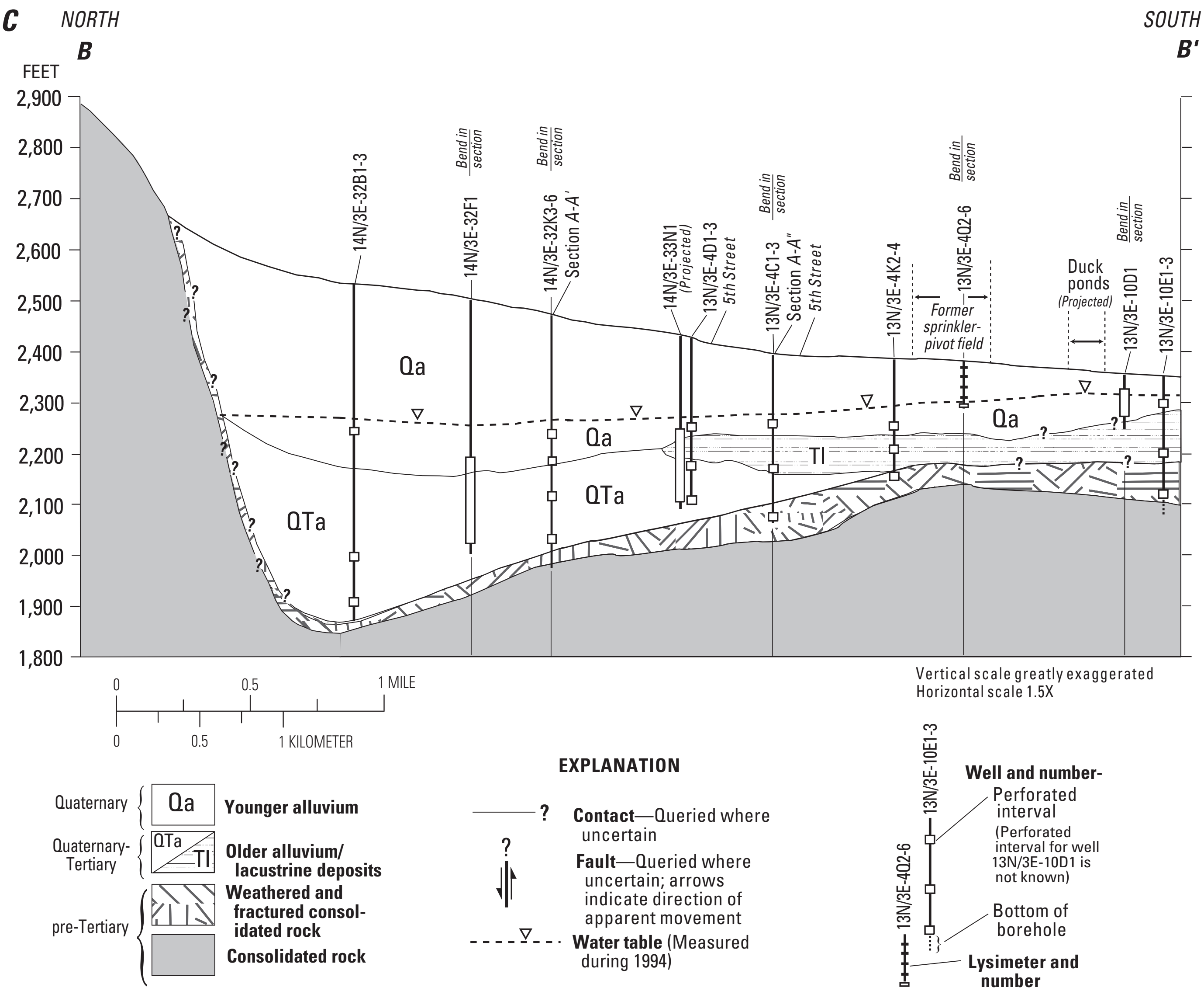


Figure 3. —Continued

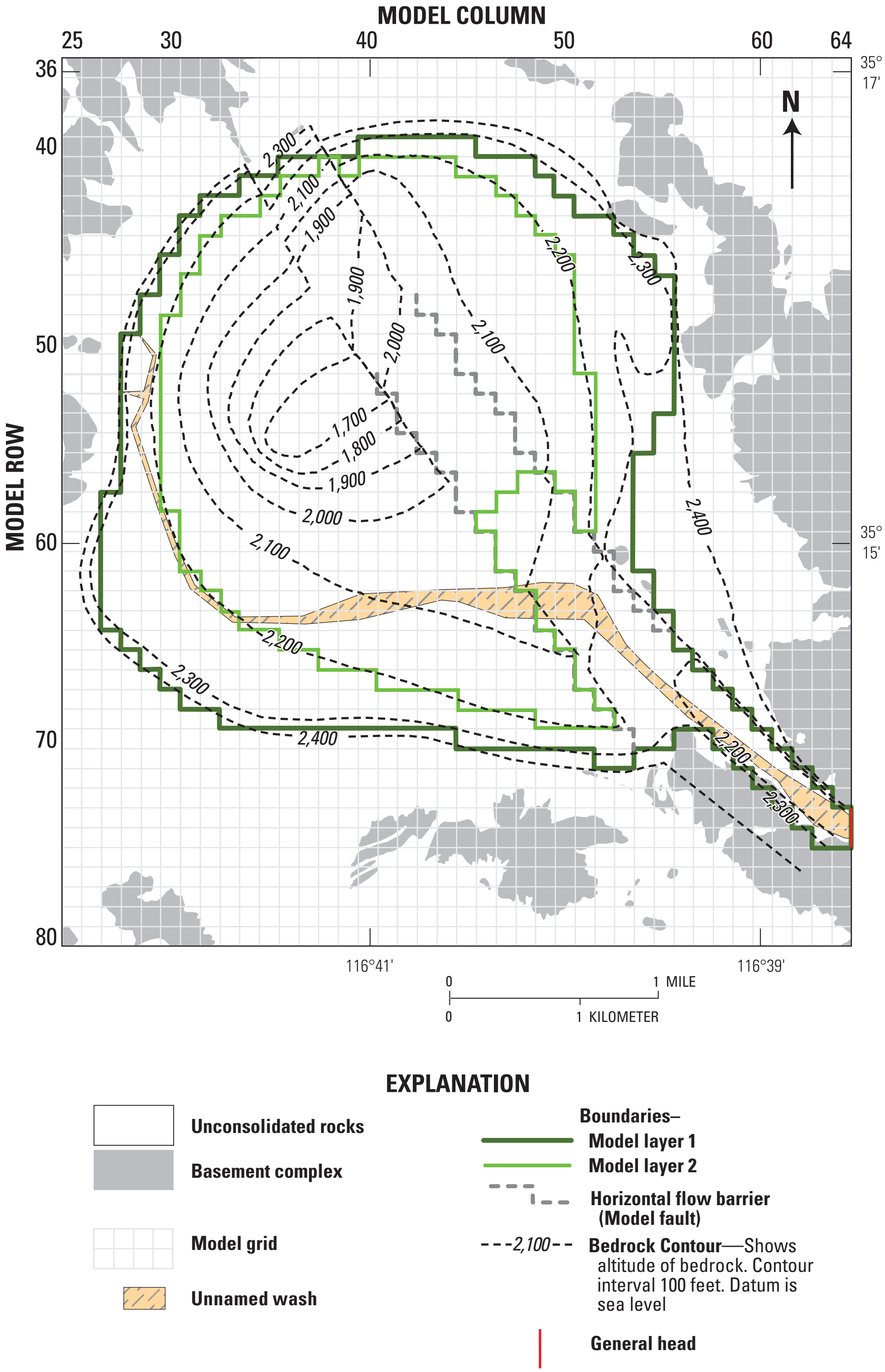


Figure 4. Altitude of the basement complex and boundaries of groundwater model layers for the Irwin Basin, Fort Irwin National Training Center, California (Densmore, 2003).

Numerous faults have been mapped in the bedrock hills surrounding the Irwin Basin (Yount and others, 1994) (figs. 2, 3); they include the Garlic Spring Fault, the Bicycle Lake Fault, and many unnamed faults. Most of these faults are buried beneath the unconsolidated deposits and thus their presence within the basin is largely unknown. Yount and others (1994) mapped the Garlic Spring Fault into the unconsolidated deposits, suggesting that the fault may cut through both the younger and the older alluvium in the southeastern part of the basin. Water-quality and water-level data, presented by Densmore and Londquist (1997), indicate that the Garlic Spring Fault and a parallel unnamed fault may be acting, in part, as a partial barrier to horizontal groundwater flow, primarily in the lower aquifer. The water-quality data indicate that vertical flow also is being impeded on the west side of the Garlic Spring Fault because of lithologic differences between the younger alluvium and the underlying lacustrine deposits of the older alluvium. Minor compaction and deformation of the water-bearing deposits immediately adjacent to the faults, fault gouge along the fault zone, and cementation of the fault zone by the deposition of minerals from groundwater are believed to create the barrier effect of the faults.

The areal extent of the aquifer system is defined by the intersection of the water table and the surrounding rocks of the basement complex. Under predevelopment conditions (pre-1941), the water table was about 2,300 feet above NAVD88. The boundary of the saturated aquifer system coincides with the 2,300-foot altitude contour of the basement complex shown in figure 4 (the approximate boundary of the aquifer system is shown in figure 2). All the alluvial deposits above this altitude were unsaturated under predevelopment conditions.

Simulation of Groundwater Flow

An existing groundwater-flow model of the aquifer system in the Irwin Basin (Densmore, 2003) was updated and used to simulate flow under four alternative withdrawal and recharge conditions, here called scenarios. Densmore (2003) developed a two-layer groundwater-flow model for the period 1941–99 for the aquifer system in the Irwin Basin to assess the long-term availability and quality of groundwater, to evaluate groundwater conditions as a result of withdrawals, and to plan for future water needs at the base. Results of the model simulations of the scenarios were used to analyze the effects of the four alternative withdrawal and recharge conditions on the aquifer system.

Model Design

The existing groundwater-flow model was constructed using the USGS Modular Three-Dimensional Finite-Difference Groundwater- Flow Model (MODFLOW-88) developed by McDonald and Harbaugh (1988). For this study, the model input data was reformatted for a newer version of MODFLOW, MODFLOW-2005 (Harbaugh, 2005), and withdrawals were updated with 2000 to 2010 data. The updated model will be referred to in this report as the 2010 model.

The time intervals simulated in the original model were 1-year stress periods from January 1941 to December 1999. For the 2010 model, the time intervals simulated were years from January 1941 to December 2007, and months from January 2008 to December 2010.

The model grid developed for the original model was used for this study and is shown in figure 4. The origin of the model grid (the upper left corner of the grid; row 1, column 1) is at an easting of 2,373,237 ft and a northing of 669,380 ft in zone 5 of the California State Plane coordinate system. The grid consists of 80 rows and 64 columns with a cell size of 500 ft on a side (fig. 4).

The MODFLOW code consists of a main program and a series of independent subroutines called modules. The MODFLOW-2005 modules used in the 2010 model include Basic (BAS6); Block-Centered Flow (BCF6); General-Head Boundary (GHB); Drain (DRN); Discretization (DIS); Horizontal-Flow-Barrier (HFB6; Hsieh and Freckleton, 1993); Multi-Node Well (MNW2, Konikow and others, 2009); and Recharge (RCH) [BAS6, BCF6, GHB, DRN, and RCH, Harbaugh, 2005, MODFLOW-2005]. The original model (Densmore, 2003) used all of the above-mentioned modules except the MNW2, the WEL module (McDonald and Harbaugh, 1988) was used. For this study, the well input file was reformatted into the format for the MNW2 module. The 2010 model uses the Geometric Multigrid Solver (GMG, Wilson and Naff, 2004), whereas the original model used the Strongly Implicit Procedure Solver (SIP, McDonald and Harbaugh, 1988).

The model representation of the aquifer system, calibrated aquifer properties, and model boundaries simulated in the original model were not changed for this study. The model representation of the aquifer system is shown in figure 5. Horizontal hydraulic conductivity of the aquifer system ranged from 3 to 25 ft/d (feet per day) for model layer 1 and 3 to 22 ft/d for layer 2. Model boundaries are shown in figure 4. The lateral boundaries of the model coincide with the lateral boundaries of the aquifer system. The top boundary of the

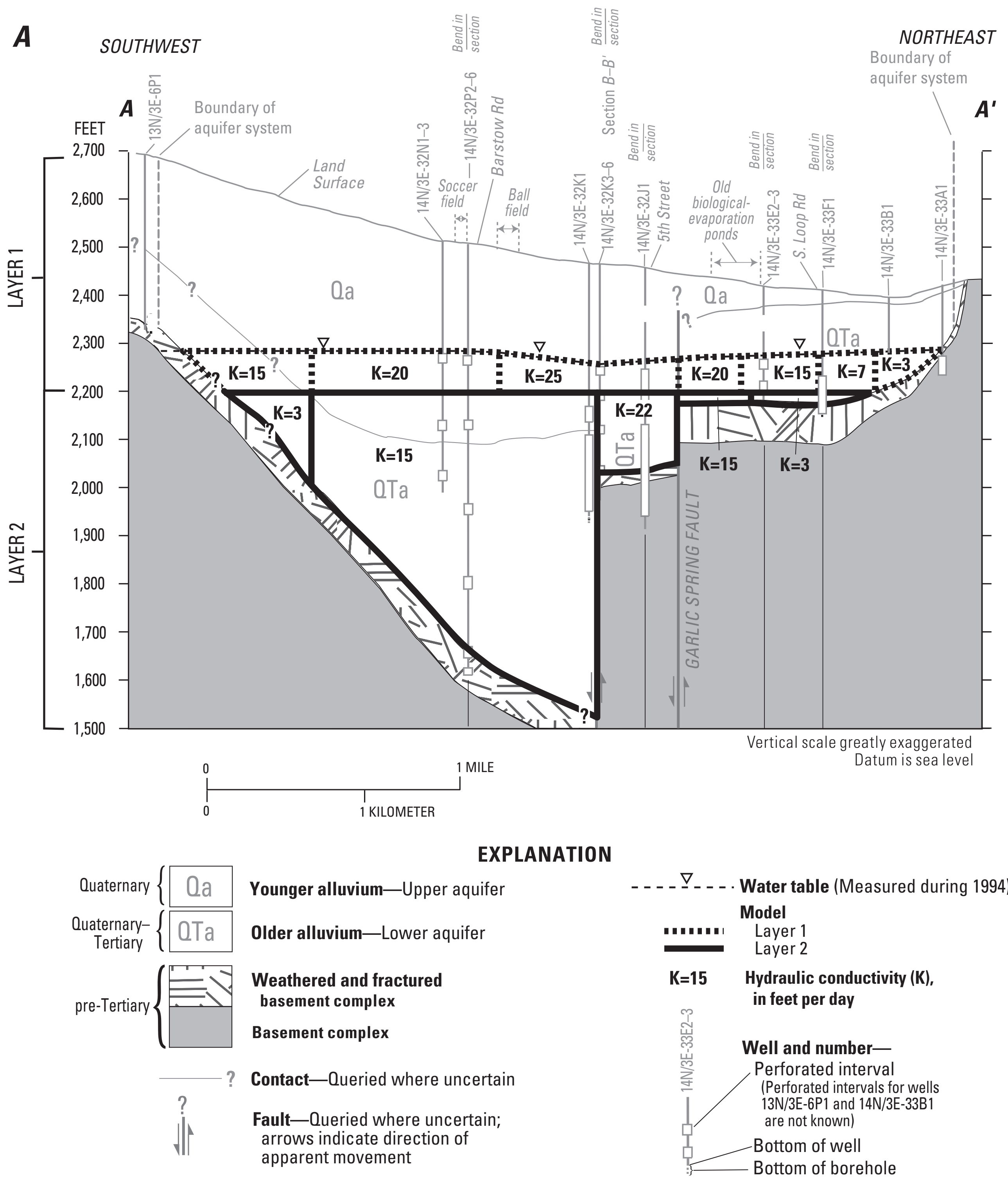


Figure 5. Cross-sectional view of model layers, hydraulic conductivities, and boundary conditions of the Irwin Basin, Fort Irwin National Training Center, California (Densmore, 2003). [Cross-section locations are shown in fig. 2]

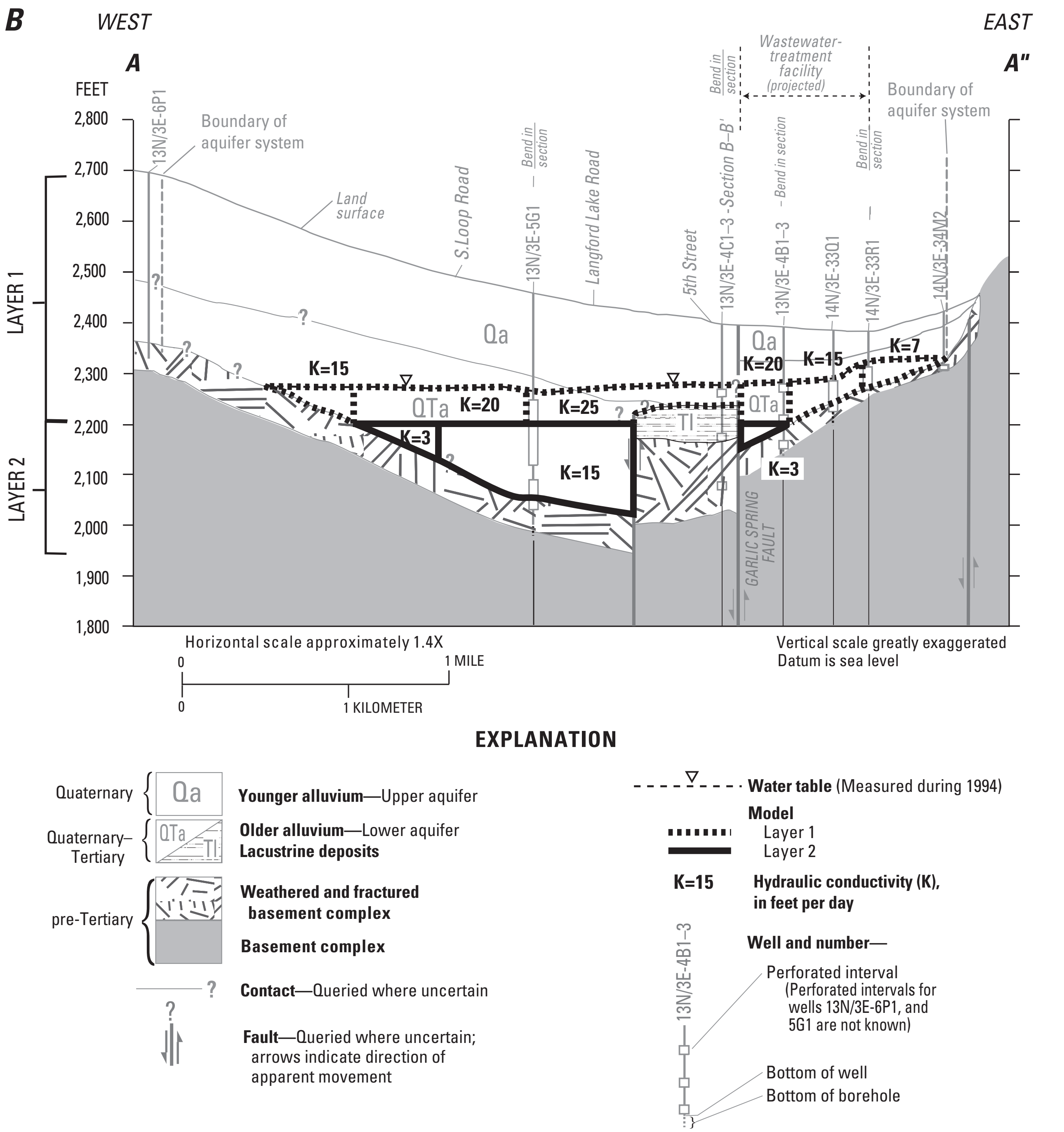


Figure 5. —Continued

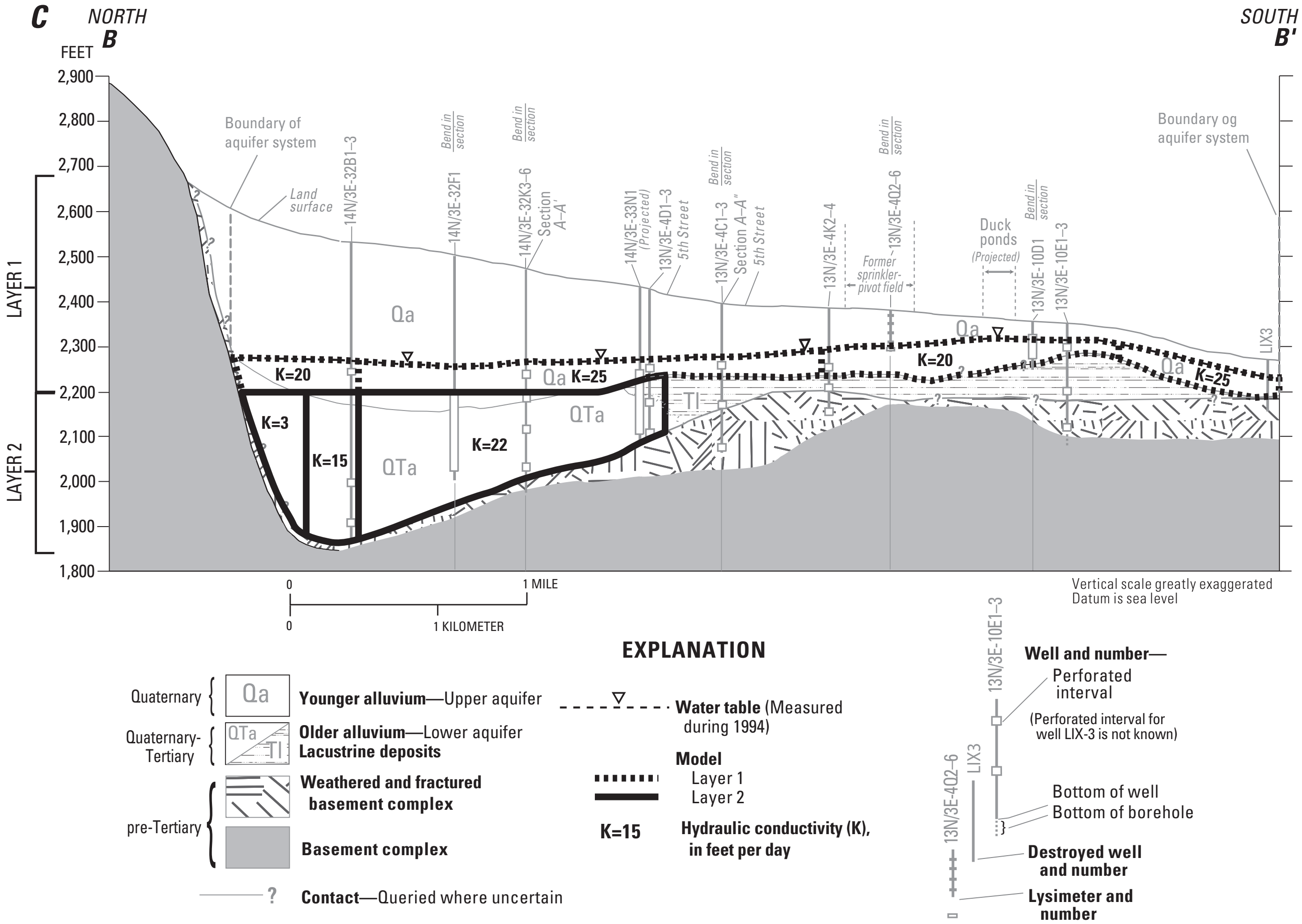


Figure 5. —Continued

model, the water table, is simulated as a free-surface boundary (unconfined) to allow vertical movement in response to changes between inflow and outflow. No-flow boundaries are used around and below the modeled area to represent contact with the basement complex. The HFB6 package was used to simulate the 2 faults that impede the horizontal flow of groundwater. The GHB package was used to simulate underflow from layer 1 through the unnamed wash near Garlic Spring. The reader is referred to Densmore (2003) for a detailed description of the aquifer system framework, aquifer properties and model boundaries.

Model Calibration

The 2010 model was not re-calibrated, but the results of the simulations made with the original model and the 2010 model were compared to ensure that the original level of calibration was maintained. Simulated 1994 hydraulic heads (or potentiometric surface) from the original model (Densmore, 2003, fig. 19) were compared with those heads simulated in the 2010 model (fig. 6). The comparisons were only visual, however, because the original 1994 hydraulic heads generated by Densmore (2003) were not archived in GIS format. Model budgets calculated for each stress period by MODFLOW in the original and 2010 model were also compared. The original list file, lst.trand114, containing the model budgets, can be requested from the USGS California Water Science Center, San Diego, Calif.

The update of the original model was done in steps to allow for evaluation and analysis of simulation results and to maintain the original level of calibration. First, the original model input data was reformatted from MODFLOW-88 to MODFLOW-2005 format, and then the well input file was reformatted to the newer MNW2 format. The simulated 1994 hydraulic heads, generated from the original model data that had been reformatted to run with MODFLOW-2005, are shown in red in figure 6 and compare well with the original 1994 hydraulic heads generated by Densmore (2003). The MODFLOW-2005 model input data was then run with the original well data reformatted for the MNW2 module. The simulated 1994 hydraulic heads, generated from the 2010 model with the MNW2 well data, are shown in purple in figure 6 and are slightly different in the area of the production wells 14N/3E-32F1, 14N/3E-32H1 and 14N/3E-32K1 (fig. 6) from the hydraulic heads simulated by using the original well data. Using the MNW2 module, the simulated 1994 hydraulic heads for layer 1 at production wells 14N/3E-32H1 and

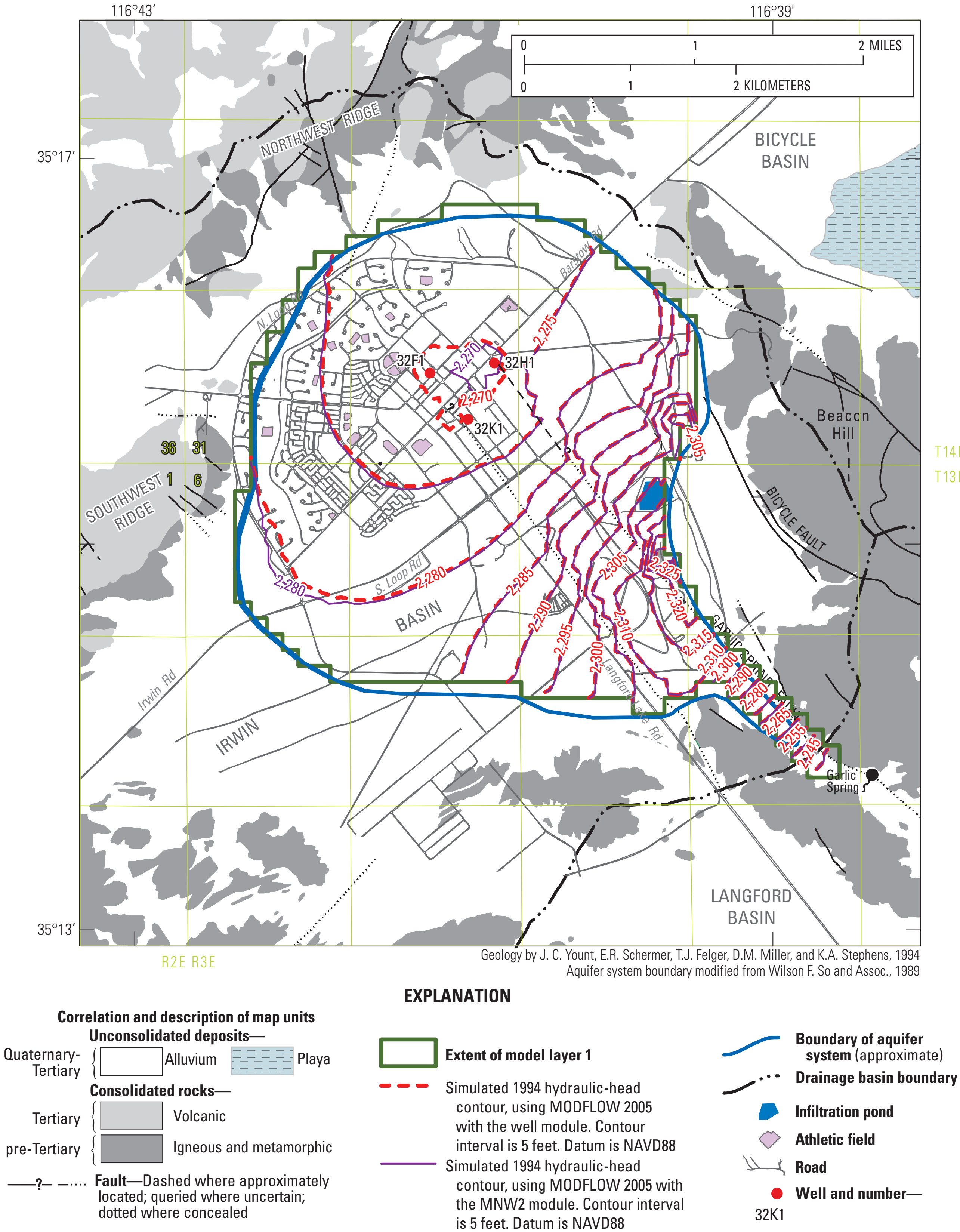


Figure 6. Simulated 1994 hydraulic heads, layer 1, Irwin Basin, Fort Irwin National Training Center, California.

14N/3E-32K1 are 2.61 and 3.51 ft higher, respectively, than the 1994 simulated hydraulic heads using the WEL module. In contrast, the 1994 hydraulic heads simulated by using the MNW2 module for layer 2 at production wells 14N/3E-32F1, 14N/3E-32H1 and 14N/3E-32K1 are 1.28, 0.88 and 1.09 ft lower, respectively, than the 1994 simulated hydraulic heads using the WEL module. With the exception of the hydraulic heads within the closed 2,270-foot contour line (fig. 6), hydraulic heads from both models agree within 0.1 foot. This difference in hydraulic head may be attributed to how the withdrawals were distributed in the original model. The withdrawals from production wells were initially distributed as two-thirds from layer 1 and one-third from layer 2; this initial distribution was then varied between the two layers during calibration in the original model (Densmore, 2003). For the 2010 model, the percentage of groundwater withdrawals from each model layer was calculated by the MNW2 module.

The volumetric model budgets, calculated by MODFLOW, for the original MODFLOW-88 model and the 2010 model for 1994 conditions, which is stress period 54, are shown in table 1. Slight differences in the values for storage and head dependent boundary are probably a result of the difference in the distribution of withdrawals of the production wells calculated by the MNW2 module. Overall, the budget items compare well.

Hydrographs for 11 selected observation wells are shown in figure 7. Wells were selected on the basis of location and number of water-level measurements available, and only wells screened in a single layer were considered. The measured water levels and simulated hydraulic heads from the 2010 model are within 11 ft. Simulated hydraulic heads also matched the upward 1992–2010 trend in measured water levels. The upward trend is probably a result of recharge from the ponds near the wastewater-treatment facility and irrigation at the training center’s base housing.

Groundwater Withdrawals

The original model simulated hydrologic conditions from January 1941 to December 1999 with yearly stress periods. In the original model, groundwater withdrawals were averaged for the year. The 2010 model included 2000 to 2010 withdrawal data. Monthly groundwater withdrawal records were available for January 2000 through December 2010. For the 2010 model, groundwater withdrawals were simulated for 1-year periods from January 1941 to December 2007 and for 1-month periods from January 2008 to December 2010. Annual groundwater withdrawals from Bicycle, Irwin, and Langford Basins are shown in figure 8.

Groundwater Recharge

There are two sources of recharge to the aquifer system in the Irwin Basin: natural recharge from precipitation and artificial recharge from wastewater-effluent infiltration at the ponds and irrigation-return flow (Densmore, 2003). Natural recharge in the basin is low because of low precipitation and high evaporation rates. The calibrated natural recharge simulated in the original model was about 50 acre-ft/yr. The natural recharge was simulated along the intermittent unnamed wash shown in figure 4. The natural recharge of 50 acre-ft/yr was used in the 2010 model and simulated in the same model cells as those in the original model that represent the intermittent unnamed wash. Groundwater is imported to the Irwin Basin from Bicycle and Langford Basins. Some water is used for irrigation at the base housing; the water that is not consumed is treated at the wastewater-treatment facility and discharged to the infiltration ponds, referred to as the wastewater treatment facility pond, golf course pond and duck ponds. Estimated groundwater recharge has exceeded groundwater withdrawals

Table 1. Simulated volumetric budget, for 1994 conditions (stress period 54), from the *A*) original, MODFLOW-88 model and *B*) 2010 model, Irwin Basin, Fort Irwin National Training Center, California.

[Values in cubic feet per day. **Abbreviation**: —, none]

Budget component	Original model (MODFLOW-88)	2010 model (MODFLOW-2005)	Percent difference between original and 2010 model
Inflow:			
Storage	6,054.70	5,951.50	0.07
Recharge	152,271.55	152,271.61	–0.00
Total in	158,330.00	158,223.11	—
Outflows:			
Storage	7,627.10	7,517.36	0.07
Groundwater withdrawals	140,691.00	140,691.00	0.00
Head dependent boundary	9,998.90	10,015.42	–0.01
Total out	158,320.00	158,223.78	—
Inflow–outflow	9.20	–0.67	—
Percent discrepancy	0.01	0.00	—

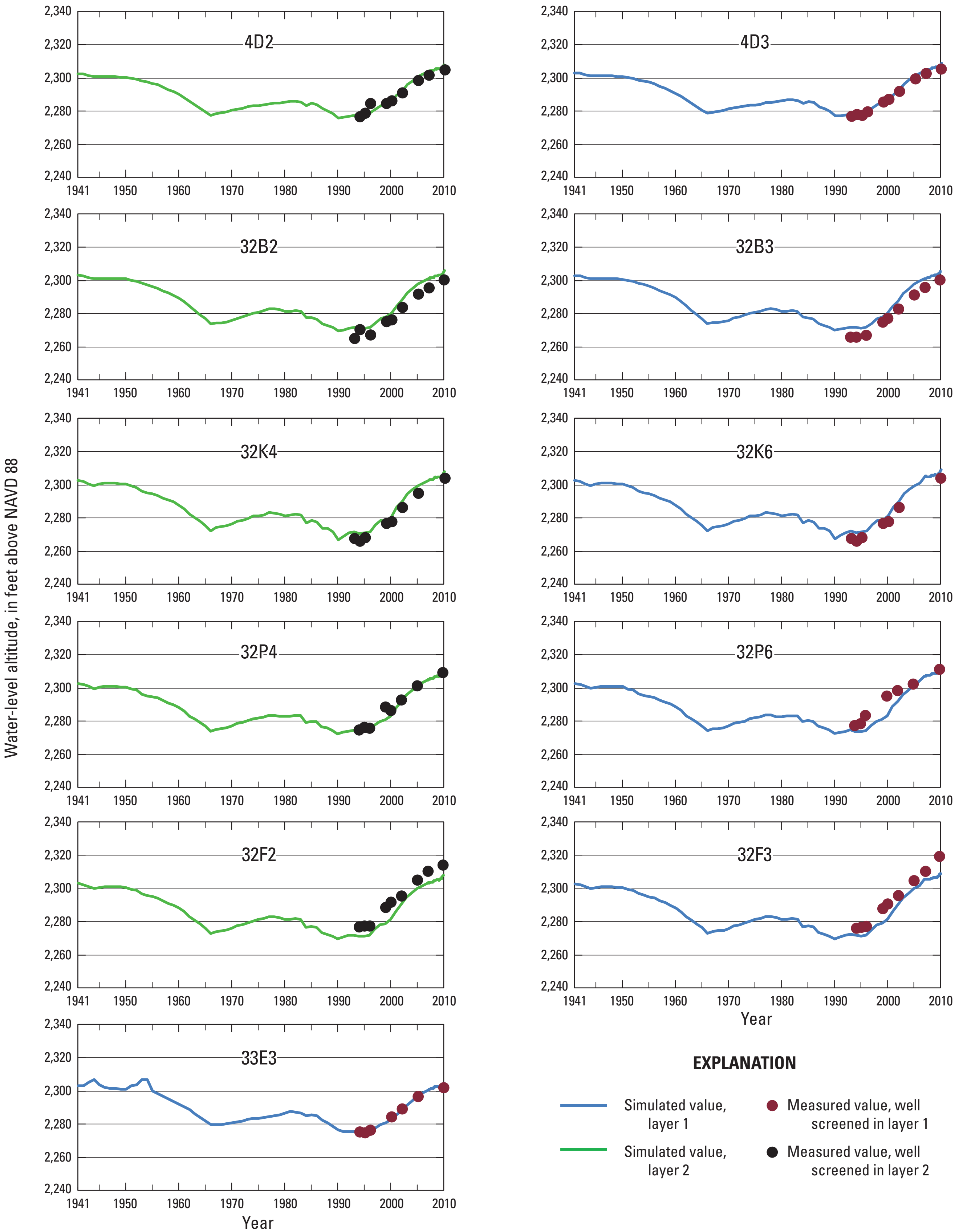


Figure 7. Hydrographs of measured water levels and simulated hydraulic heads in 11 observation wells, Irwin Basin, Fort Irwin National Training Center, California. [Well location shown in fig. 11]

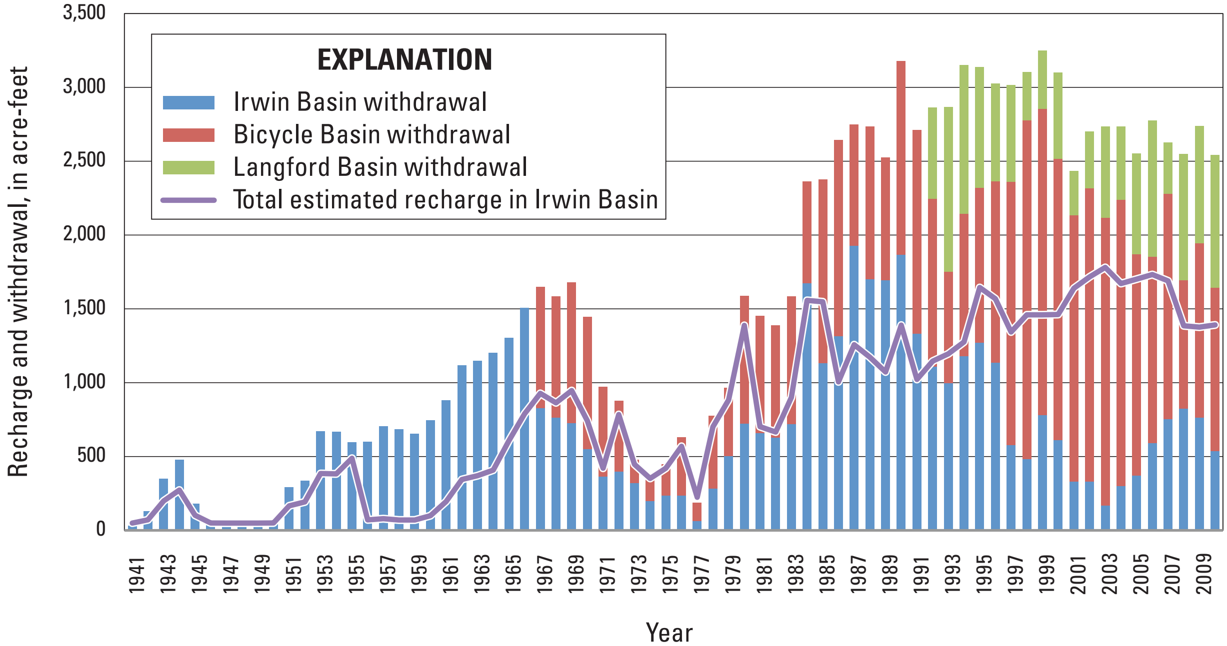


Figure 8. Annual groundwater recharge and withdrawals from Bicycle, Irwin, and Langford Basins, Fort Irwin National Training Center, California, 1941–2010.

in the Irwin Basin since 1967, except for the years 1984 and 1986–91. From 1967, about 33,980 acre-ft was withdrawn from the groundwater-flow system within the Irwin Basin and an estimated 50,600 acre-ft recharged the basin, resulting in a net gain of 16,620 acre-ft of water to the groundwater-flow system (fig. 8 and table 2). Reduced pumping in the Irwin Basin, recharge from irrigation at the base housing, and artificial recharge from treated wastewater at the infiltration ponds has caused water levels to stabilize or rise throughout most of the Irwin Basin (fig. 7).

The recharge rate used in the original model at the recreational fields (soccer, baseball, and Army ball fields) and grass areas at the base housing (fig. 2) was used in the 2010 model for January 2000 to December 2007. Additional base housing (fig. 2) was constructed in phases during May 2005, May 2008, and November 2008. Recharge was simulated in the 2010 model for these areas beginning in 2005. The original model simulated an average yearly recharge rate, in cubic feet per day, from January 1941 to December 1999. The recharge rate simulated in the original model was used in the 2010 model for the monthly stress periods from January 2008 to December 2010. At the recreational fields and grass areas at the base housing, the recharge rate was decreased by half for the winter months, January, February, November and December.

Estimates of daily evaporation and evapotranspiration from studies by the California Department of Water Resources (DWR) and the California Irrigation Management Information System (CIMIS) of DWR's Office of Water Use Efficiency, respectively, were used in the calculation of water available for monthly recharge at the wastewater infiltration ponds (pond locations shown in fig. 2), where outflow from the wastewater-treatment facility is discharged in the Irwin Basin. Using an annual evaporation rate of 5.7 ft, the 2010 evaporation from the surface of wastewater infiltration ponds (area of ponds is 47 acres) was estimated to be about 270 acre-ft (table 3). Using an annual evapotranspiration rate of 6 ft, the 2010 evapotranspiration from the area (about 40 acres) around the wastewater infiltration ponds was estimated to be 240 acre-ft. There are no data available on the depth to groundwater within 500 ft of the ponds from wells screened within 20 ft of land surface. The well nearest to any of the infiltration ponds (pond locations shown in fig. 2) is observation well 13N/3E-10D1, screened 15 to 65 ft below land surface and located about 500 ft southeast of the southernmost duck pond. The water level in this well was 15 ft below land surface on October 21, 2010. A shallow depth to groundwater was assumed for the area around the ponds because of the vegetation growing there, and the water from the ponds would flow laterally, in addition to vertically, into the surrounding aquifer. A shallow depth to groundwater, less than 10 ft, was

Table 2. Simulated annual 1941–2010 groundwater recharge and withdrawals, Irwin Basin, Fort Irwin National Training Center, California.

[Values in acre-feet per year.]

Year	Withdrawal	Recharge	Year	Withdrawal	Recharge
1941	33	49	1976	236	569
1942	130	71	1977	64	224
1943	350	199	1978	283	702
1944	480	273	1979	502	883
1945	182	102	1980	721	1,388
1946	57	50	1981	660	702
1947	55	49	1982	630	666
1948	55	49	1983	720	901
1949	55	49	1984	1,675	1,558
1950	55	50	1985	1,133	1,548
1951	293	166	1986	1,315	1,006
1952	336	193	1987	1,927	1,257
1953	671	385	1988	1,700	1,173
1954	668	382	1989	1,696	1,073
1955	598	488	1990	1,868	1,390
1956	602	71	1991	1,331	1,022
1957	704	79	1992	1,110	1,146
1958	686	70	1993	997	1,196
1959	655	70	1994	1,180	1,276
1960	746	99	1995	1,270	1,645
1961	881	195	1996	1,138	1,568
1962	1,119	344	1997	580	1,343
1963	1,147	370	1998	484	1,460
1964	1,202	408	1999	781	1,460
1965	1,305	607	2000	612	1,462
1966	1,509	790	2001	331	1,640
1967	827	928	2002	333	1,716
1968	764	864	2003	168	1,781
1969	727	947	2004	301	1,671
1970	549	742	2005	370	1,701
1971	364	421	2006	592	1,733
1972	399	785	2007	755	1,690
1973	321	447	2008	826	1,385
1974	200	352	2009	765	1,376
1975	236	421	2010	536	1,391

Table 3. Summary of 2001–10 groundwater withdrawals, and estimates of evapotranspiration, evaporation, and recharge used in the 2010 model and model scenarios, Irwin Basin, Fort Irwin National Training Center, California.

[Numbers in parentheses are model cell numbers (row, column). Scenario 1 and 3 do not have a decrease in recharge in phases. Scenario 2, phase 1 uses Scenario 1 recharge values. Scenario 2, phase 4 has no recharge in the area of the ponds near the wastewater treatment facility. Values in acre-feet unless noted otherwise. **Abbreviation**: CA, California; NE, Northeast; **->**, indicates range of cells in column; #, number]

Month	Groundwater withdrawals		Treated wastewater	Evaporation		Evapotranspiration		Total estimated evaporation and evapotranspiration in Irwin Basin	Simulated 2010 wastewater recharge			
	Average 2001–10 from all basins[1]	2010 from all basins[1]	2010 to wastewater treatment facility[2]	Average from a water surface, feet per month[3]	Estimated from the surface of ponds in Irwin Basin[4]	San Bernardino, Barstow, CA NE - #134, feet per month[5]	Estimated evapotranspiration from areas around ponds in Irwin Basin[6]		Duck ponds (64,55; 65,55; 66,55; 67,55; 68,55)	Golf course pond (59,53; 60,53; 61,53; 62,53; 62,54; 63,53; 63,54)	Wastewater-treatment facility pond (56,52->53; 57,51->53; 58,51->52; 59,51->52; 60,51->52)	Total simulated recharge from ponds in Irwin Basin
January	145	150	109	0.11	5	0.18	7	12	30	18	15	63
February	136	146	106	0.17	8	0.24	10	18	28	17	14	59
March	181	192	107	0.33	15	0.45	18	33	29	17	13	59
April	200	195	93	0.50	24	0.59	24	47	19	11	9	40
May	255	237	95	0.73	34	0.75	30	64	19	11	7	38
June	279	262	87	0.87	41	0.85	34	75	18	11	6	35
July	300	284	104	0.92	43	0.83	33	76	14	9	6	28
August	282	294	115	0.81	38	0.74	29	67	15	9	6	29
September	276	273	94	0.58	27	0.57	23	50	18	11	7	36
October	243	217	98	0.37	17	0.41	16	34	17	10	6	34
November	184	146	91	0.19	9	0.23	9	18	14	8	7	30
December	153	130	92	0.10	5	0.17	7	11	20	12	9	40
Total of column[7]	2,635	2,526	1,191	5.67	267	5.99	240	506	241	145	106	492

Table 3. Summary of 2001–10 groundwater withdrawals, and estimates of evapotranspiration, evaporation, and recharge used in the 2010 model and model scenarios, Irwin Basin, Fort Irwin National Training Center, California.—Continued

[Numbers in parentheses are model cell numbers (row, column). Scenario 1 and 3 do not have a decrease in recharge in phases. Scenario 2, phase 1 uses Scenario 1 recharge values. Scenario 2, phase 4 has no recharge in the area of the ponds near the wastewater treatment facility. Values in acre-feet unless noted otherwise. **Abbreviation**: CA, California; NE, Northeast; **->**, indicates range of cells in column; #, number]

Month	Scenario 1, January 2011 through December 2060					Scenario 2, phase 2, January 2012 through December 2013					Scenario 2, phase 3, January 2014 through December 2015				
		Simulated wastewater recharge					Simulated wastewater recharge					Simulated wastewater recharge			
	Estimated quantity of treated wastewater discharge to ponds in Irwin Basin[8]	Duck ponds (64,55; 65,55; 66,55; 67,55; 68,55)	Golf course pond (59,53; 60,53; 61,53; 62,53; 62,54; 63,53; 63,54)	Wastewater-treatment facility pond (56,52->53; 57,51->53; 58,51->52; 59,51->52; 60,51->52)	Total simulated recharge from ponds in Irwin Basin	Estimated quantity of treated wastewater discharge to ponds in Irwin Basin[8]	Duck ponds (64,55; 65,55; 66,55; 67,55; 68,55)	Golf course pond (59,53; 60,53; 61,53; 62,53; 62,54; 63,53; 63,54)	Wastewater-treatment facility pond (56,52->53; 57,51->53; 58,51->52; 59,51->52; 60,51->52)	Total simulated recharge from ponds in Irwin Basin	Estimated quantity of treated wastewater discharge to ponds in Irwin Basin[8]	Duck ponds (64,55; 65,55; 66,55; 67,55; 68,55)	Golf course pond (59,53; 60,53; 61,53; 62,53; 62,54; 63,53; 63,54)	Wastewater treatment facility pond (56,52->53; 57,51->53; 58,51->52; 59,51->52; 60,51->52)	Total simulated recharge from ponds in Irwin Basin
January	103	30	18	15	63	101	30	18	15	63	98	30	18	15	63
February	100	28	17	14	59	97	28	17	14	59	93	28	17	14	59
March	93	29	17	13	59	86	29	17	13	59	79	29	17	13	59
April	71	19	11	9	40	61	19	11	9	40	50	0	0	0	0
May	66	9	6	4	19	51	0	0	0	0	36	0	0	0	0
June	55	0	0	0	0	39	0	0	0	0	22	0	0	0	0
July	70	0	0	0	0	53	0	0	0	0	37	0	0	0	0
August	83	0	0	0	0	67	0	0	0	0	50	0	0	0	0
September	65	0	0	0	0	51	0	0	0	0	36	0	0	0	0
October	77	17	10	6	34	66	17	10	6	34	55	9	5	3	17
November	77	14	8	7	30	70	14	8	7	30	64	14	8	7	30
December	86	20	12	9	40	83	20	12	9	40	80	20	12	9	40
Total of column[7]	946	166	100	78	344	823	157	94	75	325	701	129	77	62	269

[1]Groundwater withdrawals from Bicycle, Irwin, and Langford Basins.

[2]Values from Fort Irwin National Training Center personnel.

[3]Potential evaporation values from pans download from *http://www.water.ca.gov*.

[4]Evaporation estimated from monthly pan evaporation multiplied by an estimated area of 47 acres for all ponds.

[5]Potential evapotranspiration values download from January 1, 1997 through May 31, 2001; *http://wwwcimis.water.ca.gov/cimis/frontMonthlyReport.do*.

[6]Evapotranspiration estimated from monthly evapotranspiration values and multiplied by an estimated area of 40 acres (area around all ponds with some vegetation).

[7]Values may not add to totals due to rounding.

[8]Estimated values from Fort Irwin National Training Center personnel.

assumed for a radial distance of 250 ft from the edge of the wastewater infiltration ponds and evapotranspiration would occur over 40 acres around the ponds. Evapotranspiration would decrease the water available for groundwater recharge to the aquifer system. Simulated annual 1941 to 1999 recharge in the original model ranges from 49 to 1,644 acre-ft/yr (fig. 8). Simulated annual 2000 to 2010 recharge in the updated 2010 model ranges from 1,462 to 1,781 acre-ft/yr (fig. 8).

Periodic water-level measurements by USGS personnel at six observation wells (13N/3E-4B3, -4G1, 4K1,-4K4, -4Q4, and -10D1) near the wastewater-treatment facility were compared to simulated hydraulic heads to insure the calculated 2008–10 monthly recharge rates did not have an adverse effect on model calibration. The observation wells are screened in model layer 1. The measured water levels and simulated hydraulic heads, which are within 1–20 ft, at the six observation wells (fig. 9). The larger differences between simulated and measured values may be due, in part, to inaccuracies in the distribution of pumpage to the individual wells during 1999 and 2004 and an inaccurate estimation of the quantity and distribution of artificial recharge.

Simulated Effects of Future Withdrawals and Artificial Recharge

The updated 2010 model was used to assess the possible effect of four groundwater withdrawal and artificial recharge scenarios on the groundwater-flow system within the Irwin Basin. These four scenarios were developed in cooperation with Fort Irwin National Training Center personnel and used to simulate conditions from January 2011 to December 2060. All of the model scenarios use the simulated December 2010 hydraulic heads as initial conditions. Monthly values for proposed withdrawals and estimated artificial recharge were simulated for January 2011 through December 2060.

For the scenarios, the drain module was added to simulate groundwater discharge in areas where water levels rise above land surface because of groundwater recharge simulated in those areas. Groundwater levels rise above land surface in the southern area of the Irwin Basin where the land surface is topographically low, around 2,340 NAVD88, and are described in more detail in the Results of Simulations sections.

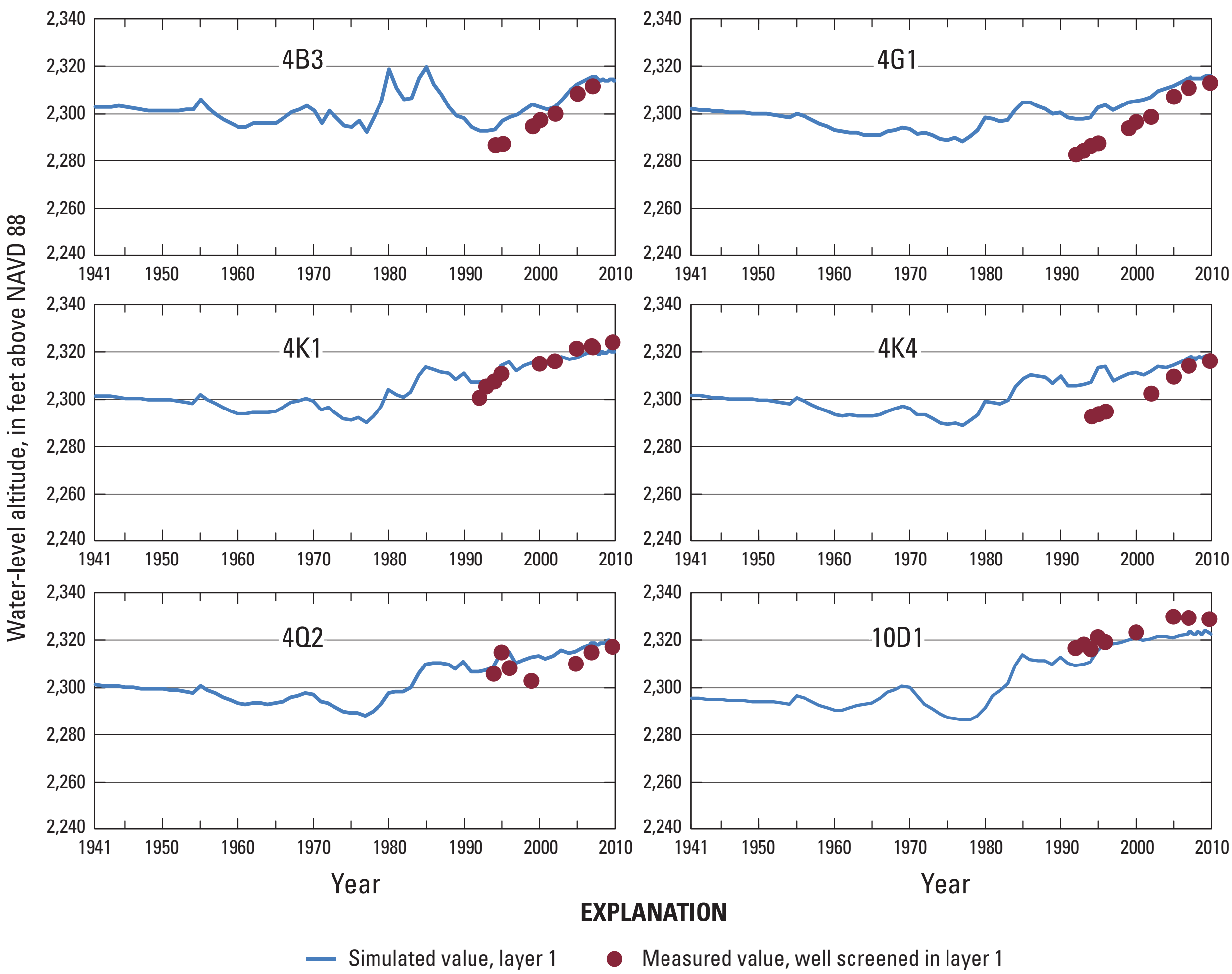


Figure 9. Hydrographs of measured water levels and simulated hydraulic heads in six observation wells near the wastewater-treatment facility, Irwin Basin, Fort Irwin National Training Center, California. [Well locations shown in fig. 11]

Description of Model Scenarios

Artificial groundwater recharge simulated for each of the model scenarios was adjusted in the area of the ponds near the wastewater-treatment facility, based on estimates by Fort Irwin personnel of the quantity of wastewater that may be discharged to the ponds in the future. The quantity of treated wastewater discharged to the ponds is anticipated to be reduced as a result of plans to use the wastewater, rather than "newly pumped" groundwater, for irrigation. Groundwater withdrawals also were adjusted for each of the scenarios to represent the redistribution or reduction of estimated amounts that are anticipated by Fort Irwin personnel. Simulated groundwater withdrawals and artificial recharge for each scenario are described below.

Scenario 1

Scenario 1 simulates the 2010 annual rate of withdrawals (536 acre-ft/yr) from production well 14N/3E-32H1 in the Irwin Basin (table 4) and remains constant from 2011 to 2060. The monthly distribution of withdrawals (fig. 10) was estimated as a percentage from the monthly withdrawals from all production wells in the Irwin, Bicycle, and Langford Basins for the 10-year period, 2001 through 2010 in order to reflect the monthly groundwater requirement needed by operations at the Fort Irwin NTC. The monthly groundwater withdrawals for the Irwin Basin were calculated by multiplying the 2010 total groundwater withdrawals (536 acre-ft/yr) from production well 14N/3E-32H1 by the percentage for a particular month. The monthly withdrawals used in scenario 1 ranged from 27 to 61 acre-ft (table 4).

The estimated quantity of treated wastewater discharged to the infiltration ponds near the wastewater-treatment facility (pond locations shown in fig. 2) for 2011 through 2060 was reduced from the 2010 values. The quantity of treated wastewater discharged to the ponds ranges from 55 to 103 acre-ft/month (table 3) for scenario 1. Because less treated wastewater will be discharged to the ponds, less water will be available for recharge. If the quantity of treated wastewater discharged to the ponds exceeded the total of the evaporation and evapotranspiration rate and was greater than the 2010 monthly recharge rate from the ponds , then the 2010 recharge rate from wastewater shown in table 3 was simulated for that month. If the quantity of treated wastewater discharged to the ponds was less than the total of the evaporation and evapotranspiration rate and there was wastewater left over from the previous month, then the simulated 2010 recharge rate from wastewater was decreased for that month. If the quantity of treated wastewater discharged to the ponds was less than the total of the evaporation and evapotranspiration rate and there was no wastewater left over from the previous month, then the simulated 2010 recharge rate is zero. The monthly recharge rate in the area of the ponds calculated from the quantity of treated wastewater in the ponds ranged from 0 to 63 acre-ft/month (table 3).

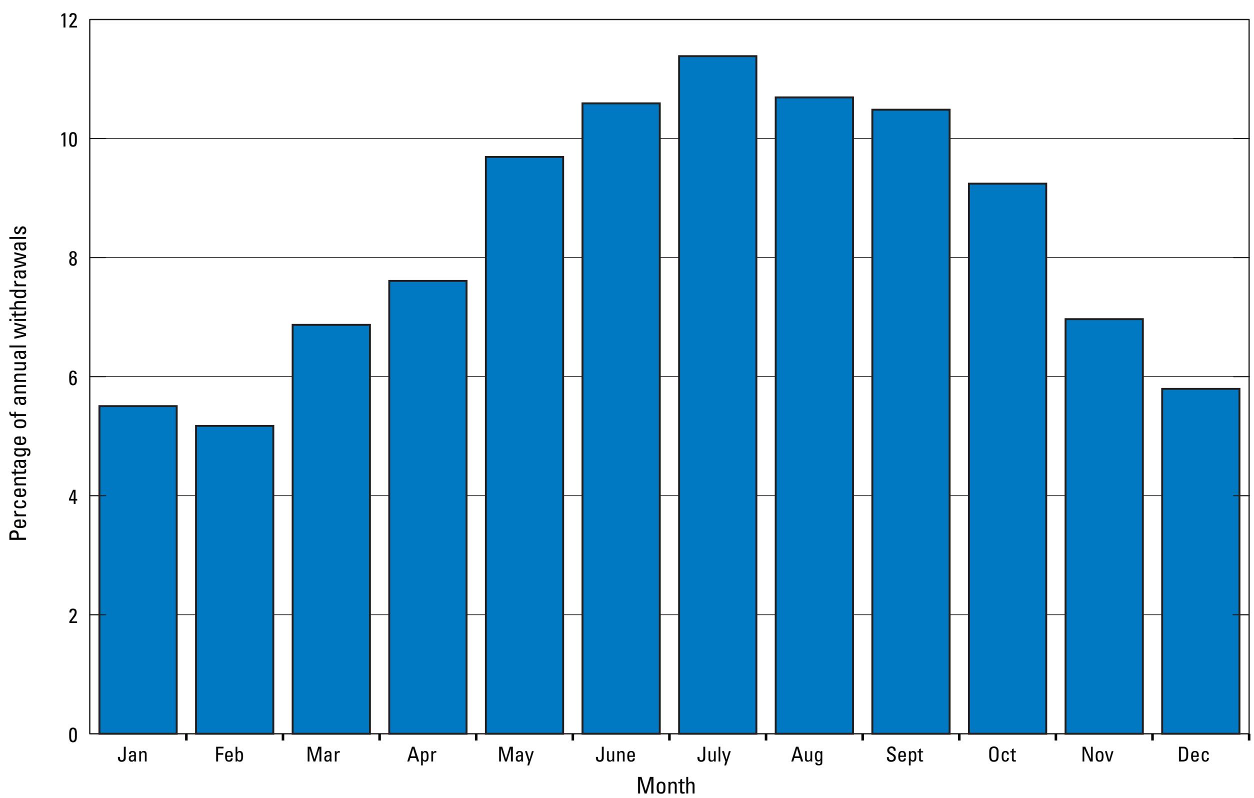


Figure 10. Average 2001 to 2010 total monthly groundwater withdrawal distribution for wells in the Bicycle, Irwin, and Langford Basins that were used to provide water to Fort Irwin National Training Center, California.

Table 4. Summary of simulated monthly groundwater withdrawals from wells in the Irwin Basin used in the four scenarios, Irwin Basin, Fort Irwin National Training Center, California.

[Values in acre-feet. 14N/3E-32M1 (I-2A), 14N/3E-32H1(I-7), 13N/3E-5G2 (I-9), State well number and local well number in parentheses.]

Month	Scenario 1	Scenario 2			[2]Scenario 3, 30 percent reduced withdrawals	[2]Scenario 4, 30 percent reduced withdrawals		
	14N/3E-32H1 (I-7)	14N/3E-32H1 (I-7)	13N/3E-5G2 (I-9)	[1]14N/3E-32M1 (I-2A)	14N/3E-32H1 (I-7)	14N/3E-32H1 (I-7)	13N/3E-5G2 (I-9)	[3]14N/3E-32M1 (I-2A)
January	30	20	10	0	21	14	7	0
Febuary	27	18	9	0	19	13	6	0
March	37	25	12	3	26	17	9	3
April	41	27	13	10	29	19	9	10
May	52	35	17	12	36	24	12	12
June	57	38	19	6	40	27	13	6
July	61	41	20	0	43	29	14	0
August	57	38	19	0	40	27	13	0
September	56	38	19	0	39	26	13	0
October	50	33	16	0	35	23	11	0
November	37	25	12	0	26	18	9	0
December	31	21	10	0	22	15	7	0
Total	536	359	177	31	375	251	124	31

[1]Simulated withdrawals begin in March 2016.

[2]Simulated withdrawals are reduced 3 percent per year for 10 years, from January 2011 to December 20, then the 30 percent reduced withdrawals are simulated January 2021 through December 2060.

[3]No reduction in simulated withdrawals.

Scenario 2

Scenario 2 simulates the 2010 groundwater withdrawals from production wells 14N/3E-32M1, -32H1 and 13N/3E-5G2 (well locations shown in fig. 11). Currently (2010), production wells 14N/3E-32M1 and 13N/3E-5G2 are inactive. The simulated monthly groundwater withdrawals calculated for scenario 1 were redistributed among production wells 14N/3E-32H1 (33 percent) and -5G2 (67 percent) during 2010–16 (table 4); groundwater withdrawals from well 14N/3E-32M1 were zero until 2016 based on future seasonal water supply demand anticipated by Fort Irwin personnel. Beginning in March 2016 and continuing until December 2060, simulated withdrawals from production well 14N/3E-32M1 for March, April, May, and June were 3, 10, 12, and 6 acre-ft/month, respectively, and zero for all other months. The withdrawals from 14N/3E-32M1 are in addition to the withdrawals from production wells 14N/3E-32H1 and -5G2.

For Scenario 2, the estimated quantity of treated wastewater discharged to the infiltration ponds was reduced in four phases from the quantity of treated wastewater in 2010 (table 3). The quantity of treated wastewater discharged to the infiltration ponds for scenario 2, phase 1, (January 2011 through December 2011) used the same values calculated for scenario 1 (January 2011 through December 2060) and ranged from 55 to 103 acre-ft/month. The simulated quantity of treated wastewater discharged to the infiltration ponds ranged from 39 to 101 acre-ft/month for phase 2, (January 2012 through December 2013), 22 to 98 acre-ft/month for phase 3, (January 2014 through December 2015) and no discharge to the infiltration ponds for phase 4, (January 2016 through December 2060).

The calculated monthly recharge rates in the area of the ponds for phase 2 and 3 of scenario 2 ranged from 0 to 63 acre-ft/month (table 3). The calculated monthly recharge was zero in the model for phase 4 in the area of the ponds. The treated wastewater for phase 4 is assumed to be used for irrigation (currently (2010) supplied by groundwater) and cooling towers and any remaining wastewater will be discharged to a proposed 2-mile-long drainage ditch. The 1,400 acre-ft/yr of water used for irrigation (1,200 acre-ft/yr) and cooling towers (200 acre-ft/yr), however, exceeds the quantity of water treated at the wastewater treatment facility, 1,190 acre-ft/yr. Hence, there will be no wastewater available to discharge to the proposed drainage ditch at the base.

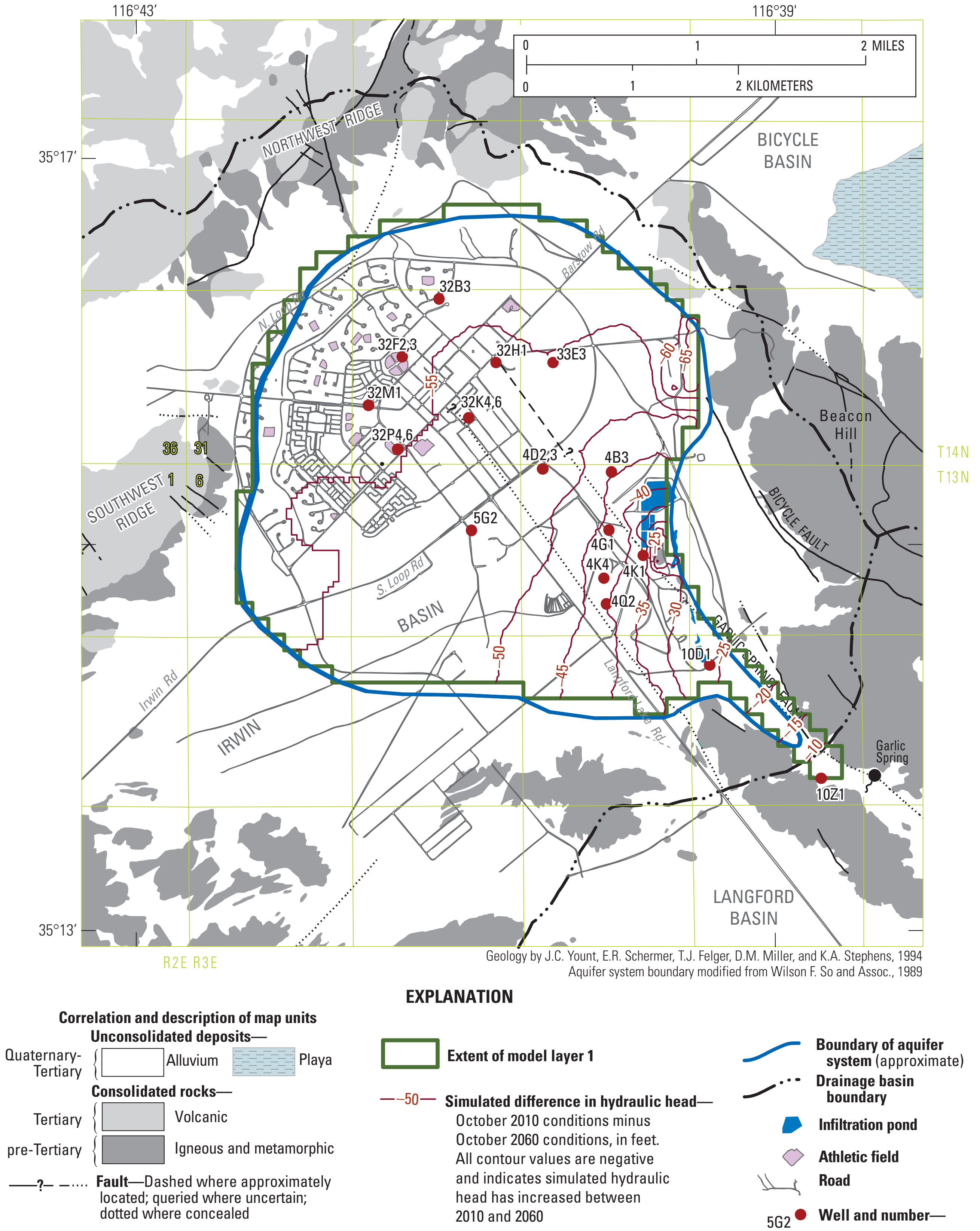


Figure 11. Simulated difference in hydraulic head from October 2010 conditions to October 2060 conditions, scenario 1, layer 1, Irwin Basin, Fort Irwin National Training Center, California.

Scenario 3

Scenario 3 simulates a 3 percent per year reduction in the 2010 withdrawal rate for 10 years, from January 2011 through December 2020. The 30 percent reduction in withdrawal rate (from the initial 2010 rate) was then applied in the simulation from January 2021 until December 2060 (table 4). The withdrawals are simulated from production well 14N/3E-32H1 (I-7). The same quantity of treated wastewater discharged to the ponds near the wastewater-treatment facility for scenario 1 was used in scenario 3 (table 3). In addition, the same recharge rate simulated in the area of the ponds in scenario 1 was used in scenario 3.

Scenario 4

Scenario 4 simulates the same distribution of withdrawals among the production wells as scenario 2, but reduces the 2010 withdrawals 3 percent per year for 10 years (January 2011 through 2020) at wells 14N/3E-32H1 and 13N/3E-5G2. As in scenario 3, the 30 percent reduction in withdrawal rates (from the initial 2010 rate) was then simulated from January 2021 until December 2060 (table 4). Withdrawals at well14N/3E-32M1 were not reduced. Similar to scenario 2, the estimated quantity of treated water discharged to the ponds near the wastewater treatment facility and the simulated recharge rate were varied in 4 phases beginning in January 2011, January 2012, January 2014, and January 2016, and are shown in table 3. The same quantity of treated wastewater discharged to the ponds near the wastewater-treatment facility for scenario 2 was used in scenario 4. The same recharge rate simulated in the area of the ponds for scenario 2 was used in scenario 4.

Results of Simulations

Results of the simulations of the four scenarios are presented as maps of the difference in hydraulic heads from October 2010 to October 2060 for model layer 1. (figs. 11–14). The head values for October are assumed to represent water levels after the high groundwater withdrawal rates during the summer. A negative value for the change in hydraulic head indicates the simulated hydraulic head has increased between 2010 and 2060.

Hydrographs showing the simulated hydraulic heads for each of the four scenarios from 2011 to 2060 at 14 well locations are presented in figure 15. Water levels in production wells 14N/3E-32M1 (I-2A), -32H1 (I-7) and 13N/3E-5G2 (I-9) are representative of conditions in a cone of depression that may form in response to groundwater withdrawals. The aquifer response in the area of a cone of depression to changes in recharge will be most evident in the hydrographs of production wells. The water levels in observation wells 13N/3E-4D3, -4G1, -4K1, -4K4, -4Q2, -10D1, 14N/3E-32B3, -32F3, -32K6, -32P6, and -33E3 are representative of groundwater conditions in the Irwin Basin. The changes in simulated hydraulic heads at the 14 wells are summarized in table 5.

Scenario 1

In scenario 1, the 2010 annual rate of withdrawals (536 acre-ft/yr) was held constant from 2011 to 2060, for a cumulative withdrawal of 26,800 acre-ft. Continuation of the 2010 withdrawal rate and recharge from irrigation at the base housing, and a decrease in the recharge at the ponds, resulted in an increase in groundwater levels throughout Irwin Basin. These increases were as much as 55 ft in the area underlying the base housing in the northwestern part of the basin and 10 ft in the southeastern area near the unnamed wash exiting the basin (fig. 11 and table 5). The rise in water levels in the northwestern part of the basin is a result of continued recharge from irrigation at the base housing. Even though there is a simulated decrease in recharge at the ponds, simulated groundwater levels continue to rise in the area of the ponds. Analysis of simulation results indicate groundwater levels rose to land surface around the golf course pond, duck ponds and well 13N/3E-10D1. Simulated groundwater discharge to the drains, which was simulated around the golf course pond, duck ponds and the unnamed wash near well 13N/3E-10D1, ranges from 1 to 205 acre-ft/year by 2060 (table 6). Beginning in March 2044, simulated hydraulic heads rise to land surface at well 13N/3E-10D1 (2,345 ft above sea level [NAVD 88] intermittently during the year (fig. 15). Prior to March 2044, simulated hydraulic heads remain below land surface. The altitude of land surface ranges from 2,344ft above sea level [NAVD 88] at well 13N/3E-10D1 to 2,310 ft above sea level [NAVD 88] at well 13N/3E-10Z1. Simulated groundwater levels remained below land surface north and west of the wastewater treatment plant.

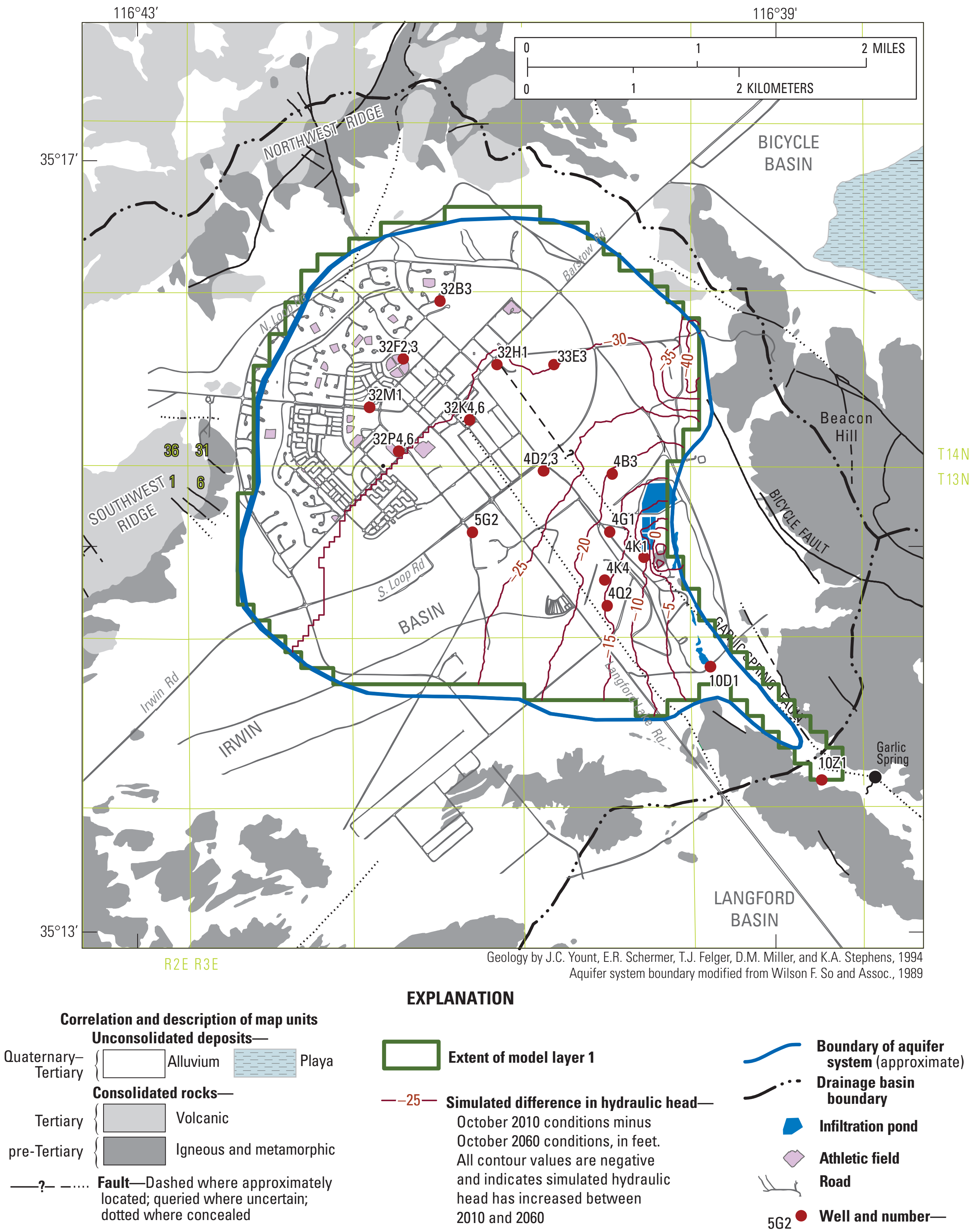


Figure 12. Simulated difference in hydraulic head from October 2010 conditions to October 2060 conditions, scenario 2, layer 1, Irwin Basin, Fort Irwin National Training Center, California.

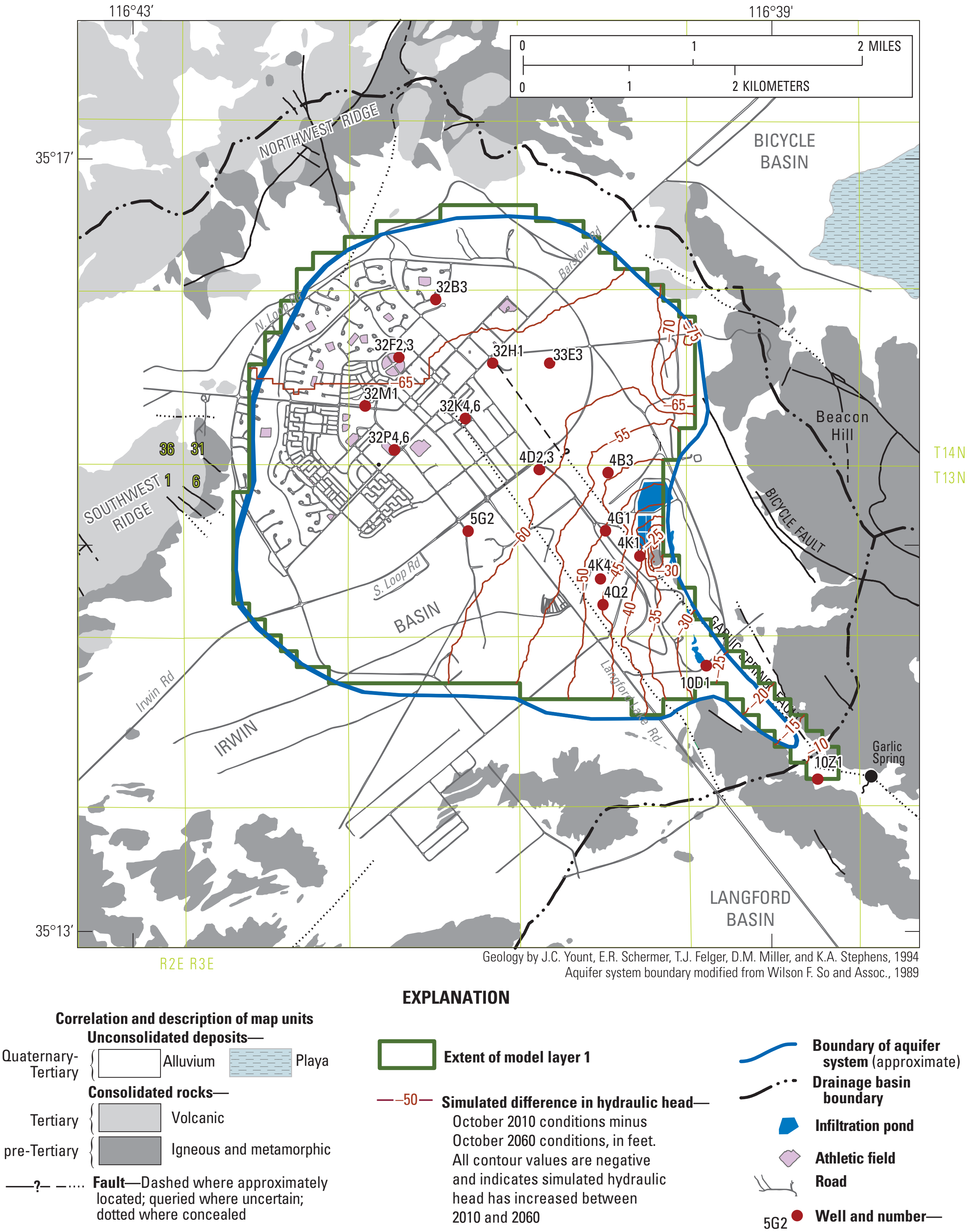


Figure 13. Simulated difference in hydraulic head from October 2010 conditions to October 2060 conditions, scenario 3, layer 1, Irwin Basin, Fort Irwin National Training Center, California.

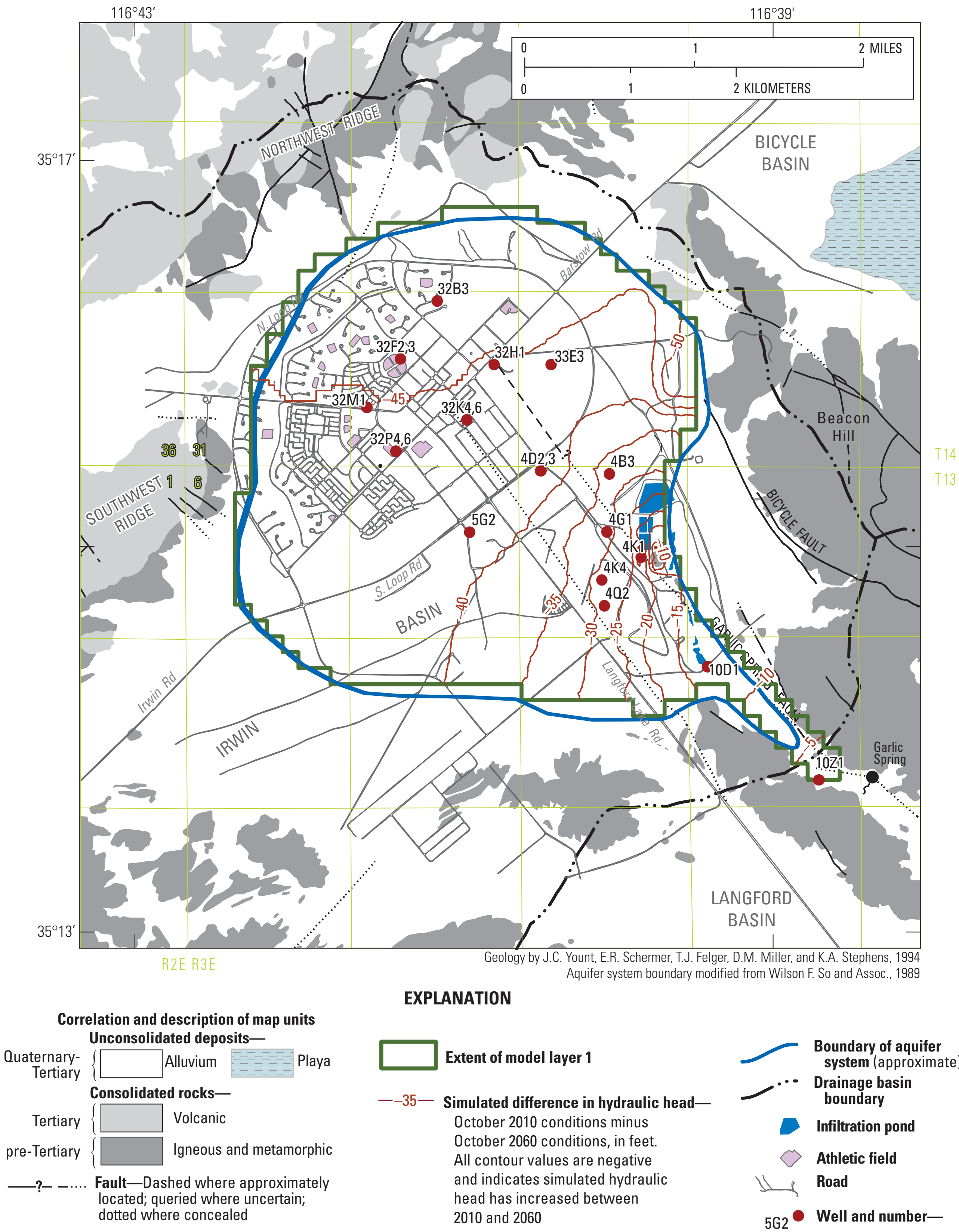


Figure 14. Simulated difference in hydraulic head from October 2010 conditions to October 2060 conditions, scenario 4, layer 1, Irwin Basin, Fort Irwin National Training Center, California.

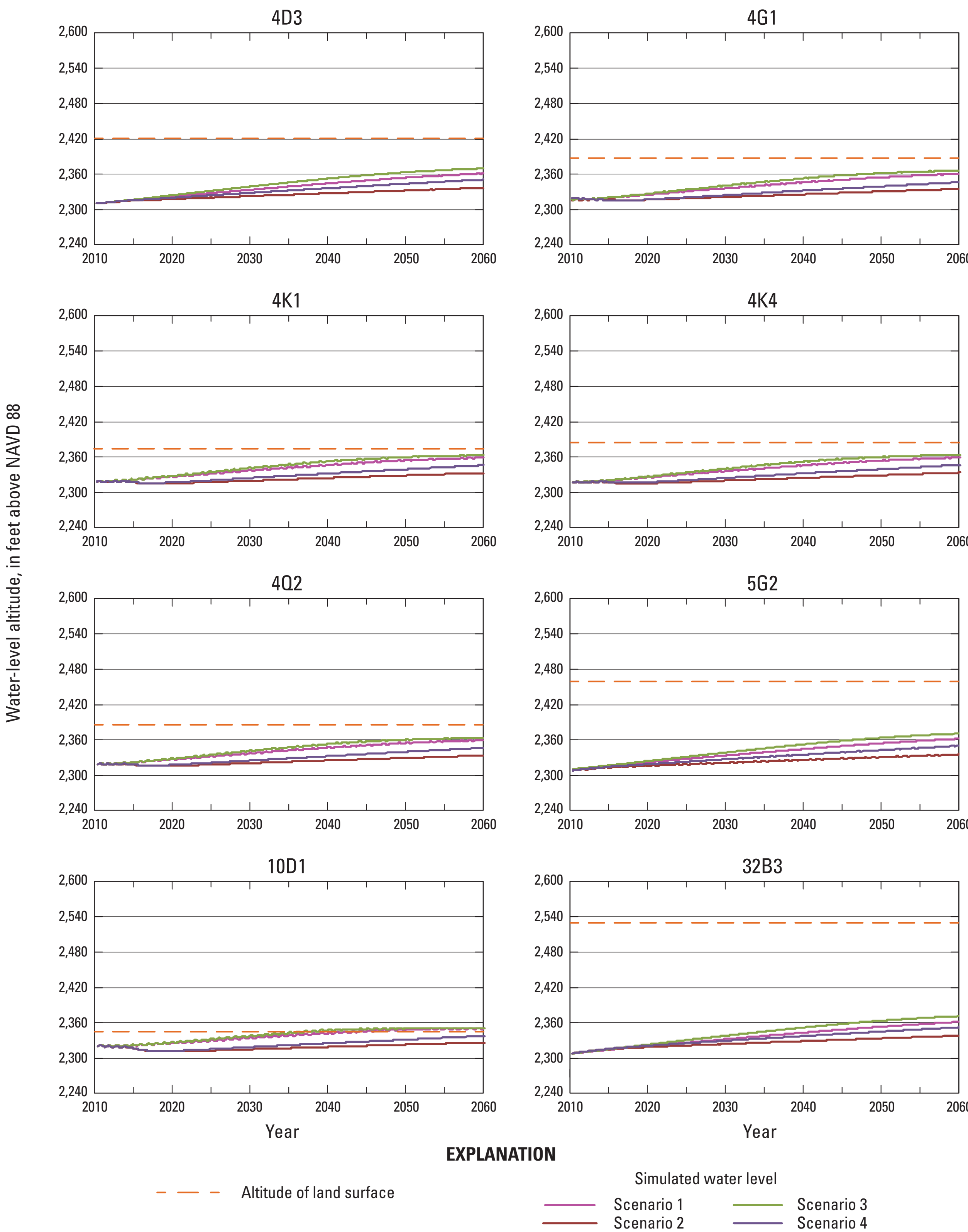


Figure 15. Hydrographs of simulated hydraulic heads at 14 wells for four scenarios, Irwin Basin, Fort Irwin National Training Center, California.

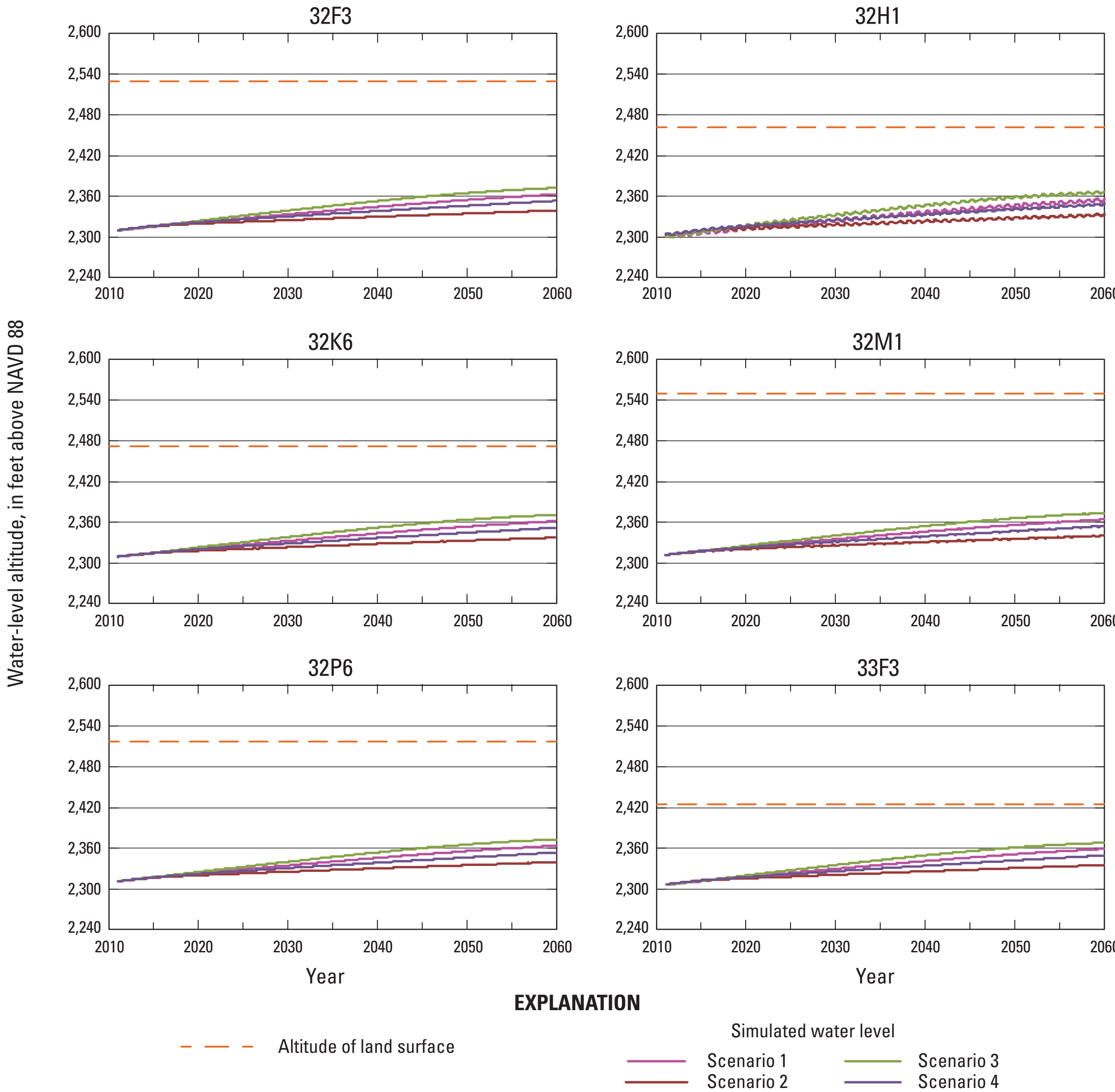


Figure 15. —Continued

Table 5. Simulated hydraulic head at 14 wells for four model scenarios, Irwin Basin, Fort Irwin National Training Center, California.

[Location of wells shown in figure 12. NOTE: Negative values for the difference in hydraulic head (between October 2010 and October 2060) reflect an increase in head. **Abbreviation**: NAVD 88, vertical coordinate information is referenced to the North American Datum of 1988; —, not applicable]

State well number	Local well name	Altitude of land surface (NAVD 88) (feet)	Row	Column	October 2010 simulated hydraulic head (NAVD 88) (feet)	Scenario 1, October 2060 simulated hydraulic head (NAVD 88) (feet)	Scenario 1, difference between October 2010 and October 2060 simulated hydraulic head (feet)	Scenario 2, October 2060 simulated hydraulic head (NAVD 88) (feet)	Scenario 2, difference between October 2010 and October 2060 simulated hydraulic head (feet)	Scenario 3, October 2060 simulated hydraulic head (NAVD 88) (feet)	Scenario 3, difference between October 2010 and October 2060 simulated hydraulic head (feet)	Scenario 4, October 2060 simulated hydraulic head (NAVD 88) (feet)	Scenario 4, difference between October 2010 and October 2060 simulated hydraulic head (feet)
13N/3E-4D3	WC2-170	2,419.85	56	46	2,307.3	2,359.8	–52	2,335.4	–28	2,368.4	–61	2,349.5	–42
13N/3E-4G1	STP1	2,385.63	60	50	2,315.6	2,359.4	–44	2,334.1	–18	2,365.3	–50	2,347.4	–32
13N/3E-4K1	STP4	2,375.28	62	52	2,319.9	2,358.6	–39	2,333.2	–13	2,363.0	–43	2,346.2	–26
13N/3E-4K4	NIT2-135	2,385.00	63	50	2,318.1	2,358.8	–41	2,333.4	–15	2,363.6	–46	2,346.4	–28
13N/3E-4Q2	NIT1	2,385.00	65	50	2,319.1	2,358.2	–39	2,332.9	–14	2,362.6	–43	2,345.7	–27
13N/3E-5G2	I-9	2,460.00	60	41	2,308.3	2,361.8	–53	2,335.1	–27	2,370.5	–62	2,349.7	–41
13N/3E-10D1	STP6	2,344.85	68	57	2,321.4	2,346.0	–25	2,323.4	–2	2,346.4	–25	2,334.1	–13
14N/3E-32B3	NH1-300	2,530.00	45	39	2,304.6	2,360.6	–56	2,337.4	–33	2,370.6	–66	2,351.7	–47
14N/3E-32F3	BASEBALL-290	2,530.00	49	37	2,307.1	2,362.4	–55	2,339.0	–32	2,372.2	–65	2,353.3	–46
14N/3E-32H1	I-7	2,461.00	49	43	2,303.9	2,354.3	–50	2,332.4	–28	2,365.9	–62	2,348.2	–44
14N/3E-32K6	FI1-230	2,472.43	53	41	2,306.7	2,361.3	–55	2,337.3	–31	2,370.8	–64	2,351.7	–45
14N/3E-32M1	I-2A	2,550.00	52	35	2,309.3	2,364.3	–55	2,340.6	–31	2,373.9	–65	2,354.7	–45
14N/3E-32P6	SOCFLD-270	2,517.00	55	37	2,309.1	2,363.7	–55	2,339.6	–31	2,373.1	–64	2,353.7	–45
14N/3E-33E3	PICNIC-175	2,425.00	49	46	2,304.0	2,358.9	–55	2,335.1	–31	2,368.0	–64	2,349.3	–45
Minimum hydraulic head increase in the south eastern area of model		—	—	—	—	—	10	—	less than 5	—	10	—	5
Maximum hydraulic head increase in area underlying the base housing		—	—	—	—	—	55	—	31	—	65	—	45

Table 6. Summary of simulated groundwater discharge to drains, Irwin Basin, Fort Irwin National Training Center, California.

[Values in acre-feet.]

Year	Scenario 1	Scenario 3
2011–27	0	0
2028	0	1
2029	0	3
2030	0	5
2031	1	8
2032	2	11
2033	3	14
2034	6	19
2035	8	23
2036	10	26
2037	12	32
2038	15	39
2039	19	45
2040	22	51
2041	24	60
2042	28	78
2043	32	96
2044	37	115
2045	41	134
2046	46	153
2047	50	171
2048	56	189
2049	68	207
2050	82	225
2051	94	242
2052	107	259
2053	120	281
2054	133	304
2055	145	327
2056	157	350
2057	169	373
2058	181	394
2059	193	414
2060	205	432

Scenario 2

Scenario 2 simulates the monthly groundwater withdrawals that were calculated for scenario 1 distributed initially between two production wells and additional withdrawals later from a third production well. The total volume of simulated groundwater withdrawals was about 28,350 acre-ft in scenario 2. Discharge to the wastewater treatment plant used to calculate recharge is estimated to decrease from 2010 values, in 4 phases. The results from the scenario 2 simulation show the least rise in groundwater levels in the Irwin Basin of the four scenarios. Groundwater levels rise about 30 ft near the base housing to less than 5 ft in the unnamed wash exiting Irwin Basin near well 13N/3E-10Z1S (fig. 12 and table 5). Groundwater levels remain below land surface throughout Irwin Basin (fig. 15).

Scenario 3

Scenario 3 simulated a reduction of 3 percent per year in 2010 withdrawals from 2011 to 2020 and then held withdrawals at a constant rate (30 percent less than in 2010) from 2021 to 2060. The total volume of simulated groundwater withdrawals was reduced from about 26,800 acre-ft in scenario 1 to about 18,760 acre-ft in scenario 3. The reduced recharge rate simulated in scenario 1 was used in scenario 3. The simulated reduction in groundwater withdrawals and recharge rate at the wastewater treatment facility resulted in a rise in groundwater levels throughout the Irwin Basin. Groundwater levels rise 65 ft in the area underlying the base housing in the northwestern part of the basin and by 10 ft in the unnamed wash near 13N/3E-10Z1 (fig. 13 and table 5). The results from this scenario show the greatest rise in groundwater levels in the Irwin Basin of the 4 scenarios. Analysis of simulation results indicate groundwater levels will rise to land surface around the golf course pond, duck ponds and well 13N/3E-10D1 (fig. 15). Groundwater discharge to the drains, simulated around the golf course pond, duck ponds and an unnamed wash near well 13N/3E-10D1, ranges from 1 acre-ft/year in 2028 to 432 acre-ft/year by 2060 (table 6).

Scenario 4

Scenario 4 simulated a reduction of 3 percent per year in 2010 withdrawals from 2011 to 2020 distributed among 2 wells, and then a constant rate of withdrawal from 2021 to 2060. Beginning in 2016, an additional withdrawal of 31 acre-ft/yr is simulated from an inactive production well 14N/3E-32M1. The total volume of simulated groundwater withdrawals was about 20,300 acre-ft in scenario 4. The reduced recharge rate simulated in scenario 2 was used in scenario 4. Analysis of results from this simulation indicate groundwater levels rise by 45 ft near the base housing to less than 5 ft in the unnamed wash near 13N/3E-10Z1 (fig. 14). Groundwater levels remain below land surface in the Irwin Basin (fig. 15 and table 5). There is no simulated groundwater discharge to the drains.

Model Limitations

A numerical model is useful for testing and refining a conceptual model of a groundwater flow system, developing an understanding of the system, guiding data collection, and projecting aquifer responses to changes in aquifer stresses within specified limits. However, a model can only approximate the actual system and is based on simplified assumptions and estimated conditions. Thus, the results of model simulations are only as accurate as the input data and assumed boundary conditions used to constrain the simulations.

As designed and calibrated, the groundwater-flow model of the Irwin Basin is best used for analyzing basin-wide issues of water use and supply. The model is particularly useful for estimating changes in groundwater levels and flows in the Irwin Basin and flows in response to groundwater withdrawal and artificial recharge. Simulated water levels at locations adjacent to active production wells may not accurately reflect water levels at these locations because simulated water levels are averaged over each model cell and reflect general trends in water levels across a broad area.

Because the model was used to test different quantities and distributions of artificial recharge, the artificial recharge estimates were as representative as possible considering the data limitations. The original model estimated artificial recharge from pumpage data because historical records on the quantities of water used for irrigation and discharged from the wastewater-treatment facility either were not available or may be inaccurate. For the model scenarios, artificial recharge at the wastewater-treatment facility ponds was estimated from 2010 metered data of the quantity of wastewater processed at the wastewater-treatment facility. Estimating artificial recharge in the ponds from the quantity of water processed at the wastewater-treatment facility may be an improvement, but more accurate estimates of artificial recharge quantities and distribution could be used to update and verify the model as they become available. More accurate estimates of artificial recharge from irrigation could be derived if the quantity of water used for irrigation was metered.

Summary and Conclusions

Fort Irwin National Training Center presently (2012) obtains its potable water supply by pumping from wells in the Irwin, Bicycle, and Langford Basins. Groundwater development began in the Irwin Basin in 1941. Pumping from the Bicycle and Langford Basins began in 1967 and 1992, respectively; pumping from these basins has resulted in a decrease in the groundwater demand from the Irwin Basin. Groundwater from Bicycle and Langford basins is imported into the Irwin Basin. Some water is used for irrigation at the base housing; the water that is not consumed is treated at the wastewater-treatment facility and discharged to infiltration ponds. Estimated groundwater recharge has exceeded groundwater withdrawals in the Irwin Basin since 1967, except for the years 1984 and 1986–91. From 1967, about 33,980 acre-ft was withdrawn from the groundwater-flow system within the Irwin Basin and an estimated 50,600 acre-ft recharged the basin, resulting in a net gain of 16,620 acre-ft of water to the groundwater-flow system. Reduced pumping in the Irwin Basin, recharge from irrigation at the base housing, and artificial recharge from treated wastewater at the infiltration ponds has caused water levels to stabilize or rise throughout most of the Irwin Basin.

An existing groundwater-flow model of the aquifer system in the Irwin Basin (Densmore, 2003) was updated and used to simulate flow under four alternative withdrawal and recharge conditions, here called scenarios. The updated groundwater-flow model is a useful tool to help estimate the long-term availability of groundwater from the basin by evaluating differences in groundwater-level altitudes (or water levels) among scenarios simulating different withdrawal and recharge rates. The updated model was used to evaluate the potential spatial effects on groundwater levels as a consequence of 1) continued withdrawals at the 2010 average rate of pumping, 2) supplementing water-supply needs with withdrawals from an inactive production well, and, 3) a reduction in groundwater recharge from treated wastewater. The four scenarios simulate conditions from January 2011 to December 2060. Scenario 1 simulates the 2010 annual rate of withdrawals (536 acre-ft/yr) from a production well in the Irwin Basin and remains constant from 2011 to 2060. The estimated quantity of treated wastewater discharged to the infiltration ponds near the wastewater-treatment facility for 2011 through 2060 was reduced from the 2010 values in scenario 1. Scenario 2 simulates the 2010 annual rate of withdrawals (536 acre-ft/yr) from two production wells in the Irwin Basin until 2060 and additional withdrawals of 31 acre-ft/yr from an inactive well. Discharge to the wastewater treatment plant used to calculate recharge is estimated to decrease from 2010 values, in 4 phases in scenario 2. Scenario 3 simulated a reduction of 3 percent per year in 2010 withdrawals from 2011 to 2020 and then held withdrawals at a constant rate (30 percent less than in 2010) from 2021 to 2060. Scenario 3 uses the same recharge rate simulated in scenario 1. Scenario 4 simulated a reduction of 3 percent per year in 2010 withdrawals from 2011 to 2020 distributed among two wells, and then a constant rate of withdrawal from 2021 to 2060. Beginning in 2016, an additional withdrawal of 31 acre-ft/yr is simulated from an inactive production well. The reduced recharge rate simulated in scenario 2 was used in scenario 4.

Analysis of the results from scenario 1 and 3 indicate groundwater levels rise throughout Irwin Basin. These increases were as much as 65 ft in the area underlying the base housing in the northwestern part of the basin and 10 ft in the southeastern area near the unnamed wash exiting the basin. The rise in water levels in the northwestern part of the basin is a result of continued recharge from irrigation at the base housing. Water levels rise to land surface around the golf course pond, duck ponds and in the southeastern area near the unnamed wash exiting the basin. Groundwater discharge to the drains, simulated around the golf course pond, duck ponds and the unnamed wash, ranges from 1 to 432 acre-ft/year by 2060.

The results from the scenario 2 and 4 simulations show the least rise in groundwater levels in the Irwin Basin of the four scenarios. These increases were as much as 45 ft in the area underlying the base housing in the northwestern part of the basin and 5 ft in the southeastern area near the unnamed wash exiting the basin. Groundwater levels remain below land surface throughout the Irwin Basin in scenarios 2 and 4.

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