Numerical Simulation of Ground-Water Flow and Land Subsidence at Edwards Air Force Base, Antelope Valley, California

By Tracy Nishikawa, Diane L. Rewis, *and* Peter Martin

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 01-4038

Prepared in cooperation with the

U.S. DEPARTMENT OF THE AIR FORCE

U. S. DEPOSITORY

AUG 8 - 2001

Sacramento, California
2001

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GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
Placer Hall, Suite 2012
6000 J Street
Sacramento, CA 95819-6129

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PWS-0206-0002

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ABSTRACT

Edwards Air Force Base (EAFB) in southern California historically has relied on ground water for its water-supply needs. Pumping of ground water at the base has led to problems such as declining water levels and land subsidence. For this study, a MODFLOW-based ground-water flow model was developed for EAFB to estimate the effects of pumping and injection strategies on water levels and on land subsidence.

The ground-water flow model grid has 154 rows and 126 columns of 660- by 660-foot cells, and the boundary of the active model grid basically corresponds to bedrock outcrops. The model has seven layers of varying thickness; model layers 2, 3, and 4 correspond to a thick clay layer in the southern half of the model area and model layer 5 corresponds to the middle aquifer which is the primary source of water supply for EAFB. The model was calibrated using a trial-and-error approach. Because relatively little ground-water development took place prior to the establishment of EAFB in 1947, assumed (predevelopment) steady-state conditions for model calibration were represented by a compilation of data from 1913–46. The steady-state simulated hydraulic gradient was northward for all model layers. The transient-state 1996 simulated hydraulic heads indicate that a ground-water divide is located near the middle of the basin and that south of the divide ground water flows southward and north of the divide ground water flows northward. There are two subsidence centers located in the vicinity of the two primary pumping centers on the base. The maximum simulated hydraulic head change was about 150 feet and the maximum simulated subsidence was about 5 feet. The simulated results indicate that the greatest amount of compaction occurs in the middle aquifer (model layer 5). The simulated water budget rates for 1947, 1961, and 1996 indicate that about 97, 98, and 76 percent, respectively, of the net discharge was derived from storage.

Results of the sensitivity analysis indicate that the model was sensitive to changes in the hydraulic-characteristic values of Faults 1 and 4 and the hydraulic conductivity values and inelastic storage values in layer 5. Specifically, increasing or decreasing the hydraulic-characteristic value of Fault 1 by an order of magnitude affected simulated hydraulic heads by as much as 45.0 feet and simulated subsidence by as much as 0.5 foot. Decreasing the hydraulic-characteristic value of Fault 4 by an order of magnitude affected simulated hydraulic heads by as much as 10.0 feet and simulated subsidence by as much as 0.5 foot. Decreasing the hydraulic conductivity values for layer 5 by 50 percent affected simulated hydraulic heads by as much as 10.0 feet and simulated subsidence by as much as 0.8 foot, and decreasing the inelastic storage values for layer 5 by an order of magnitude affected simulated hydraulic heads by as much as 45.0 feet and simulated subsidence by as much as 10.0 feet.

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The simulated hydraulic head and subsidence results were not sensitive to vertical conductance in areas 2 and 4; however, the results indicate that the clay layers in area 4 hydraulically control water levels and subsidence in these areas. When the vertical conductance was varied in area 2, the resulting simulated hydraulic heads and subsidence showed little change in either area; however, when the vertical conductance was varied in area 4, simulated hydraulic heads and simulated subsidence were affected in both areas.

Three water-management scenarios were tested for Edwards Air Force Base: for scenario 1 (base case), 1997 pumping rates were maintained for 10 years (1997–2006); for scenario 2, water was injected steadily into the middle aquifer at well 8N/10W-1C2 in the South Tract well field between December and February, concurrent with base-case pumping; and for scenario 3, water was injected steadily into the middle aquifer at well 9N/10W-24E3 in the South Base well field, concurrent with base-case pumping. For scenarios 2 and 3, two separate cases were simulated: in the first case, about 3 acre-feet per day of water was injected, and in the second case about 30 acre-feet per day of water was injected. Injecting 3 acre-feet per day had little effect on simulated hydraulic heads; however, injecting 30 acre-feet per day raised simulated hydraulic heads more than 100.0 feet for both scenarios. In general, the injection of 3 acre-feet per day of water had little or no effect on the total subsidence over the 10-year simulation. Subsidence still accumulated with time when 30 acre-feet per day was injected at either site, but at a much lower rate than when 3 acre-feet per day was injected. Simulated subsidence decreased 60 percent more at the S-5 production well when 30 acre-feet per day of water was injected at well 8N/10W-1C2 than when 3 acre-feet per day was injected, and simulated subsidence decreased 90 percent more at the South Base well field when 30 acre-feet per day of water was injected at well 9N/10W-24E3 than when 3 acre-feet per day was injected.

INTRODUCTION

Edwards Air Force Base (EAFB) (fig. 1) historically has relied on ground water for its water-supply needs. Pumping of ground water at the base has led to declining water levels [about 90 ft between 1950–96 (Londquist and others, 1993; Carlson and others, 1998)] and land subsidence [more than 3.5 ft between 1926–92 (Ikehara and Phillips, 1994)]. Land subsidence at EAFB has caused surface deformation of its runways, sink-like depressions, earth fissures, erosion of the Rogers Lake playa, and collapsed production-well casings. In 1992, EAFB began purchasing imported water from the Antelope Valley–East Kern Water Agency (AVEK) to reduce dependence on ground water at the base. To address the concerns of EAFB on the use of ground water as an emergency water source during drought years without exacerbating the land subsidence problem, methods are needed to evaluate and project ground-water and subsidence conditions that may result from current and planned ground-water pumping at EAFB.

Purpose and Scope

In 1988, the U.S. Geological Survey (USGS), in cooperation with the Department of the Air Force, began investigations of the effects of land subsidence and declining ground-water levels at EAFB. Data collected during these investigations were obtained by leveling and global positioning surveys, surface and borehole geophysical surveys, and ground-water-level and sediment compaction monitoring. These data indicated that the regional ground-water levels declined more than 90 ft between 1950 and 1996 (Londquist and others, 1993) and that as much as 3.5 ft of subsidence occurred between 1926 and 1992, affecting areas surrounding the production wells at the base (Ikehara and Phillips, 1994).

The purpose of this current study is to define the geohydrology of the ground-water flow system, emphasizing the effects of pumping or recharge, or both, on the ground-water flow system and on land subsidence. As part of this study, a numerical ground-water flow model was developed using the U.S. Geological Survey modular ground-water flow model, MODFLOW (McDonald and Harbaugh, 1988), to estimate the effects of pumping and injection strategies on water levels and on land subsidence. The model was

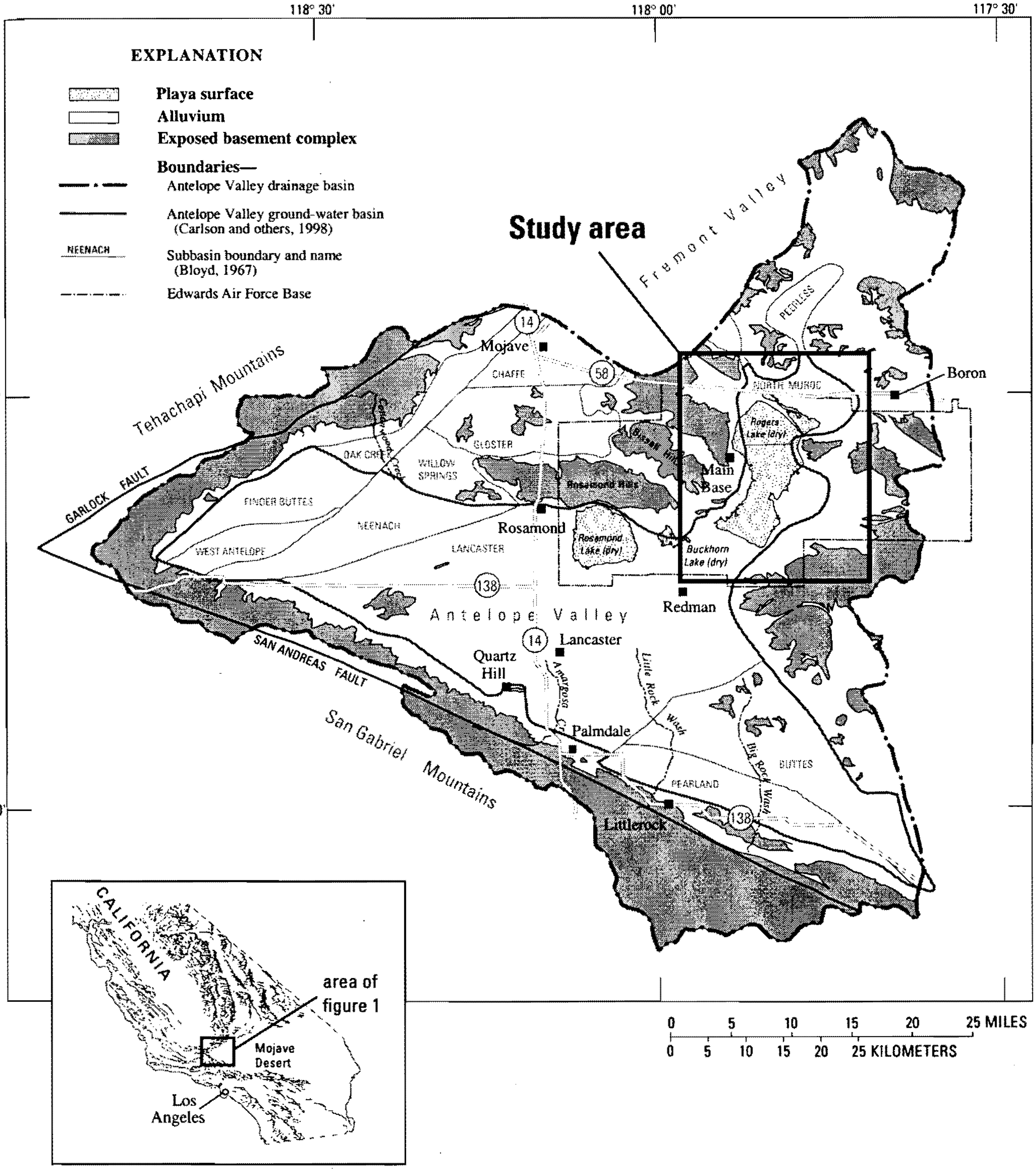

Figure 1. Location of study area, Edwards Force Base, Antelope Valley, California.

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areas and was discharged by evapotranspiration (39,400 acre-ft/yr), subsurface discharge into Fremont Valley (1,000 acre-ft/yr), and springs (300 acre-ft/yr) (Durbin, 1978).

Under predevelopment conditions inflow must equal outflow; therefore, to estimate the rate of steady-state ground-water inflow into the study area one may consider the two components of subsurface outflow—subsurface outflow into Fremont Valley and ground water discharged as evapotranspiration. Durbin (1978) estimated that the subsurface outflow was about 1,000 acre-ft/yr. In order to estimate the amount of ground-water discharge by evapotranspiration in the study area, aerial photographs of EAFB taken in 1972 were analyzed; approximately 650 acres of phreatophytes were identified having an areal density of 11 to 40 percent. In 1998, there were approximately 277 acres of mesquite on EAFB (Ric Williams, Mojave Desert Ecosystem Program, written commun., 2000). Because some development (and mesquite removal) had occurred by 1972, the use of 650 acres to estimate evapotranspiration may result in underestimates of ground-water discharge from this sink; hence 650 acres is conservative for estimating total predevelopment inflow to the basin. Lines and Bilhorn (1996) estimated that the average annual water use of mesquite at an areal density of 11 to 40 percent is 0.6 ft/yr in the Mojave River Basin. Assuming that the results of the study by Lines and Bilhorn (1996) are relevant to the EAFB area, the resulting average annual loss of ground water by evapotranspiration is approximately 390 acre-ft/yr. This implies that the total inflow into the study area under predevelopment conditions was about 1,390 acre-ft/yr.

At EAFB, a small amount of runoff may recharge the subbasins along the base of the surrounding low-lying hills and through the coarse-grained sediments of the intermittent stream channels in the eastern and northwestern parts of the base and in the North Muroc subbasin. This recharge is probably small because average annual precipitation is low (less than 5 in./yr), average annual pan evaporation is high [about 114 in./yr (Bloyd, 1967)], and the surrounding low-lying hills are not of sufficient elevation to produce orographic effects. Some direct recharge to the aquifer system from storm runoff has been observed; Rewis (1995) stated that when storm runoff inundates the playas, it can infiltrate into the subsurface through desiccation cracks and linear and polygonal fissures in the playa surface. The volume of this recharge is difficult to estimate, but it is assumed small because the vertical pathways of the cracks and fissures become plugged with low permeability sediments washed in from the surface (Rewis, 1995). Rewis (1995) also stated that most of the water that reaches the playa probably evaporates.

Ground-Water Development

Ground-water use in the Antelope Valley began in the 1880's with only a few widely scattered shallow, small-diameter wells (Thompson, 1929; Snyder, 1955). Drilling of large-diameter wells did not begin until about 1915; most of the wells were drilled in the southern and central part of the valley. As the number of wells in the Antelope Valley increased, the total pumpage volume increased from about 55,000 acre-ft in 1924 to a high of about 300,000 acre-ft in 1950 (Snyder, 1955). Only a minimal amount of this pumpage occurred in the EAFB area north of the Willow Springs Fault prior to 1947 and the establishment of EAFB.

Before the establishment of EAFB, homesteaders in the area around Rogers Lake generally used shallow wells for domestic and livestock water supplies. The wells ranged from 50 to 300 ft deep (Thompson, 1929; Dutcher and others, 1962). In the area around what is now the Graham Ranch well field (fig. 2), alfalfa fields were irrigated from wells that ranged from about 300 to 700 ft deep. In 1913, the Atchison, Topeka and Santa Fe Railway at Muroc Station, which was located at what is now the main base complex of EAFB, began using ground water from a well 218 ft deep. The Muroc Army Air Base, which was established on the northeast part of Rogers Lake in 1942, was supplied with ground water from wells that ranged from about 140 to 200 ft deep. After the establishment of EAFB in 1947, most of these wells were abandoned but not destroyed, except for a short time when a few of the wells were used at the military facilities while new well fields were developed in the Main Base, South Base, and North Base areas. Eventually well fields also were developed in the South Tract and Air Force Research Laboratory (formerly known as Phillips Laboratory) areas.

Records of pumpage for EAFB have been kept since the base was established in 1947 and were summarized by Londquist and others (1993). Total pumpage increased steadily from about 790 acre-ft in 1947 to a high of about 7,500 acre-ft in 1965 (fig. 4). Pumpage data for 1968 to 1975 were not available for the Graham Ranch, Branch Park, Air Force Research Laboratory, and South Base well fields and, therefore, pumpage for this period was estimated by linearly interpolating between the measured 1967 and 1976 pumpage data for each well field. From 1976 to 1990, total annual pumpage ranged from 5,000 to 7,000 acre-ft/yr. From 1991 to 1996, total annual pumpage ranged from about 3,600 to 5,200 acre-ft/yr (MSgt. Frazier S. Speaks, Jr., Chief of Utilities Systems, Edwards Air Force Base, written commun., 1998). Figure 5 shows annual pumpage for each well field at EAFB and for the water-supply districts in the North Muroc subbasin (John Siefke, Mine Department, U.S. Borax Inc., written commun., 1997).

Ground-Water Levels and Movement

Ground-water data for 1915 and 1961 (Durbin, 1978) and 1996 (Carlson and others, 1998) were used for this current study to describe ground-water movement in the study area. For the purposes of the current study, we assumed that ground-water levels prior to 1947 represent predevelopment conditions because the major development of ground-water resources in the study area took place after 1947. In 1915, ground-water levels in the middle and lower aquifers [the deep aquifer as defined by Durbin (1978)] were about 2,300 to 2,380 ft above sea level south of the Willow Springs Fault, about 2,280 ft above sea level (9 ft above the lakebed surface of Rogers Lake) in the southern part of Rogers Lake, and about 2,200 ft above sea level in the North Muroc subbasin (Durbin, 1978, plate 2). The hydraulic gradient was about 0.001 to the north, indicating that ground-water movement was from the southern boundary of the study area to the north.

The 1961 ground-water levels represent conditions after 15 years of ground-water pumping at EAFB. In 1961, ground-water levels in the upper aquifer were about 2,260 ft above sea level in well 8N/10W-8R3 in the southern part of the study area, about 2,255 ft above sea level in well 8N/9W-6D1 in the southern part of Rogers Lake, and about 2,210 ft above sea level in well 11N/9W-36R1 in the North Muroc subbasin (fig. 6). In 1961, the ground-water levels in the middle and the lower aquifers ranged from

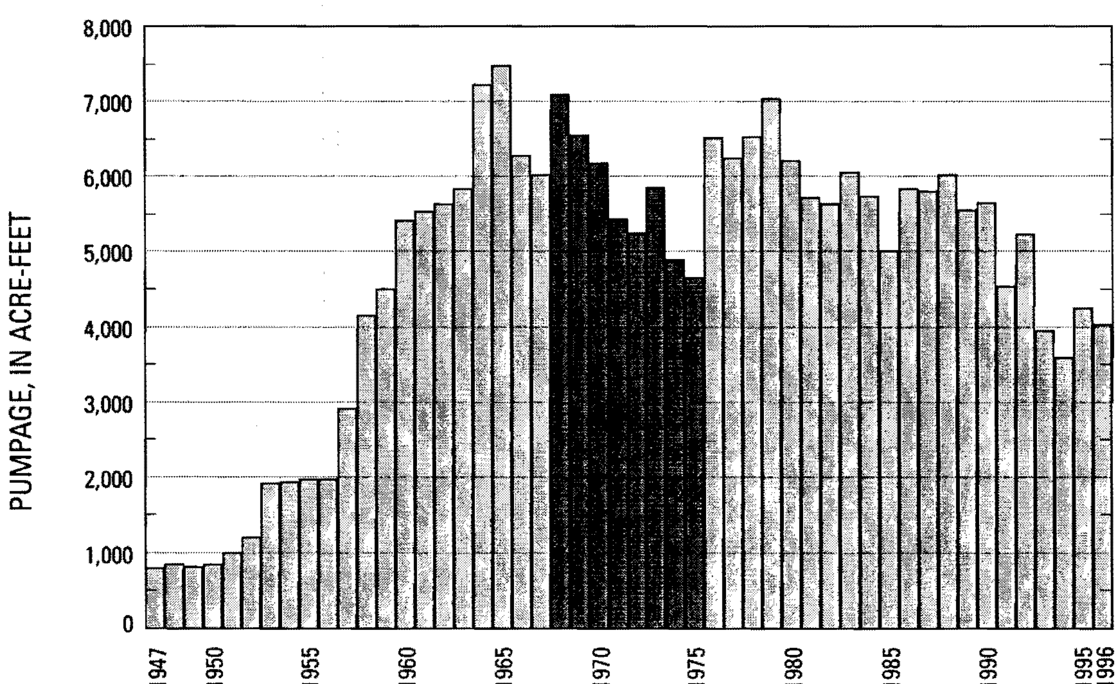

Figure 4. Annual pumpage at Edwards Air Force Base, Antelope Valley, California, 1947–96. Because pumpage data for 1967 through 1975, indicated by the dark shading, were not available, values for individual well fields (see figure 5) were estimated by linearly interpolating between the measured pumpage data for 1967 and 1976.

about 2,240 to 2,280 ft above sea level in the southern part of Rogers Lake (Durbin, 1978, plate 3), and was about 2,240 ft above sea level in the middle part of Rogers Lake (Durbin, 1978, plate 3) and about 2,210 ft above sea level in well 11N/8W-29K1 in the North Muroc subbasin (fig. 6). These data indicate that, in general, ground-water movement in the upper, middle, and lower aquifers was from the southern boundary of the study area to the north. The 1961 ground-water-level data for the middle and the lower aquifers indicate a pumping depression in the South Base well field; the data also indicate that ground water in the upper aquifer south of the Willow Springs Fault flowed southward (a reversal of flow) toward the major pumping centers in

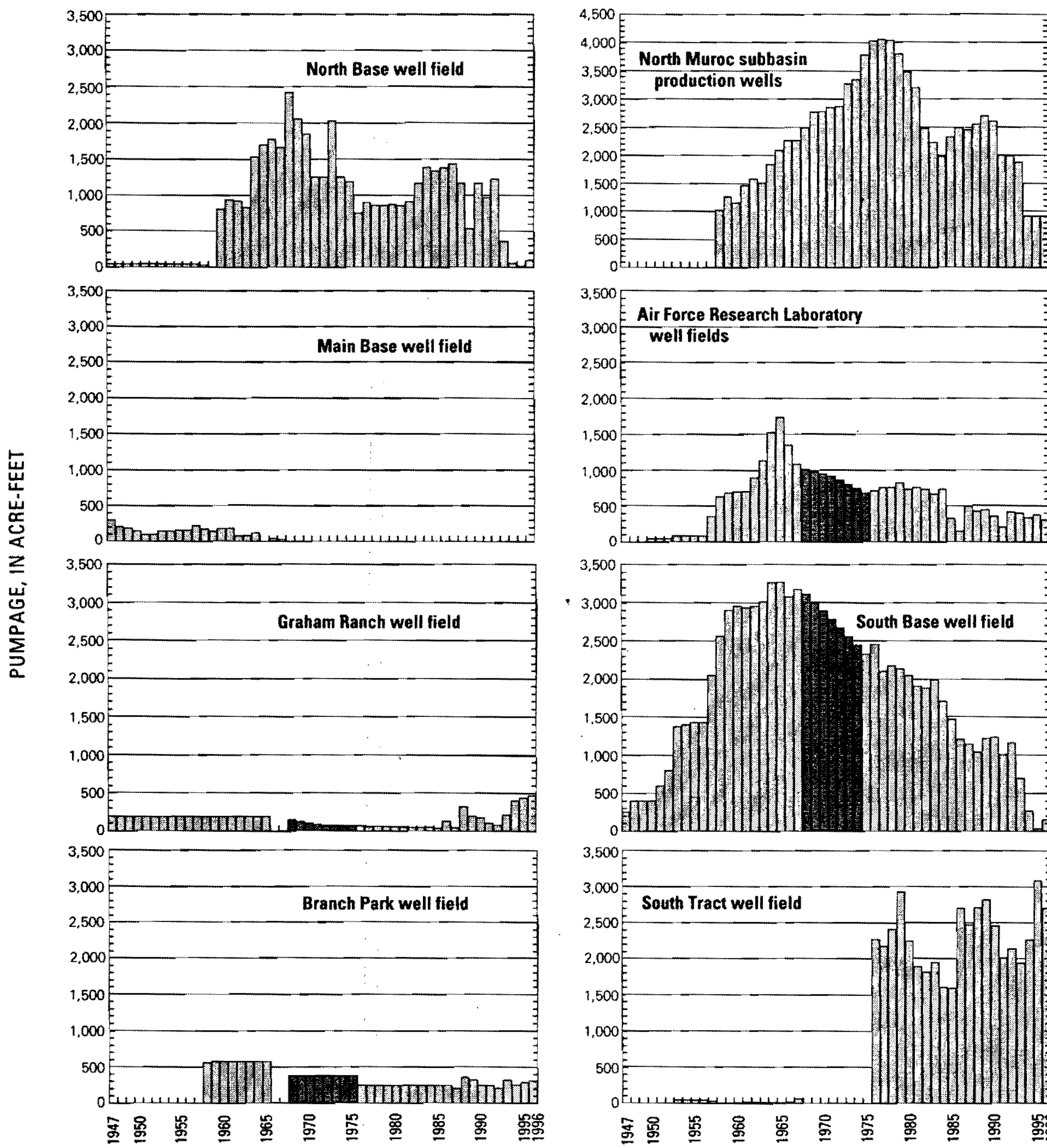

Figure 5. Annual pumpage from the well fields at Edwards Air Force Base and from production wells in the North Muroc subbasin, Antelope Valley, California, 1947–96. See figure 2 for location of well fields.

the central part of the Lancaster subbasin (Durbin, 1978).

The 1996 ground-water levels represent conditions after 50 years of ground-water pumping at EAFB. In 1996, ground-water levels in the upper aquifer in the southern part of the study area were about 2,245 ft above sea level (Carlson and others, 1998). Ground-water levels in the middle and lower aquifers were about 2,228 ft above sea level in the southern part of the study area south of the Willow Springs Fault, about 2,165 ft above sea level in the southern part of the study area north of the Willow Springs Fault, about

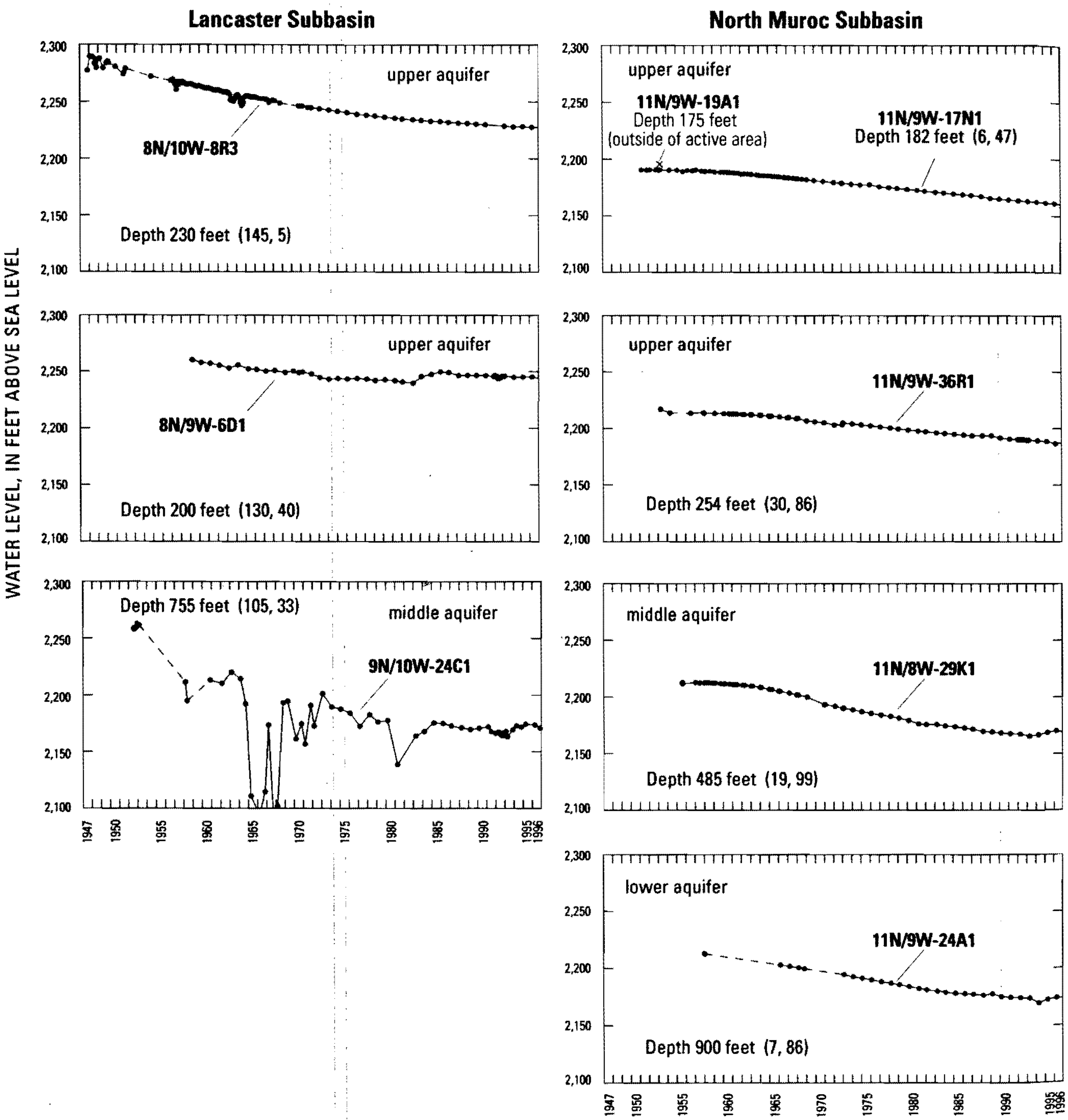

Figure 6. Water levels at selected wells of the Antelope Valley–East Kern Water Agency at Edwards Air Force Base, Antelope Valley, California. Numbers in parenthesis represent the row and column, respectively, of the model cell.

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2,190 ft above sea level in the middle of Rogers Lake, and about 2,180 ft above sea level in the North Muroc subbasin (Carlson and others, 1998). These data indicate that in the middle and lower aquifers south of the basement-complex ridge at Rogers Lake, ground water flows in a southward direction and north of the basement-complex ridge ground water flows in a northward direction. These data also indicate that the Willow Springs Fault is a barrier to ground-water flow; there is about a 70 ft water-level difference across the fault.

Long-term hydrographs for selected wells in the study area show that from 1960 to 1996 ground-water levels declined (fig. 6). In the upper aquifer of the Lancaster subbasin, water levels in well 8N/9W-6D1 declined about 15 ft, and in the upper aquifer of the North Muroc subbasin, water levels in wells 11N/9W-17N1 and 36R1 declined about 25 ft. In the upper aquifer of the Lancaster subbasin in the southern part of the study area south of the Willow Springs Fault, water levels in well 8N/10W-8R3 declined as much as 35 ft. Water levels in the middle aquifer also declined during this period: in the Lancaster subbasin, water levels in well 9N/10W-24C1 declined 50 ft, and in the North Muroc subbasin, water levels in wells 11N/9W-24A1 and 11N/8W-29K1 declined about 40 ft. Well-construction data for these wells and the other wells used in this study are presented in the appendix (tables A-1 and A-2).

Land Subsidence

Land subsidence is a gradual settling or sudden sinking of the Earth's surface owing to subsurface movement of earth materials. It is caused by natural geologic processes, tectonic movements, or human activities such as subsurface mining and oil or ground-water pumping. Subsidence of the land surface in Antelope Valley is related to the compaction of fine-grained sediments resulting primarily from ground-water withdrawals (Lofgren, 1965; Lewis and Miller, 1968). Compaction of fine-grained sediments in an aquifer system caused by long-term pumping reduces water pressure in an aquifer thereby increasing the effective stress on the subsurface sediments (Bear, 1979).

In 1988, some effects of land subsidence were observed at EAFB with the occurrence of surface deformation features, such as sink-like depressions and giant linear and polygonal desiccation fissures, on the playa surface of Rogers Lake (Blodgett and Williams, 1992; Londquist and others, 1993). In 1989, an extensometer and four monitoring wells were installed by the USGS at a site, referred to as the Holly site, south of the South Tract well field (fig. 2). A monitoring program was established to record hourly compaction and ground-water levels at the Holly site and ground-water levels at seven other sites on EAFB (Freeman, 1996). In 1991, a linear earth fissure about 3 to 6 ft wide and about 4,000 ft long opened across an emergency runway on the playa surface near the south end of Rogers Lake (Ward and others, 1993). Two shallow extensometers were installed at the fissure, referred to as the Fissure site, to monitor the compaction of the playa clays and to determine the cause of fissuring (Freeman, 1996) (fig. 2). Other indications of land subsidence at EAFB include the failure of production wells caused by collapsed well casings and the protrusion of well casings, pump platforms, and survey bench marks above land surface.

Londquist and others (1993) reported that land subsidence greater than 1 ft affects more than 100 mi^2 of EAFB. Ikehara and Phillips (1994) reported 3.3 ft of subsidence at the Holly site and 3.7 ft of subsidence near the South Tract well field (fig. 2).

Dinehart and McPherson (1998) surveyed 31 separate third-order-accurate (12 mm × (distance [in km])$^{1/2}$) transects across Rogers Lake playa. Results from their survey indicate a decrease in elevation of about 3 ft on Rogers Lake between the El Mirage Fault and the southern edge of the lakebed. This change in elevation may have been caused by land subsidence in that part of the lakebed.

GROUND-WATER FLOW MODEL

The objective of developing a numerical ground-water flow model of the aquifer system at EAFB was to better understand the dynamics of ground-water flow and land subsidence. The model is a tool that can simulate the effect of ground-water pumping stresses on ground-water levels and on compaction of the fine-grained sediments, which causes surface deformation and land subsidence. The model can be used to predict the affects of ground-water management options on controlling water-level declines and the resulting land subsidence. The numerical model used for this current study is the U.S. Geological Survey Modular Three-Dimensional Finite-Difference Ground-Water Flow the accuracy of the input data used in the model calibration and is inversely related to the magnitude of the proposed changes in the stresses being applied to the model as well as to the length of the simulation horizon.

In this study, the model was calibrated using manual trial-and-error techniques. Owing to the complexity and unknowns of the system being represented, it is worth noting that model construction and calibration (formal or not) result in a non-unique product and that model predictions are subject to potentially large errors (Konikow and Bredehoeft, 1992). Automated approaches could be used in subsequent studies to more formally characterize uncertainties in the parameters and perhaps improve the fit of the model to calibration data (Yeh, 1986).

The model for this study did not perform well in the Graham Ranch area (model area 3); however, this area is not important to EAFB in terms of water supply nor has this area experienced land subsidence. If the Graham Ranch area does become important to EAFB, additional work will be required to improve the model in this area.

Simulated hydraulic-head responses to pumping show that faults strongly compartmentalize the ground-water flow system. It is likely that there are additional concealed faults crossing the study area that have not yet been mapped in areas that are not being pumped. If additional pumping occurs in these areas, then these concealed faults may become apparent and may need to be added to the model.

Predictive simulations should not be made in area 1 and in area 6 near the northern boundaries because the use of time-varying specified head and general-head boundaries provide unrealistic, infinite sources of water. If predictive simulations are to be made, refinement of these boundaries (probably within the context of the regional flow model) will be required.

An accurate transient-state simulation [initial value problem (Bear, 1972)] requires the accurate simulation of the initial conditions. Most of the observed pre-development water levels were measured in the upper aquifer (model layer 1); therefore, the water levels in the aquitard (model layers 2 to 4), middle (model layers 5 and 6), and lower aquifers (model layer 7) were not well defined.

To better understand the ground-water flow system and to improve the model, additional information is required. Improved hydrogeological characterization would allow corrections and refinement of the model. Installation of new wells perforated in different aquifers and clay layers would provide depth-specific data that can be used to gain a better understanding of the ground-water flow system. If new wells are installed, they initially should be installed in areas where the greatest pumping occurs (areas 2, 4, and 8). Similarly, the installation of additional extensometers, both shallow and deep, would provide data needed to better understand subsidence. The new extensometers, combined with the existing extensometers, would yield subsidence data from the individual aquifers (upper, middle, and lower) and the older lacustrine deposits (fig. 3). A formalized sensitivity study would help identify areas of model weakness and guide expenditures of observational resources (Nishikawa and Yeh, 1989).

CONCLUSIONS

A numerical ground-water flow model was developed for Edwards Air Force Base in southern California to model and help better understand ground-water flow and land subsidence at the base. The model has seven horizontal layers that correspond to the major hydrogeologic units in the study area and incorporate time-varying specified-head boundaries, no-flow boundaries, faults, drains, evapotranspiration, and interbed storage. The model was calibrated using a trial-and-error approach during which simulated hydraulic head and subsidence values were compared with measured values for selected sites. In accordance with previous studies, the simulated steady-state gradient was northward and the simulated total outflow rate was about 990 acre-feet per year.

At the end of a 50-year simulation period (1947–96), the simulated hydraulic heads generally were within 10 feet of the measured water levels and the simulated subsidence at the Holly site was 3.3 feet, which was comparable to measured subsidence values in that area. Most of the simulated compaction occurred in model layer 5. The 1996 transient-state simulation produced two subsidence centers corresponding to hydraulic-head depressions near the South Base and South Tract pumping centers. By the end of 1996, the hydraulic gradient was southward south of the basement-complex ridge located in the northern half of Rogers Lake and northward north of

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this ridge. The simulated water budget rates for 1947, 1961, and 1996 indicated that about 97, 98, and 76 percent, respectively, of the net discharge was derived from storage.

The sensitivity analysis of the model, which considered parameters specific to model areas 2 and 4, indicated that the model was sensitive to changes in the hydraulic-characteristic values of Faults 1 and 4 and in the hydraulic-conductivity and inelastic-storage values for layer 5. Specifically, increasing or decreasing the hydraulic-characteristic value of Fault 1 by an order of magnitude affected simulated hydraulic heads by as much as 45 feet and simulated subsidence by as much as 0.5 foot. Decreasing the hydraulic-characteristic value of Fault 4 by an order of magnitude affected simulated hydraulic heads by as much as 10 feet and simulated subsidence by as much as 0.5 foot. Decreasing the hydraulic-conductivity values for layer 5 by 50 percent affected simulated hydraulic heads by as much as 10 feet and simulated subsidence by as much as 0.8 foot. Decreasing the inelastic-storage values for layer 5 by an order of magnitude affected simulated hydraulic heads by as much as 45 feet and simulated subsidence by as much as 10.0 feet.

Although simulated hydraulic head and subsidence were not sensitive to vertical conductance (*VCONT*) in areas 2 and 4, the results indicated that the clay layers in area 4 hydraulically control water levels and subsidence in these areas. When *VCONT* was varied in area 2, the resulting simulated hydraulic heads and subsidence showed little change in either area; however, when *VCONT* was varied in area 4, simulated hydraulic heads and simulated subsidence were affected in both areas.

Three water-management scenarios were tested for Edwards Air Force Base: for scenario 1 (base case), 1997 pumping rates were maintained for 10 years (1997–2006); for scenario 2, water was injected steadily into the middle aquifer at well 8N/10W-1C2 in the South Tract well field between December and February, concurrent with base-case pumping; and for scenario 3, water was injected steadily into the middle aquifer at well 9N/10W-24E3 in the South Base well field, concurrent with base-case pumping. For the second and third scenarios, two separate cases were simulated: in the first case about 3 acre-feet per day of water was injected; in the second case about 30 acre-feet per day of water was injected. Injecting 3 acre-feet per day had little effect on simulated hydraulic heads; however, injecting 30 acre-feet per day raised simulated hydraulic heads more than 100 feet for both scenarios. In general, injecting 3 acre-feet per day of water had little or no effect on the total subsidence over the 10-year simulation. Subsidence still accumulated with time when 30 acre-feet per day was injected at either site, but at a much lower rate then when 3 acre-feet per day was injected. Simulated subsidence decreased 60 percent more at the S-5 production well when 30 acre-feet per day of water was injected at well 8N/10W-1C2 then when 3 acre-feet per day was injected, and simulated subsidence decreased 90 percent more at the South Base well field when 30 acre-feet per day of water was injected at well 9N/10W-24E3 than when 3 acre-feet per day was injected.

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