

#123

WATER-LEVEL

FOR INDIAN WELLS VALLEY

GROUND-WATER BASIN,

CALIFORNIA, 1978



U.S. Geological Survey

Open-File Report 79-254



EASTERN KERN CO. RCD
P.O. BOX 626

INYOKERN, CA 93527

Prepared in cooperation with the
Indian Wells Valley County Water District and the
Department of the Navy

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-LEVEL PREDICTIONS FOR
INDIAN WELLS VALLEY GROUND-WATER BASIN,
CALIFORNIA, 1978

By Michael J. Mallory

Open-File Report 79-254

Prepared in cooperation with the
Indian Wells Valley County Water District and the
Department of the Navy

7211-32

February 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

For additional information write to:

District Chief
Water Resources Division
U.S. Geological Survey
345 Middlefield Rd.
Menlo Park, Calif. 94025

CONTENTS

	Page
Conversion factors-----	IV
Abstract-----	1
Introduction-----	2
Purpose and scope-----	2
Description of the area-----	2
Previous investigations and description of the ground-water model-----	5
Water levels-----	6
Summary of water levels through 1968-----	6
Water levels from 1969 through 1976-----	11
Ground-water pumpage-----	15
Summary of ground-water pumpage through 1968-----	15
Ground-water pumpage from 1969 through 1976-----	15
Trends in areal distribution and rate of ground-water pumpage assumed for model prediction from 1977 through 2020-----	17
Water-level predictions, using the ground-water model-----	22
Summary and conclusions-----	26
Effects of the revised pumping pattern-----	26
Suggestions for future investigations-----	27
Selected references-----	27

ILLUSTRATIONS

	Page
Figure 1. Map showing location of Indian Wells Valley ground-water basin-----	3
2-7. Maps showing:	
2. Configuration of model, location of ground-water barriers, and the nodal network-----	7
3. Water-level contours for the deep aquifer, 1920-21, constructed from water-level measurements-----	8
4. Water-level contours for the deep aquifer, 1968, constructed from water-level measurements-----	9
5. Model-generated 1968 water-level contours for the deep aquifer-----	10
6. Water-level contours for the deep aquifer, 1976, constructed from water-level measurements-----	12
7. Model-generated 1976 water-level contours for the deep aquifer-----	13

Figure 8. Hydrographs of selected wells and model-generated water levels-----	Page 14
9-11. Maps showing model-generated water-level contour for the deep aquifer:	
9. For 1986-----	23
10. For 1998-----	24
11. For 2020-----	25

TABLES

Table 1. Pumpage, in acre-feet, by node for the deep aquifer for the period 1969-76, averaged for 2-year periods-----	Page 16
2. Projected pumpage, in acre-feet, by node for the deep aquifer for the period 1977-2020, averaged for 2-year periods-----	18

CONVERSION FACTORS

The inch-pound system of units is used in this report. For readers who prefer metric units, conversion factors for the terms used in this report are listed below.

<u>Multiply inch-pound unit</u>	<u>By</u>	<u>To obtain metric unit</u>
acre-ft (acre-foot)	0.001233	hm ³ (cubic hectometer)
acre-ft/yr (acre-foot per year)	0.001233	hm ³ /yr (cubic hectometer per year)
ft (foot)	0.3048	m (meter)
ft ² /d (foot squared per day)	0.0929	m ² /d (meter squared per day)
gal/min (gallon per minute)	0.003785	m ³ /min (cubic meter per minute)
inch	25.40	mm (millimeter)
mi (mile)	1.609	km (kilometer)

WATER-LEVEL PREDICTIONS FOR
INDIAN WELLS VALLEY GROUND-WATER BASIN,
CALIFORNIA, 1978

By Michael J. Mallory

ABSTRACT

Ground-water pumpage in Indian Wells Valley, virtually a closed basin in the Mojave Desert of southern California, has increased gradually since 1945 and presently exceeds the long-term mean annual recharge (perennial supply). In order to aid in the understanding and management of the ground-water basin, a digital ground-water model was constructed by the U.S. Geological Survey. Since the original development of this model, conditions in the basin, including areal distribution and rates of ground-water pumpage, have changed.

The results of the present simulation for the period 1969-76 constitute a second verification of the original model. Calculated heads for 1976 agree well with the observed heads, indicating a good calibration of the original model.

A predictive simulation for the period 1977-2020 used pumpage values increasing from about 15,500 acre-feet per year to about 26,000 acre-feet per year. The pumpage used in this report reflects a slightly slower growth rate and a more concentrated pattern of development than that investigated when the model was originally developed. The effects of this pattern of pumpage are reflected in the water levels simulated by the model. Predicted drawdowns for 1983 are less extensive but locally more severe than those predicted earlier.

The reversal of the hydraulic gradient between China Lake playa and the city of Ridgecrest, as produced by these drawdowns by the year 2020, suggests that the water-quality effects of such drawdowns should be investigated, as this could result in inferior water from the China Lake playa area flowing southward into areas of withdrawal.

INTRODUCTION

Purpose and Scope

Ground-water pumpage in Indian Wells Valley has increased gradually since 1945 and presently exceeds the long-term mean annual recharge (perennial supply). In order to aid in the understanding and management of the ground-water basin, a digital ground-water flow model was constructed by the U.S. Geological Survey (Bloyd and Robson, 1971).

The purpose of this investigation was to apply the model developed by Bloyd and Robson to a pattern of ground-water development that is consistent with current conditions and with management philosophies for the basin. Nearly 10 years of additional data have been collected since the model was first constructed. Changing conditions in the basin, including areal distribution and rates of ground-water withdrawals, have been documented by the data collected. Using these conditions, water-level predictions were made for the basin through the year 2020.

The scope of the investigation consisted of:

1. Evaluation of changes in land use and ground-water withdrawal patterns since the last comprehensive canvass in 1968.

2. Reevaluation of the future water-demand rates used by Bloyd and Robson (1971) in making an initial prediction of ground-water levels in Indian Wells Valley through 1983. In making this reevaluation, quantitative records of water use and water-level data for the basin, collected annually by the Geological Survey, were utilized.

3. Prediction, based on current development plans and growth rates, of ground-water levels in Indian Wells Valley through 2020.

Description of the Area

Indian Wells Valley (fig. 1) is in the western part of the Mojave Desert in southern California, about 125 mi north of Los Angeles. It is bounded on the west by the Sierra Nevada, on the east by the Argus Range, on the south by the El Paso Mountains, on the north by the Coso Range and a low ridge, and on the southeast by low, unnamed bedrock hills.

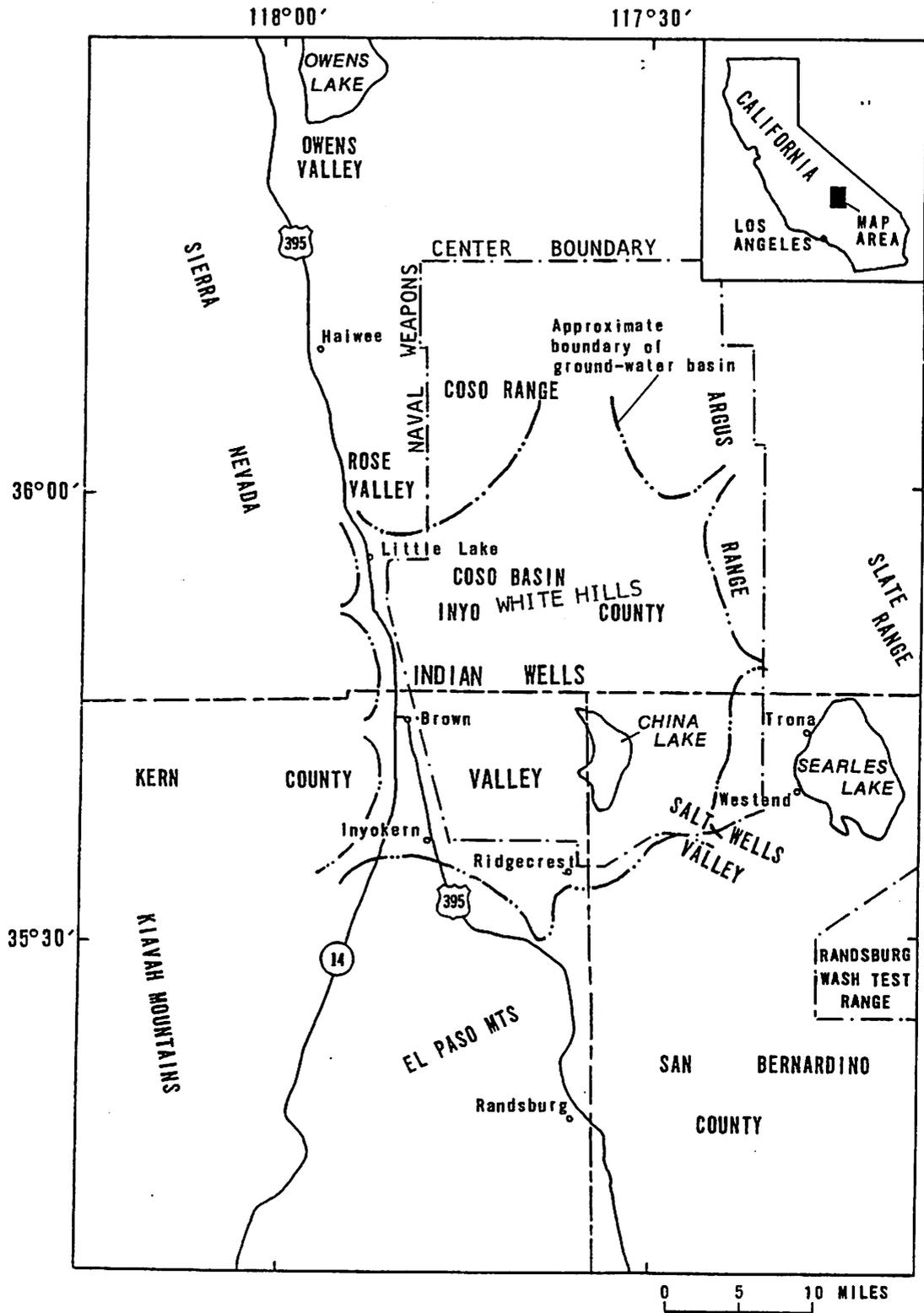


FIGURE 1. --Location of Indian Wells Valley ground-water basin.

The valley is a structural and topographic depression with internal surface drainage. Major physiographic features of the valley are the steep fault scarp along the base of the Sierra Nevada, the broad alluvial fans that extend from the mouths of the Sierra Nevada canyons, and the flat playas that occupy the east-central part of the valley. The alluvial fans have coalesced to form alluvial plains several miles wide, that slope with decreasing steepness from the escarpment eastward toward the playas. Most of the central part of the valley is less than 2,400 ft above sea level. The lowest of the playas, China Lake, is 2,152 ft above sea level.

The climate of Indian Wells Valley is arid. Average rainfall on the valley floor is 4 to 6 inches. Most of the precipitation occurs during the period October-March; during the remainder of the year, rain falls infrequently as summer thundershowers. Hot days and cool nights characterize the summers in the valley; warm days and cold nights are usual in the winter.

The geology, aquifer characteristics, and ground-water flow were described and documented in two previous hydrologic studies of Indian Wells Valley by Kunkel and Chase (1969) and Dutcher and Moyle (1973).

Alluvium of Pleistocene and Holocene age is the principal water-bearing unit in the valley. The deposits are unconsolidated and consist of moderately well-sorted gravel, sand, silt, and clay. They overlie a non-water-bearing granitic basement complex of pre-Jurassic age that forms the structural basin in which the younger units have been deposited. They are variable in permeability and, where saturated and well sorted, yield water to wells at rates of more than 4,000 gal/min. The alluvium consists of lenticular beds of clastic material derived from the surrounding uplands. Local units are heterogeneous mixtures ranging in grain size from gravel to silt or clay. In general, however, much of the alluvium is fairly well-sorted coarse sand and gravel with a gradual decrease in grain size and a higher proportion of bedded sand and silt toward the central part of the valley. In the eastern part of the valley, extensive silt and clay beds, presumably deposited in perennial lakes, partly confine ground water in the deep aquifers. The thickness of the alluvium probably is about 2,000 ft in the deepest part of the basin (Zbur, 1963). These deposits are represented as the deep aquifer in the digital model.

Overlying the alluvium in the east-central part of the valley are playa deposits of Holocene age that consist mainly of silt and clay and are of low permeability. Water in these deposits usually has a moderate to very high concentration of dissolved solids. These deposits are represented as the shallow aquifer in the digital model.

Geologic, geophysical, and hydrologic data for the valley indicate several major faults along which the basement complex and the alluvium have been displaced. Several of the faults that cut the alluvium restrict the movement of ground water between the recharge areas on the west and the discharge, or playa, areas on the east (Dutcher and Moyle, 1973, pls. 1, 2, and 3). Most of the major faults in the valley strike northwest; the faults divide the basin into a series of ground-water subunits. How these faults are treated in the ground-water model is discussed in the following section.

Previous Investigations and Description of the Ground-Water Model

Hydrologic work in Indian Wells Valley was started by Lee (1913) who estimated the perennial yield. Kunkel and Chase (1969) and Dutcher and Moyle (1973), in addition to studying the geology as previously mentioned, described the hydrology of the valley and estimated the recharge, discharge, perennial yield, and storage in two ground-water units in the central and western parts of the valley. Also, the report by Dutcher and Moyle (1973) presented initial estimates of transmissivity and storage coefficient to be used in developing a ground-water model.

Bloyd and Robson (1971) refined the estimates of aquifer parameters made by Dutcher and Moyle (1973) in the process of calibrating the digital model of the Indian Wells Valley area that was used again in this study. Their final values of the aquifer characteristics were hydrologically reasonable and in general agreement with the estimates of Dutcher and Moyle (1973).

The transmissivity used for the deep aquifer in the model ranged from about 33,500 ft²/d in the south-central part of the valley to less than 2,900 ft²/d in the extreme southeastern part of the valley. The ground-water barriers or faults were simulated in the model by use of a narrow zone of transmissivity ranging from 27 ft²/d to 3,300 ft²/d.

The storage coefficient used in the model for the deep aquifer ranged from 0.0001 to 0.20. Where the deep aquifer is overlain by the shallow aquifer or, as in the White Hills area, by volcanic rocks, the deep aquifer was assumed to be confined and to have a storage coefficient of 0.0001. Elsewhere the deep aquifer was assumed to be unconfined and to have a storage coefficient of 0.05 to 0.20.

Dutcher and Moyle (1973) and Kunkel and Chase (1969) determined the steady-state discharge, and consequently the steady-state recharge, because under steady-state conditions recharge must equal discharge. Their determination was 11,000 acre-ft/yr. Bloyd and Robson (1971) modified this value to 9,850 acre-ft/yr during their calibration of the digital model. The above values for aquifer characteristics and average annual recharge developed by Bloyd and Robson (1971) were used without modification in the present study.

The digital model developed by Bloyd and Robson (1971) used the alternating-direction implicit method (Peaceman and Rachford, 1955) to solve a finite-difference approximation of the two-dimensional equation of ground-water flow. A detailed theoretical development of the digital model was reported by Pinder and Bredehoeft (1968) and is not repeated in this report. The programming techniques used in the Indian Wells Valley model were described in a report by Maddock (1970).

Figure 2 shows the model boundary, location of ground-water barriers, and nodal network used in the digital model.

WATER LEVELS

Summary of Water Levels through 1968

Bloyd and Robson (1971) calibrated the ground-water model by simulating the water levels of the basin from 1920 through 1968. Initial calibration of the model was made by simulating the measured water-level distribution for 1920-21 (fig. 3) in the valley. This distribution was assumed to represent a steady-state condition where recharge and discharge were equal, and no change in storage was taking place. Dynamic or nonsteady-state calibration was accomplished by adjusting the storage coefficients and transmissivities used in the model until the model satisfactorily simulated the measured water levels from 1930 through 1953.

After a model is calibrated and before it is used for prediction, it should be verified by successfully simulating the effects of a set of discharge stresses different from those used in the calibration and comparing the model-generated water levels with the measured water levels. For Bloyd and Robson's (1971) model, this was done by simulating the period 1954-68 with the same aquifer characteristics determined during the calibration and using observed water-level measurements for 1954 through 1968. The 1968 distribution of measured water levels is shown in figure 4. These measured water levels compared favorably with the model-generated water-level contours for this date (fig. 5).

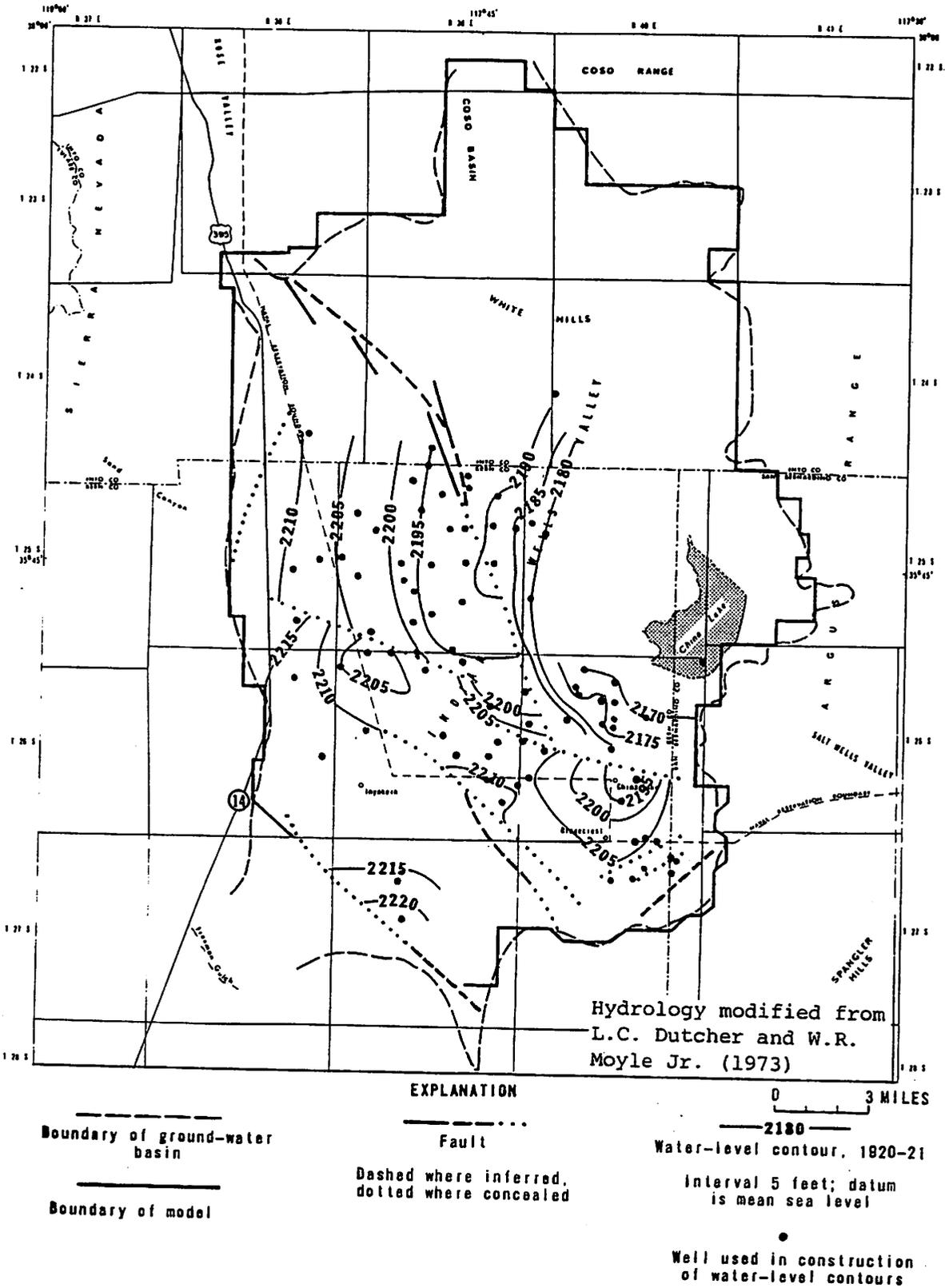


FIGURE 3. --Water-level contours for the deep aquifer, 1920-21, constructed from water-level measurements (from Bloyd and Robson, 1971).

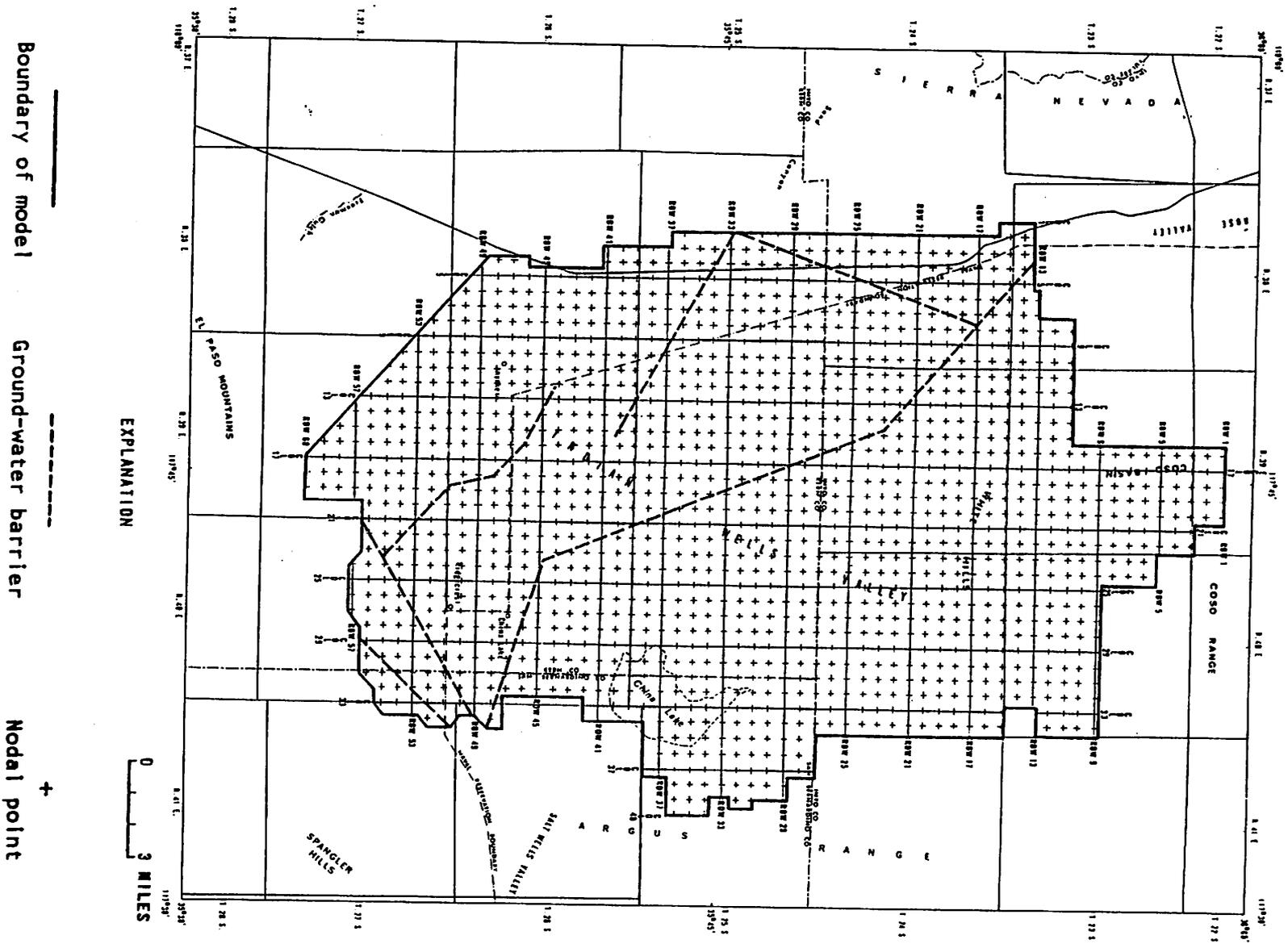


FIGURE 2. ---Configuration of Indian Wells Valley model, location of ground-water barriers, and the nodal network (modified from Bloyd and Robson, 1971).

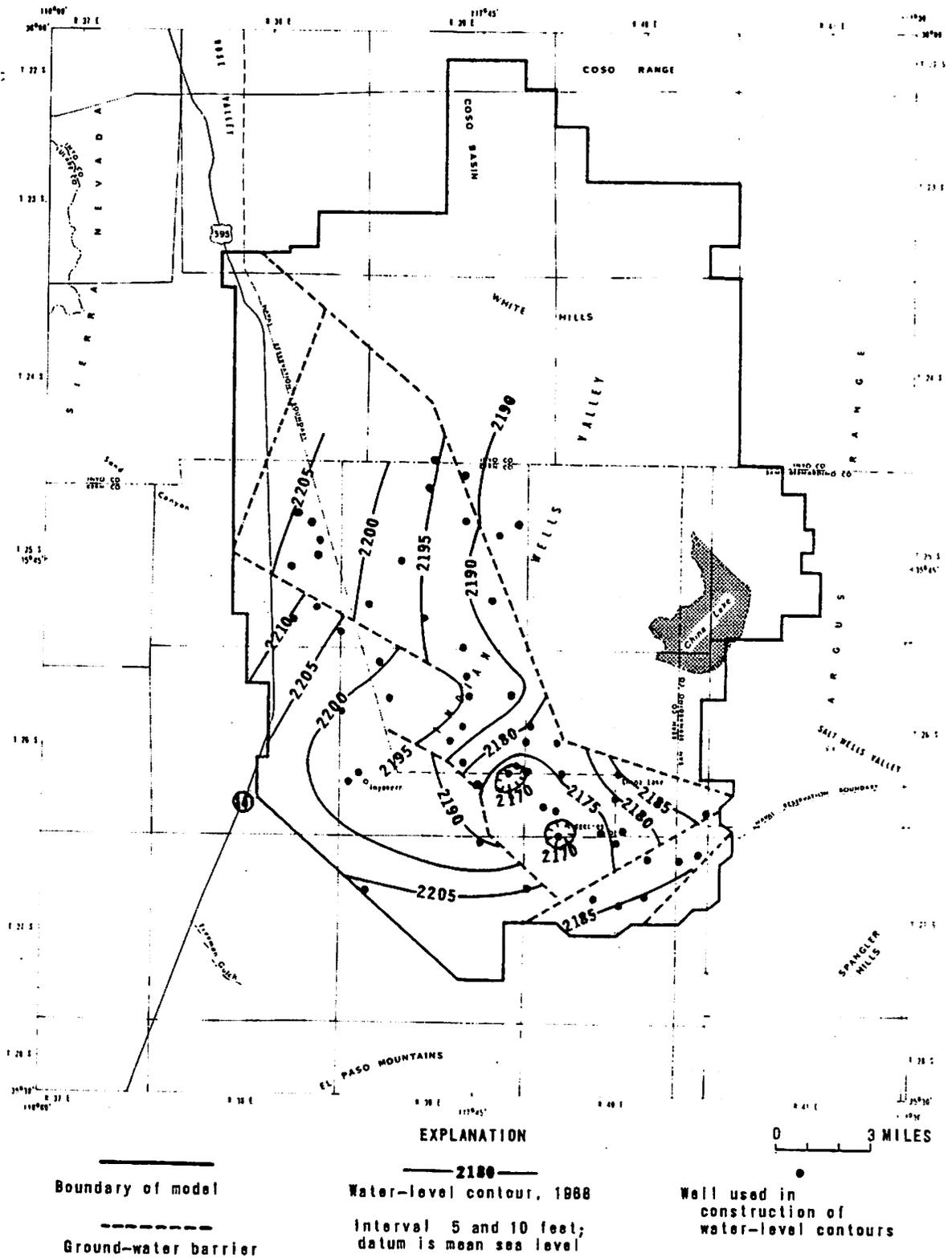
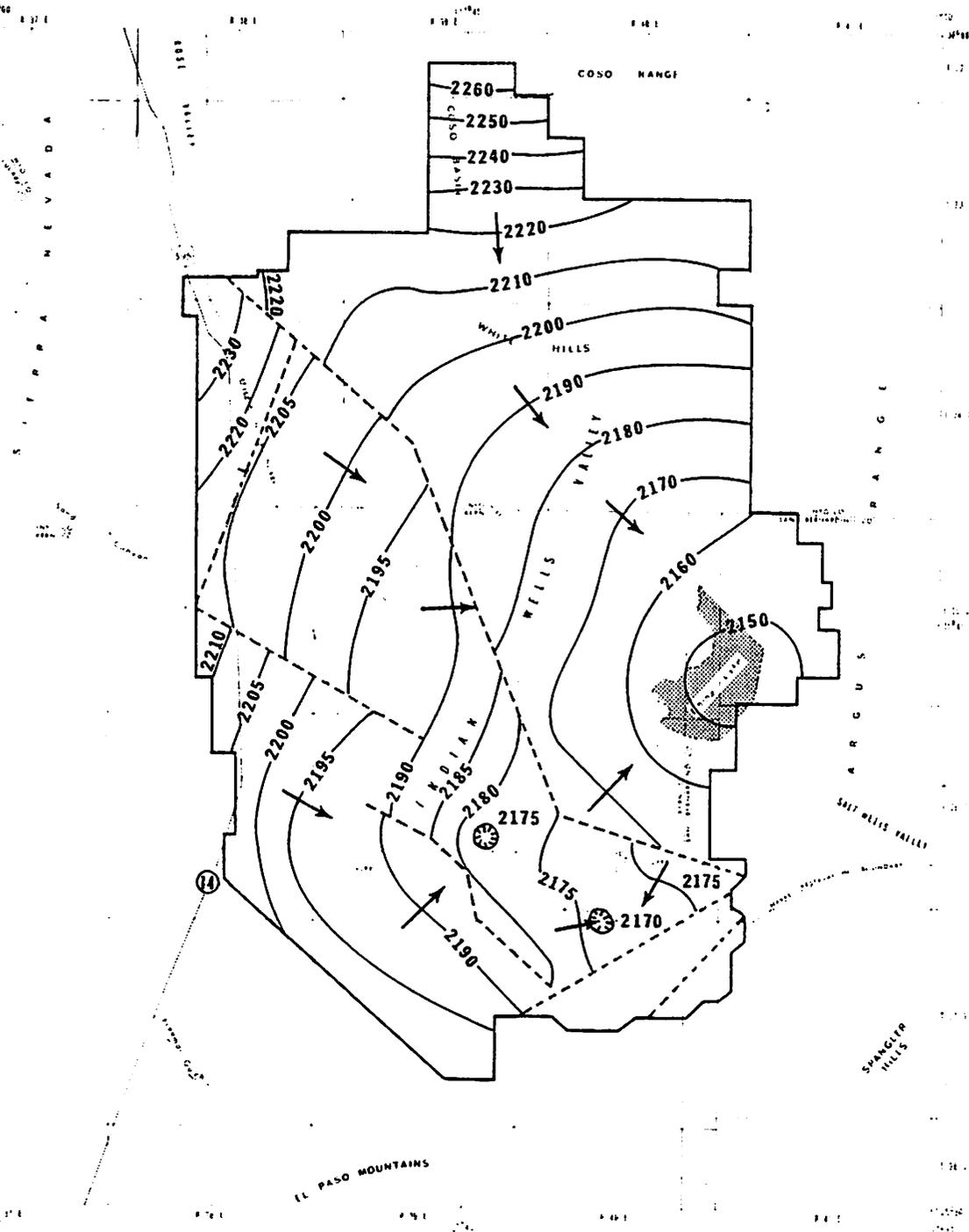


FIGURE 4. --Water-level contours for the deep aquifer, 1968, constructed from water-level measurements (from Bloyd and Robson, 1971).



EXPLANATION

<p>————— Boundary of model</p> <p>----- Ground-water barrier</p>	<p>————— 2150 ————— Water-level contour</p> <p>Interval 5 and 10 feet; datum is mean sea level</p> <p>—————>————— Direction of flow</p>
--	--

0 3 MILES

FIGURE 5. --Model-generated 1968 water-level contours for the deep aquifer (from Bloyd and Robson, 1971).

Water Levels from 1969 through 1976

Because 1968 was the last year for which a measured water-level map was available to Bloyd and Robson (1971), the period 1969-76 was used as a second verification of the digital model in the present study. Figure 6 is a contour map based on measured water levels for 1976, and figure 7 is a contour map based on the model-generated water levels for 1976 developed as part of this study. The model-generated map was produced by using the reported pumpage for the valley for the period 1969-76. Simulation was begun at a time representing January 1, 1969. The map of figure 7 is for the last day of 1976, but, because all pumpages were modeled as an average annual pumping rate, the contours represent the average water level for that year.

Figure 8 presents hydrographs of selected wells and model-generated water levels for the nodes representing the same sites. Comparison of the water levels is generally good. However, drawdown at the node (51,25) nearest well 26S/40E-30E2, which was pumping at the time measurements for the 1976 water-level map were made, is about 30 ft less than that measured at the nearest nonpumping well. Model-generated water levels reflect the effect of withdrawals as if they were uniformly distributed across the area of the grid cell. Reduction of this areal average drawdown generated by the model may account for some of the difference between measured and simulated water levels.

A method used by Trescott and others (1976) can be used to quantify this correction of an areal average drawdown to real-well radius. This computation uses the radius, r_e , of a hypothetical well for which the average value of head for the grid cell applies. An approximating equation is then used to make the extrapolation from r_e to the radius of the real well. The radius r_e can be computed (Prickett, 1967) as:

$$r_e = r_l / 4.81 \quad (1)$$

where r_l equals the dimension of a side of the grid cell. For this study all nodes are on $\frac{1}{2}$ -mile centers; therefore r_l equals 2,640 ft. The Theim equation is used to extrapolate from the average hydraulic head for the cell at radius r_e to the head, h_w , at the desired well radius, r_w (Prickett and Longquist, 1971). The equation can be written:

$$h_w = h - \frac{Q_w}{2\pi T} \ln \left(\frac{r_e}{r_w} \right) \quad (2)$$

where Q_w is the well discharge, h is the model-generated head, and T is transmissivity. This equation assumes that the aquifer is homogeneous and isotropic within the grid cell and that all discharge from the grid cell comes from one fully penetrating well at the center of the grid cell.

For the grid cell surrounding node 51,26, well discharge, Q_w , is 1,420 acre-ft/yr; transmissivity, T , is 28,000 ft²/d; storage coefficient, S , is 0.10; and the model-generated head, h , is 2,162 ft. The radius of well 26S/40E-30E2, which is near the center of the pumping depression, is 7 inches, and r_e can be taken as 550 ft. Applying equation 2 yields a water level, at real-well radius, of 2,153 ft above mean sea level, which is in better agreement with the measured water level at well 26S/40E-30E2.

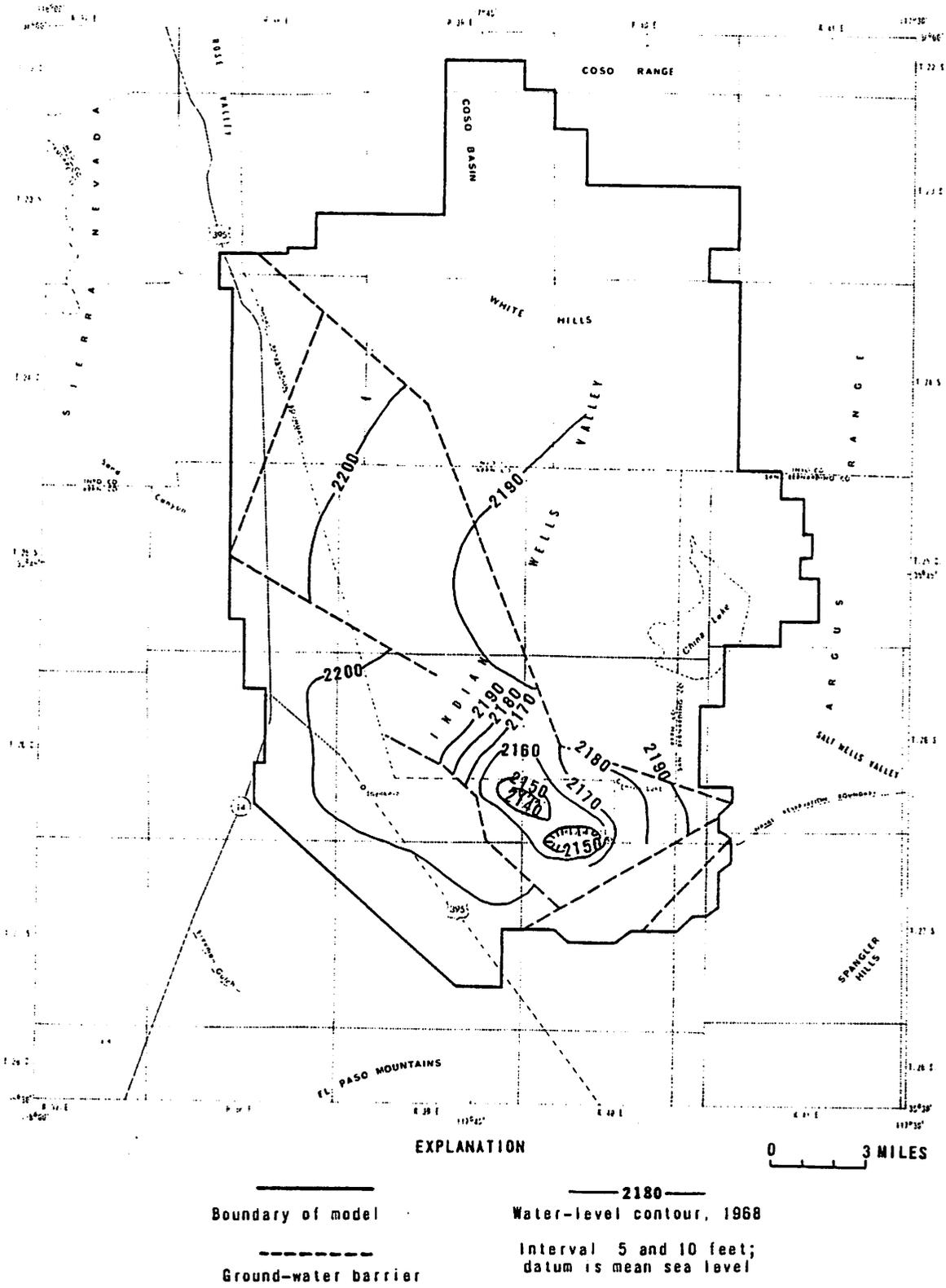


FIGURE 6. --Water-level contours for the deep aquifer, 1976, constructed from water-level measurements (modified from Lamb and Downing, 1978).

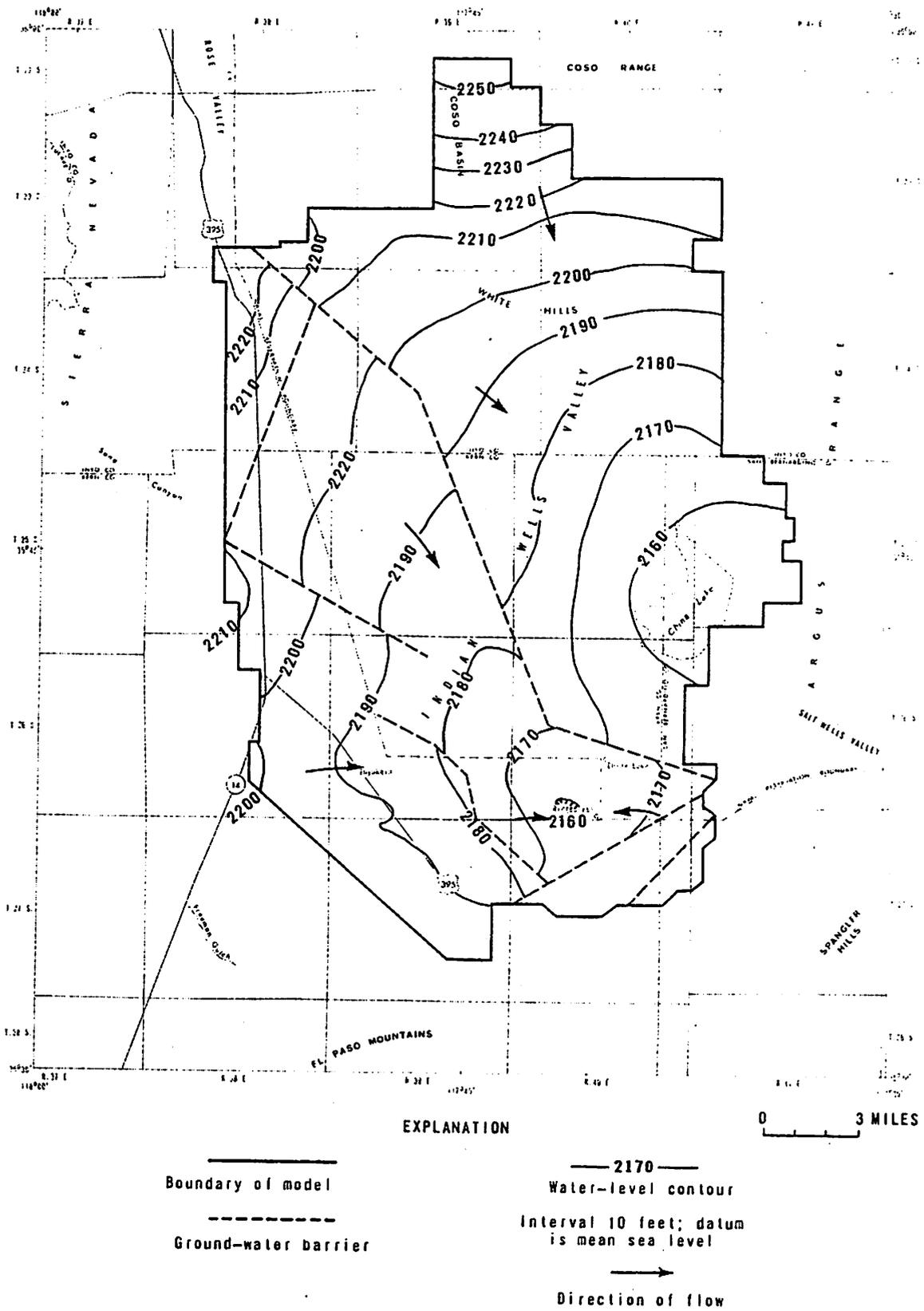


FIGURE 7. --Model-generated 1976 water-level contours for the deep aquifer.

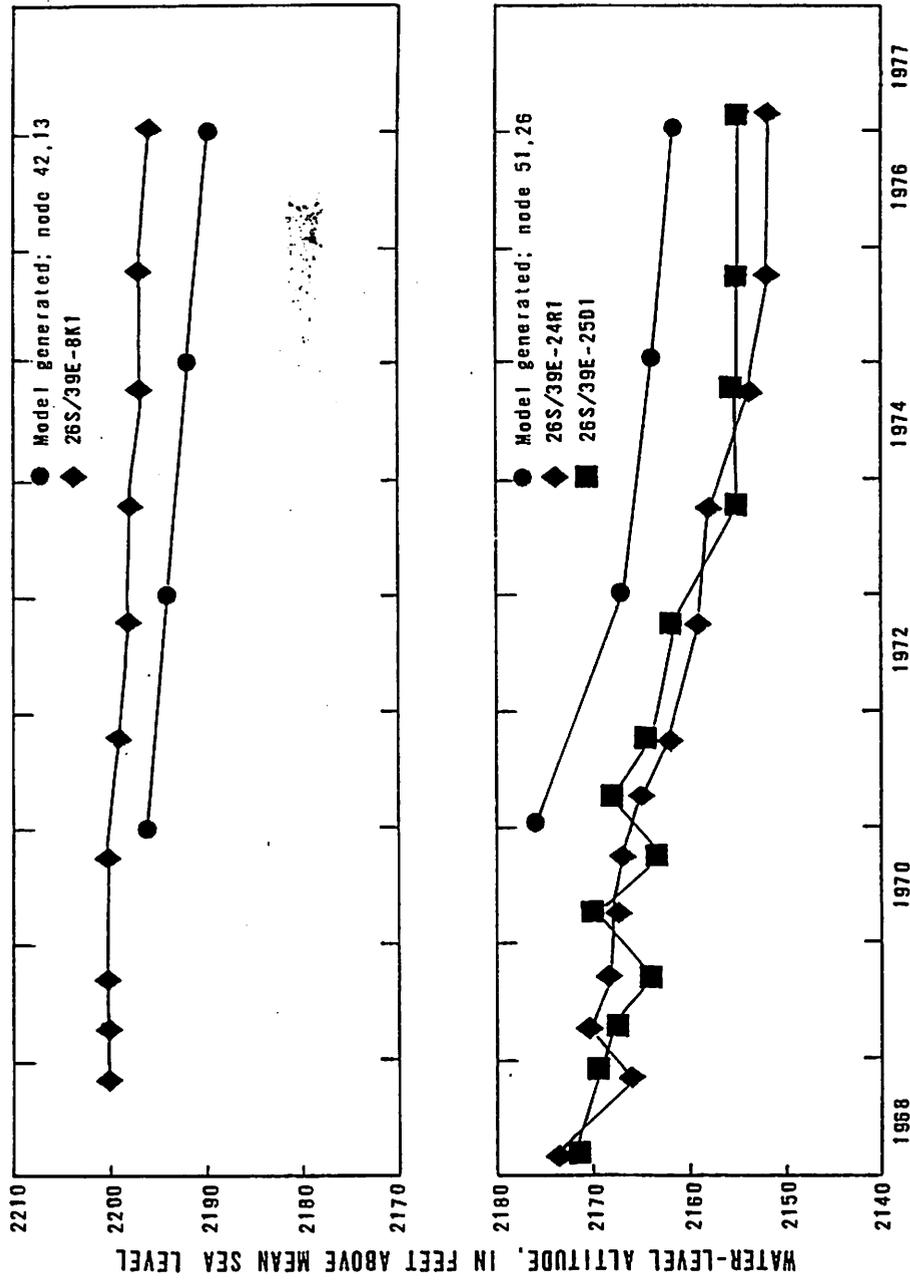


FIGURE 8. --Hydrographs of selected wells and model-generated water levels.

GROUND-WATER PUMPAGE

Summary of Ground-Water Pumpage through 1968

In the process of calibrating and verifying the ground-water model for the period 1930-68, Bloyd and Robson (1971) collected data on ground-water pumpage for that period. These data were summarized in table 5 of their report. Withdrawals were compiled from records of metered pumpage, and they established the trends of ground-water pumpage used in projections to 1983. The records show that, historically, the Navy has been the largest water user in the valley since about 1945, followed by Indian Wells Valley County Water District, Stauffer Chemical Co. (now owned by Kerr McGee Chemical Corp.), and American Potash and Chemical Co. (also now owned by Kerr McGee). The records also show that major ground-water developments were near Ridgecrest and near Inyokern and in an area midway between the two.

Ground-Water Pumpage from 1969 through 1976

Metered pumpage data for the period 1969-76 (shown in table 1 as modeled for 2-year periods) show some deviation from the pumpage predicted by Bloyd and Robson. The pumpage assumed for this period by Bloyd and Robson (1971) increased from 13,307 acre-ft/yr in 1969 to 16,670 acre-ft/yr in 1976. The metered pumpage figures now available for this period show that actual pumpage increased from 13,500 acre-ft in 1969 to about 14,100 acre-ft in 1976. These figures suggest that, although the pumpage for 1969 was slightly underestimated by Bloyd and Robson (1971), the rate of growth of water use estimated by them was considerably greater than the rate that occurred in the valley during this period. In fact, metered pumpage data show an actual decline in ground-water use from 1975 to 1976, withdrawals for these years being 14,500 acre-ft and 14,100 acre-ft, respectively.

Agricultural water use in the valley was estimated by multiplying consumptive use factors times the area planted in crops and pasture. A canvass of agricultural land use was made as part of this project in October 1977.

TABLE 1.--Pumpage, in acre-feet, by node for the deep aquifer for the period 1969-76, averaged for 2-year periods
 [Negative pumpage indicates recharge]

NODE	1969-70	1971-72	1973-74	1975-76
20.13	0	0	0	0
21.13	0	0	0	0
29.15	12	4	9	13
30.7	0	0	0	0
30.15	0	17	11	7
31.21	5	11	6	2
35.8	0	0	0	0
36.9	20	60	175	400
36.19	17	8	10	11
37.8	280	250	150	60
38.9	20	60	175	400
39.17	11	3	3	3
40.12	0	4	5	5
41.24	11	48	17	18
42.18	29	29	34	40
45.17	100	0	0	0
45.28	-23	-23	-23	-23
45.29	-43	-43	-43	-43
46.10	633	411	557	965
46.19	3847	3388	2915	2741
46.29	-43	-43	-43	-43
46.30	-43	-43	-43	-43
46.31	-23	-23	-23	-23
47.10	1855	2094	1650	1174
47.14	35	30	23	18
47.19	734	585	591	599
47.20	593	1000	1133	689
47.21	284	0	0	0
48.10	864	950	1132	975
48.17	16	19	26	33
48.19	284	585	591	599
48.21	284	0	0	0
48.22	980	1275	1475	1993
48.23	0	0	0	0
49.23	0	0	0	0
49.24	0	0	0	0
50.23	35	33	28	23
50.24	0	0	0	0
51.23	1713	820	690	690
51.24	0	0	0	0
51.25	0	585	591	599
51.26	370	1685	1574	1420
51.27	0	12	11	0
52.23	75	85	90	80
52.24	75	75	75	0
52.26	500	500	700	590
52.30	-25	-25	-25	-25
52.31	-25	-25	-25	-25
53.24	150	180	200	231
53.25	70	85	75	77
54.23	70	85	75	77
<hr/>				
TOTAL	13747	14748	14567	14302

Trends in Areal Distribution and Rate of Ground-Water Pumpage

Assumed for Model Prediction from 1977 through 2020

The ground-water withdrawals shown in table 2 for the years 1977 through 2020 are the assumed pumpages for this period used to make the water-level predictions presented in this report. Locations and amounts of proposed withdrawals for the Indian Wells Valley County Water District were taken from a report which was prepared for the District by Krieger and Stewart, Engineering Consultants (1977). Their report proposes the drilling of eight new wells between 1978 and the year 2015 to supply an anticipated 200-percent growth in service by the District by the year 2020. At the 200-percent growth level, it is predicted that the District would pump 12,622 acre-ft of water per year. This figure is based on the assumption that the Water District may, at some time in the future, acquire responsibility for supplying water to the "Annexation No. 18" area, which includes "Wherry Housing," a tract of houses in the community of China Lake presently served by the Navy, and the Ridgecrest Heights area in Ridgecrest, which is presently served by a private utility.

Because of this shift of responsibility for supplying water to Wherry Housing, pumpage assumed for the Navy is reduced by this amount. Furthermore, the amount of water pumped by the Naval Weapons Center for research and development purposes declined during the period 1969-77. On the basis of these factors, the modeled pumpage assumed for the Navy was held constant at the rate determined for 1977 until the mid-1980's, after which it was gradually increased at a much smaller rate than that assumed by Bloyd and Robson (1971).

Water withdrawals for agricultural use were held constant at the rates determined for 1977. This does not imply that agricultural water use in the area is not expected to increase. Future investigations are planned which will attempt to quantify the effects of various levels of agricultural growth.

TABLE 2.--Projected pumpage, in acre-feet, by node for the deep aquifer
for the period 1977-2020, averaged for 2-year periods
 [Negative pumpage indicates recharge]

NODE	1977-78	1979-80	1981-82	1983-84	1985-86	1987-88
20,13	63	125	125	125	125	125
21,13	63	125	125	125	125	125
29,15	11	10	10	10	10	10
30, 7	400	800	800	800	800	800
30,15	9	10	10	10	10	10
31,21	2	2	2	2	2	2
35, 8	200	400	400	400	400	400
36, 9	550	550	550	550	550	550
36,19	10	10	10	10	10	10
37, 8	10	0	0	0	0	0
38, 9	550	550	550	550	550	550
39,17	3	3	3	3	3	3
40,12	5	5	5	5	5	5
41,24	17	15	15	15	15	15
42,18	46	50	50	50	50	50
45,17	0	0	0	0	0	0
45,28	-23	-23	-23	-23	-23	-23
45,29	-43	-43	-43	-43	-43	-43
46,10	819	633	633	633	633	633
46,19	3214	3847	3847	3847	3847	3847
46,29	-43	-43	-43	-43	-43	-43
46,30	-43	-43	-43	-43	-43	-43
46,31	-23	-23	-23	-23	-23	-23
47,10	1618	1855	1855	1855	1855	1855
47,14	16	16	16	16	16	16
47,19	606	707	807	807	807	807
47,20	556	593	593	593	593	593
47,21	0	0	0	0	0	0
48,10	727	798	864	864	864	864
48,17	35	35	35	35	35	35
48,19	606	707	807	807	807	807
48,21	0	0	0	0	0	0
48,22	2535	2624	2712	2718	2567	2409
48,23	0	0	0	0	0	0
49,23	0	0	0	0	0	0
49,24	0	0	0	0	0	803
50,23	20	20	20	20	20	20
50,24	0	452	904	906	856	803
51,23	691	798	905	916	931	935
51,24	0	0	0	454	856	803
51,25	606	707	807	807	807	807
51,26	756	707	807	807	807	807
51,27	0	0	0	0	0	0
52,23	85	92	98	109	124	128
52,24	0	0	0	0	0	0
52,26	400	475	550	550	550	550
52,30	-25	-25	-25	-25	-25	-25
52,31	-25	-25	-25	-25	-25	-25
53,24	341	367	393	437	496	511
53,25	85	92	98	109	124	128
54,23	85	92	98	109	124	128
<hr/>						
TOTAL	15511	18043	19279	19829	20148	20719

TABLE 2.--Projected pumpage, in acre-feet, by node for the deep aquifer for the period 1977-2020, averaged for 2-year periods--Continued

NODE	1989-90	1991-92	1993-94	1995-96	1997-98
20,13	125	125	125	125	125
21,13	125	125	125	125	125
29,15	10	10	10	10	10
30, 7	800	800	800	800	800
30,15	10	10	10	10	10
31,21	2	2	2	2	2
35, 8	400	400	400	400	400
36, 9	550	550	550	550	550
36,19	10	10	10	10	10
37, 8	0	0	0	0	0
38, 9	550	550	550	550	550
39,17	3	3	3	3	3
40,12	5	5	5	5	5
41,24	15	15	15	15	15
42,18	50	50	50	50	50
45,17	0	0	0	0	0
45,28	-23	-23	-23	-23	-23
45,29	-43	-43	-43	-43	-43
46,10	633	633	633	633	633
46,19	3847	3847	3847	3847	3847
46,29	-43	-43	-43	-43	-43
46,30	-43	-43	-43	-43	-43
46,31	-23	-23	-23	-23	-23
47,10	1855	1855	1855	1855	1855
47,14	16	16	16	16	16
47,19	807	807	807	807	807
47,20	593	593	593	593	593
47,21	0	0	0	0	0
48,10	864	864	864	864	864
48,17	35	35	35	35	35
48,19	807	807	807	807	807
48,21	0	0	0	0	0
48,22	2526	2643	2643	2643	2571
48,23	0	0	0	0	0
49,23	0	0	0	0	417
49,24	842	881	881	881	857
50,23	20	20	20	20	427
50,24	842	881	881	881	857
51,23	941	946	946	946	931
51,24	842	881	881	881	857
51,25	807	807	807	807	807
51,26	807	807	807	807	807
51,27	0	0	0	0	0
52,23	134	139	139	139	124
52,24	0	0	0	0	250
52,26	550	550	550	550	550
52,30	-25	-25	-25	-25	-25
52,31	-25	-25	-25	-25	-25
53,24	533	555	555	555	493
53,25	134	139	139	139	124
54,23	134	139	139	139	124
<hr/>					
TOTAL	20997	21275	21275	21275	22080

TABLE 2.--Projected pumpage, in acre-feet, by node for the deep aquifer for the period 1977-2020, averaged for 2-year periods--Continued

NODE	1999-2000	2001-02:	2003-04	2005-06	2007-08
20,13	125	125	125	125	125
21,13	125	125	125	125	125
29,15	10	10	10	10	10
30, 7	800	800	800	800	800
30,15	10	10	10	10	10
31,21	2	2	2	2	2
35, 8	400	400	400	400	400
36, 9	550	550	550	550	550
36,19	10	10	10	10	10
37, 8	0	0	0	0	0
38, 9	550	550	550	550	550
39,17	3	3	3	3	3
40,12	5	5	5	5	5
41,24	15	15	15	15	15
42,18	50	50	50	50	50
45,17	0	0	0	0	0
45,28	-23	-23	-23	-23	-23
45,29	-43	-43	-43	-43	-43
46,10	633	633	633	633	633
46,19	3847	3847	3847	3847	3847
46,29	-43	-43	-43	-43	-43
46,30	-43	-43	-43	-43	-43
46,31	-23	-23	-23	-23	-23
47,10	1855	1855	1855	1855	1855
47,14	16	16	16	16	16
47,19	807	807	807	807	807
47,20	593	593	593	593	593
47,21	0	0	0	0	0
48,10	864	864	864	864	864
48,17	35	35	35	35	35
48,19	807	807	807	807	807
48,21	0	0	0	0	0
48,22	2555	2610	2610	2610	2610
48,23	0	0	0	0	0
49,23	852	870	870	870	870
49,24	852	870	870	870	870
50,23	852	870	870	870	870
50,24	852	870	870	870	870
51,23	861	807	807	807	807
51,24	852	870	870	870	870
51,25	807	807	807	807	807
51,26	807	807	807	807	807
51,27	0	0	0	0	0
52,23	111	113	113	113	113
52,24	507	513	513	513	513
52,26	550	550	550	550	550
52,30	-25	-25	-25	-25	-25
52,31	-25	-25	-25	-25	-25
53,24	441	450	450	450	450
53,25	111	113	113	113	113
54,23	111	113	113	113	113

TOTAL	23003	23120	23120	23120	23120
-------	-------	-------	-------	-------	-------

TABLE 2.--Projected pumpage, in acre-feet, by node for the deep aquifer for the period 1977-2020, averaged for 2-year periods--Continued

NODE	2009-10	2011-12	2013-14	2015-16	2017-18	2019-20
20,13	125	125	125	125	125	125
21,13	125	125	125	125	125	125
29,15	10	10	10	10	10	10
30, 7	800	800	800	800	800	800
30,15	10	10	10	10	10	10
31,21	2	2	2	2	2	2
35, 8	400	400	400	400	400	400
36, 9	550	550	550	550	550	550
36,19	10	10	10	10	10	10
37, 8	0	0	0	0	0	0
38, 9	550	550	550	550	550	550
39,17	3	3	3	3	3	3
40,12	5	5	5	5	5	5
41,24	15	15	15	15	15	15
42,18	50	50	50	50	50	50
45,17	0	0	0	0	0	0
45,28	-23	-23	-23	-23	-23	-23
45,29	-43	-43	-43	-43	-43	-43
46,10	633	633	633	633	633	633
46,19	3847	3847	3847	3847	3847	3847
46,29	-43	-43	-43	-43	-43	-43
46,30	-43	-43	-43	-43	-43	-43
46,31	-23	-23	-23	-23	-23	-23
47,10	1855	1855	1855	1855	1855	1855
47,14	16	16	16	16	16	16
47,19	807	807	807	807	807	807
47,20	593	593	593	593	593	593
47,21	0	0	0	0	0	0
48,10	864	864	864	864	864	864
48,17	35	35	35	35	35	35
48,19	807	807	807	807	807	807
48,21	0	0	0	0	0	0
48,22	2721	2832	2832	2832	2832	2832
48,23	0	0	0	0	0	502
49,23	907	944	944	944	944	974
49,24	1379	1888	1888	1888	1888	1947
50,23	907	944	944	944	944	974
50,24	907	944	944	944	944	974
51,23	869	931	931	931	931	932
51,24	907	944	944	944	944	974
51,25	807	807	807	807	807	807
51,26	807	807	807	807	807	807
51,27	0	0	0	0	0	0
52,23	119	125	125	125	125	125
52,24	620	727	727	727	727	885
52,26	550	550	550	550	550	550
52,30	-25	-25	-25	-25	-25	-25
52,31	-25	-25	-25	-25	-25	-25
53,24	475	500	500	500	500	500
53,25	119	125	125	125	125	125
54,23	119	125	125	125	125	125

TOTAL	24100	25080	25080	25080	25080	25917
-------	-------	-------	-------	-------	-------	-------

WATER-LEVEL PREDICTIONS, USING THE GROUND-WATER MODEL

Figures 9, 10, and 11 are model-generated water-level maps for December 31 in 1986, 1998, and 2020, respectively. Population projections for the valley indicate that these dates will represent growth milestones of 50, 100, and 200 percent. These maps, and the model output for other years for which maps are not reproduced here, indicate that the northeastward component of gradient across the "China Lake barrier" (the ground-water barrier northeast of the community of China Lake) will be greatly reduced, and may be locally reversed, as early as 1984. The maintenance of a northeastward gradient in this area probably is a major factor in preventing water of poor quality underlying China Lake playa from migrating into the area southwest of the barrier where most ground-water withdrawals occur. By 2020 a pronounced southwestward gradient across the barrier is indicated by the model (fig. 11). Under these circumstances, it is possible that some quality degradation might occur in the Ridgecrest area. The amount of possible degradation cannot be quantified by a flow model alone.

The model indicates that by 2020 the water levels in some areas near Ridgecrest will have declined to approximately 2,080 ft above sea level. This water level represents a decline of about 125 ft from the 1921, or steady state, water level and is about 84 ft lower than the lowest model-generated water levels for 1976. The center of this drawdown would be near the proposed Indian Wells Valley County Water District Well "B," which is modeled at node 51,24.

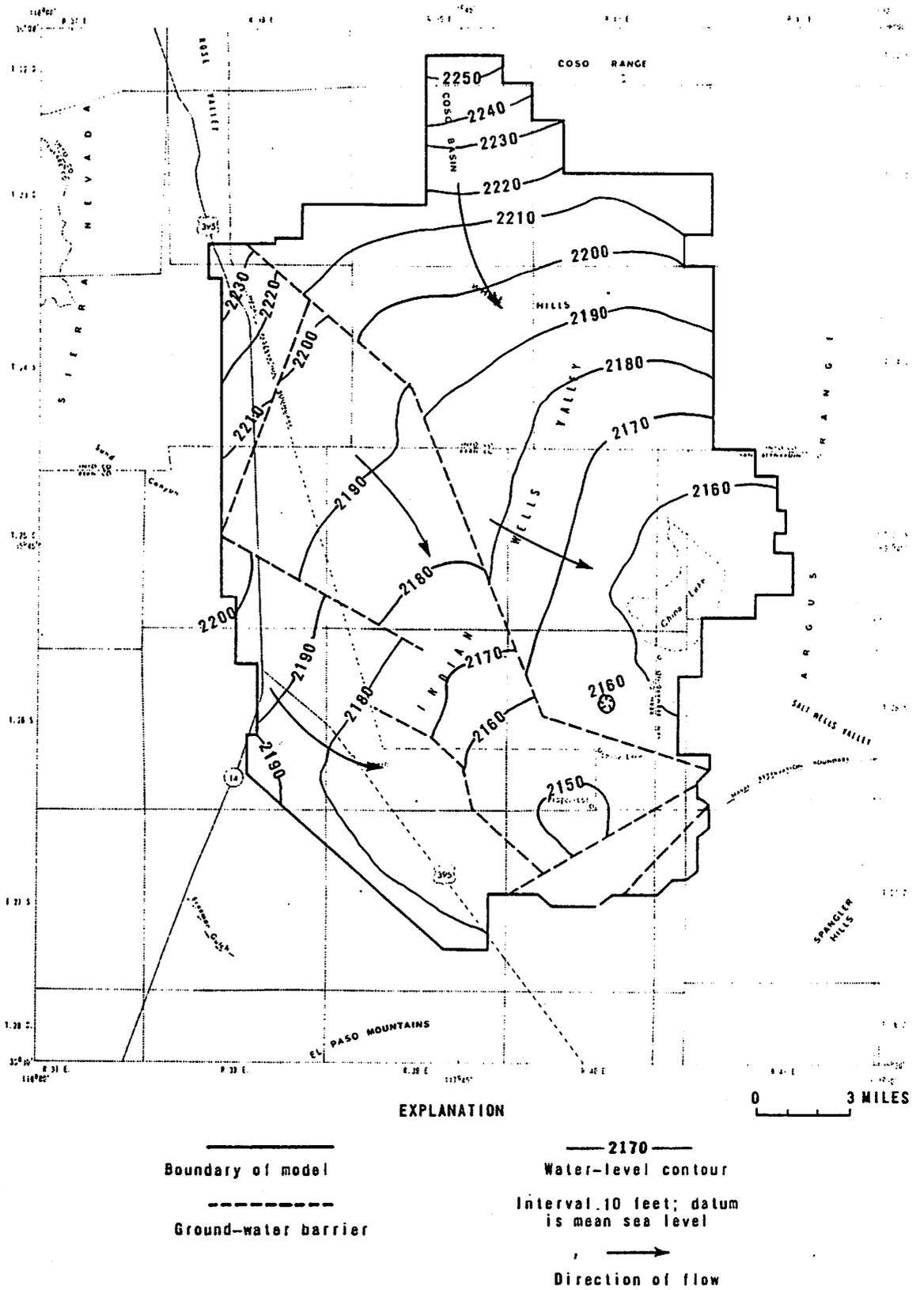
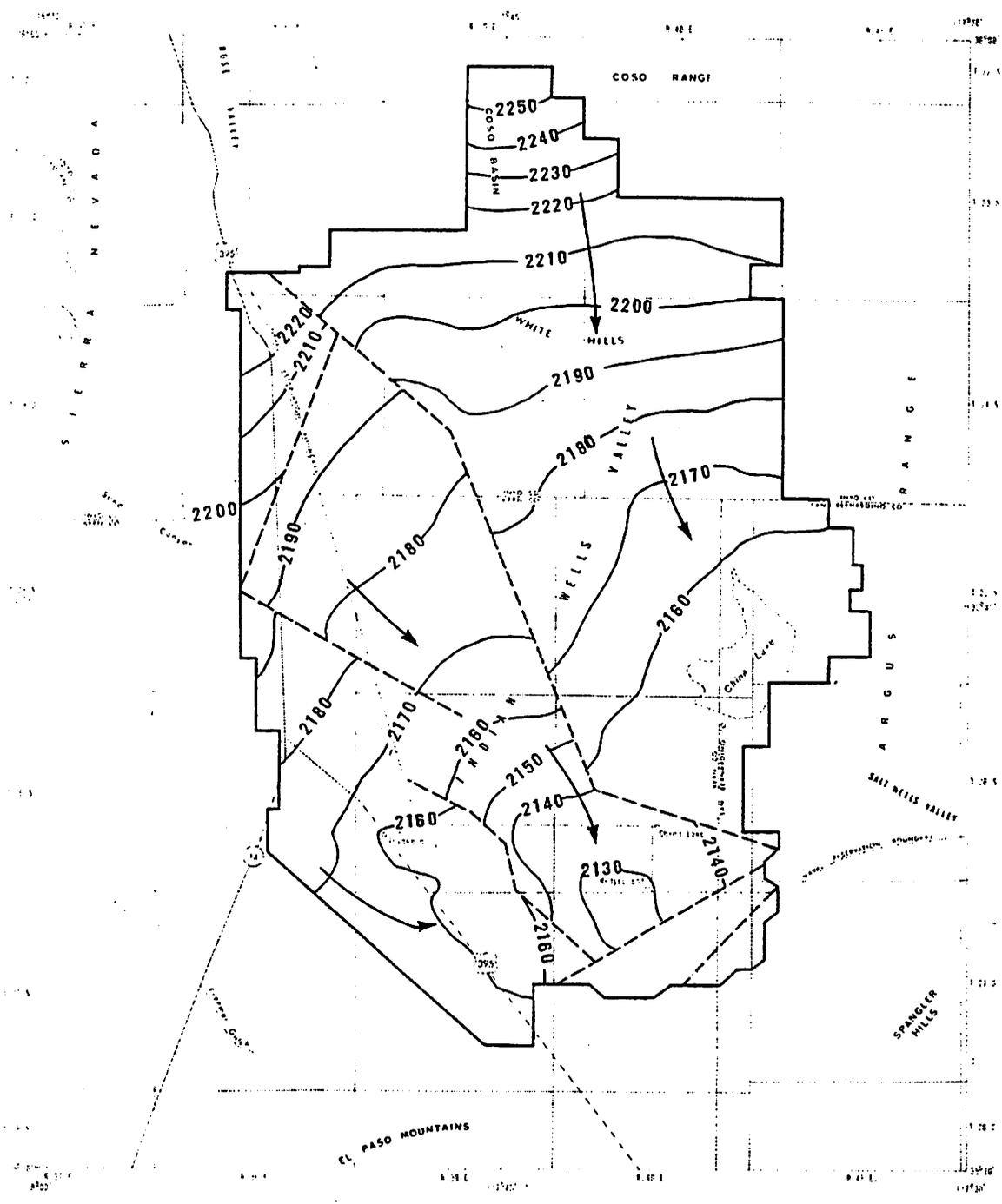


FIGURE 9. --Model-generated 1986 water-level contours for the deep aquifer.
23



EXPLANATION

- Boundary of model
- Ground-water barrier
- 2170—— Water-level contour
- Interval 10 feet; datum is mean sea level
- Direction of flow

0 3 MILES

FIGURE 10. --Model-generated 1998 water-level contours for the deep aquifer.

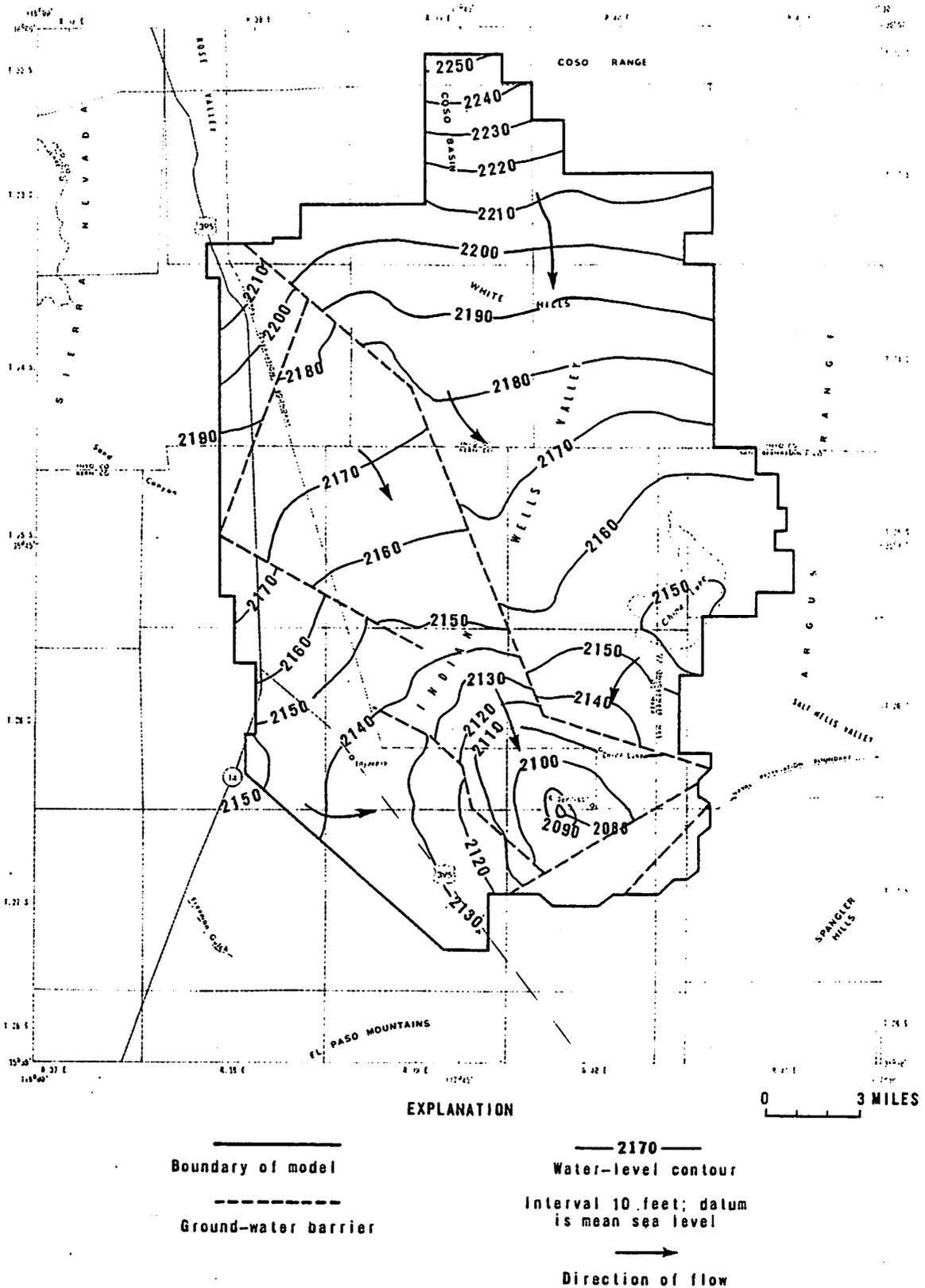


FIGURE 11. --Model-generated 2020 water-level contours for the deep aquifer.

SUMMARY AND CONCLUSIONS

Effects of the Revised Pumping Pattern

The present model analysis using the calibrated digital model developed by Bloyd and Robson (1971), simulated water levels for the period 1977-2020. Because none of the hydrologic properties of the original model were changed in the present analysis, differences between the water-level predictions in this report and those made by Bloyd and Robson (1971) can be attributed entirely to changes in assumed amounts and distribution of future pumpage.

Comparing the pattern of pumpage used for this analysis with the pattern used by Bloyd and Robson (1971) for their water-level predictions, the following differences can be noted:

1. The pumpage used in this report shows a slightly slower growth rate with time than that used by Bloyd and Robson (1971). Bloyd and Robson (1971) projected a pumpage of 21,436 acre-ft for 1990, the last year modeled in their analysis, whereas the pumpage used for the simulations reported here was predicted as 20,997 acre-ft for the same year. Furthermore, when Bloyd and Robson (1971) made their projections in 1969, they estimated that the 1976 pumpage would be 16,670 acre-ft, about 2,400 acre-ft more than the figure later obtained from metered pumpage data.

2. In the projection for this report, new wells to supply anticipated increases in water demand are concentrated in a much smaller area than they were in the pattern of assumed growth used by Bloyd and Robson (1971). Krieger and Stewart (1977) stated in their report that they recognized the theoretical desirability of dispersing points of ground-water withdrawal, but that economic considerations dictate the more concentrated development of wells if at all possible. Determining whether such a concentration of development is hydrologically feasible is a major purpose of these model studies.

3. The pumpage used in this prediction reflects the fact that Navy pumpage has declined in the last several years, rather than showing the steady increase assumed by Bloyd and Robson (1971). This reduced pumpage by the Navy may be helping to delay a reversal of the gradient across the China Lake barrier.

The effects of the pattern of pumpage assumed are readily apparent in the projected water-level maps presented in this report. Generally these maps show drawdowns that are less widespread but locally more severe than those predicted by Bloyd and Robson (1971); for example, model results indicate more severe drawdown for 1982 by using these pumping conditions than Bloyd and Robson's projection showed for 1983. The maximum predicted drawdown in the year 2020, locally 84 ft below the 1976 water levels, may be acceptable from the standpoint of pumping costs; however, the gradient reversal across the China Lake barrier may cause some quality degradation in the Ridgecrest area. Future investigations should be directed toward determining whether an unacceptable amount of water-quality degradation would accompany such drawdowns.

Suggestions for Future Investigations

In the nearly 10 years since the original development of the model used in this study, significant advances have been made in the simulation of ground-water systems. This model and most other early ground-water models solve a finite-difference approximation of the equation of ground-water flow. Models utilizing a finite-element solution scheme have since been developed. The latter are sometimes more easily adapted to the irregular geometry of real ground-water basins. The present model assumes a two-dimensional idealized representation of the actual ground-water system of Indian Wells Valley. More recently developed models that simulate three-dimensional flow of ground water would allow a more realistic representation of the Indian Wells Valley area, particularly in regard to the upward leakage from the deep aquifer to the shallow aquifer and the evaporation discharge from the shallow aquifer in the playa area. Probably of most importance to the Indian Wells Valley area, however, is the development of practical ground-water-quality models.

SELECTED REFERENCES

- Bloyd, R. M., and Robson, S. G., 1971, Mathematical ground-water model of Indian Wells Valley, California: U.S. Geological Survey open-file report. 36 p.
- Dutcher, L. C., and Moyle, W. R., Jr., 1973, Geologic and hydrologic features of Indian Wells Valley, California: U.S. Geological Survey Water-Supply Paper 2007, 30 p.
- Krieger and Stewart, Engineering Consultants, 1977, Indian Wells Valley County Water District--General plan for water supply and water distribution: Riverside, Calif., 140 p.
- Kunkel, Fred, 1973, Data requirements for modeling a ground-water system in an arid region: Menlo Park, Calif., U.S. Geological Survey Water Resources Investigations 4-73, 21 p.
- Kunkel, Fred, and Chase, G. H., 1969, Geology and ground water in Indian Wells Valley, California: U.S. Geological Survey open-file report, 84 p.
- Lamb, C. E., and Downing, D. J., 1978, Ground-water data, 1974-76, Indian Wells Valley, Kern, Inyo, and San Bernardino Counties, California: U.S. Geological Survey Open-File Report 78-335, 42 p.
- Lee, C. H., 1913, Ground-water resources of Indian Wells Valley, California: California State Conservation Commission report, p. 403-429.

- Maddock, Thomas, III, 1970, A program to simulate an aquifer using alternating direction implicit-iterative procedure: U.S. Geological Survey open-file report, 73 p.
- Peaceman, D. W., and Rachford, H. H., Jr., 1955, The numerical solution of parabolic and elliptic differential equations: Journal of the Society for Industrial and Applied Mathematics, v. 3, no. 1, p. 28-48.
- Pinder, G. F., and Bredehoeft, J. D., 1968, Application of digital computer for aquifer evaluation: Water Resources Research, v. 4, no. 5, p. 1069-1093.
- Prickett, T. A., 1967, Designing pumped well characteristics into electric analog models: Ground Water, v. 5, no. 4., p. 38-46.
- Prickett, T. A., and Lonquist, C. G., 1971, Selected digital computer techniques for ground-water resources evaluation: Urbana, Ill., Illinois State Water Survey Bulletin 55, 62 p.
- Trescott, P. C., Pinder, G. F., and Larson, S. P., 1976, Finite-difference model for aquifer simulation in two dimensions with results of numerical experiments: U.S. Geological Survey Techniques Water-Resources Investigations, book 7, chapter C1, 116 p.
- Zbur, R. T., 1963, A geophysical investigation of Indian Wells Valley, California: U.S. Naval Ordnance Test Station, China Lake, Calif., NOTS Technical Publication 2795, 98 p.