SIMULATION OF THE GROUND-WATER FLOW SYSTEM AND PROPOSED WITHDRAWALS IN THE NORTHERN PART OF VEKOL VALLEY, ARIZONA

By Kenneth J. Hollett and James R. Marie

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 86-4340

Prepared in cooperation with the

U.S. BUREAU OF INDIAN AFFAIRS

Tucson, Arizona
January 1987

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

For readers who prefer to use metric (International System) units, the conversion factors for the inch-pound units used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
acre-foot per year per mile [(acre-ft/yr)/mi]	0.00077	cubic hectometer per year per kilometer [(hm^3/yr)/km]
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
gallon per minute (gal/min)	0.06309	liter per second (L/s)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

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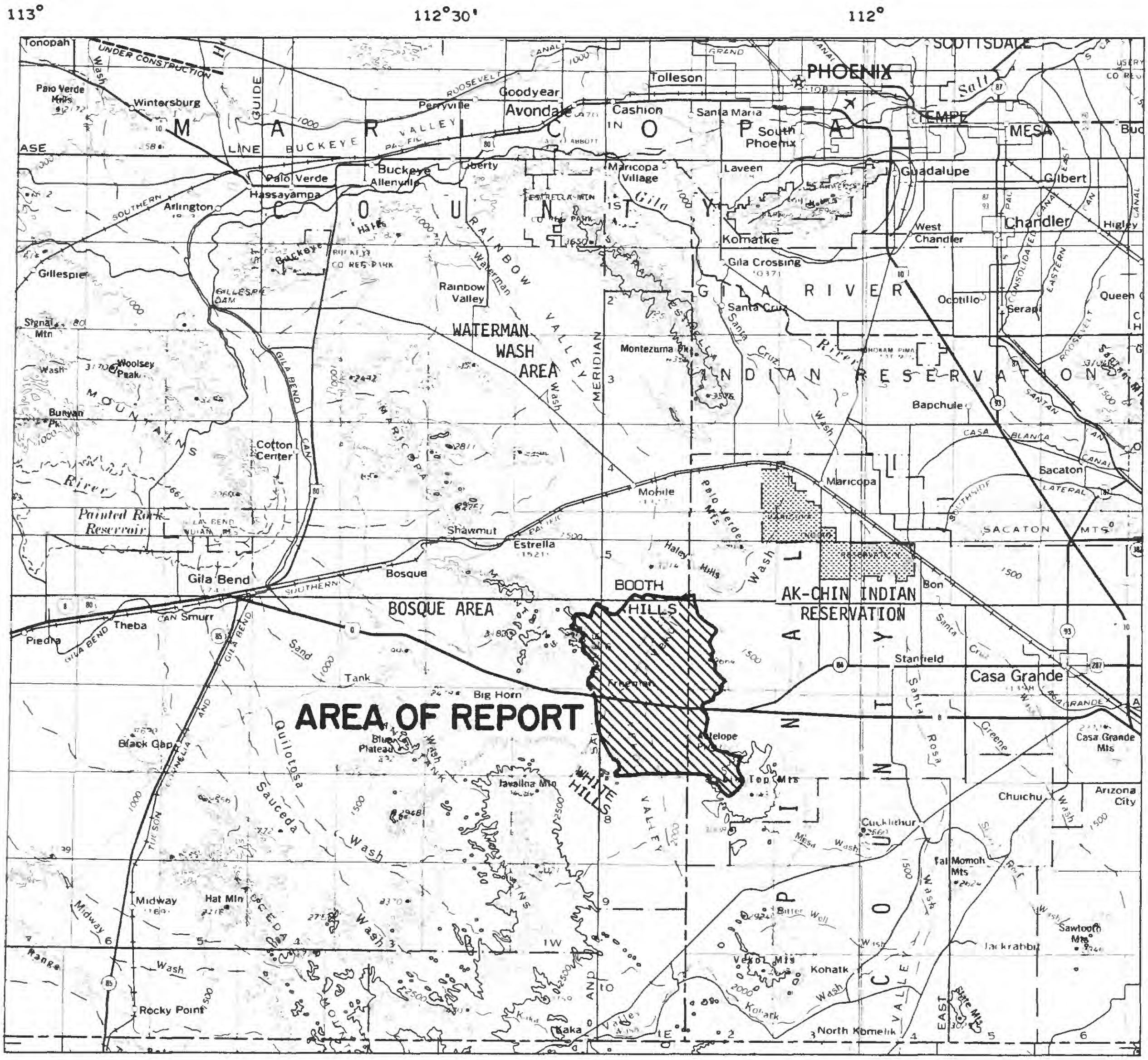
ABSTRACT

Pursuant to the Ak-Chin Indian Community Water Rights Settlement Act—Public Law 95-328—enacted on July 28, 1978, a study was undertaken to assess the effect of proposed ground-water withdrawal from Federal lands near the reservation. The first area to be evaluated was the northern part of Vekol Valley. The evaluation was made using a numerical model based on the detailed geohydrologic concepts developed during the study. The numerical model, which was calibrated to steady-state and transient ground-water conditions in the northern part of Vekol Valley, adequately duplicated the conceptual model and was used to estimate the effect of withdrawing approximately 174,000 acre-feet from the system during a 25-year period. At the end of the 25-year period, the water level was drawn down an average of about 95 feet, and about 150,500 acre-feet of water was removed from storage. The 150,500 acre-feet of water represents 43 percent of the estimated recoverable ground water in storage.

INTRODUCTION

The Ak-Chin Indian Community Water Rights Settlement Act—Public Law 95-328—enacted on July 28, 1978, directs the Secretary of the Interior to deliver a permanent supply of 85,000 acre-ft/yr of water to the Ak-Chin Indian Reservation no later than 25 years from the date of the enactment. The Settlement Act further directed the Secretary of the Interior to determine if sufficient ground water is available beneath Federal lands near the reservation to meet the interim emergency needs of the community. If sufficient ground water is available, a well field and a pipeline would be constructed to deliver the emergency supply. Studies by Wilson (1979) and Matlock (1981) indicate that at least three areas near the Reservation—Vekol Valley, the Waterman Wash area, and the Bosque area (fig. 1)—could supply the required ground water to the reservation. On the basis of these studies and other available information, the Secretary of the Interior selected Vekol Valley as the area to be developed. The Secretary specified that a well field and pipeline capable of delivering 30,000 acre-ft of water annually to the Ak-Chin Indian Community be constructed. In addition 58,300 acre-ft would be delivered annually from the Central Arizona Project (CAP). Total deliveries were not to exceed 85,000 acre-ft annually.



BASE FROM U.S. GEOLOGICAL SURVEY
STATE TOPOGRAPHIC MAP, 1:500,000

0 10 20 MILES

0 10 20 KILOMETERS

CONTOUR INTERVAL 500 FEET
NATIONAL GEODETIC VERTICAL
DATUM OF 1929

INDEX MAP SHOWING AREA
OF REPORT (SHADED)

Figure 1.--Area of report.

Purpose and Scope

The model study described in this report is a part of a larger project, which was done in cooperation with the U.S. Bureau of Indian Affairs, to define the hydrogeologic characteristics of the aquifer systems that underlie the entire Vekol Valley. Information derived from the larger project was used to establish the boundary conditions, fluxes, and aquifer characteristics for the ground-water flow system in the northern part of Vekol Valley. Data consist of surface and subsurface information derived from borehole and surface-geophysical surveys, well logs, geologic maps, and aquifer tests.

This report describes the results of the detailed study to assess the effects of the proposed ground-water withdrawal on the ground-water resources in the northern part of Vekol Valley. The primary purpose of the report is to present the concepts and methods used to design, construct, calibrate, and implement a numerical model that was used to analyze the ground-water flow system in the northern part of Vekol Valley. The purpose of the model is to (1) evaluate the conceptualized ground-water flow system, (2) evaluate and refine estimates of aquifer characteristics, and (3) predict aquifer response to the proposed pumping.

Study Area

The study area is in the northern part of Vekol Valley and is about halfway between Gila Bend and Casa Grande on Interstate Highway 8. The north-trending valley includes about 90 mi^2 in south-central Arizona (fig. 1). The northern part of Vekol Valley is about 8 mi wide and extends 12 mi south from the Booth Hills to a bedrock ridge that separates Vekol Valley into distinct northern and southern parts. The area is bounded on the east by the Table Top Mountains and on the west by the White Hills and Maricopa Mountains. The mountains average about 2,500 ft above the National Geodetic Vertical Datum of 1929; isolated peaks exceed 4,000 ft. The valley floor slopes gently from south to north at about 40 ft/mi, is sparsely to densely covered by low stands of riparian desert plants and some grass, and is cut by small streams that drain from the mountains into Vekol Wash (fig. 1). The northern part of Vekol Valley is sparsely populated, and most of the land is Federally owned. Livestock-grazing rights are leased to a few local ranchers, and as of 1983, no land was being irrigated.

Surface-water runoff in the study area generally is the result of precipitation from local summer thunderstorms and regional winter storms. Precipitation is about 8 in/yr in the mountains (Sellers and Hill, 1974). Combined runoff from both the northern and southern parts of Vekol Valley is carried out of the northern end of the valley by Vekol Wash. Precipitation and runoff are highly variable, and most of the washes are dry more than 80 percent of the time.

Previous and Current Investigations

Most of the detailed hydrogeologic investigations in the northern part of Vekol Valley were done in accordance with the Ak-Chin Indian Community Water Rights Settlement Act. Regional studies (Wilson and others, 1969; U.S. Geological Survey, 1980a, 1980b; Lysonski and others, 1981) were helpful in delineating geologic units and structure within the study area. Studies by Wilson (1979) and Matlock (1981) were useful in developing a conceptual water budget and in delineating areas where additional data were needed.

To provide the best possible information for the aquifer characteristics, aquifer geometry, and initial and boundary conditions for a system that would be heavily stressed over a 25-year period, an extensive data-collection program was undertaken. The program designed to obtain this information consisted of a number of facets. First, a drilling program was conducted that included two core holes that were drilled through the entire aquifer system and into the crystalline basement rock—one to a depth of 1,553 ft, the other to a depth of 2,000 ft. Core recovery was better than 90 percent. Eighteen wells were installed, fully developed, and tested. Some of the wells are screened throughout the aquifer system. Others are screened only in specific aquifers. Most of the wells are finished using wire-wrapped, high-flow, stainless-steel screen. The wells range in diameter from 2 to 26 in. and in depth from 200 to 3,014 ft.

In addition to the test-drilling and well-installation programs, other facets included the definitions of faults in the valley by geologic mapping, aerial photointerpretation, and a detailed geophysical survey. Aquifer characteristics were determined from four short- and long-term aquifer tests. All aquifer tests were made using 1 to 12 observation wells and an array of sophisticated instrumentation to monitor and record the results. Delineation of subsurface geologic units was based on well and core logs, geophysical logs, and geologic information extrapolated from surface-geologic maps. The results of the aquifer tests and hydrogeologic studies are given in a companion report that is in preparation.

CONCEPTUAL GROUND-WATER FLOW SYSTEM

A concept of the relation between the physical aquifer system and the movement of ground water must be defined in order to develop a numerical model of a ground-water system. The physical system in the northern part of Vekol Valley is comprised of an elongated north- to south-trending structural trough that is bounded by block-faulted mountains and filled primarily with sediments that were eroded from the adjacent mountains (fig. 2). The ground-water resource of the area is the water stored within these porous sediments. In comparison to the volume in storage, the amount of ground water that enters, moves through, and leaves the system is small.

The main source of ground-water recharge is the infiltration of runoff through the valley-fill deposits along the mountain fronts that surround the valley and, to a lesser extent, the amount that infiltrates through the alluvial deposits associated with Vekol Wash. Recharge probably begins immediately adjacent to the mountain fronts and may occur in an area several miles wide toward the basin axis. Most of the water is from the Table Top Mountains and the area from the White Hills to the Maricopa Mountains. Fractures in the consolidated rocks of the mountains may allow a minor amount of water to infiltrate and recharge the ground-water system; however, for purposes of this study, the contribution is considered insignificant. Also, because the rocks of the mountains are relatively impermeable, no movement of ground water from adjacent basins is presumed. A secondary source of ground-water recharge occurs through the bottom sediments of Vekol Wash. Most of this recharge probably occurs within the first 2-mile reach of the wash after it crosses the bedrock boundary separating the northern and southern parts of Vekol Valley.

Ground water moves from the basin margins toward the axis of the valley and northward to an outflow point between the Booth Hills and the Table Top Mountains. Directions and rates of ground-water movement within the aquifer are controlled by the hydraulic properties of the aquifer and the spatial and temporal distribution of recharge and discharge. These aspects of the ground-water system are discussed in detail in later sections of this report.

Aquifer Geometry and Hydraulic Properties

The upper boundary of the multilayered aquifer system in the northern part of Vekol Valley is the water table, and the lower boundary is the impermeable sedimentary or igneous rock. Depth to the base of the aquifer system for most of the area is based on drill-hole and geophysical data and ranges from 600 ft in the northern part to nearly 3,000 ft in the southern part. The gravity contours depicted in figure 2 generally mimic the configuration of the base of the aquifer system, with the deepest part represented by the closed contour of -10 milligal.

Four rock units compose the aquifer system as modeled in the northern part of Vekol Valley (figs. 3 and 4) for this study. The upper two units are unconsolidated alluvial-fan, stream-channel, and flood-plain deposits. A discontinuous silty sand bed forms the base of unit 1 and acts as a confining bed to unit 2. The lower part of unit 1 becomes less hydraulically conductive to the south and is designated unit 1a (fig. 3). Unit 3 is a moderately to well-consolidated conglomerate that thins to the south and becomes extinct about 1 mi south of well V-5. Where it exists, unit 3 acts as a confining bed to unit 4. Unit 4 consists of discontinuous lenses of moderately consolidated to unconsolidated silty sand and sand

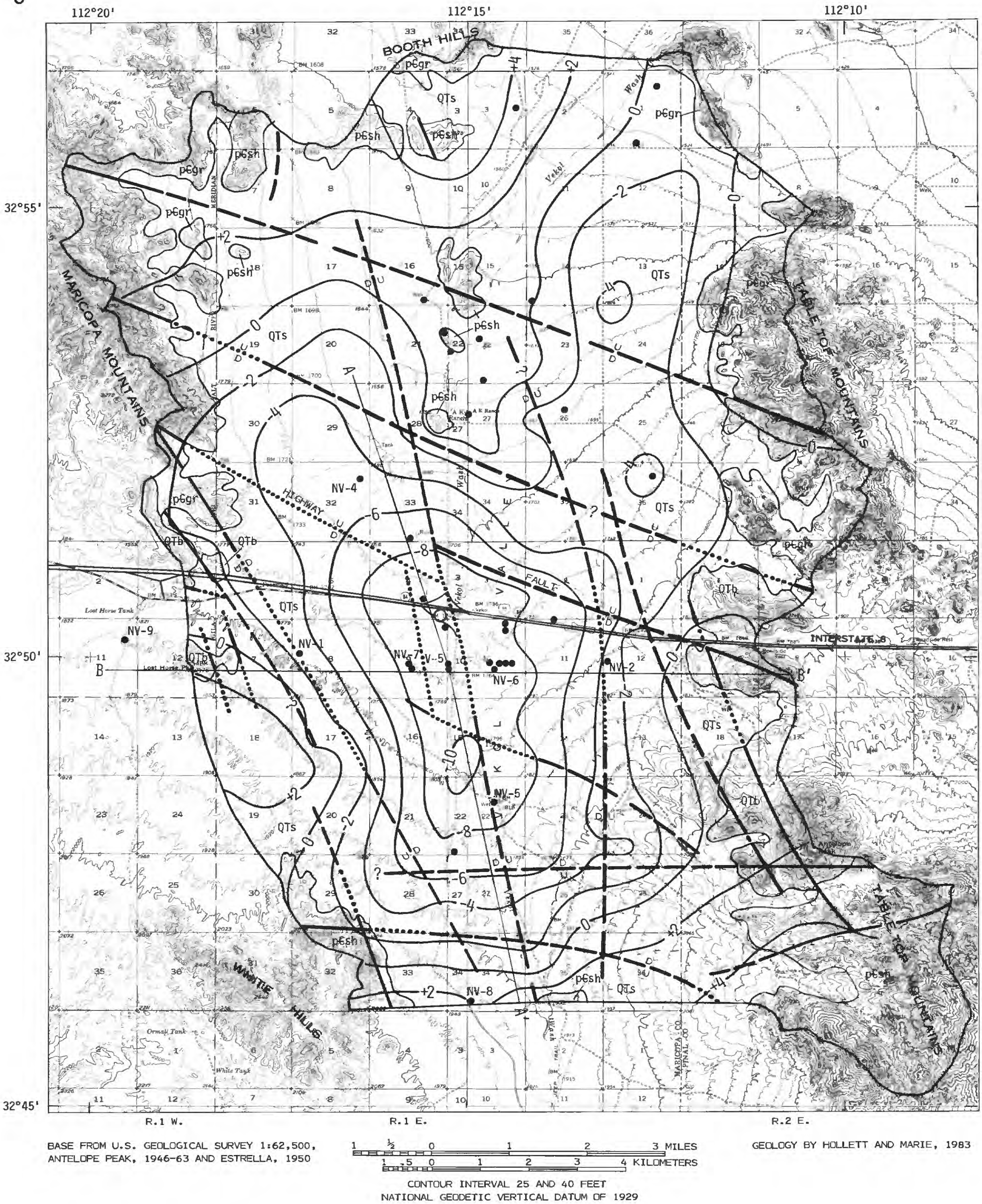


Figure 2.--Bedrock geology, first-order residual-gravity anomaly, and distribution of major block faults.

E X P L A N A T I O N

GENERALIZED GEOLOGIC UNITS

QTs	BASIN FILL—Unconsolidated to moderately consolidated; includes pre-Pleistocene deposits
QTb	OLIVINE BASALT AND BASALTIC ANDESITE
p€sh	SCHIST
p€gr	GRANITE
	GENERALIZED GEOLOGIC CONTACT
U D ?	FAULT—Dashed where inferred; dotted where concealed; queried where uncertain. U, upthrown side; D, downthrown side
NV-4	WELL OR COREHOLE USED TO ESTABLISH HYDROGEOLOGIC BOUNDARY CONDITIONS—Identifier, NV-4, is number of well or corehole shown in geologic sections on figures 3 and 4
-2	FIRST-ORDER RESIDUAL-GRAVITY ANOMALY—Contour interval 2 milligals (Steven Pape, U.S. Geological Survey, written commun., 1983)
A——A′	LINE OF SECTION—Section shown in figure 3
B——B′	LINE OF SECTION—Section shown in figure 4
	BOUNDARY OF STUDY AND DRAINAGE AREA

Figure 2

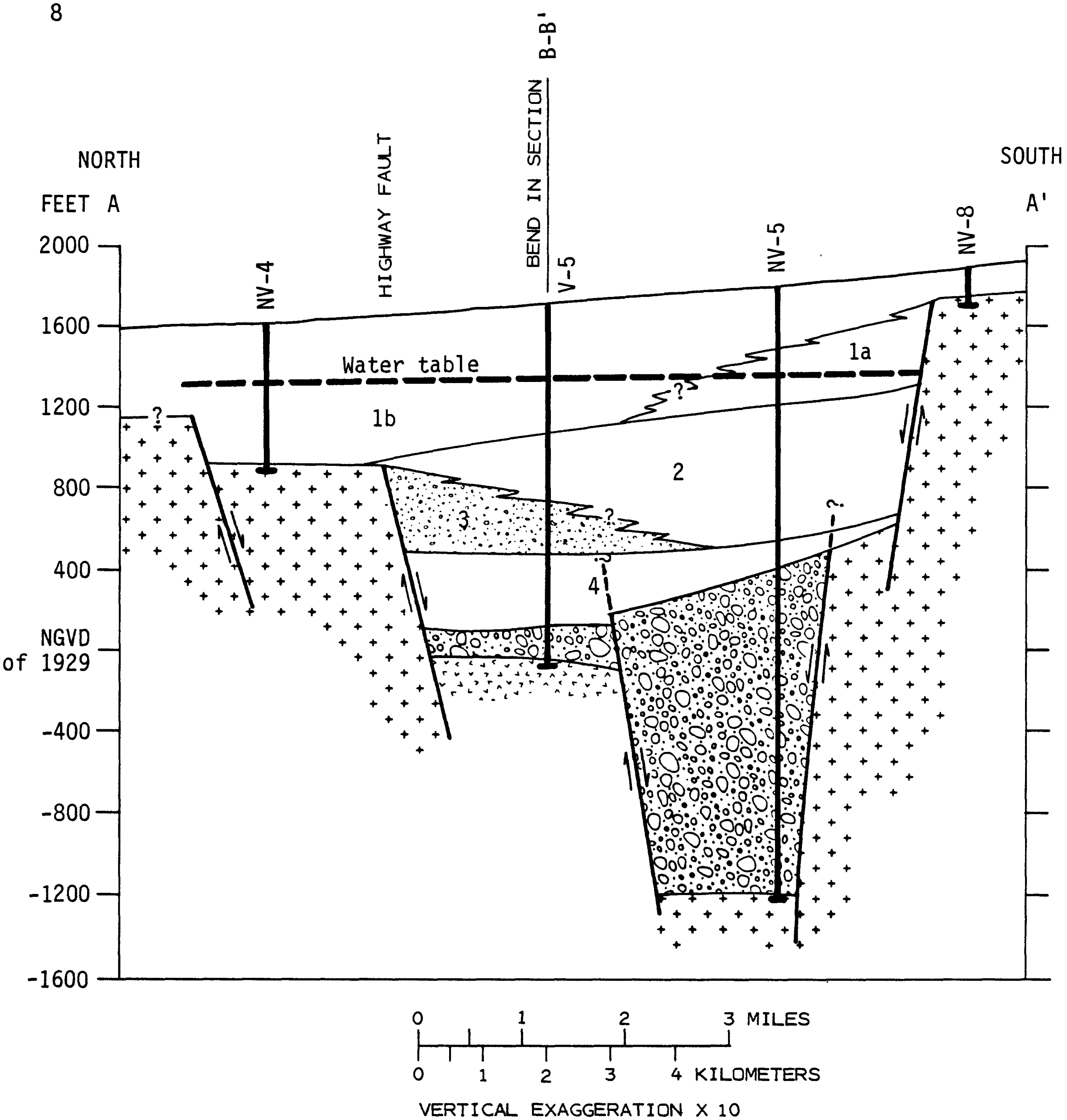


Figure 3.--Geologic section A-A' representing hydrogeologic conditions along a north-south line in the northern part of Vekol Valley.

EXPLANATION

GENERALIZED GEOLOGIC UNITS

1b 1a / 2 — Basin fill—Unconsolidated alluvial-fan, stream-channel, and flood-plain deposits. Unit 1b is more permeable than unit 1a. Units 1b and 1a are unconfined. Unit 2 is confined. Numbers, 1a and 1b, correspond to model layer 1. Number, 2, corresponds to model layer 2

3 — Basin fill—Moderately to well-consolidated conglomerate. Number, 3, corresponds to model layer 3

4 — Basin fill—Unconsolidated to moderately consolidated silty sand and sand with intercolated conglomerate. Number, 4, corresponds to model layer 4

Conglomerate

Volcanic rocks

Granite or schist

——— ? —— GENERALIZED GEOLOGIC CONTACT—Queried where uncertain

? — — FAULT—Arrow indicates movement of fault block. Queried where uncertain

A ——— A' LINE OF SECTION—Shown in figure 2

NV-4 WELL OR COREHOLE—Identifier, NV-4, is number of well or corehole

Figure 3

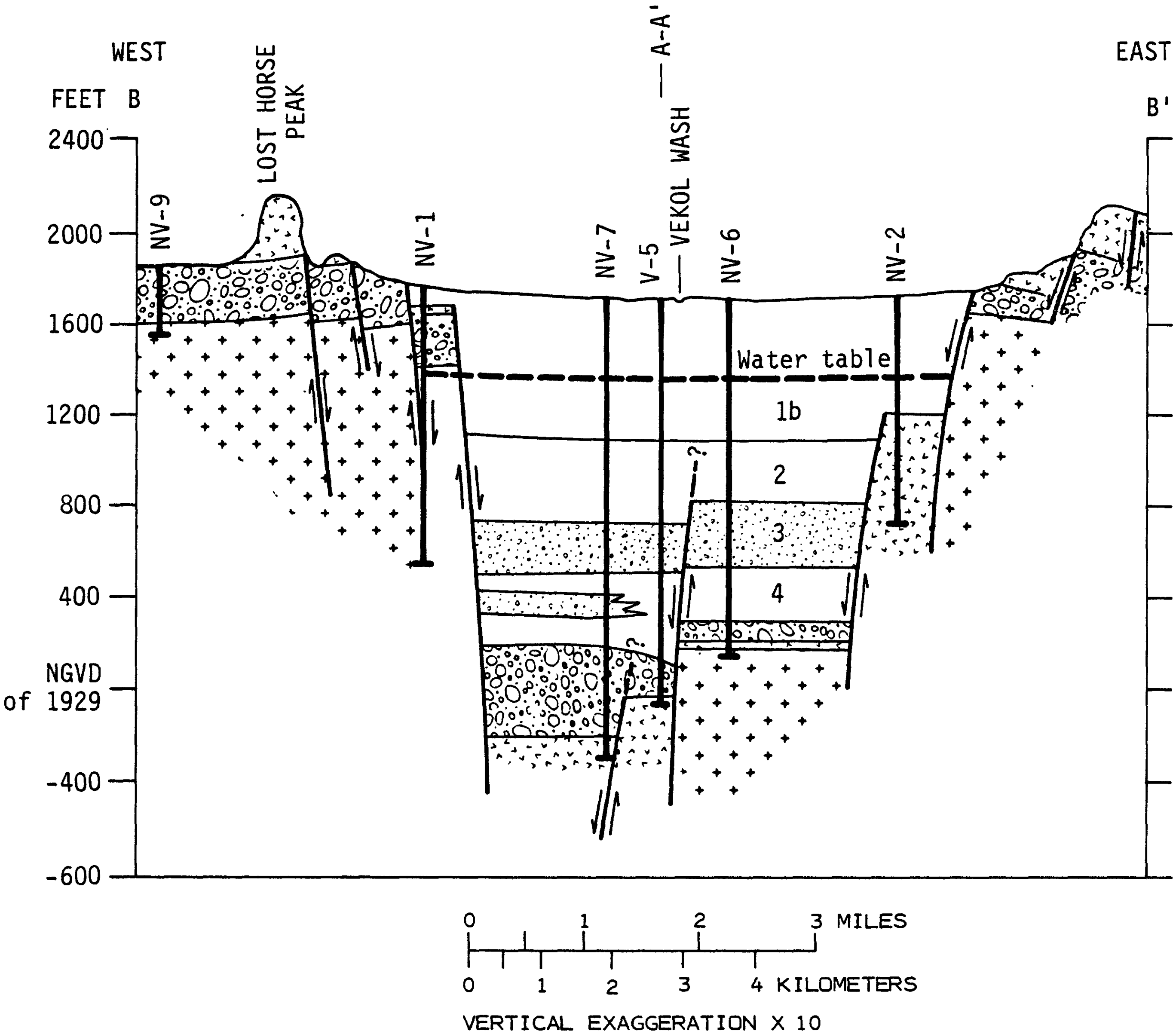


Figure 4.--Geologic section B-B' representing hydrogeologic conditions along an east-west line in the northern part of Vekol Valley.

E X P L A N A T I O N

GENERALIZED GEOLOGIC UNITS

1b / 2 — Basin fill—Unconsolidated alluvial-fan, stream-channel, and flood-plain deposits. Unit 1b is unconfined. Unit 2 is confined. Numbers, 1 and 2, correspond to model layers 1 and 2

3 — Basin fill—Moderately to well-consolidated conglomerate. Number, 3, corresponds to model layer 3

4 — Basin fill—Unconsolidated to moderately consolidated silty sand and sand with intercolated conglomerate. Number, 4, corresponds to model layer 4

Conglomerate

Volcanic rocks

Granite or schist

? — GENERALIZED GEOLOGIC CONTACT—Queried where uncertain

? — FAULT—Arrow indicates movement of fault block. Queried where uncertain

B —— B' LINE OF SECTION—Shown in figure 2

V-5 WELL OR COREHOLE—Identifier, V-5, is number of well or corehole

Figure 4

with intercalated lens of conglomerate. Unit 4 lies on a well-consolidated conglomerate at depths ranging from about 1,300 ft to about 1,600 ft. The hydraulic conductivity of the conglomerate is much lower than that of any of the upper four rock units and therefore the conglomerate represents the base of the aquifer system modeled for purposes of this study.

The lateral extent of the aquifer system is limited by major blocks of faulted igneous and sedimentary rock (figs. 2, 3, and 4). Vertical offset along these faults ranges from tens to thousands of feet. Within the valley, faults offset the various units of the aquifer in a stepped configuration. Units 2, 3, and 4 are bounded on all sides by fault blocks, whereas unit 1 is continuous across the valley to the mountain fronts, overlaps the buried fault blocks, and extends northward out of the study area.

Ground water in unit 1 is under unconfined (water-table) conditions, whereas ground water in units 2, 3, and 4 is under confined conditions. Recharge enters the aquifer system through an area along the mountain fronts and through the bottom of Vekol Wash into unit 1 (figs. 3 and 4). The ground water either moves into the deeper units or remains in unit 1; however, in either case it moves northward through the units to the outflow point near the Booth Hills. The regional direction of ground-water flow, the areas of recharge along the mountain fronts, and the area of outflow are indicated by the configuration of the water table (fig. 5). The gradient of the water table ranges from more than 10 ft/mi near the mountain fronts to less than 2 ft/mi along the axis of the valley. The depth to the water table averages about 450 ft throughout the study area. Differences in water levels measured within the various units of the aquifer system were extremely small, generally less than a foot within a large area underlying the central part of the valley. The water table is slightly higher than the water levels in the underlying units in the areas along the mountain fronts and along Vekol Wash in the southern part of the valley. Water levels in the underlying units are slightly higher than the water table in an area along the Highway fault where water moves into unit 1 and then toward the discharge area to the north near the Booth Hills.

The saturated thickness of each unit in the aquifer system was determined from geologic analyses of drill-hole cores and cuttings and borehole-geophysical logs. The top of unit 1 is the water table. The bottom of unit 1 is a discontinuous silty sand bed that separates unit 1 from unit 2. North of the Highway fault (fig. 3) and along the margin of the valley (figs. 3 and 4), unit 1 lies directly on crystalline rock. The saturated thickness of unit 1 is shown in figure 6. The saturated thickness of unit 2 ranges from less than 50 ft along the Highway fault to more than 700 ft in the southwestern part of the valley (fig. 7). A north- to south-trending fault offsets the base of unit 2 (fig. 4), and the east half of the unit is about 100 ft thinner than the west half. Unit 3 thins from a saturated thickness of about 450 ft near the Highway fault to where it becomes extinct about 1 mi south of well V-5 (fig. 3). Unit 3 has relatively low hydraulic conductivity, acts as a confining bed between units 2 and 4 (fig. 3), and is about 90 ft thicker on the east side of the valley-center fault than on the west side (fig. 4). The saturated thickness of unit 4 thins from about 285 ft on the west side of the valley to zero near the margin faults on the south side (figs. 3 and 4). The base of unit 4 is the top of the underlying conglomerate.

Hydraulic conductivities for the four hydrologic units were needed as input to the numerical ground-water flow model. In order to calculate the hydraulic conductivities, the transmissivities for the various units were determined from short- and long-term multiobservation well aquifer tests at wells V-5, NV-5, NV-6, and NV-7 (fig. 5). The transmissivities of the units were divided by the corresponding thickness of that unit at various well sites for which the transmissivities were determined. Hydraulic conductivity ranged from 35 to 50 ft/d for unit 1, 8 to 16 ft/d for unit 2, 1 to 2 ft/d for unit 3, and 5 to 6 ft/d for unit 4.

The amount of ground water that can be stored and subsequently released from the aquifer is a function of the geologic materials that form the aquifer framework. Average values of the storage properties for the various units were, again, based on aquifer tests at wells V-5, NV-5, NV-6, and NV-7 (table 1). Estimates of storage coefficient and specific yield are shown for unit 2. These storage characteristics for unit 2 were needed because the proposed pumping at the planned well field would probably draw the water table down below the top of unit 2. If the water table were drawn down below the top of unit 2, unit 2 would convert from confined to unconfined conditions with a corresponding conversion from the storage coefficient to the specific yield shown in table 1. Using the storage values from table 1 and a water-level decline of 450 ft and considering the effect of dewatering a unit thickness of aquifer material, the amount of ground water that would be produced from properly constructed and developed wells in the aquifer system is estimated to be 350,000 acre-ft.

Table 1.--Average storage properties of units 1-4 at wells V-5, NV-5, NV-6, and NV-7

Unit	Specific yield	Storage coefficient	Specific storage
1	0.12	-----------------------	----------
2	[1]0.08	2.0×10^{-3} - 8.1×10^{-5}	2.7×10^{-6}
3	-----	4.4×10^{-5} - 4.4×10^{-6}	2.2×10^{-7}
4	-----	2.0×10^{-4} - 6.0×10^{-5}	5.5×10^{-7}

[1]Unit 2 converts to unconfined conditions when water level is drawn down below the top of the unit.

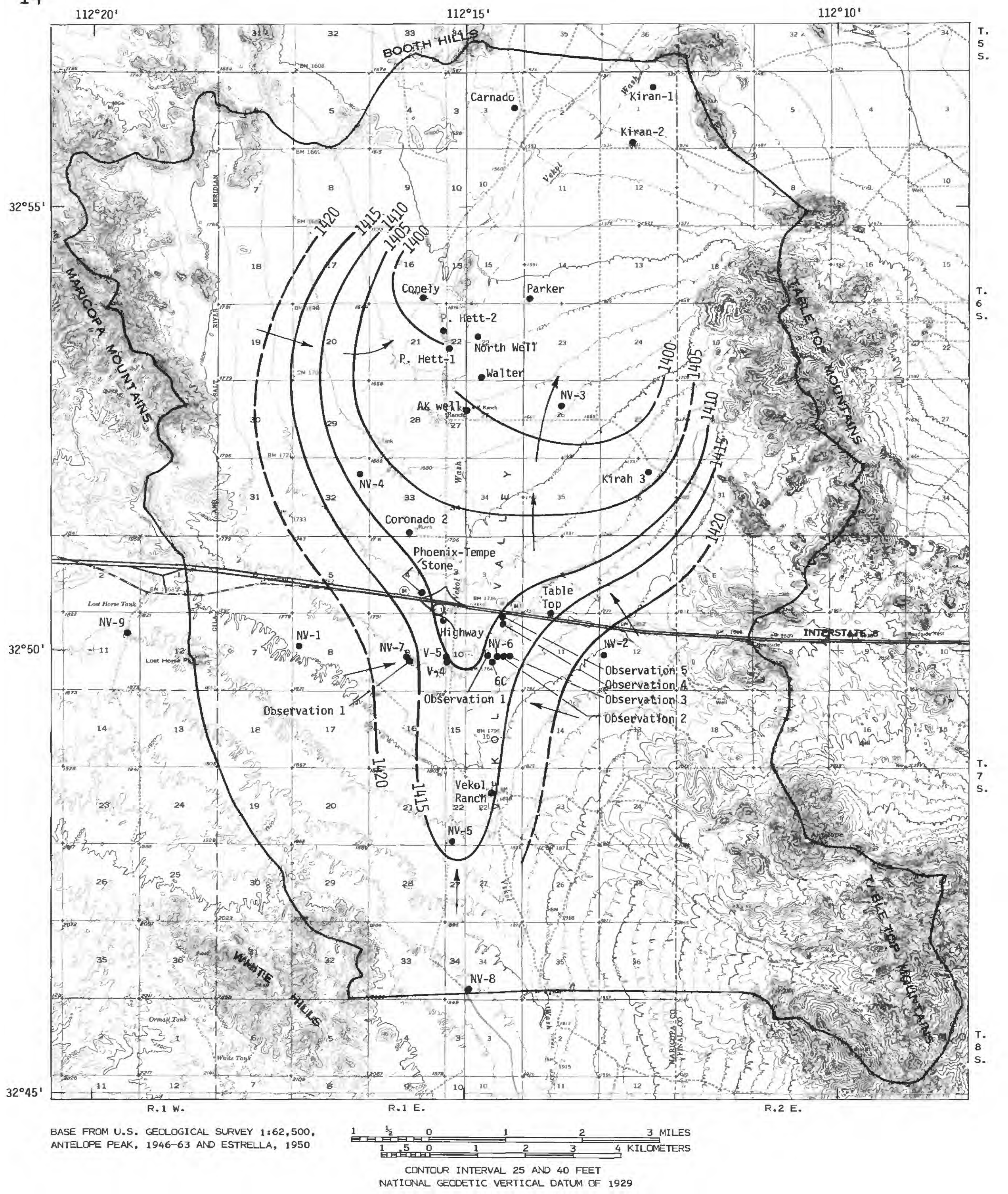


Figure 5.--Location of wells and configuration of the water table (1983) in unit 1.

EXPLANATION

——1410— —	WATER LEVEL CONTOUR—Shows altitude of the water table in unit 1. Dashed where approximately located. Contour interval 5 feet. National Geodetic Vertical Datum of 1929
● NV-6	WELL—Identifier, NV-6, is number or name of well
——→	GENERALIZED DIRECTION OF GROUND-WATER FLOW
———	BOUNDARY OF STUDY AREA

Figure 5

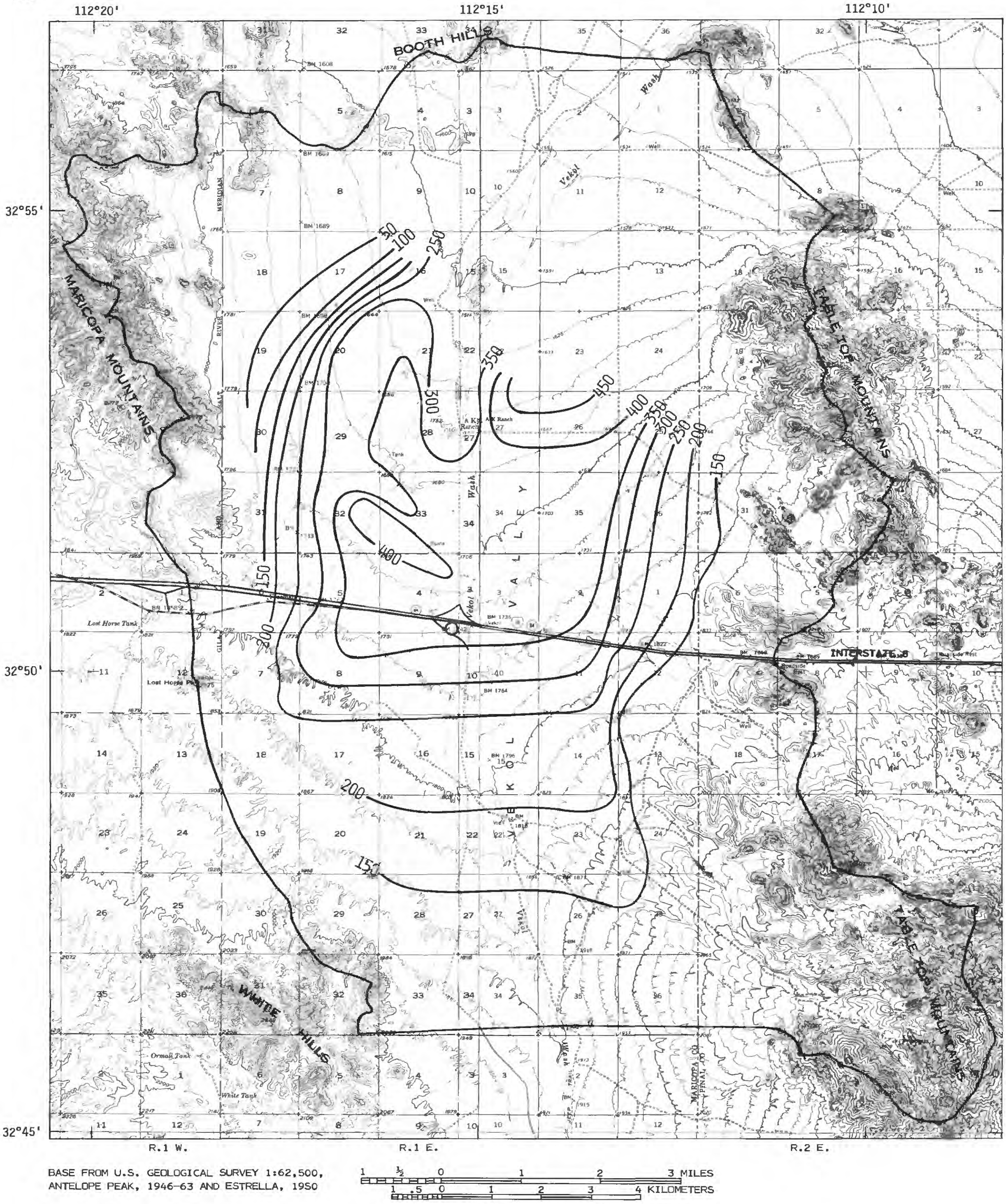


Figure 6.--Saturated thickness of unit 1.

EXPLANATION

——400—— LINE OF EQUAL APPROXIMATE SATURATED THICKNESS OF UNIT 1—Interval 50 feet

———— BOUNDARY OF STUDY AREA

Figure 6

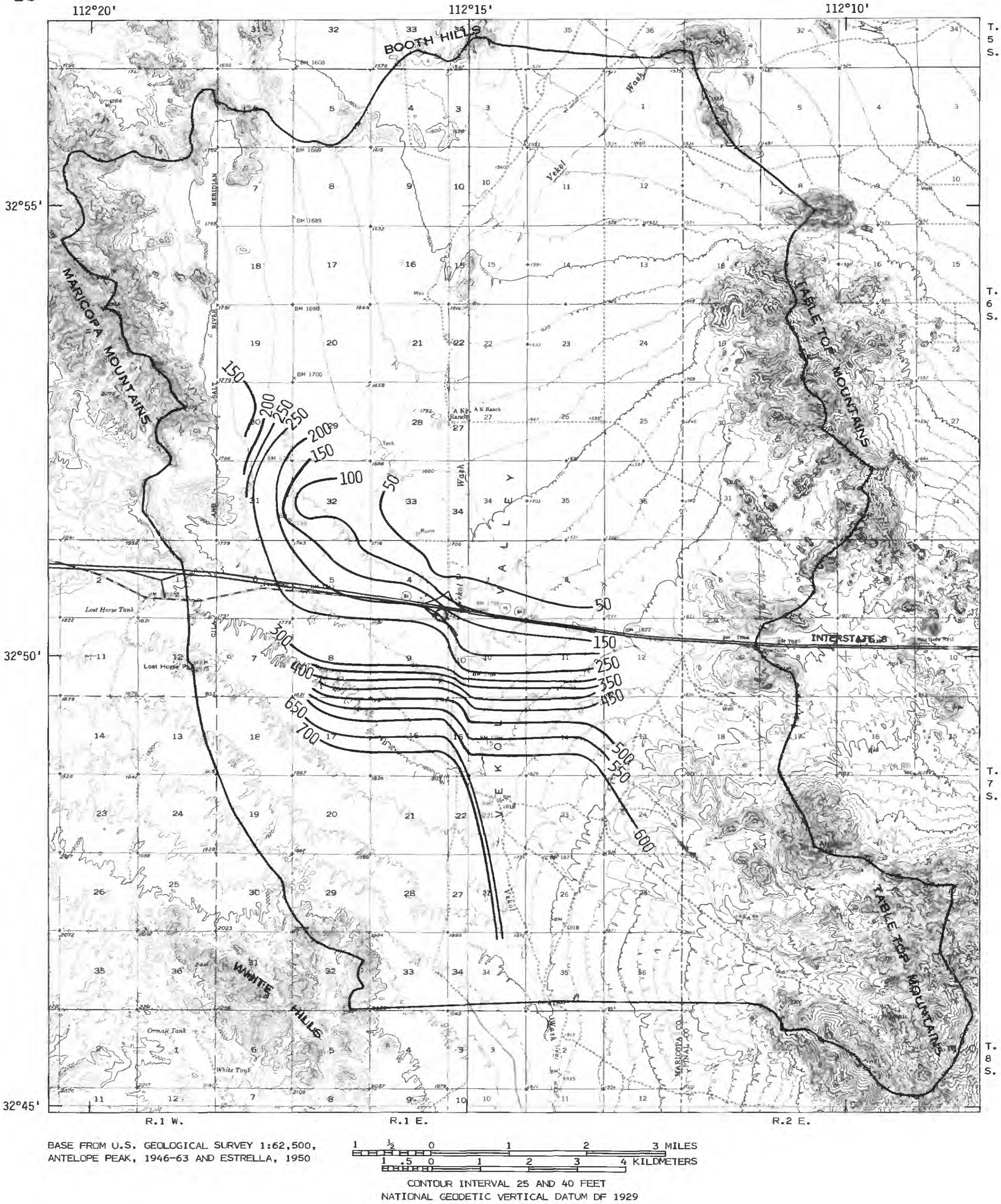


Figure 7.--Saturated thickness of unit 2.

EXPLANATION

——400—— LINE OF EQUAL APPROXIMATE SATURATED THICKNESS OF UNIT 2—Interval 50 feet

———— BOUNDARY OF STUDY AREA

Figure 7

Water Budget

Recharge

Recharge is the amount of surface flow that infiltrates into the aquifer during runoff and includes infiltration from stream channels, along mountain fronts, and through the valley floor. Most of this infiltration probably occurs through the colluvial deposits and the heads of alluvial fans that cover pediments along the mountain fronts. Some water may enter the aquifer through the bedrock composing the mountains; however, if recharge does occur in this manner, the amount is small.

Several factors affect the amount of recharge along the mountain fronts; the most significant is the total amount of precipitation falling on the mountains. The average precipitation in the northern part of Vekol Valley is about 8 in/yr. Of this total and on the basis of a precipitation-elevation-location relation, an estimated 5 to 10 percent recharged the aquifer system in this part of Arizona (Water Resources Research Center, 1980). The annual recharge from about 19,000 acres of mountains in the study area is estimated to be 1,200 acre-ft/yr and to range from 630 to 1,300 acre-ft/yr or about 25 to 50 (acre-ft/yr)/mi of mountain front surrounding the valley.

Recharge to the aquifer system also includes some runoff from the southern part of Vekol Valley that infiltrates through the bottom sediments of Vekol Wash after it enters the northern part of the valley. Most of this recharge probably occurs within the first 2-mile reach after the wash crosses the southern boundary of the study area. On the basis of infiltration tests in the valley, recharge to the aquifer from Vekol Wash is estimated to be 10 percent of the total recharge to the system. Recharge contribution by the numerous small tributaries to Vekol Wash was considered in the calculation of the mountain-front recharge. Infiltration from direct precipitation to the valley floor was not considered significant for purposes of this study because of high evaporation rates.

Discharge

Ground water in the study area originates as recharge, moves from the margins toward the axis of the valley, and then moves northward to a discharge point near the Booth Hills (fig. 5). In a steady-state flow system, inflow equals outflow. In the study area the amount of recharge (about 1,200 acre-ft/yr) to the system equals discharge near Booth Hills. Water losses from the ground-water system owing to evapotranspiration and spring discharge are negligible.

Withdrawals

No significant withdrawals of ground water occurred in the study area before ground-water exploration and aquifer testing began in 1979. About 15 domestic and livestock wells exist in the valley; however, withdrawal from these wells probably totals less than 50 acre-ft/yr. Withdrawal is insignificant in relation to the annual ground-water inflow and the amount of ground water in storage. Withdrawals owing to well drilling and aquifer testing probably did not exceed 500 acre-ft during 1979-83. The ground-water system in the study area is considered to be in a steady-state condition.

SIMULATION OF THE GROUND-WATER FLOW SYSTEM

The objectives in the development of a numerical ground-water flow model were threefold. The first objective was to analyze the reliability of the conceptual model of the ground-water system. The second objective was to evaluate and refine estimates of aquifer characteristics. The third objective was to predict aquifer response to proposed pumping and thus be helpful as a management tool for evaluating the well-field design and development of the aquifer.

Technique

The simulation of the hydrologic system used a three-dimensional, finite-difference numerical model. A numerical ground-water flow model is a group of mathematical equations that approximate the ground-water flow through an aquifer system as a function of the hydraulic characteristics of the system and rates of inflow and outflow. The method of solving these equations involves solving the finite-difference approximations of the partial differential equations of three-dimensional ground-water flow (Trescott, 1975; Trescott and others, 1976; Larson and Trescott, 1977; Pinder and Bredehoeft, 1968; McDonald and Fleck, 1978; Wang and Anderson, 1982).

The model developed by McDonald and Harbaugh (1984) was used for this study because the necessary simulative options were available and output was easily adapted to graphical display and statistical evaluation.

Model Characteristics and Data Input

Any model is, at best, an approximation of the real hydrologic system because all the characteristics of the actual system cannot be included even if known. Simplifying assumptions are required to make the model a manageable representation of the actual aquifer system.

The following model characteristics and assumptions were used for simulating the aquifer-flow system.

1. In order to simulate the aquifer-flow system by finite-difference approximations, the aquifer was divided into a network of blocks (fig. 8). Average physical and hydraulic characteristics of the aquifer were assigned at a point or node in the center of each block. The aquifer was presumed to be homogeneous and isotropic within a given block. A variable block size was used to produce a higher block density and consequently a better resolution in areas where (a) data density was high, (b) large variations in aquifer stress occurred or was proposed, or (c) large variations in aquifer characteristics occurred. Lower block densities were used near margins of the modeled area to reduce computer storage requirements. Variation in block size was less than 1.5 times the size of any adjacent block. The network of blocks was oriented north to south in order to align with the major ground-water flow direction.

2. The four previously described hydrogeologic units are represented by four layers in the model. Layer 1 represents unit 1 (figs. 3 and 4), spans the entire modeled area shown in figure 8, and is divided into 1,851 active blocks. Layer 2 represents unit 2, extends from the Highway fault (fig. 2) to the south end of the modeled area, and has 1,418 active blocks. Layer 3 represents unit 3, extends from the Highway fault to an east-west line about 1 mi south of well V-5 (fig. 5), and has 999 active blocks. Layer 4 represents unit 4 and has the same number of active blocks and areal extent as layer 2. The total number of active blocks in the three-dimensional network is 5,686.

3. Layer 1 simulates the unconfined aquifer (unit 1). Layers 2, 3, and 4 simulates the confined aquifers (units 2, 3, and 4). Layer 2 had the additional option of conversion to unconfined conditions if the head was drawn down below the top of layer 2.

4. Water-level contours shown in figure 5 represent steady-state potentiometric conditions in all

layers of the aquifer system in 1983. Initial water levels were interpolated from these contours for each active block in the model.

5. All mountain-front recharge (about 1,200 acre-ft/yr) simulated in the model was distributed to blocks in the uppermost layer along the model boundary based on a flow-net analysis. Infiltration of surface water to the water table from Vekol Wash was simulated as areal recharge in the uppermost layer of the model (fig. 8).

6. All model boundaries of the ground-water flow system (fig. 8) coincide with limits defined by the previously discussed hydrogeologic characteristics of the system (figs. 2, 3, 4, 6, and 7). The lateral boundaries of all layers are streamline (no-flow) boundaries except for the outflow point in layer 1. The boundary at the outflow point (fig. 8) is a constant-head boundary during the steady-state analysis. The constant-head boundary allowed the flux to vary during simulation while maintaining the observed heads constant at the outflow. During transient analysis, the outflow point was converted to a head-dependent flux boundary. The head-dependent flux boundary allowed the fluxes determined by the steady-state analysis to decrease as the head declined during ground-water withdrawal. Outflow was equal to zero when the head declined 5 ft, which is the point at which the water-table gradient is horizontal or zero. The bottom of layer 4 is a steamline boundary. The uppermost boundary of the system is a free-surface (water-table) boundary. All boundaries were selected using the methods discussed by Franke and others (1984).

7. Flow is permitted either horizontally and (or) vertically between all interior blocks of all layers. Horizontal and vertical flow is governed by the hydraulic characteristics and flow regimes of adjacent blocks. Physical (size and shape) characteristics of the aquifer system were not changed after initial input.

8. The hydraulic characteristics determined from aquifer tests at wells V-5, NV-5, NV-6, and NV-7 reasonably represent the characteristics for the modeled aquifer system.

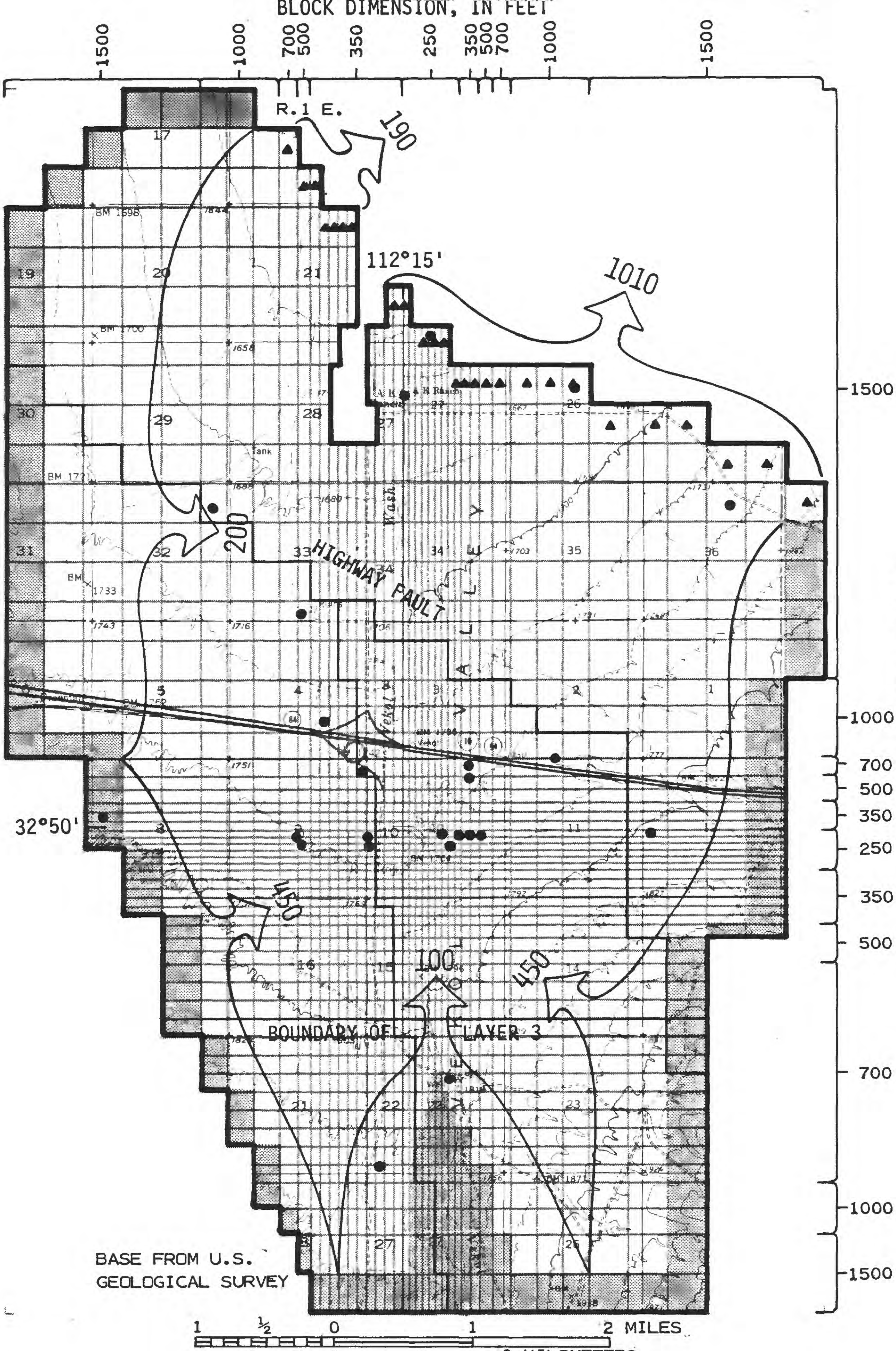
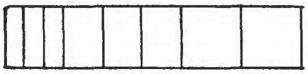


Figure 8.--Finite-difference network of blocks and boundary conditions used in the numerical ground-water flow model.

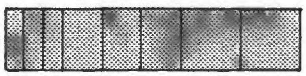
E X P L A N A T I O N

WELL

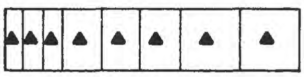


BLOCK—Dimensions range from 250 to 1,500 feet on a side. A node at the center of each block represents average aquifer conditions for that block in the model

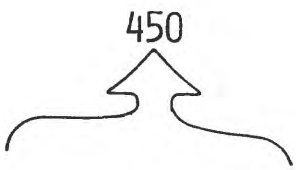
BLOCK AREA IN WHICH INFLOW AND OUTFLOW TO THE AQUIFER IS SIMULATED



Mountain-front recharge—Distribution of inflow only to layer 1 as recharge of precipitation over each indicated block



Outflow—Blocks in which the water table was maintained at a constant head during steady-state simulation in order to produce an outflow equal to inflow. During transient simulation, blocks simulated a head-dependent flux that allowed outflow to decrease as heads declined in response to ground-water withdrawal



Flux—Number, 450, is amount of inflow or outflow, in acre-feet per year, used in simulation. Direction of arrow indicates whether flux is inflow to or outflow from modeled area

BOUNDARY OF NUMERICAL GROUND-WATER FLOW MODEL—Outermost boundary represents extent of unit 1; Highway fault line represents northern boundary of units 2, 3, and 4; interior line labeled unit 3 is southern extent of unit 3; and north-south line in units 2, 3, and 4 represents a midunit offset as illustrated in figure 4

Figure 8

9. Vertical conductances for each layer were calculated on the basis of a vertical-to-horizontal conductivity ratio of 1:12. This ratio was determined from the aquifer test conducted at well NV-6. The ratio is assumed to be applicable to all layers. The vertical conductance between each block in the model was calculated using the methods of McDonald and Harbaugh (1984, p. 138-147).

10. The average pumping rate calculated for each aquifer test and used for transient-model calibration adequately represented the actual stress caused by those tests on the aquifer system.

Steady-State Simulation

The development of the numerical ground-water flow model was begun by using established aquifer characteristics and estimated water-budget components in order to simulate the steady-state conditions. The model-calibration procedure consisted of changing hydrologic characteristic values within the limits indicated by the hydrogeology and estimated water budget until the model-calculated head distribution reasonably matched observed head distribution (fig. 9). The procedure required a trial-and-error adjustment of one hydrologic parameter while all other parameters were kept constant. Horizontal hydraulic conductivity in layer 1 affected the shape and gradient of the calculated heads more than any other parameter. Thus, all modeled characteristics in the lower layers were kept constant while changing hydraulic conductivity in layer 1. When a reasonable head match had been established for layer 1, hydrologic characteristics for each lower layer were changed within predetermined limits until the flow between layers and the calculated-head distribution reasonably matched the observed-head distribution. Recharge was redistributed to modify the shape of the calculated-head contours along the mountain fronts. A comparison of the calculated- and observed-head distributions is shown in figure 9.

The distribution of transmissivity determined for each layer during the steady-state analysis is shown in figures 10-13. Distribution of transmissivity in layer 1 and 2 (figs. 10 and 11) is based primarily on the distribution of hydraulic conductivity determined from the steady-state analysis. Both layers 1 and 2, but more clearly layer 1, indicate a zone of higher transmissivity along the axis of the valley. This zone may be associated with the stream-channel deposits of an ancient Vekol Wash. Limited transmissivity data precluded a similar analysis of spatial distribution of transmissivity for layers 3 and 4.

In addition to a comparison of the head contours (fig. 9), another measure of the agreement between the simulated- and observed-head distribution can be statistically determined by means of the root-mean square (RMS) deviation (Hoxie, 1977). The RMS deviation is analogous to the standard deviation in statistics. The RMS deviation is defined as:

$$\text{RMS} = \left[\frac{1}{N} \sum_{i=1}^{N} (h_s - h_o)^2 \right]^{\frac{1}{2}} \tag{1}$$

where

N = Number of blocks per layer in the finite-difference network;

h_s = simulated head, in feet;

h_o = observed head, in feet.

The RMS deviation, therefore, is a measure of the mean departure of the simulated-head distribution from the observed-head distribution.

In the steady-state simulation, the RMS deviation of the simulated heads from the observed heads was calculated for each layer in the model (table 2). The RMS deviations shown in table 2 indicate that the match of the simulated to observed heads in the steady-state model are less than 5 ft for all four layers. The data used to construct the steady-state water-level surface map (fig. 5) ranged in accuracy from less than 1 ft to about 10 ft. The RMS deviation of simulated to observed heads was within the accuracy limits of the data used in the conceptual model.

Table 2.--Root-mean square deviation of the simulated heads from the observed heads in the steady-state model

Model layer	Root-mean square deviation, in feet	Maximum departure, in feet
1	3.32	10.81
2	3.49	10.94
3	4.36	9.55
4	4.82	10.57

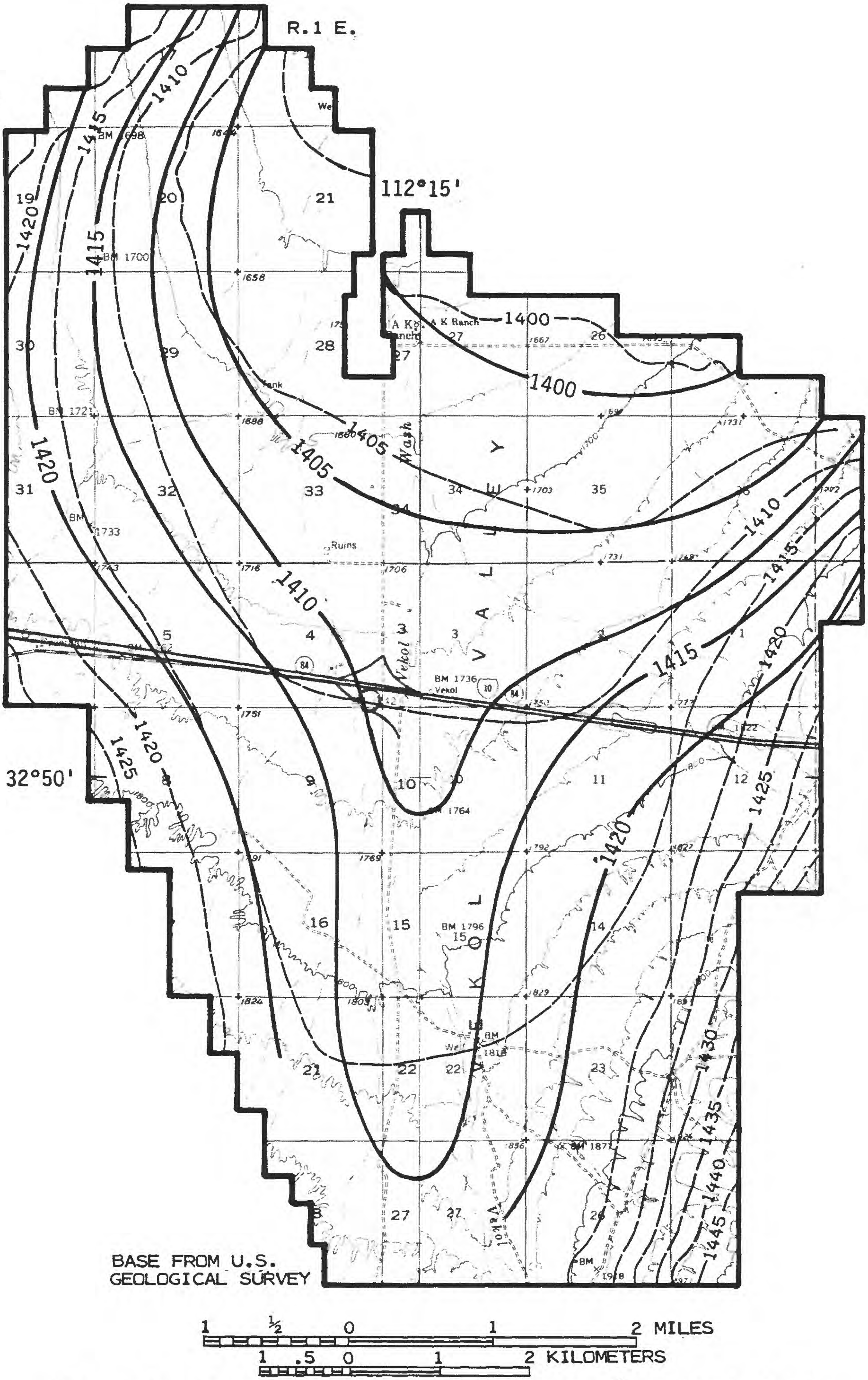


Figure 9.--Distribution and comparison of observed and simulated potentiometric heads for the steady-state system.

EXPLANATION

— — — 1400 — — —	SIMULATED POTENTIOMETRIC HEAD CONTOUR—Number, 1400, is altitude of the potentiometric surface as calculated by the steady-state numerical-flow model. Contour interval 5 feet. National Geodetic Vertical Datum of 1929
——— 1405 ———	OBSERVED POTENTIOMETRIC HEAD CONTOUR—Number, 1405, is altitude of the observed potentiometric surface (from fig. 5). Contour interval 5 feet. National Geodetic Vertical Datum of 1929
————————	BOUNDARY OF MODEL AREA

Figure 9

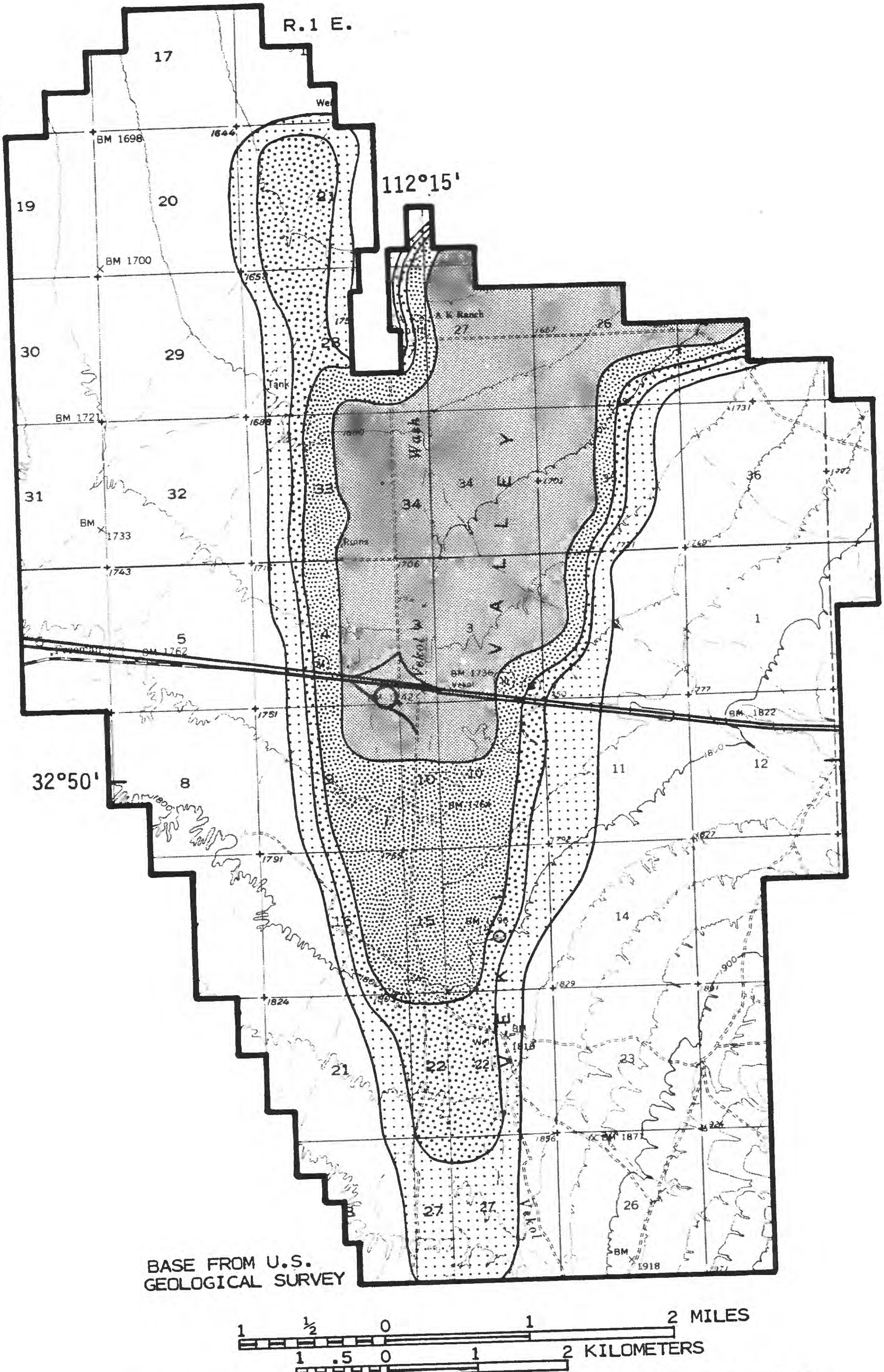


Figure 10.--Distribution of transmissivity, layer 1, of the steady-state simulation.

EXPLANATION

TRANSMISSIVITY, IN FEET SQUARED PER DAY

Less than 2,500

2,500 to 5,000

5,000 to 7,500

7,500 to 12,500

More than 12,500

BOUNDARY OF MODEL AREA

Figure 10

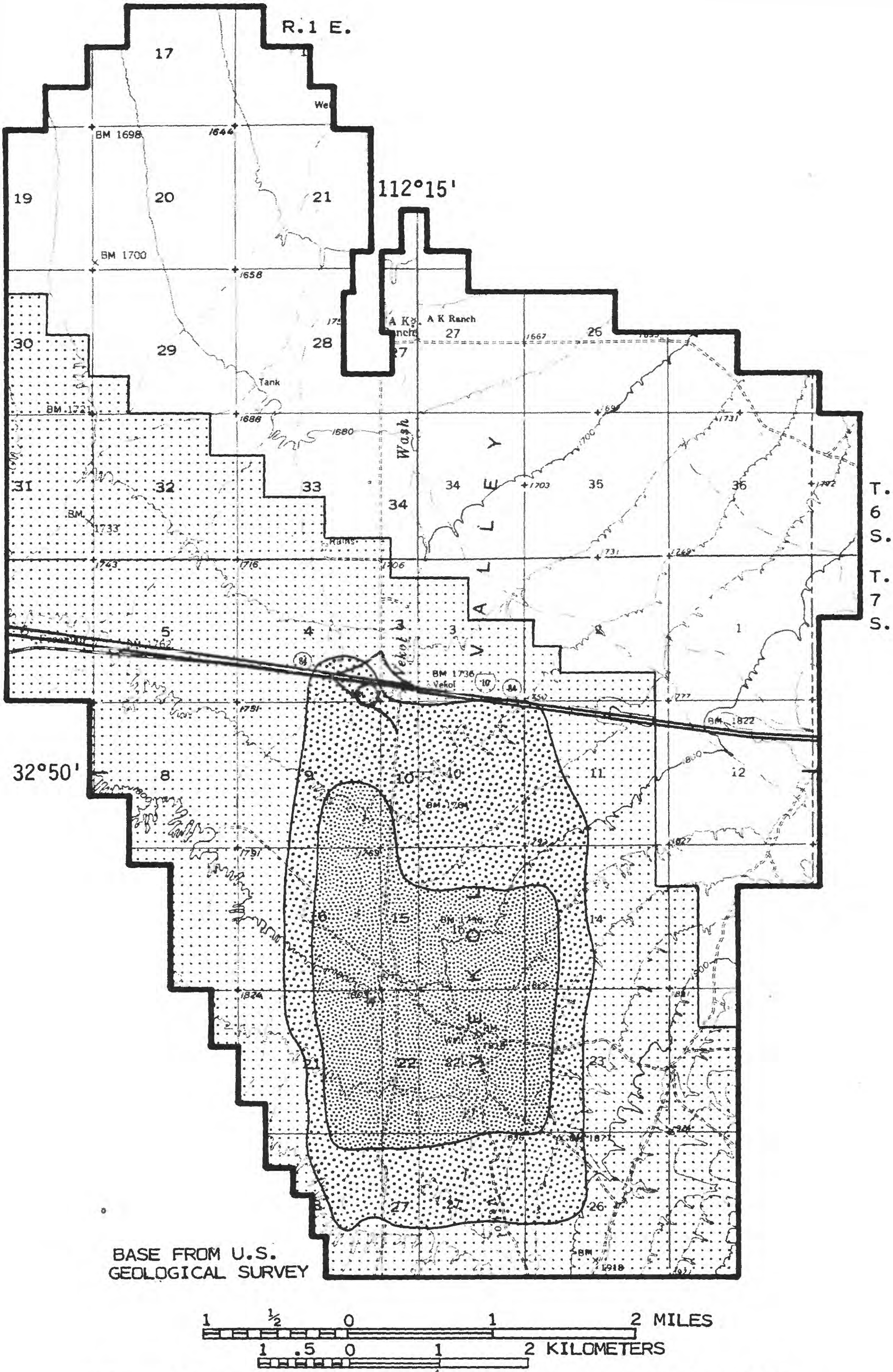


Figure 11.--Distribution of transmissivity, layer 2, of the steady-state simulation.

EXPLANATION

TRANSMISSIVITY, IN FEET SQUARED PER DAY

Less than 2,500

2,500 to 5,000

More than 5,000

BOUNDARY OF LAYER 2

BOUNDARY OF MODEL AREA

Figure 11

34

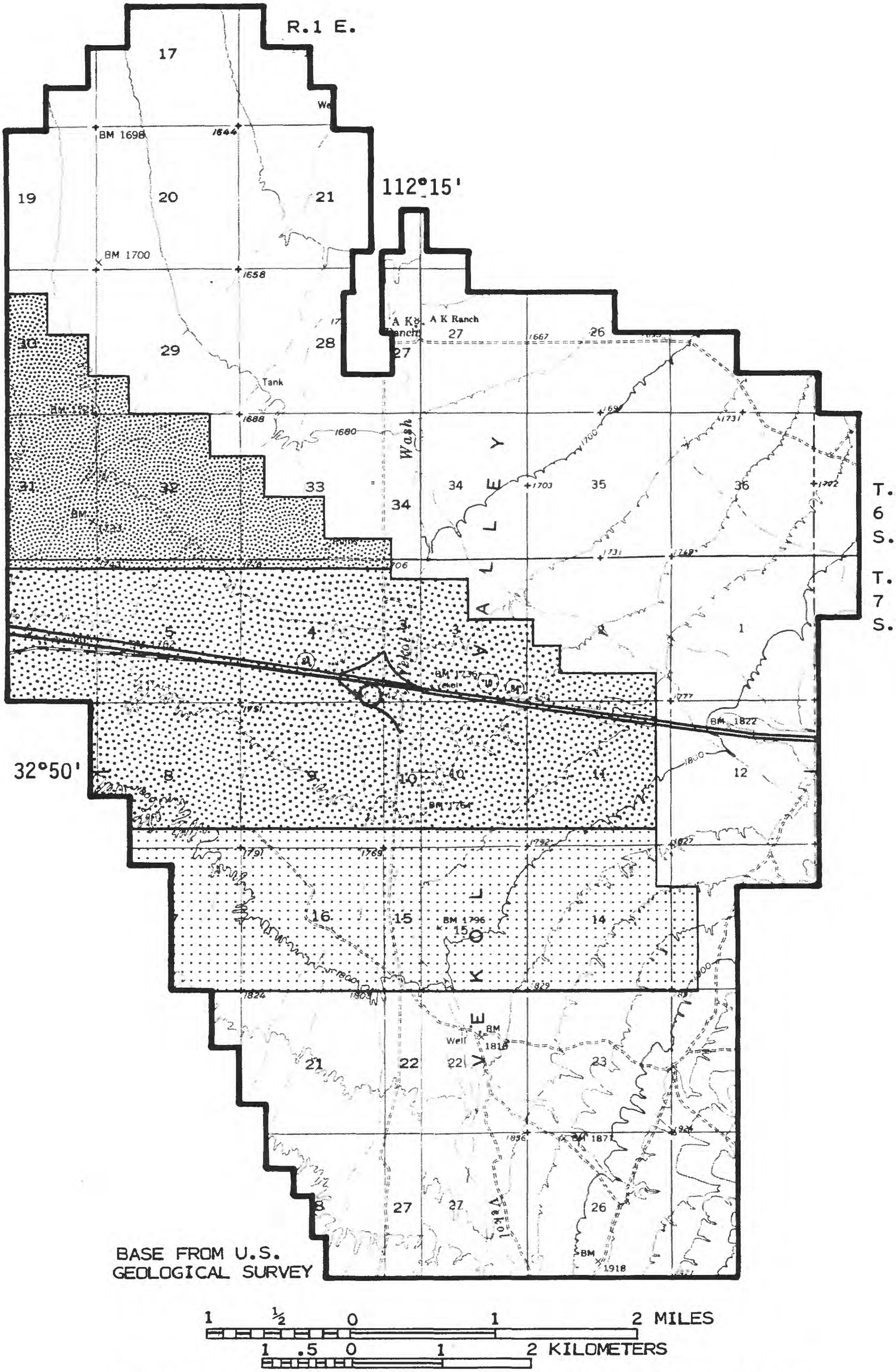


Figure 12.--Distribution of transmissivity, layer 3, of the steady-state simulation.

EXPLANATION

TRANSMISSIVITY, IN FEET SQUARED PER DAY

0 to 200

200 to 400

More than 400

BOUNDARY OF LAYER 3

BOUNDARY OF MODEL AREA

Figure 12

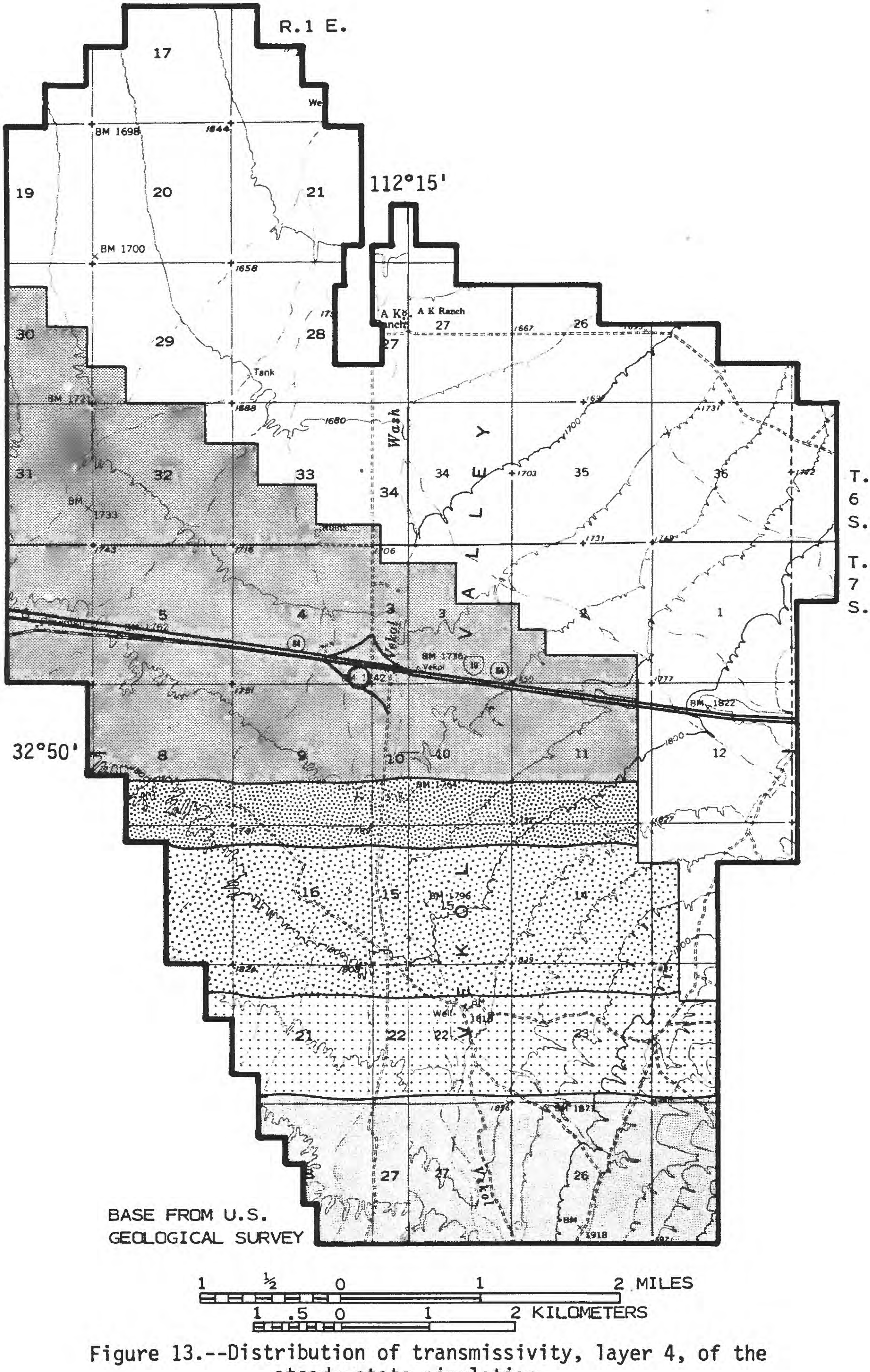


Figure 13.--Distribution of transmissivity, layer 4, of the steady-state simulation.

E X P L A N A T I O N

TRANSMISSIVITY, IN FEET SQUARED PER DAY

Less than 500

500 to 700

700 to 1,000

1,000 to 1,400

More than 1,400

BOUNDARY OF LAYER 4

BOUNDARY OF MODEL AREA

Figure 13

Transient Simulation

In order to test the hypothesis that the steady-state model reasonably represents the ground-water flow system, a transient simulation was made. A transient simulation is one in which the aquifer system is pumped or otherwise stressed and changes in the amount of water in storage along with corresponding changes of the potential surface(s) within the aquifer system are determined with time. The computed heads from the steady-state simulation were used as initial heads in the transient model to eliminate calculations in the transient model that might be due to slight discrepancies between simulated and observed heads rather as than a rigorous response to ground-water withdrawals.

The constant-head outflow boundary near the Booth Hills in the steady-state model (fig. 8) was changed to a head-dependent flux (drain) boundary in the transient analysis. This drain boundary allowed the outflow from the system to decrease as the water level in layer 1 declined in response to ground-water pumping. This drain boundary allowed outflow to decrease linearly as head declined to a level at which the water-level gradient through the drain block became zero. For modeling purposes, a drawdown of 5 feet in the drain blocks reduced the outflow to zero and is comparable to the prevailing water-table gradient at the outflow point. The drain boundary did not allow water to flow into the modeled area as the gradient reversed along this boundary. A reversible, head-dependent flux boundary (general head boundary), one that would allow water to flow into the modeled area when drawdown in each outflow block exceeded 5 ft, was used in earlier simulations. The general-head boundary, however, allowed more water to flow into the modeled area from the aquifer north of the boundary than was estimated to be available. Therefore, a drain boundary was used in this analysis because the simulation produced a maximum value of drawdown at the end of the pumping period.

Three pumping periods were used in the transient analysis and calibration of the aquifer system (table 3). The pumping periods were designed to coincide with phases of a 23-day aquifer test conducted during 1982 at well NV-6. The test involved one pumping well that stressed the aquifer at 2,500 gal/min for about 23 days. The pumping well fully penetrated the aquifer system, and ground water was withdrawn from layers 1, 2, and 4. Data from 12 observation wells that ranged in distance from 82 ft to 3.8 mi from the pumped well were used to record the aquifer response to ground-water withdrawal and to calibrate the transient model. During the transient analysis, vertical-conductance values for layers 1 to 2 were held constant at values calculated from the NV-6 aquifer test and values for layers 2 to 3 and 3 to 4 were systematically modified until the simulated response in layers 2 and 4 matched the aquifer response observed during the 23-day aquifer test. The results of this analysis indicated that slightly smaller values of vertical conductance were needed than originally estimated. The resultant values of vertical conductance, however, were within the range of values expected for aquifer material in the northern part of Vekol Valley. The values are given below.

Layers	Range in vertical-conductance values in day^{-1} From	To
1 and 2	5.1×10^{-3}	6.1×10^{-4}
2 and 3	7.9×10^{-3}	4.7×10^{-4}
3 and 4	7.9×10^{-3}	4.7×10^{-4}
2 and 4	1.1×10^{-3}	----------

Table 3.--Withdrawal rates used during the transient simulation

Pumping period	Layer	Rate of withdrawal, in cubic feet per day	Total withdrawal, in acre-feet
1 (0.75 day)	1	370,781	6.38
Do.	2	75,850	1.31
Do.	4	34,652	.60
2 (0.42 days)	-	0	0
3 (22.8 days)	1	370,781	194.07
Do.	2	75,850	39.70
Do.	4	34,652	18.14
TOTAL			260.20

Storage values used in the transient simulation were based on storage values determined from a compilation of results for four aquifer tests (table 2). The aquifer tests indicated that specific yield for layer 1 was generally consistent throughout the modeled area. Specific yield, therefore, was input to layer 1 in the model as a single value (0.12) and not altered. In layers 2, 3, and 4, storage was input as specific storage multiplied by layer thickness. A single value for specific yield (0.08) was specified in the model and was to be used if (when) layer 2 converted from confined to unconfined conditions.

The results of the transient analysis indicate that the model reasonably simulated the 23-day aquifer test from the 10th day throughout the remainder of the test. The model does not, however, adequately deal with early time transient flow because delayed-gravity drainage is not simulated. Transient, unconfined flow to a discharging well during early time is a combination of water released from storage by compaction of the aquifer material, expansion of the water, and gravity drainage near the water table (Neuman, 1972). The gravity-drainage function is not included in the computer code used; consequently, the simulated drawdowns were less than those observed during the first 10 days of the aquifer test. After 10 days, however, the simulated water levels converged with those observed during the aquifer test. For purposes of this study, the model-generated water levels during early time will not be detrimental to the overall analysis. Thus, all water-level predictions in this study are values derived from the end of the pumping periods and all pumping periods are longer than the time required for convergence of simulated and observed water levels.

Analysis of Model Response and Sensitivity

The steady-state model was developed from a conceptual model that was based on detailed studies in Vekol Valley. The hydrologic properties of the aquifer, aquifer boundaries, configuration of the water-level surface, and thickness of the geologic units (model layers) were established from these studies. Other model variables—mountain-front and stream recharge, distribution of hydraulic conductivity and transmissivity, vertical conductance, and storage—were extrapolated from site-specific data points and tested by the model. The model was further used to refine the distribution of specific hydrologic parameters within the limits set by the conceptual model.

The sensitivity of the model response to changes in certain modeled hydraulic characteristics, such as the magnitude and distribution of (1) hydraulic conductivity and transmissivity, (2) vertical conductance between upper and lower layers, and (3) storage characteristics, was tested by varying the values of these characteristics individually within the limits of the conceptual model and comparing computed to observed heads. The results of varying the value of each characteristic indicates the sensitivity of the model to the value of that characteristic. These sensitivity-analysis results were measured in terms of percent change in the average steady-state flux (fig. 8) and (or) changes in configuration or slope of the simulated potentiometric surface (fig. 9).

During steady-state analysis, distribution and magnitude of hydraulic conductivity in layers 1 and 2 were determined to exert more control on the ground-water flow system than any other hydraulic characteristic tested. The hydraulic conductivity of layers 1 and 2 was based on results from four aquifer tests conducted at widely spaced sites that covered the principal part of the aquifer system. Thus, the hydraulic-conductivity values derived from these tests are widely spaced; however, the values are representative of the average aquifer material extant within the cones of depression caused by the pumping wells. Values of hydraulic conductivity for the aquifers along the margin of the area are not known and had to be determined during steady-state calibration. Thus, hydraulic-conductivity values in layers 1 and 2 of the model were changed systematically from the outflow point and points of known hydraulic conductivity up the water-level gradient to the margins until the simulated configuration of the potentiometric surface approximated the observed potentiometric surface. Changes were made within the constraints established by the conceptual ground-water flow system. For example, figure 14 shows the changes resulting from two of these experiments. First, the hydraulic conductivity was increased by 20 percent then the recharge was increased by 20 percent above the previously determined values for these two parameters. The potentiometric surfaces resulting from these two experiments (fig. 14) illustrate the effects on the potential surface caused by such changes. A 20-percent change in the value of hydraulic conductivity changed the simulated water-level gradient by about 30 percent (fig. 14).

The mountain-front and stream-recharge values input to the model control the net flux through the system as well as the configuration of the potentiometric-surface contours. Changing the recharge values in the calibrated steady-state model by 20 percent altered the potentiometric gradient by as much as 50 percent near inflow and outflow points. Net flux through the system, of course, changed 20 percent (fig. 14). Thus, recharge was systematically increased or decreased and redistributed until a reasonable match of mountain-front and stream-recharge values and configuration of the simulated heads fell within the constraints of the conceptual ground-water flow system.

Modeling the aquifer system as a multilayered system necessitated a determination of vertical conductance between layers. Vertical conductance was not derived from aquifer tests directly but was estimated using the vertical to horizontal hydraulic-conductivity ratios and transmissivity-hydraulic conductivity relations obtained from the aquifer tests and the thickness of each geohydrologic unit. The estimates of vertical conductance used in this analysis were compared to published (Freethey, 1982; Eychaner, 1983) and unpublished estimates used in ground-water flow analyses of systems with similar hydrogeologic characteristics. The values compared well. Distribution and magnitudes of vertical conductance controlled the vertical flow in the steady-state model so that water moved primarily down to deeper layers near the mountain fronts and under the southern part of Vekol Wash and up to layer 1 near the Highway fault. More than 95 percent of ground-water flow in the steady-state system occurred in layers 1 and 2; flow to, through, and from layers 3 and 4 was less than 5 percent of the total flux. Vertical flow was essentially unaffected by changes in values of vertical conductance greater than about 1×10^{-6} day^{-1} because flow within the system was primarily controlled by other hydrologic properties. However, reducing vertical-conductance values much below 1×10^{-6} day^{-1} in the steady-state analysis produced simulated heads in layers 2, 3, and 4 that were unacceptably higher than in the observed heads.

Changes in vertical conductance during transient analysis had more effect on vertical flow of ground water in the system than in the

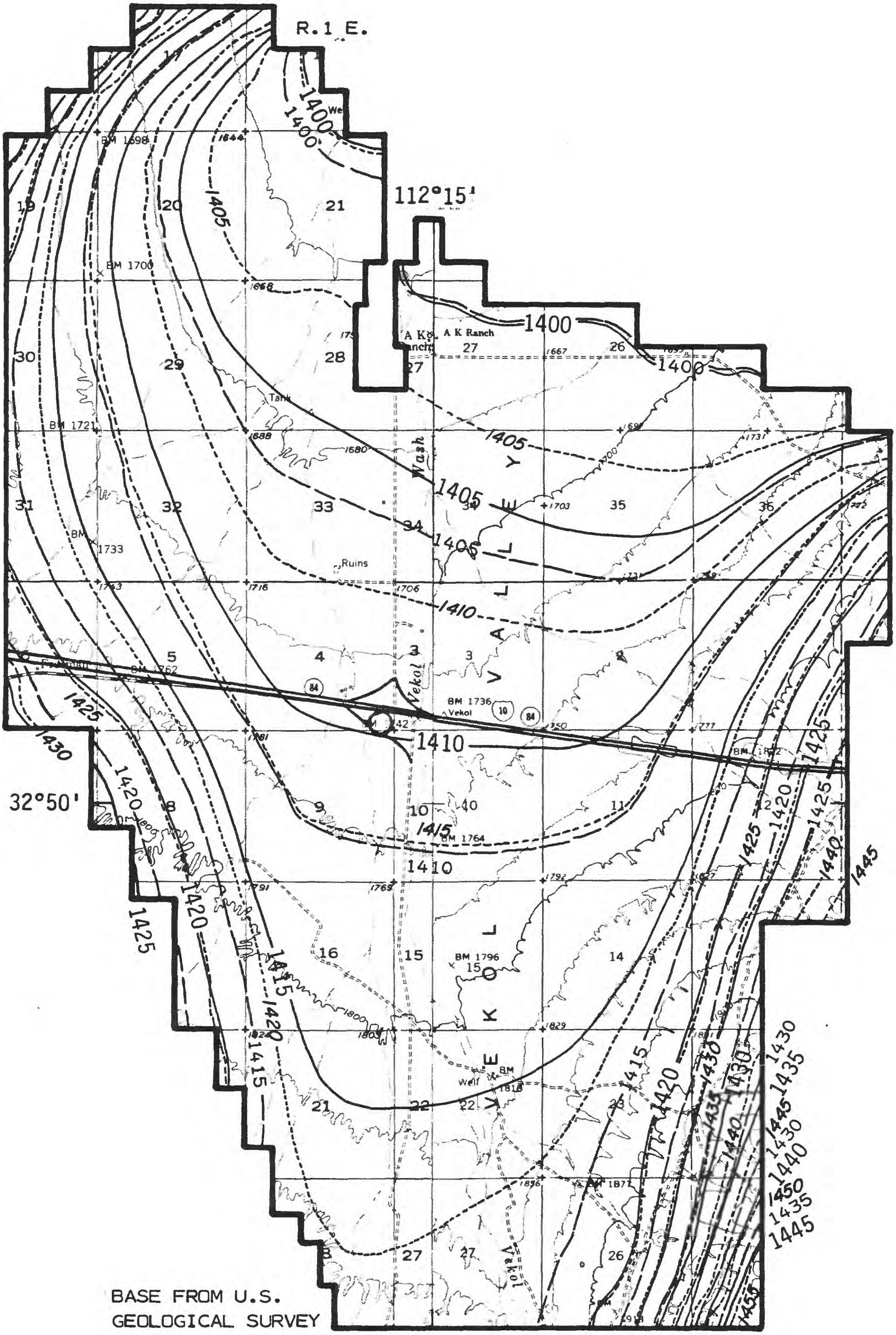


Figure 14.--Comparison of simulated steady-state potentiometric head with heads simulated using mountain-front recharge and hydraulic conductivity individually increased 20 percent.

EXPLANATION

———1425———	SIMULATED POTENTIOMETRIC HEAD CONTOUR—Number, 1,425, is altitude of the potentiometric surface as calculated by the steady-state model (fig. 9). Contour interval 5 feet. National Geodetic Vertical Datum of 1929
— — — 1400— — —	SIMULATED POTENTIOMETRIC HEAD CONTOUR AT A HIGHER VALUE OF HYDRAULIC CONDUCTIVITY IN LAYER 1—Number, 1,400, is altitude of the potentiometric surface as calculated by the steady-state model with the values of hydraulic conductivity increased 20 percent. Contour interval 5 feet. National Geodetic Vertical Datum of 1929
--------*1425*--------	SIMULATED POTENTIOMETRIC HEAD CONTOUR AT A HIGHER VALUE OF MOUNTAIN-FRONT RECHARGE—Number, 1,425, is altitude of the potentiometric surface as calculated by the steady-state numerical flow model with the values of areally distributed, mountain-front recharge increased 20 percent. Contour interval 5 feet. National Geodetic Vertical Datum of 1929
━━━━━━━━	BOUNDARY OF MODEL AREA

Figure 14

steady-state analysis. As the aquifer system was simulated under stress, small changes in vertical-conductance values during successive simulations caused substantial changes in the system response to a given stress. Thus, the process of matching the simulated system response to the actual response as recorded from the aquifer test allowed vertical conductance to be more adequately tested and defined. The model response to changes in vertical conductance during transient analysis indicated that layers 1 and 2 responded basically as a two-dimensional, unconfined system, whereas layers 3 and 4, which were simulated with much smaller values of vertical conductance, responded as a true confined, three-dimensional system.

Storage values used in the transient simulation were based on aquifer-test results and therefore represent mean values for a large part of the aquifer system actually contributing water during the test. These storage values were evaluated by varying them systematically in the model to simulate the aquifer tests and then compare the model-generated results to those observed during the actual tests. For example, reducing specific yield by 0.02 in layer 1 and storage coefficient by one order of magnitude in layer 2 resulted in a 16-percent increase in average drawdown across the modeled area. This model-generated drawdown exceeded the conceptual limits. Numerous similar tests were made and evaluated and ultimately led to the conclusion that the values derived from aquifer tests produced the best match between computed and observed conditions.

An overall evaluation of how well the steady-state analyses matched the conceptual ground-water flow system was based on the RMS deviation. The model was considered a good match to the conceptual system when the percent difference between the simulated and observed heads was less than 5 percent for 95 percent of the modeled area. The limits of RMS deviation used for this study were 4.0 ft for layers 1 and 2 and 5.0 ft for layers 3 and 4. Final RMS deviation values calculated at the end of the steady-state analysis were less than these limits (table 2).

The transient simulation was judged to be a good match with the conceptual ground-water flow system when the simulated heads in layers 1, 2, and 4 for nine observation wells reasonably matched those observed during the 10- to 23-day period of the 23-day aquifer test. A change not to exceed 1 to 2 ft between observed and simulated heads was set as a limit of deviation. The deviation between observed and simulated heads for the transient analysis was about 1.0 ft.

SIMULATION OF PROPOSED WITHDRAWALS

On the basis of the planned withdrawals designed by Franzoy, Corey, and Associates (written commun., 1983) to meet the water requirements of the Ak-Chin Indian Community Water Rights Settlement Act, a projection was made of these future pumping rates in order to evaluate water-level changes and changes in ground-water storage. The projection spanned 25 years—1984-2009—and was divided into nine time periods to best simulate the planned pumping scenario (table 4). Periods 2, 4, 6, and 8 represent recovery periods during which no pumping would take place. At the end of 25 years, a total of about 174,000 acre-ft of water would have been removed from the study area.

Table 4.--Simulated ground-water withdrawals, 1984-2009

[Modified from Franzoy, Corey and Associates, written commun., 1983]

Pumping or recovery period	Number of wells pumping during time period	Length of time period, in days	Total withdrawal, in acre-feet
1	11	365	33,987
2	0	165	0
3	11	92	6,710
4	0	169	0
5	11	199	14,615
6	0	169	0
7	11	199	14,615
8	0	169	0
9	4	7,598	104,100
TOTAL		[1]9,125	174,027

[1]Total equals 25 years.

As shown in figures 15-23, the effects of pumping from the centrally located well field extended out from the well field in a nearly symmetrical manner. The drawdown cone intersected the west and south boundaries of the modeled area as early as pumping period 1. Where the drawdown cone intersects a boundary, drawdown accelerates. Natural discharge of ground water at the outflow point began to slow during pumping period 5 and completely ceased during pumping period 7. At the end of pumping period 9, all boundaries of the modeled area had been intersected and maximum drawdown in the well field was estimated to be about 95 ft. The fact should be emphasized that the water-level declines shown in figures 15-23 represent drawdowns that were averaged over each model block and are not to be expected in a specific well. Drawdown observed within each pumping well will be greater than the amount shown and is dependent on the hydraulic characteristics of each individual well and that part of the aquifer system providing water to that well.

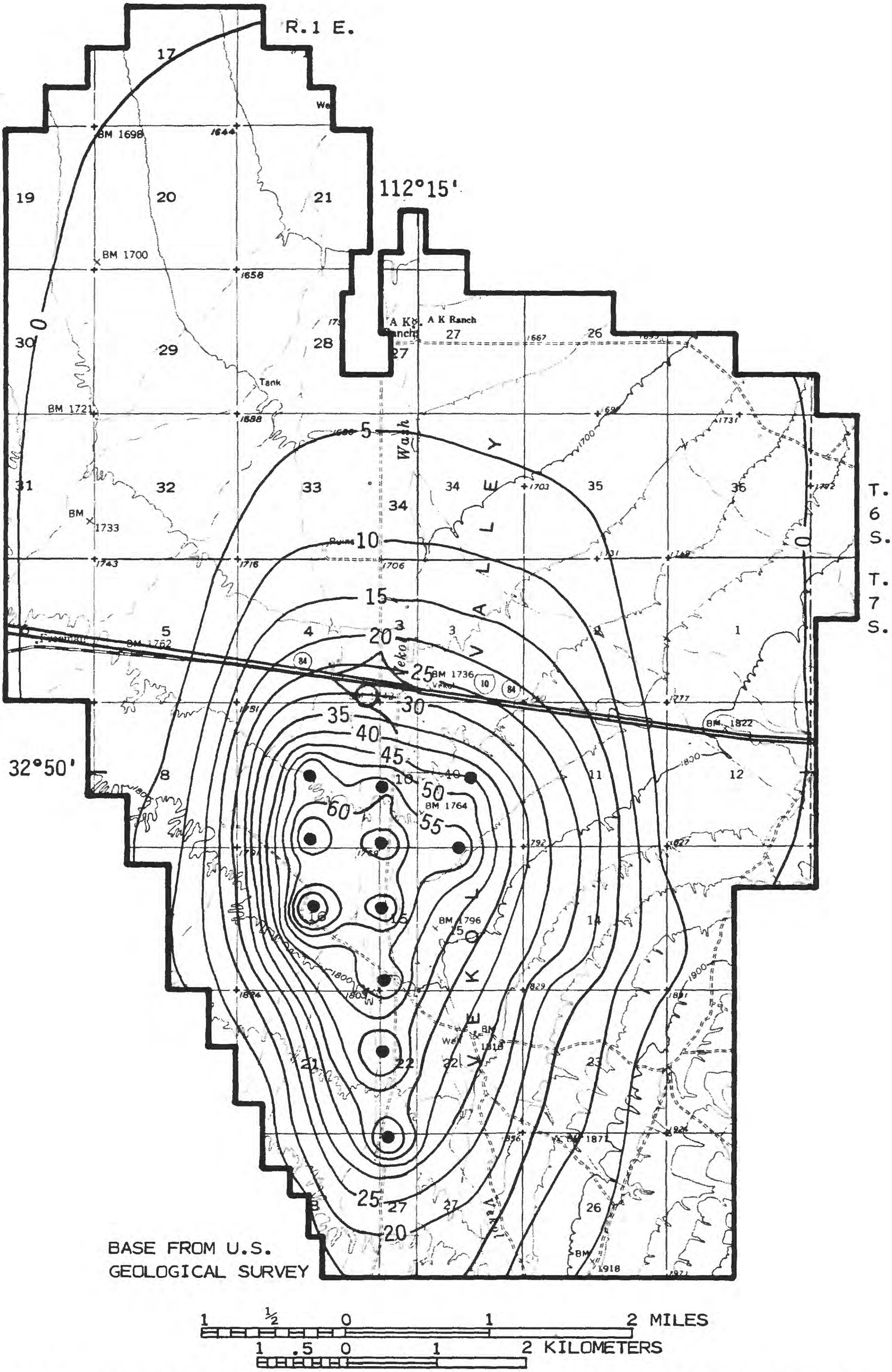


Figure 15.--Simulated water-level declines, pumping period 1 (table 4).

EXPLANATION

——— 50 ——— LINE OF EQUAL SIMULATED WATER-LEVEL DECLINE—Interval 5 feet

● BLOCK IN WHICH A WITHDRAWAL WELL WAS SIMULATED

——— BOUNDARY OF MODEL AREA

Figure 15

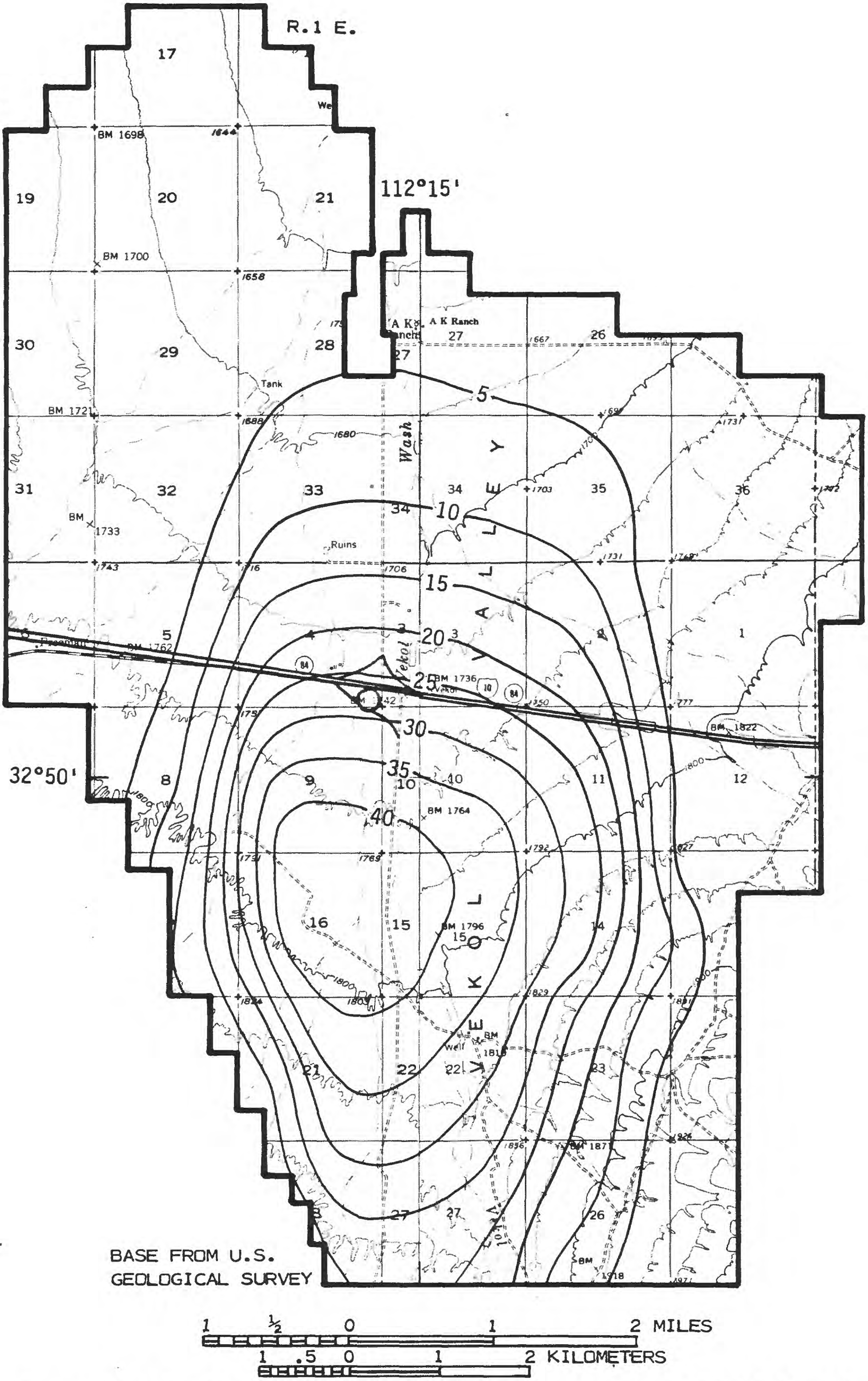


Figure 16.--Simulated water-level declines, pumping period 2 (table 4).

EXPLANATION

———25———	LINE OF EQUAL SIMULATED WATER-LEVEL DECLINE—Interval 5 feet
———————	BOUNDARY OF MODEL AREA

Figure 16

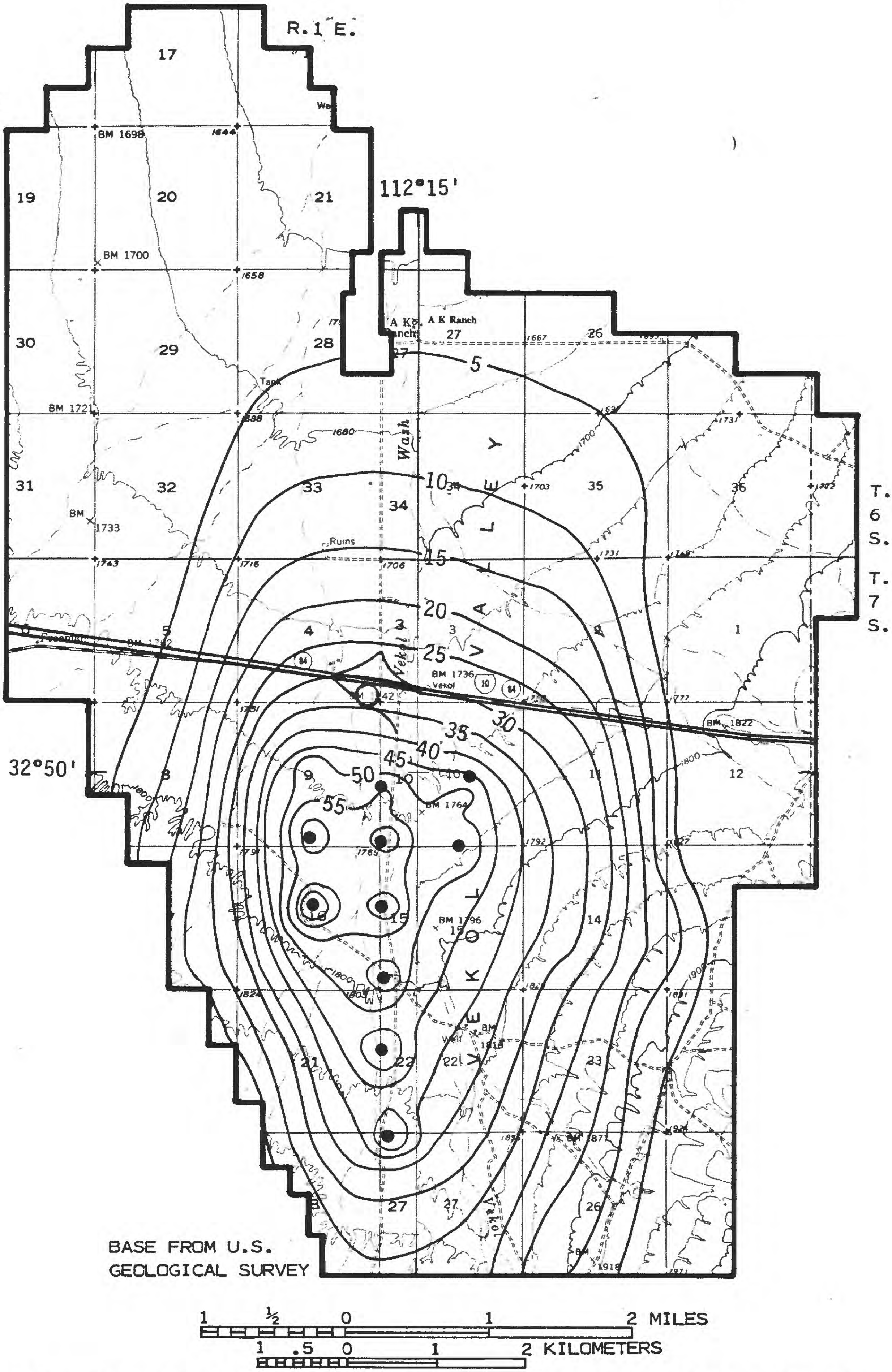


Figure 17.--Simulated water-level declines, pumping period 3 (table 4).

EXPLANATION

—— 50 —— LINE OF EQUAL SIMULATED WATER-LEVEL DECLINE—Interval 5 feet

● BLOCK IN WHICH A WITHDRAWAL WELL WAS SIMULATED

———— BOUNDARY OF MODEL AREA

Figure 17

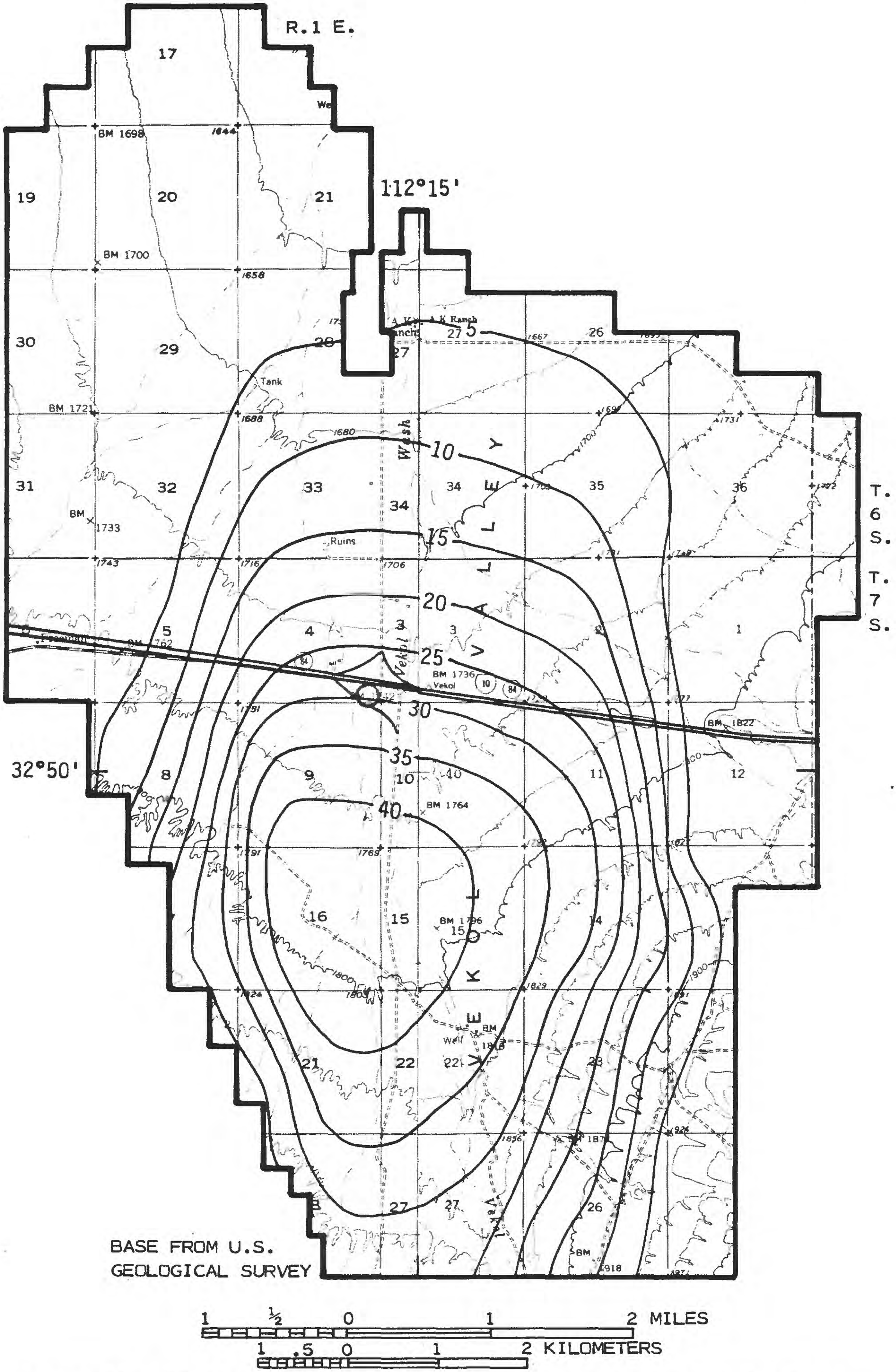


Figure 18.--Simulated water-level declines, pumping period 4 (table 4).

EXPLANATION

——25——	LINE OF EQUAL SIMULATED WATER-LEVEL DECLINE—Interval 5 feet
————	BOUNDARY OF MODEL AREA

Figure 18

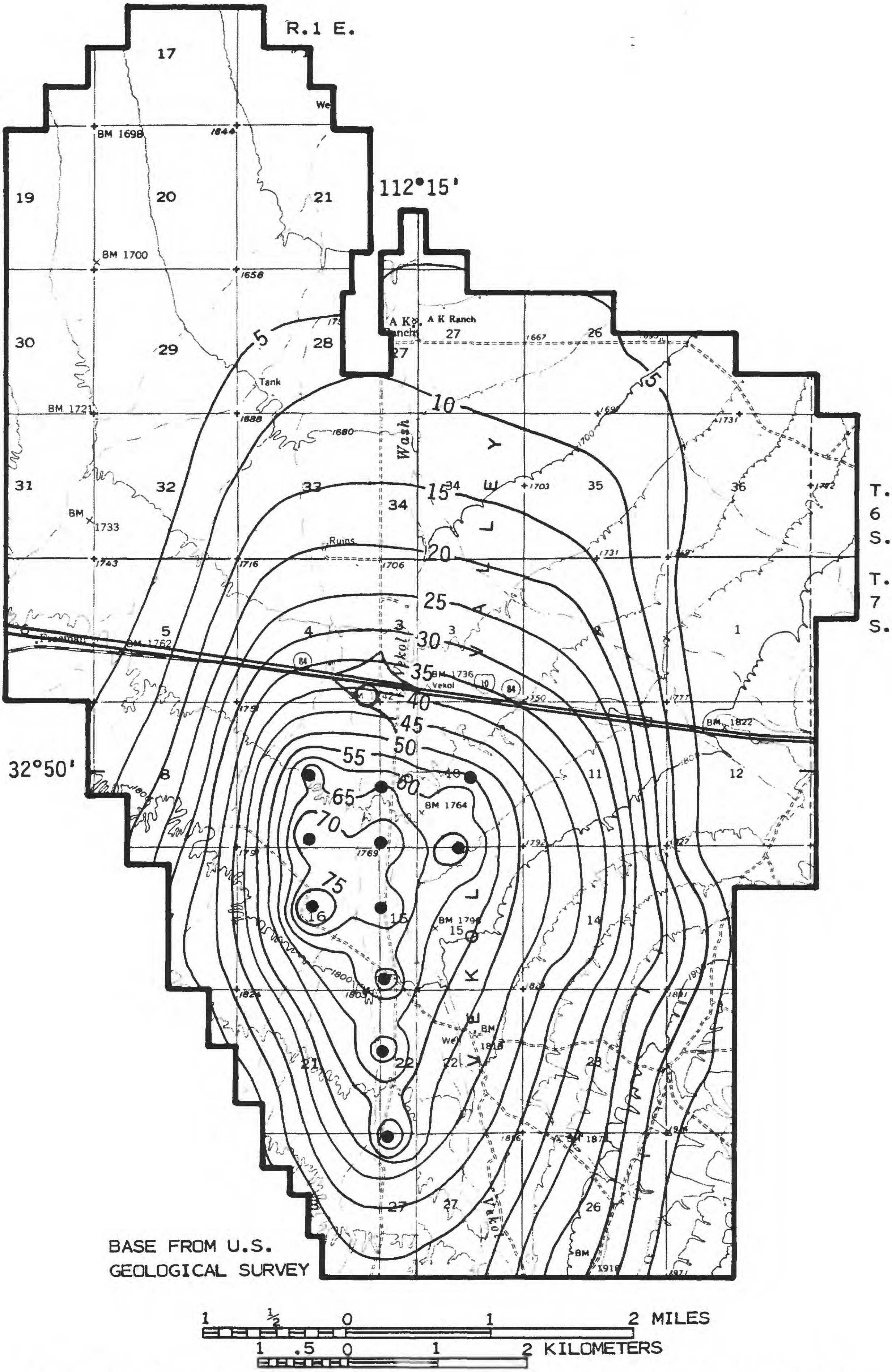


Figure 19.--Simulated water-level declines, pumping period 5 (table 4).

EXPLANATION

—— 25 ——	LINE OF EQUAL SIMULATED WATER-LEVEL DECLINE—Interval 5 feet
●	BLOCK IN WHICH A WITHDRAWAL WELL WAS SIMULATED
———	BOUNDARY OF MODEL AREA

Figure 19

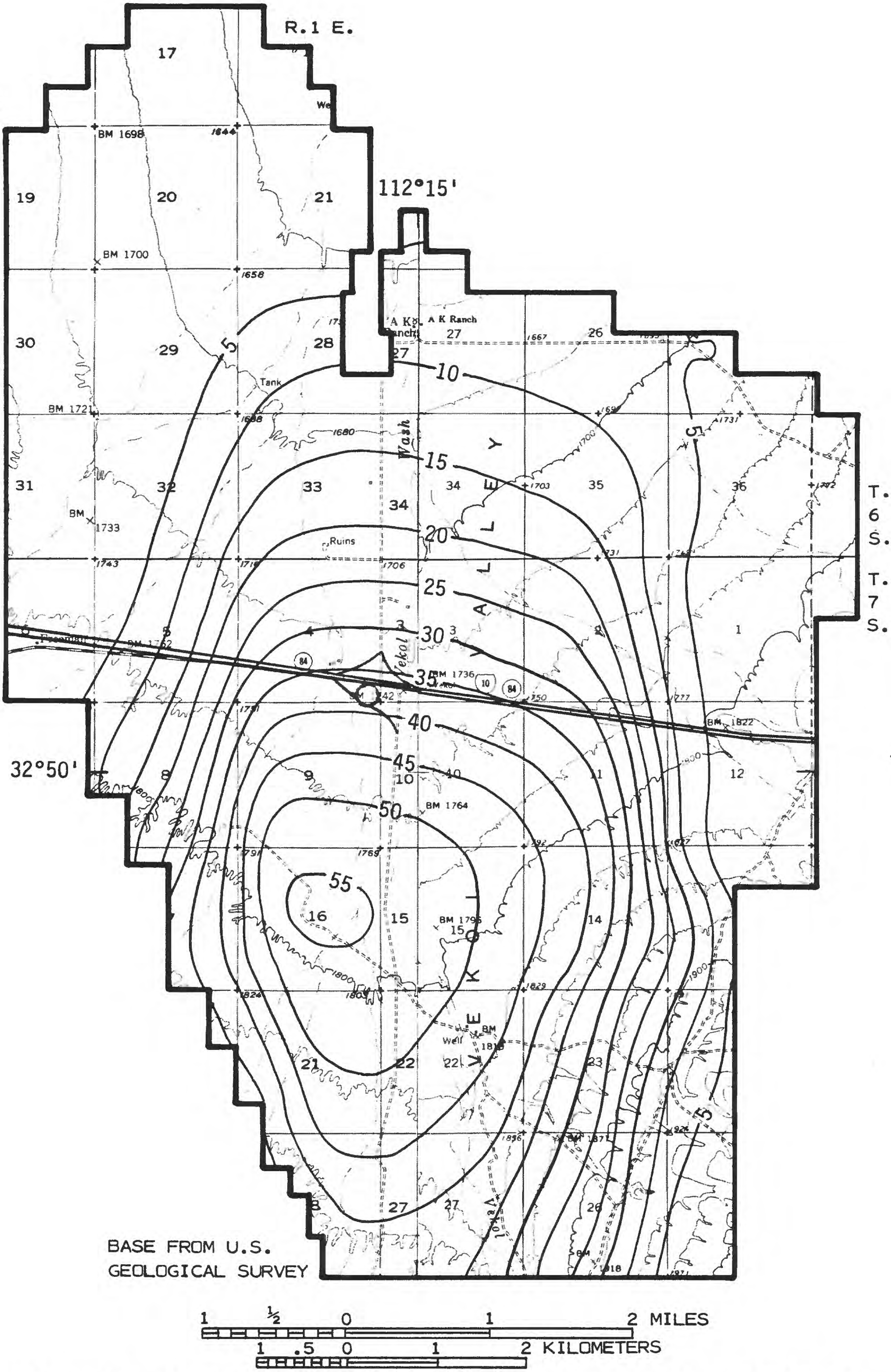


Figure 20.--Simulated water-level declines, pumping period 6 (table 4).

EXPLANATION

——25—— LINE OF EQUAL SIMULATED WATER-LEVEL DECLINE—Interval 5 feet

BOUNDARY OF MODEL AREA

Figure 20

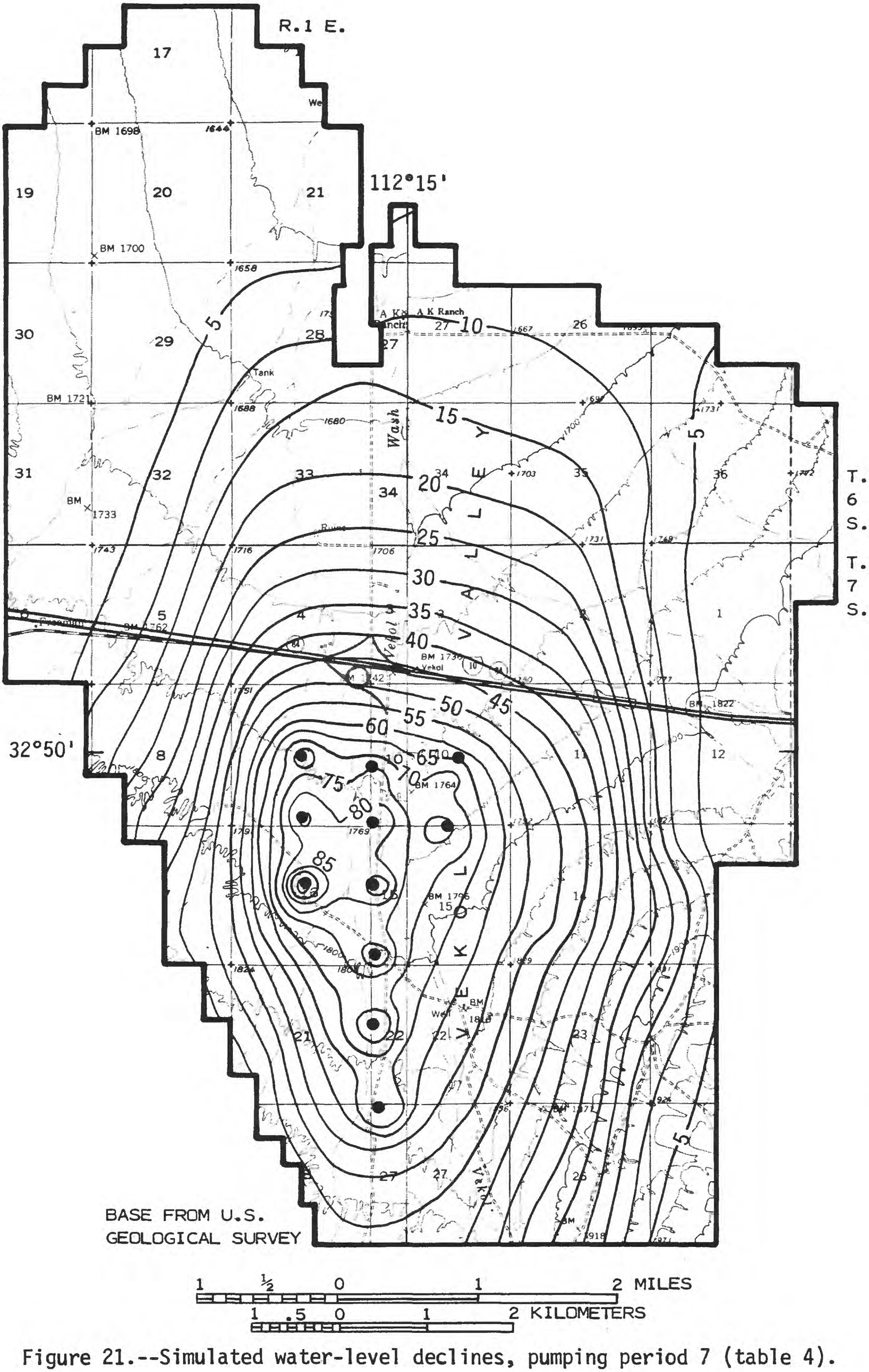


Figure 21.--Simulated water-level declines, pumping period 7 (table 4).

EXPLANATION

——25—— LINE OF EQUAL SIMULATED WATER-LEVEL DECLINE—Interval 5 feet

● BLOCK IN WHICH A WITHDRAWAL WELL WAS SIMULATED

BOUNDARY OF MODEL AREA

Figure 21

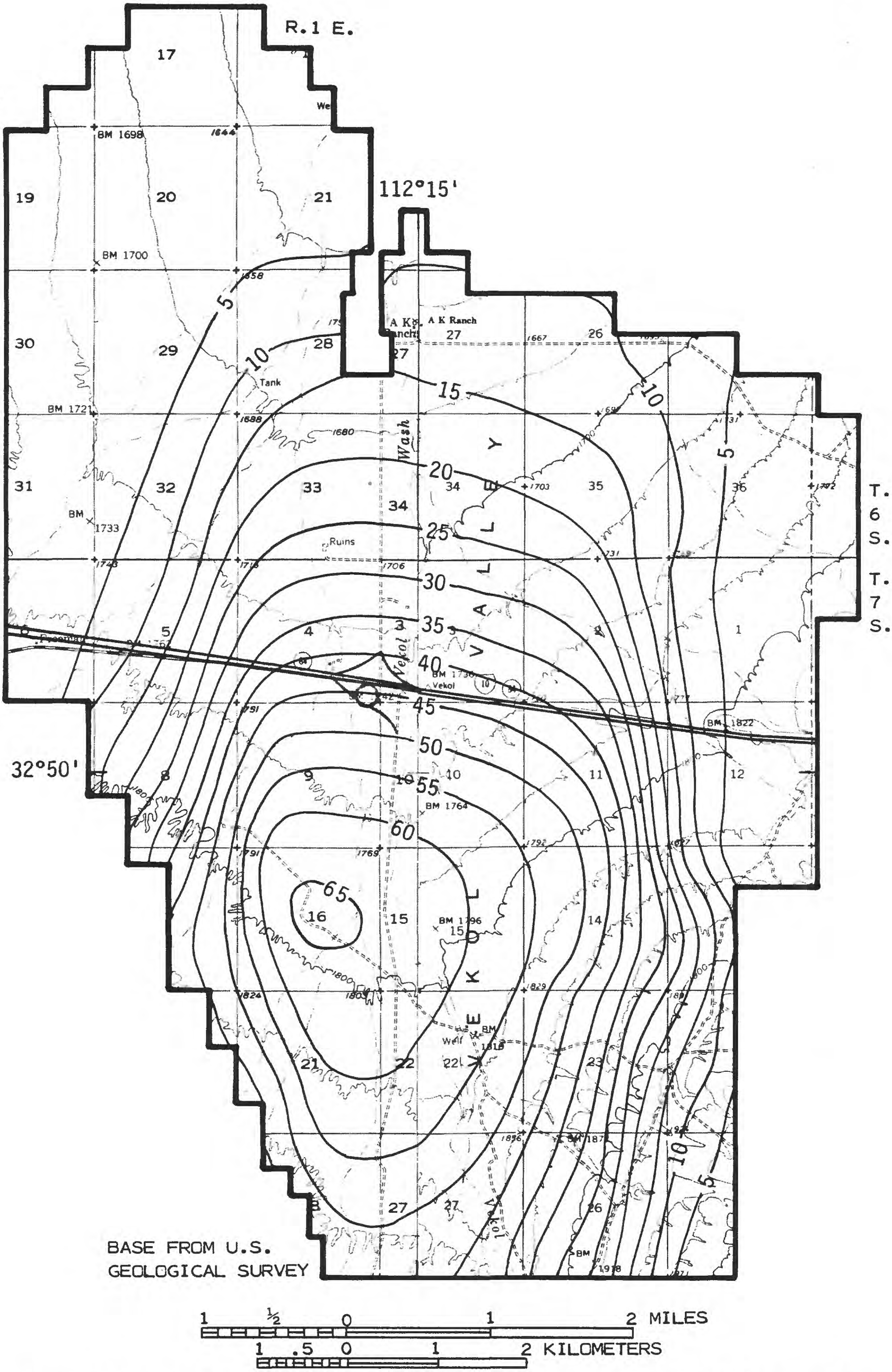


Figure 22.--Simulated water-level declines, pumping period 8 (table 4).

EXPLANATION

——25—— LINE OF EQUAL SIMULATED WATER-LEVEL DECLINE—Interval 5 feet

———— BOUNDARY OF MODEL AREA

Figure 22

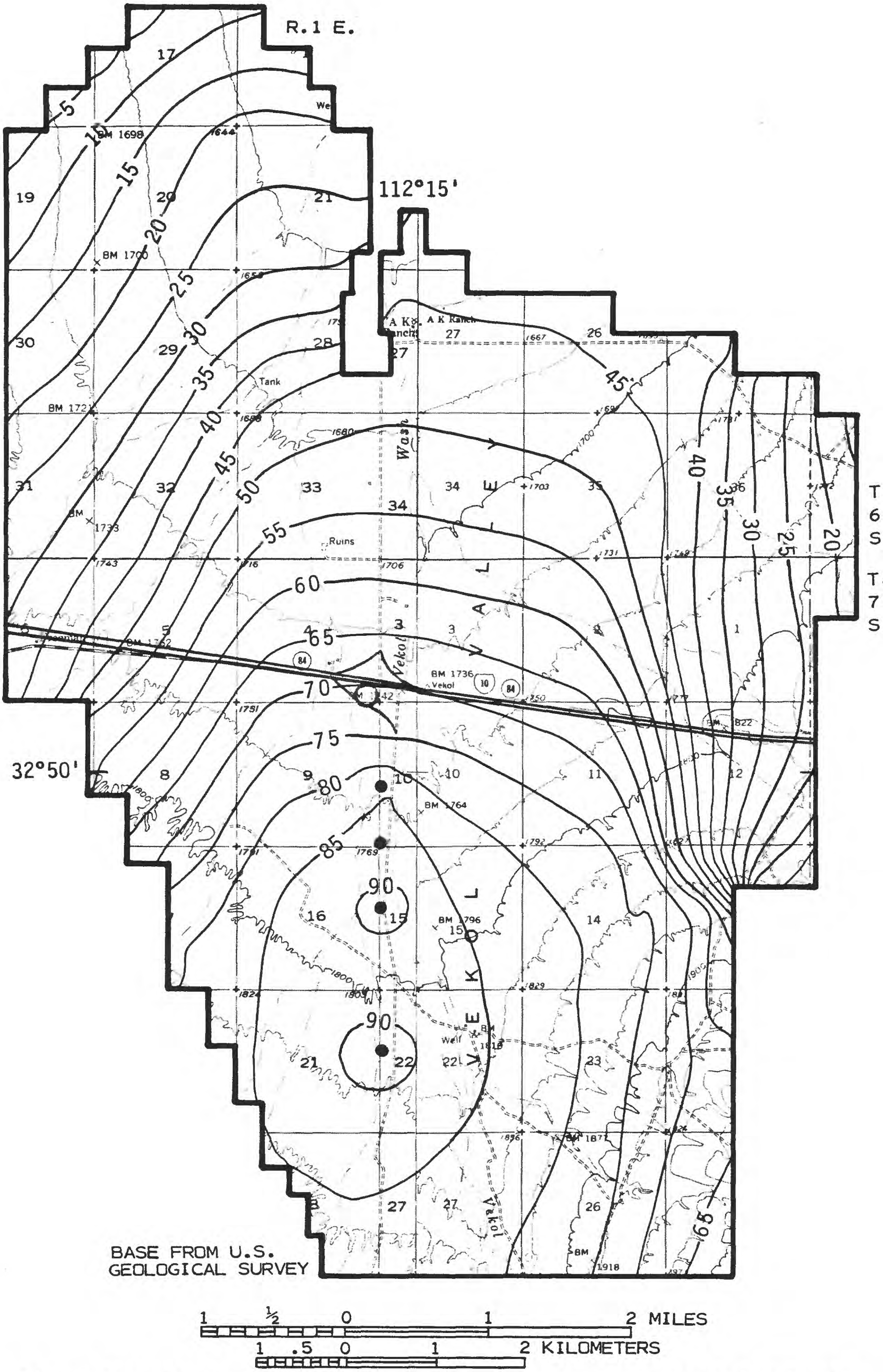


Figure 23.--Simulated water-level declines, pumping period 9 (table 4).

EXPLANATION

25 — LINE OF EQUAL SIMULATED WATER-LEVEL DECLINE—Interval 5 feet

● BLOCK IN WHICH A WITHDRAWAL WELL WAS SIMULATED

BOUNDARY OF MODEL AREA

Figure 23

The simulated water budget through the end of pumping period 9 indicates that 174,000 acre-ft would be removed from the valley during the 25-year simulation period (table 5). Of that amount, about 150,500 acre-ft would come from ground-water storage, which represents about 43 percent of the total water estimated to be recoverable from storage using available (1984) well and pump technology.

Table 5.--Model-derived water budget for simulated development of the northern part of Vekol Valley, 1984-2009

[Values, in acre-feet]

Inflow:	
Recharge from infiltration of runoff from precipitation	25,305
Total	25,305
Outflow:	
Discharge at the outflow point of the model	1,829
Withdrawals	174,027
Total	175,856
Change in storage:	
Outflow minus inflow	150,551

MODEL EVALUATION

The aquifer system in the northern part of Vekol Valley is principally a series of nearly flat-lying aquifers confined at the margins by impermeable rocks. Large quantities of water are held in storage and comparatively small quantities flow in and flow out of the aquifer system. Results of the steady- and transient-state simulations indicate that magnitude and distribution of ground-water transmission and storage properties of the aquifers control the flow of water through the aquifer and the release of water from storage. The model results also indicate that the simulated response was comparable to the observed response of the aquifer during the 23-day aquifer test. Simulated and observed responses were compared to provide a basis to estimate future drawdown from the proposed well field. The 23-day aquifer test was the only historic stress of significant magnitude that could be used to calibrate and verify the transient simulation of the aquifer system. Calibration of the steady- and transient-state conditions indicate that the model could provide reasonable estimates of maximum drawdown for proposed pumping plans.

The predictive accuracy of most ground-water flow models is directly proportional to the magnitude and duration of pumping or stress imposed during transient calibration (Durbin, 1978, p. 35). Mercer and Faust (1981) quantify the predictive capability of models by indicating that predictions should not be made for more than twice the period used during calibration. Although the simulation of proposed drawdown in this analysis far exceeds limits of predictive accuracy suggested by Durbin (1978) and Mercer and Faust (1981), the simulation of proposed withdrawal was needed to evaluate the practicability of the well field and no other method of evaluating the long-term effects of pumping the well field would be as reliable nor practical. A long-term projection based on short-term calibration is risky; however, the following factors may serve to reduce that risk.

1. Proposed withdrawal of ground water was primarily from storage. Recharge accounted for only about 13 percent of the total ground water withdrawn during the 25-year simulation.

2. A drain boundary was selected for the system at the outflow point to reduce flow out of the model to zero when the heads in the outflow model blocks were drawn down to a flat or zero gradient. At zero gradient, the drain boundary became a streamline (no-flow) boundary and drawdown throughout the model area was maximized for the duration of the predictive simulation.

3. The boundary conditions were significantly well defined to simulate the maximum amount of water removed from storage as a result of the proposed withdrawals.

SUMMARY

Pursuant to the Ak-Chin Indian Community Water Rights Settlement Act—Public Law 95-328—enacted on July 28, 1978, a study was undertaken to assess the effects of proposed ground-water withdrawals from Federal lands near the reservation. The first area to be evaluated was the northern part of Vekol Valley. This study was accomplished using a numerical model to simulate the ground-water flow system in the valley. The model was constrained by a detailed conceptual geohydrologic model of the aquifer system.

The aquifer system consists of four definable units—termed layers for modeling purposes—that store and transmit ground water within and through the system. The aquifer system is bounded along the margins and the bottom by essentially impermeable crystalline rock. Ground water in the upper unit of the aquifer system is under unconfined conditions, whereas ground water in the lower three units is under confined conditions. Recharge enters the aquifer system along the margins of the valley and through the major streambeds, moves toward the axis of the valley, and discharges as underflow at the north end of the valley. The recharge averages about 1,200 acre-ft/yr, ranges from about 630 to 1,300 acre-ft/yr, and is distributed, for purposes of modeling the system, at a rate of about 25 to 50 (acre-ft/yr)/mi of mountain front surrounding the valley. Less than 10 percent of the recharge enters through stream channels. The water-table gradient ranges from 5 ft/mi over most of the valley to about 20 ft/mi along the margins.

Withdrawals from the northern part of Vekol Valley have been minimal. The ground-water flow system in the valley is in an undisturbed (or natural) steady-state condition where inflow equals outflow. The amount of ground water that can be recovered from storage within the aquifer system is estimated to be 350,000 acre-ft. This volume of water far exceeds the annual flux (about 1,200 acre-ft) of ground-water that moves through the system.

A numerical model that depicts the aquifer system underlying the northern part of Vekol Valley was constructed using known and assumed aquifer characteristics, geology, water levels, and a conceptualized flow system. The model was then calibrated using observed water-level responses caused by pumping during aquifer testing. The calibrated model was used to estimate drawdowns for a proposed 25-year pumping plan that was designed to provide the needed water to supply the Ak-Chin Indian Community from the year 1984 to 2009. Model projections indicate that of the 174,000 acre-ft withdrawn from the valley during the 25-year simulation period, 150,500 acre-ft would come from storage and would cause the water table to decline an average of about 95 ft. The 150,500 acre-ft represents a depletion of about 43 percent of estimated recoverable ground water in storage.

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