

Ground-Water Storage Depletion In Pahrump Valley, Nevada-California, 1962-75

By JAMES R. HARRILL

Prepared in cooperation with the
Nevada Department of Conservation
and Natural Resources, Division of
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CONTENTS

Abstract	1
Introduction	1
Purpose and approach	1
Location and general features	2
Previous work	3
Numbering system for wells and springs	3
Nevada system	4
California system	4
Basic data	4
Acknowledgments	4
Geologic framework	4
Lithologic units	6
Structural features	6
Ground-water reservoirs	6
Consolidated-rock reservoirs	6
Carbonate-rock aquifers	6
Clastic aquitards	7
Valley-fill reservoir	7
Areal extent	7
Thickness	7
Hydraulic properties of the valley fill	10
Hydraulic conductivity	10
Transmissivity	11
Indices of ground-water storage	11
Outline of ground-water hydrology	15
Source, occurrence, and movement of ground water	15
Ground-water storage	15
Ground-water development	18
Development prior to 1962	18
Development 1962-75	18
Effects of development	19
Water-level changes	19
Declines in spring discharge	22
Ground-water recharge and discharge	22
Conceptualization of the ground-water system	25
Development of the mathematical model	26
Governing equations of ground-water flow	28
Application of flow equations to a finite-difference model	29
Parameter values used and assumptions made	29
Boundary conditions	29
Initial conditions	29
Transmissivity	31
Evapotranspiration of ground water	31
Vertical hydraulic conductivities	31
Storage coefficient	31

Ground-water recharge and discharge—Continued	
Method of analysis	32
Simulated natural conditions	32
Response through 1975	32
Water-level changes	32
Variations in natural discharge	38
Ground-water storage depletion	38
Future response	39
Accuracy of model results	43
The available water supply	43
Ground-water budget	43
Maximum steady-state pumping rates	47
Overdraft	49
Conclusions	49
References cited	51
Metric conversion factors	53

PLATES

[Plates are in pocket at back of report]

1. Map showing generalized geology of Pahrump Valley, Nevada and California
2. Maps and cross sections showing gravity information and thickness of valley fill, Pahrump Valley, Nevada and California
3. Maps showing distribution of phreatophytes and simulated distribution of evapotranspiration, Pahrump Valley, Nevada and California

FIGURES

1. Map showing location and general features of the study area 2
2. Diagrams showing numbering systems for wells and springs, Nevada and California 5
- 3-10. Maps showing:
 3. Estimated distribution of average vertical hydraulic conductivity in upper 500 ft of saturated valley fill 12
 4. Estimated transmissivity of upper 1,000 ft of saturated valley fill 13
 5. Estimated specific yield 14
 6. Depth to water, March 1976 16
 7. Water-level contours for deep wells under predevelopment conditions 17
 8. Distribution of pumpage in 1962 20
 9. Distribution of pumpage in 1975 21
 10. Location of selected observation wells 23
11. Hydrographs showing water-level changes in six observation wells 24
12. Hydrograph showing annual discharge of Bennetts and Manse Springs, 1875-1975 25
13. Cross sections showing conceptualization of the ground-water flow system in and downgradient from Pahrump Valley 27
14. Map of Pahrump Valley and adjacent area showing the finite-difference grid and transmissivity used in bottom layer of the model 30
15. Map showing contours of a simulated potentiometric surface for natural conditions 33
16. Graph showing relation between observed and simulated heads for natural conditions 34

- 17-21. Maps showing:
17. Simulated net changes in the water table, February 1913 - February 1976 **35**
 18. Measured and simulated net water-level declines in deep wells, 1913-76 **36**
 19. Measured and simulated net water-level declines in deep wells, 1962-76 **40**
 20. Estimated land-surface subsidence **42**
 21. Areas used in figure 22 to indicate simulated long-term water-level declines **44**
22. Hydrographs showing simulated long-term trends in selected hydrologic parameters, 1910-2040 **45**
23. Graph showing relation between maximum steady-state pumping rate and average return flow **48**

TABLES

1. Principal lithologic units and their hydrologic properties **8**
2. Estimated recoverable ground-water storage **18**
3. Summary of population, irrigated-land area, and ground-water withdrawals 1962-75 **19**
4. Summary of estimates of recharge and discharge for natural conditions **26**
5. Pumpage data used in simulation **34**
6. Summary of estimates of storage depletion **39**
7. Ground-water budgets **46**
8. Cumulative mass balance **47**

Ground-Water Storage Depletion in Pahrump Valley, Nevada-California, 1962-75

By James R. Harrill

Abstract

During the 13-year period February 1962 to February 1975, about 540,000 acre-feet of ground water was pumped from Pahrump Valley. This resulted in significant water-level declines along the base of the Pahrump and Manse fans where pumping was concentrated. Maximum observed net decline was slightly more than 60 feet. Much smaller declines occurred in the central valley; and, locally, water levels in some shallow wells rose owing to recharge derived from the deep percolation of irrigation water. The pumping resulted in about 219,000 acre-feet of storage depletion. Of this, 155,000 acre-feet was from the draining of unconsolidated material, 46,000 acre-feet was from the compaction of fine-grained sediments, and 18,000 acre-feet was from the elastic response of the aquifer and water. The total storage depletion was equal to about 40 percent of the total pumpage. The remaining pumped water was derived from the capture of natural ground-water discharge and reuse of pumped water that had recirculated back to ground water.

Natural recharge to and discharge from the ground-water system is estimated to be 37,000 acre-feet per year. Of this, 18,000 acre-feet per year leaves the area as subsurface outflow through carbonate-rock aquifers which form a multivalley flow system. The extent of this system was not precisely determined by this study. The most probable discharge area for this outflow is along the flood plain of the Amargosa River between the towns of Shoshone and Tecopa. This outflow probably cannot be economically captured by pumping from Pahrump Valley. Consequently, the maximum amount of natural discharge available for capture is 19,000 acre-feet per year. This is larger than the 12,000 acre-feet per year estimated in a previous study; the difference is due to different techniques used in the analysis.

As of 1975, pumping was causing an overdraft of 11,000 acre-feet per year on the ground-water system. No new equilibrium is probable in the foreseeable future. Water levels will probably continue to decline slowly until pumping is reduced. The moderate rates of decline and the very large amounts of ground water stored in the valley-fill reservoir suggest that it will be a long time before the valleywide depletion of ground-water storage becomes critical. Problems involving water quality, land subsidence, and well interference will probably occur first.

INTRODUCTION

This study, made in cooperation with the Nevada Division of Water Resources, Department of Conservation and Natural Resources, evaluates the effects of ground-water withdrawals during the period February 1962 through February 1975 on depletion of storage in Pahrump Valley. The study updates an earlier report by Malmberg (1967) which indicated an overdraft on the ground-water system of about 13,000 acre-ft/yr during the 4-year period 1959-62. Since that time, pumping has increased substantially and large tracts of former agricultural land are being subdivided for residential development. Concern about the effects of sustained overdraft on a valley that contains permanent residential development is the basic reason for this study.

Purpose and Approach

The objectives of this study are to (1) determine or estimate, for the period 1962 through 1975, the areal extent and amount of water-level decline, the magnitude of ground-water storage depletion, and the annual pumpage, (2) evaluate any additional impacts of development, to date, on the hydrologic system, and (3) to the extent possible, demonstrate some general long-term effects likely to occur if pumping is maintained at the 1975 rate.

In scope, the study included the Pahrump Valley and part of the mountainous area on three sides. Considered were water levels, pumpage, well records, and aquifer hydraulics. A digital ground-water flow model provided insight into long-term pumping effects.

Work began early in 1975. Principal work included (1) reviewing published information, (2) compiling available well-construction, water-level, and pumpage information, (3) canvassing selected wells, (4) collecting a fairly comprehensive set of water-level measurements in February 1976, (5) drilling 11 small-diameter water-level observation wells, (6) conducting short-term pumping

tests on 5 wells, (7) evaluating and analyzing the information obtained, and (8) using a digital ground-water flow model to test and refine the analysis of the ground-water system to gain insight into possible long-term effects if pumping is continued at the 1975 rate. Most of the field-work was done between early 1975 and June 1976.

The net effect of seasonal pumping during the 14 irrigation seasons starting in 1962 and continuing through 1975 was evaluated by water-level measurements made between February 1962 and February 1976. Evaluation of net changes in ground-water levels was based on measurements made when conditions are least affected by

pumping, usually in late winter of each year. For example, the change in water level from February 1975 to February 1976 largely reflected the residual effects of pumping during the previous spring, summer, and fall 1975.

Location and General Features

Pahrump Valley encompasses about 1,050 mi² in Nye and Clark Counties, Nev., and Inyo and San Bernardino Counties, Calif. The area discussed in this report conforms with boundaries of the Pahrump Valley hydro-

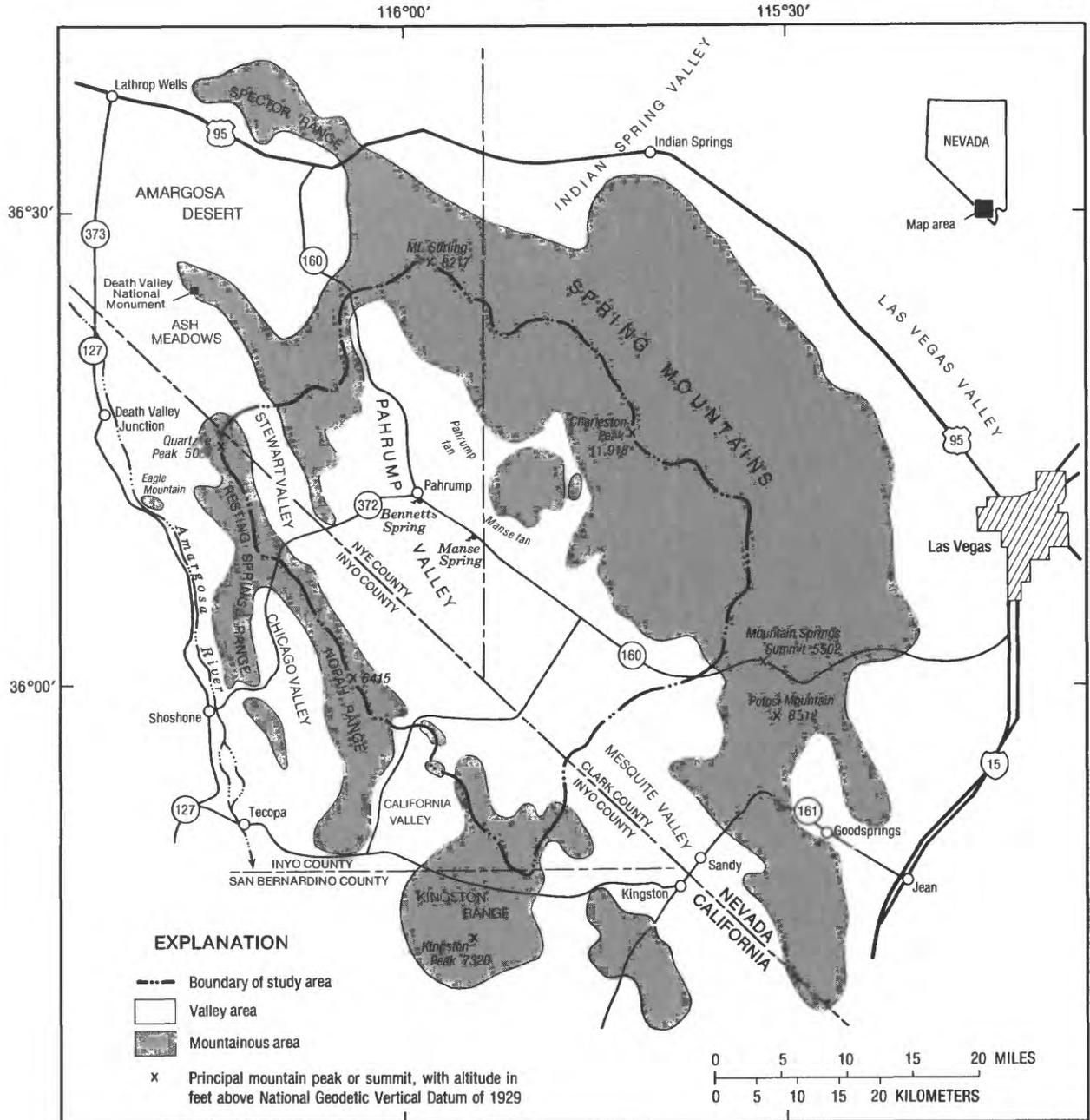


Figure 1. Location and general features of the study area.

graphic area designated by Rush (1968) and also with the area used by Malmberg (1967) in his earlier study. Boundaries and general features of the study area are shown in figure 1.

The Spring Mountains form the northeast border of the area and are the dominant topographic feature. They are the source area for virtually all the area's water supply.

Charleston Peak (altitude 11,918 ft) is the highest point in the area. Altitude of much of the valley floor is between 2,500 and 2,800 ft, so the maximum topographic relief is more than 9,000 ft. For most of the area, however, topographic relief between the valley floor and adjacent mountains is between 2,000 and 6,000 ft.

The southwest side of the Spring Mountains is characterized by large alluvial fans that head high in the canyons leading from Mount Charleston. The most prominent of these fans have coalesced to form the major fans called the Pahrump and Manse fans (Malmberg, 1967, p. 8).

Pahrump Valley is part of an intervalley ground-water flow system that contributes ground water to low areas adjacent to Death Valley. The closest major areas of ground-water discharge downgradient from Pahrump Valley are between the towns of Tecopa and Shoshone, Calif., 10 to 15 mi southwest of the topographic boundary of Pahrump Valley (fig. 1).

Previous Work

About 20 previous studies deal with various aspects of the hydrology and geology of Pahrump Valley. Most of these studies are evaluations of larger areas and either include only descriptive information about Pahrump Valley or include quantitative information about only parts of the area. Only two studies contain detailed information that deals specifically with the hydrology of Pahrump Valley (Maxey and Jameson, 1948; Malmberg, 1967). The following paragraphs outline the general scope of the principal existing studies.

Mendenhall (1909) made a reconnaissance of the water resources of southwestern Nevada and southeastern California which included information on some springs in Pahrump Valley. This constituted one of the first investigations of the valley's water resources.

Waring (1921) studied the water resources of Pahrump, Mesquite, and Ivanpah Valleys in more detail. This report included data on wells and springs in Pahrump Valley and discussed the source and occurrence of ground water.

During the period 1922-36, the University of Nevada Agricultural Experiment Station at Las Vegas studied the occurrence and use of ground water in Las Vegas and Pahrump Valleys (Hardman and Miller, 1934; Hardman and Mason, 1949) and collected data on well and spring discharges, water levels, and chemical quality.

In 1944, a reappraisal of the ground-water resources of Pahrump Valley (Maxey and Jameson, 1948) was made which summarized all available information at that time. This study also included the first quantitative estimates of recharge to and discharge from the ground-water reservoir. Two other reports (Maxey and Robinson, 1947; Robinson and others, 1947) contain additional data compiled during this evaluation.

Data on wells in the California part of the valley are summarized in an office report by the California Division of Water Resources (1956).

A comprehensive evaluation of the hydrology of the study area was made by Malmberg (1967). This study included a reappraisal of the hydrology of the valley, documentation of the extent of development as of 1962, and a first evaluation of cause-effect relationships associated with pumping ground water. Three major contributions of this study were (1) detailed mapping of the surficial geology of the valley fill, including mapping of faults that affect ground-water flow; (2) demonstration that appreciable subsurface outflow occurs through consolidated rocks beneath the Nopah Range; and (3) formulation of a reasonably balanced ground-water budget that allows better estimates of the long-term yield of the basin. Geology of the valley has been mapped at 1:250,000 scale (Jennings, 1958, 1961; Jennings and others, 1962; Longwell and others, 1965; Cornwall, 1972; Wright and others, 1981). Gravity studies by Healey and Miller (1965), Kane and Carlson (1964), Chapman, Healey, and Troxel (1971), Healey (1973), and Nilsen and Chapman (1971) provided additional information about the structural basin. A regional study by Winograd and Thordarson (1975) that evaluated the hydrologic and hydrochemical framework of the south-central Great Basin provided information about flow characteristics of consolidated rock units and the regional structural framework.

The U.S. Bureau of Reclamation has included Pahrump Valley in one of the areas encompassed by the Inland Basins Project (U.S. Bureau of Reclamation, 1969, 1972). These reports contain summaries of hydrologic and other information about the valleys and evaluate the feasibility of large-scale pumping projects in selected areas.

Hydrologic studies of adjacent areas (Malmberg and Eakin, 1962; Malmberg, 1965; Hughes, 1966; Glancy, 1968; Dudley and Larson, 1976; Harrill, 1976) provided supplemental information that has transfer value for some areas and conditions in Pahrump Valley.

Numbering System for Wells and Springs

Pahrump Valley straddles the Nevada-California State line. A different well-numbering system is used in each State; both systems are used in this report to permit

each well to be numbered compatibly for the State in which it is located.

Nevada System

The numbering system used for Nevada is based on an index of hydrographic areas (Rush, 1968) and the rectangular subdivision of the public lands referenced to the Mount Diablo base line and meridian or, in one small area, the San Bernardino base line and meridian. Each number consists of four units separated by spaces. The first unit is the hydrographic area number. The second unit is the township, preceded by an N or S to indicate location north or south of the base line. The third unit is the range, preceded by an E to indicate location east of the meridian. The fourth unit is the section number, followed by letters and a number that indicate location and sequence within the section. The letters "A" through "D" indicate quarter sections, counterclockwise beginning with "A" for the northeast quarter section. Where field maps are sufficiently accurate, additional letters "A" through "D" are also assigned in counterclockwise sequence to further subdivide the quarter sections into 40- or 10-acre tracts. The letters are followed by a number indicating the order in which the well was recorded in that particular tract. For example (see fig. 2), well 162 S19 E53 01ADA1 is in Pahrump Valley (hydrographic area 162), and it is the first well recorded in the NE $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$, sec. 1, T. 19 S., R. 53 E., Mount Diablo base line and meridian, in Nevada. Wells located in Nevada between the Von Schmidt line and the State line, and west of R. 53 E., are referenced to the San Bernardino base line and meridian. This is indicated by an S in front of the township designation. For example, well 162 SN24 E08 26BAB1 is in the NW $\frac{1}{4}$ NE $\frac{1}{4}$ NW $\frac{1}{4}$, sec. 26, T. 24 N., R. 8 E., referenced to the San Bernadino base line and meridian.

California System

Wells in the California part of Pahrump Valley are numbered according to their location in the rectangular system for subdivision of public land, referenced to the San Bernardino base line and meridian. For example, in the well number 22N/10E-1H1, the number and letter preceding the slash indicate the township (T. 22 N.), the number and letter following the slash indicate the range (R. 10 E.), the number following the hyphen indicates the section (sec. 1), and the letter following the section number indicates the 40-acre subdivision of the section, according to the lettered diagram in figure 2. The final digit is a serial number for wells in each 40-acre subdivision.

Basic Data

The basic data on water wells and ground-water levels collected during this study are stored in the ground-

water site inventory files of the U.S. Geological Survey WATSTORE data base. This information may be retrieved through the U.S. Geological Survey District Office in Carson City, Nev., or through any designated NAWDEX assistance center.

Acknowledgments

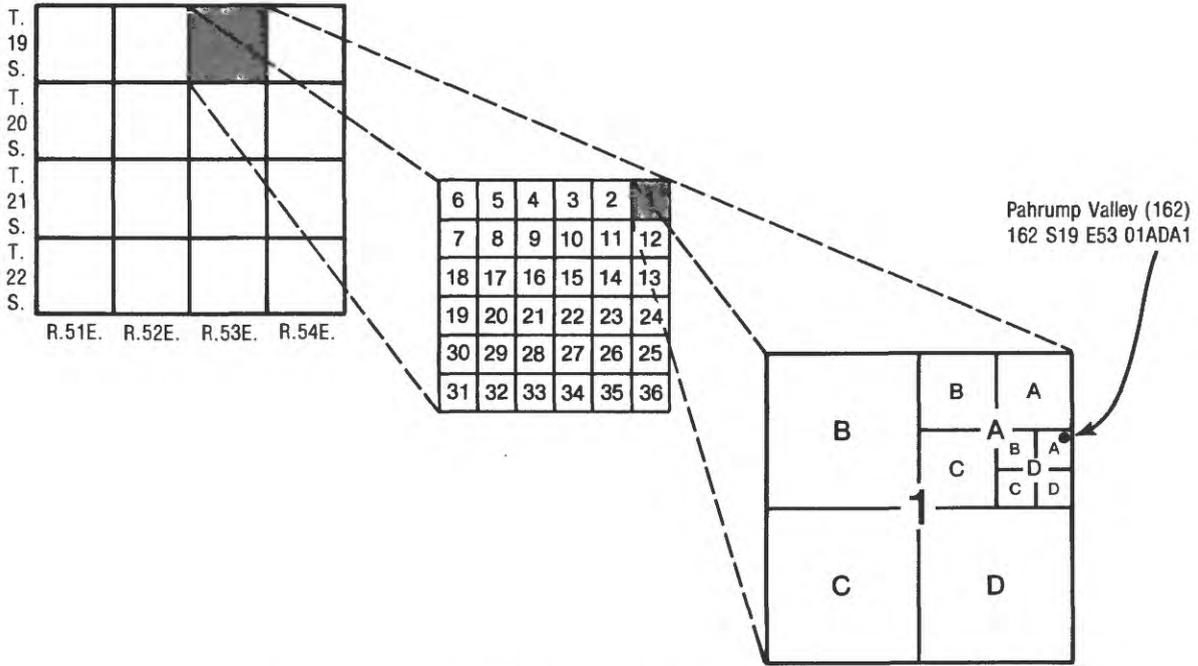
Acknowledgment is made of the cooperation of residents of the valley in supplying data and permitting the use of their wells in the course of this investigation. Considerable information on historical water-level measurements, pumpage, and other well data was provided by Francis Thorne and Keith Cutler of the Nevada Division of Water Resources office in Las Vegas. Most of the drillers' logs and detailed data on well construction used in this investigation were furnished by the Nevada Division of Water Resources in Carson City, Nev. The Valley Electric Association furnished information on power consumption for irrigation and public-supply pumpage.

GEOLOGIC FRAMEWORK

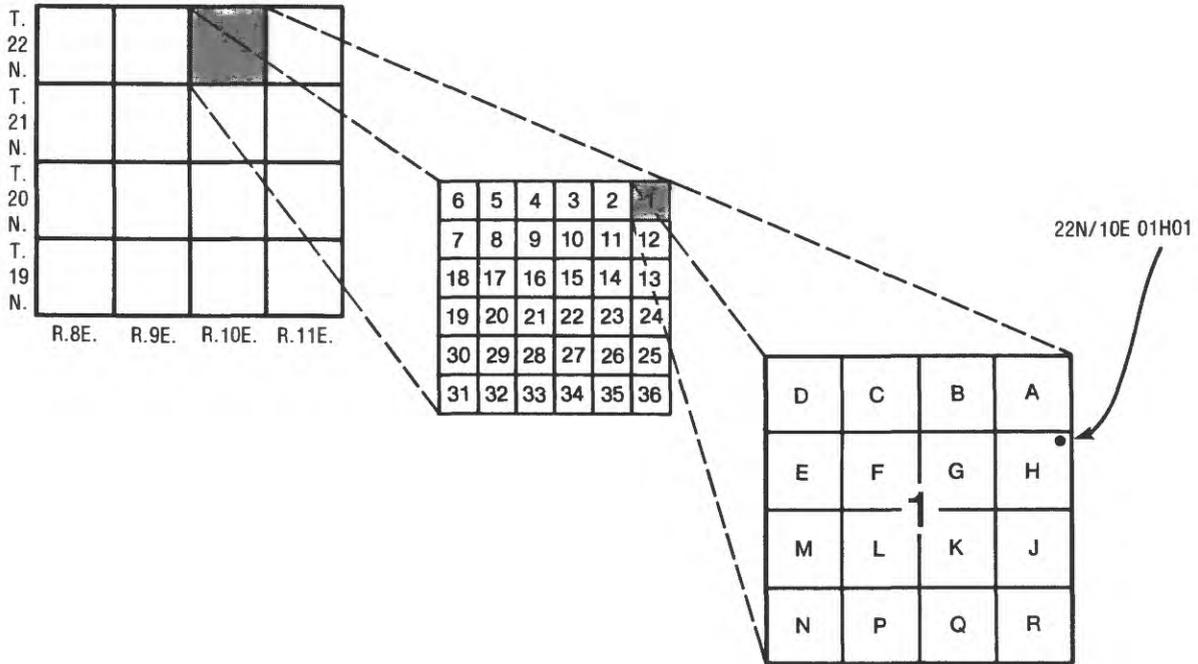
The geologic framework determines many characteristics of a ground-water flow system. The processes of structural deformation and erosion determine the location, orientation, and altitude of mountain masses and also the extent and depth of structural basins. The rock type or lithology strongly affects water-bearing properties of consolidated rocks and valley-fill deposits. These factors can be related to the hydrology as follows:

1. The altitude and area of the mountains determine, to a large extent, the amount of precipitation that will be available to recharge the ground-water reservoir. The precipitation that falls on the mountains, primarily from winter storms, generally exceeds 15 in/yr in the higher mountain areas. This water provides virtually all natural recharge to the ground-water reservoir.
2. The amount of ground water that is stored in saturated materials is largely a function of the extent, thickness, and lithology of unconsolidated deposits that occupy the structural depression that typically underlies a valley in the Great Basin region.
3. Lithology may strongly affect the hydrologic regimen of a valley, particularly if a certain lithology predominates. For example, thick sequences of permeable carbonate rocks may transmit water well enough to cause a topographically closed basin to be either drained or recharged by subsurface flow, depending on the direction of hydraulic gradients between adjacent areas.

In this study, the geologic framework is evaluated in terms of the lithology of the consolidated rocks and unconsolidated deposits and the character of the structural basin that underlies the valley.



A. Numbering system used by Nevada



B. Numbering system used by California

Figure 2. Numbering systems for wells and springs, Nevada and California.

Lithologic Units

For purposes of this report, the principal lithologic units in Pahrump Valley are grouped into two general categories: (1) unconsolidated and partly consolidated deposits, which form the valley fill and are generally highly porous (coarser grained deposits of this group generally transmit water readily), and (2) consolidated rocks, which compose the mountains and underlie the valley fill (commonly they have low porosity and permeability and do not readily transmit water except where highly fractured or where fractures in carbonate rocks have been enlarged by solution).

Each major group has been subdivided into several subcategories on the basis of lithologic and water-bearing properties. Nine lithologic units are described in table 1; descriptions are adapted from Longwell and others (1965), Cornwall (1972), Malmberg (1967), Winograd and Thordarson (1975), and Jennings (1958 and 1961). Distribution of these units is shown on plate 1.

The valley-fill deposits and the consolidated-rock aquifers form the two principal ground-water reservoirs in the area. They will be discussed in greater detail in a later section of this report.

Structural Features

Longwell and others (1965, p. 60) state that major orogenic, or mountain-building, activity in southern Nevada began in the late Mesozoic Era and continued into the Cenozoic Era. They list a number of events that relate to southern Nevada in general; however, two appear to have had the most direct effects on the ground-water regimen in Pahrump Valley. These are large-scale thrust faulting with associated folding in the late Mesozoic Era and normal faulting in the Tertiary Period of the Cenozoic Era.

Several large thrust faults are exposed in the Spring Mountains and at the north end of the Nopah Range (pl. 1). In some places, low-permeability clastic sedimentary rocks have been thrust above or adjacent to water-bearing carbonate rocks and restrict ground-water movement. Also, under some conditions, brecciated zones along fault planes may be conduits for ground water. Folding, which also occurred at this same general time, promotes development of sets of joints, and this process can result in significant secondary permeability under the right conditions.

Normal faulting in Cenozoic time, associated with the development of the Basin and Range province, formed the structural depression underlying Pahrump Valley and the adjacent mountain masses. Normal faults of large displacement are inferred to be present along the margins of Spring Mountains and Nopah Range. Stewart Valley (fig. 1) occupies a narrow structural

trough; Malmberg (1967, pl. 1) mapped a fault in the valley fill that extends southeast from Stewart Valley parallel to the State line for about 15 miles. Wright and others (1981) mapped several faults with right-lateral components of movement in this area and referred to it as the Pahrump fault zone. These are the faults shown on plate 1. Springs and stands of mesquite along the north-east side of this feature suggest that it forms a partial barrier to ground-water flow.

GROUND-WATER RESERVOIRS

There are two distinct ground-water reservoirs in the study area: (1) the consolidated rocks that form the mountains surrounding Pahrump Valley and underlie the valley at depth, and (2) the unconsolidated deposits that have accumulated in the structural depression underlying Pahrump Valley.

Certain types of consolidated rocks transmit water well enough to carry significant underflow from Pahrump Valley. However, there has been virtually no development of this reservoir, and significant future development is improbable. Consequently, the consolidated-rock reservoir will be evaluated primarily in terms of its effect on the flow regimen of the valley-fill reservoir.

The valley-fill reservoir contains the most productive known aquifers in the area and supports virtually all existing development. It is the most feasible source for future development. Consequently, the analysis presented in this report will be made largely in terms of the hydrology of the valley-fill reservoir

Consolidated-Rock Reservoirs

Carbonate-Rock Aquifers

The carbonate-rock aquifers are composed primarily of carbonate sedimentary rocks from Cambrian to Permian age that crop out in the Spring Mountains, underlie the valley fill of Pahrump Valley, and extend westward through the Nopah and Resting Springs Ranges into California and Chicago Valleys (table 1, fig. 1, pl. 1). These aquifers are roughly equivalent to the lower and upper carbonate aquifers defined by Winograd and Thordarson (1975, p. C14-C31) in their evaluation of regional flow systems in the south-central Great Basin.

No wells in the study area penetrate the carbonate aquifers, so their properties must be inferred from information about other areas. The aggregate stratigraphic thickness of this sequence of rocks may be as much as 18,000 ft; however, these rocks have been complexly faulted and folded, and the aggregate vertical thickness at

any one place may be substantially more or less than this stratigraphic thickness.

Hydraulic continuity is probably achieved through extensive fractures and, to a small degree, by localized solution channels. The effective fracture porosity of the lower carbonate aquifer was estimated by Winograd and Thordarson to average probably less than 1 percent, although locally it may be much higher. If these rocks were to be dewatered by pumping or other means, the average specific yield would be low, probably on the order of 0.5 percent.

Transmissivity is highly variable. Winograd and Thordarson (1975, p. C22) computed or estimated transmissivities from the results of pumping tests of 10 wells that penetrated one or more formations in the lower carbonate aquifer. Values ranged from about 130 to 120,000 ft²/d (feet squared per day). They suggested that the wide range in transmissivity may not be randomly distributed but may be structurally controlled. They concluded that in the vicinity of the test site, extensive zones of above-average fracture transmissivity over long distances are improbable.

They also estimated the gross fracture transmissivity of the lower carbonate aquifer at several places, using potentiometric contour maps and known or estimated amounts of flow. In areas of high fracture permeability, such as the Spector Range, transmissivity was estimated to be in the hundreds of thousands to millions of feet squared per day. In contrast, beneath Yucca Flat (about 50 mi north of Pahrump Valley) transmissivity of the lower carbonate aquifer was estimated to average less than 1,300 ft²/d. For purposes of this study, average transmissivity of the carbonate-rock aquifers around and beneath Pahrump Valley is estimated to be between 1,500 and 2,500 ft²/d.

Clastic Aquitards

The term "clastic aquitard" was used by Winograd and Thordarson (1975) to categorize certain assemblages of low-permeability rocks in parts of the south-central Great Basin. The same concept is used in this report. The principal clastic aquitards in the vicinity of Pahrump Valley are a sequence of clastic sedimentary rocks of Cambrian and Precambrian age and a younger sequence of continental deposits of Cretaceous to Triassic age (table 1). In addition, there is a sequence of interbedded limestone and fine-grained clastic sedimentary rocks of Permian age which are probably more permeable than the first two units mentioned but still transmit water slowly enough to be relative barriers to ground-water flow.

The surficial distribution of these rocks is shown on plate 1. There is virtually no information about the distribution of these rocks beneath areas of valley fill. It was

assumed that the rocks exposed in the mountains were general indicators of the rock type probably present beneath adjacent areas of valley fill. Thus, the northwest and southeast ends of the valley are presumed to be underlain by rocks of comparatively low permeability.

No wells in the area tap the clastic aquitards, so their hydraulic properties had to be inferred from information from nearby areas. Winograd and Thordarson (1975, p. C42–C43) evaluated the water-bearing characteristics of two units they termed the "upper" and "lower" clastic aquitards. They stated that although, where locally fractured, transmissivity may be as high as 1,300 ft²/d for the lower aquitard, transmissivity for the bulk of the aquitard probably does not exceed 130 ft²/d. They estimated that transmissivity was probably less than 70 ft²/d for the upper clastic aquitard. Conditions are presumed to be similar in Pahrump Valley, and the average transmissivity of the clastic aquitards is estimated to be between 30 and 60 ft²/d.

Valley-Fill Reservoir

The valley-fill reservoir is composed of unconsolidated alluvial, colluvial, and lacustrine deposits that partly fill the structural depression underlying Pahrump Valley. Some volcanic tuff is interbedded with the fill deposits.

Areal Extent

The approximate areal extent of the valley-fill reservoir is shown on plate 1. Total surface area is about 650 mi², or about two-thirds of the total area of Pahrump Valley. The reservoir is bounded on the northeast, northwest, and southwest by consolidated rocks of the Spring Mountains, Resting Springs Range, Nopah Range, and Kingston Range (fig. 1). The southeast end of the valley is generally continuous with the valley-fill reservoir in Mesquite Valley. For the purposes of this study, the southeast boundary of the reservoir is regarded to be coincident with the topographic divide between Pahrump and Mesquite Valleys. The topographic divide approximates a flow line along the predevelopment potentiometric surface, so there was no significant flow across this boundary under natural conditions.

Thickness

Wells drilled in the valley-fill reservoir range from several tens to more than a thousand feet deep. With the exception of one or two wells on the margins of the reservoir, they do not fully penetrate the valley fill and encounter bedrock. Consequently, it was necessary to use gravity data to obtain generalized information about the

Table 1. Principal lithologic units and their hydrologic properties

Age	Unit	Thickness (feet)	Lithology	Occurrence	General hydrologic properties
Holocene and Pleistocene	Playa deposits	0-50	Unconsolidated; clay, silt, and fine sand.	Playas in Stewart Valley and southwestern Pahrump Valley.	High porosity and very low permeability. Deposits function as confining beds and do not readily yield water to wells.
Holocene and Pleistocene at and near surface to Pliocene or Miocene at depth	Lacustrine and associated fine-grained deposits Fanglomerate and associated coarse-grained deposits	 0-5,000	Predominantly clay, silt, and some fine sand. Some mudflow debris and beds of caliche. Youngest deposits typically calcareous. Unconsolidated to cemented alluvial-fan deposits and mudflow debris composed of boulders, sand, silt, and clay. Contains lenses of relatively clean, well-sorted sand and gravel.	Occupies valley floor at surface and at depth. Includes medial lacustrine deposits and older lacustrine deposits as mapped by Malmberg (1967). Occurs over margins of valley. Occupies areas on intermediate slope between comparatively flat valley floor and mountains. Deposits at depth occupy same general position, and interfinger with lacustrine and associated fine-grained deposits toward center of valley. Includes some surficial deposits, younger fan deposits, medial fanglomerate, and older fanglomerate as mapped by Malmberg (1967).	Fine-grained materials generally have high porosity and low permeability. Beds of fine sand may yield moderate amounts of water to wells. Deposits at depth presumably more compacted, with lower porosity and permeability. Highly permeable lenses of gravel and sand readily yield water to wells, and are the most productive aquifers in the valley.
Pliocene or Miocene	Tuff		White and light-yellow to light-green beds of thinly laminated tuff; extensively faulted or folded.	Exposed at base of the upthrown fault block along the Nevada-California border; may be interbedded with other valley-fill deposits at depth.	Consolidated and partly to highly indurated; has very low permeability. Would yield virtually no water to wells.
Tertiary or Cretaceous	Megabreccia		Landslide blocks of monolithologic dolomite breccia from Bonanza King Formation.	Occurs along south end of ridge between Pahrump Valley and Stewart Valley. Unconformably overlies Stirling Quartzite in this area.	May transmit significant amounts of water along fractures and breccia openings enlarged by solution.

Cretaceous to Triassic	Continental deposits	1,500±	Sandstone, shale, and conglomerate. Some interbedded limestone and gypsum.	Exposed in Spring Mountains in southeastern part of study area. Includes Chinle and Moenkopi Formations.	Generally low permeability; may transmit small to moderate amounts of water along fractures. Gypsum may increase sulfate content of ground water.
Permian	Limestone and fine-grained clastic rocks	800±	Limestone, dolomite, shale, conglomerate, and sandstone. Sequence contains significant gypsum.	Exposed in Spring Mountains in southeastern part of study area. Includes Kaibab Limestone, Toroweap Formation, and red beds.	Generally impermeable; may transmit moderate amounts of water where fractured or where fractures have been enlarged by solution. Gypsum may increase sulfate content of ground water.
Permian to Cambrian	Carbonate sedimentary rocks	18,000±	Limestone, dolomite with medial shale, sandstone, and quartzite.	Exposed in Spring Mountains; in Nopah and Resting Spring Range, along southwest side of area; and in mountains at northwest end of Pahrump Valley. Also underlies valley-fill deposits in parts of area. Includes Bird Spring Formation, Monte Cristo Limestone, Devils Gate Limestone, Nevada Formation, Sultan Limestone, Lone Mountain Dolomite, Ely Springs Dolomite, Eureka Quartzite, Pogonip Group, Nopah Formation, Bonanza King Formation, and upper part of Carrara Formation.	Generally impermeable except where fractured. Where solution has caused secondary enlargement of joints and fractures, rocks may be highly permeable. Unit acts as an aquifer and transmits significant subsurface outflow from Pahrump Valley.
Cambrian and Precambrian	Clastic sedimentary rocks	10,000±	Sandstone, shale, siltstone, quartzite, minor limestone, and dolomite.	Exposed in Spring Mountains at north end of valley, in Resting Springs Range at west end of area; and probably at north end of Kingston Range at south end of valley. Includes lower part of Carrara Formation, Zabriskie Quartzite, Weed Canyon Formation, Stirling Formation, and Johnnie Formation.	Generally impermeable; may transmit moderate amounts of water where fractured. Unit acts as an aquitard.

subsurface configuration of the reservoir. When the force of gravity is measured at a given point, the reading is affected in part by the density of underlying materials. Unconsolidated valley-fill deposits typically have substantially lower densities than adjacent and underlying consolidated rocks. This results in gravity anomalies, in valley areas, that are roughly proportional to the thickness of valley-fill deposits.

Several investigators, Healey and Miller (1965), Kane and Carlson (1964), Chapman and others (1971), and Healey (1973), have constructed Bouguer gravity anomaly maps that include parts of Pahrump Valley. A composite map of the complete Bouguer gravity anomalies for Pahrump was constructed from their work (pl. 2).

Anomalies shown on plate 2A are affected by both regional trends and local conditions. The regional trends were eliminated from the data by drawing 20 sections and subtracting a regional gradient from the observed anomalies along each section. The residual anomalies were then plotted on a map and contoured. The resulting map is shown on plate 2B. These anomalies give a very rough approximation of the subsurface configuration of the valley-fill reservoir.

Rough quantitative estimates of the thickness of the valley-fill deposits were developed by making a two-dimensional analysis of the anomalies along four cross sections (*A-A'*, *B-B'*, *C-C'*, and *D-D'* on pl. 2A). The analysis was performed by using the Talwani method (Talwani and others, 1959) and a computer program developed by the Geological Survey. Density of the valley fill was assumed to average about 2.2 g/cm³ (grams per cubic centimeter) and density of consolidated rocks was assumed to average about 2.7 g/cm³, resulting in a density contrast of 0.5 g/cm³. These values are the same as those used by Healey and Miller (1965, p. 7) in their gravity survey of the adjacent Amargosa Desert area. Profiles computed from this analysis are shown on plate 2D. The relation between residual anomalies and computed depth along the four sections was applied to the anomalies on plate 2B to estimate approximate thicknesses of fill throughout the valley. The estimated thicknesses are shown on plate 2C. Maximum computed thickness of about 4,800 ft occurred along section *D-D'* in the central part of the valley.

In general, the thickest accumulations of valley fill are along the axis of the valley south of State route 372. The area of maximum thickness is offset slightly toward the south end of the valley, which suggests some structural relief in that area. Also, the shape of the structural depression changes from a broad shallow trough north of State route 372 (section *A-A'*) to a composite depression south of route 372 (sections *C-C'* and *D-D'*). In this area the basin consists of (1) a broad upper trough that spans the entire width of the valley and has a maximum depth of 2,000 to 2,500 ft, and (2) a second trough 1,000 to 2,000

ft deeper that occupies the central part of the first depression. This suggests that the basin probably contains significant internal structures and that the history of deformation may be complex. However, since only reconnaissance-level data were available for analysis, additional fieldwork with a higher density of gravity stations is needed before anything but generalized approximations can be made regarding subsurface structure.

An example of the inadequacy of the present information to handle details concerns the fault, mapped on plate 1, which parallels the State line in townships 21, 22, and 23 south. This feature has been mapped as a normal fault upthrown on the northeast side (Malmborg, 1967, pl. 1) and as a fault with a right-lateral component of movement (Wright and others, 1981). An eroded fault-line scarp with a maximum relief of about 80 ft and tilted bedding on the upthrown side support some vertical movement; however, sections *C-C'* and *D-D'* show no offset on the bedrock. There are a number of possible explanations for this apparent discrepancy. One of the simplest is that the structural relief was too small to register in the analysis of the available data. This emphasizes the need for additional subsurface information.

Hydraulic Properties of the Valley Fill

Hydraulic Conductivity

Hydraulic conductivity is a measure of how easily a material will transmit water. Hydraulic conductivity is customarily expressed in terms of unit values for the area of aquifer through which a fluid moves under unit gradient per unit of time. Many natural materials transmit water in the horizontal direction much more readily than in the vertical direction. Approximate values of the horizontal conductivity of deposits typical of those in the valley-fill reservoir are listed below (values modified from Chow, 1964, fig. 13-8).

Lithologic unit (table 1)	Typical materials	Probable range of hydraulic conductivity (ft/d)
Playa deposits	Clay and silt	0.001-0.3
	Very fine sand	0.1-1.6
Lacustrine and associated fine-grained deposits.	Silt and clay	0.1-0.5
	Fine sand	1-4
Fanglomerate and associated coarse gravel.	Mostly silt, sand, and gravel	0.1-4
	Sand	4-30+
	Gravel	20-150+

These values illustrate that well-sorted gravel and sand are by far the most prolific water-yielding materials in the valley fill. Consequently, most of the water produced by wells that penetrate a variety of materials may be derived from only a few beds of coarse sand and gravel.

The average vertical hydraulic conductivity of a sequence of deposits typically is much less than the average horizontal hydraulic conductivity. The ratio between the two generally varies according to the type of material. Sequences of well-sorted sand and gravel commonly have higher vertical hydraulic conductivities than do sequences that contain significant amounts of clay, silt, or cemented materials. For the latter materials, average vertical hydraulic conductivity values can be as small as a hundredth to a thousandth of the horizontal hydraulic conductivity. Figure 3 shows the estimated distribution of vertical hydraulic conductivity in the upper 500 ft of valley-fill deposits. The distribution shown was first estimated using available geologic and hydrologic information and was then refined during calibration of the aquifer model described in a later section of this report.

Transmissivity

Transmissivity is a measure of the ability of an aquifer to transmit water. Transmissivity is dependent on the hydraulic conductivity and thickness of the water-bearing material. Transmissivity may be calculated from the results of aquifer tests, estimated as the product of hydraulic conductivity and thickness of the aquifer, or estimated from specific capacities of wells, provided the wells are highly efficient. Specific capacities are expressed as well yield, in gallons per minute per foot of drawdown. Properly designed wells in deposits with high transmissivity have higher specific capacities than wells tapping deposits with low transmissivity.

Figure 4 shows the approximate distribution of transmissivity of the upper 1,000 ft of saturated valley fill. This thickness was chosen because it roughly approximates the interval most affected by pumping.

Indices of Ground-Water Storage

When the hydraulic head in an aquifer changes there is a resulting change in the amount of ground water in storage. Water can come from the draining of deposits, elastic changes in the aquifer or water, or inelastic changes in the aquifer. Water produced by these processes is described in terms of the specific yield of an unconfined aquifer, the storage coefficient of an aquifer, and the specific storage of a porous medium.

Specific yield of a deposit is the ratio of (1) the volume of water which, after being saturated, the deposit will yield by gravity, to (2) its own volume, usually expressed as a percentage (Lohman and others, 1972, p. 12). Specific yield of alluvial deposits ranges from about 30 percent in well-sorted sand or gravel to less than 5 percent in compacted clay or deposits with extensive caliche development. The fanglomerate and associated coarse-grained deposits shown on plate 1 typically have specific yields of between about 13 and 25 percent. The

higher end of the range is associated with well-sorted sands and gravels, and the lower end with poorly sorted mudflow deposits and areas with significant caliche development. The lacustrine and associated fine-grained deposits shown on plate 1 typically have specific yields of between about 5 and 15 percent depending on the degree of compaction of clay and the amount of fine sand present. The distribution of specific yield used in this study is shown in figure 5.

Storage coefficient of an aquifer is the volume of water released from or taken into storage per unit of surface area per unit change in head. Water comes from expansion of the water and compression of the aquifer. Compression of the aquifer may be elastic or inelastic. Coarse-grained deposits such as sand and gravel are characterized by a relatively rigid framework that is supported by grain-to-grain contact; aquifer compression in these deposits is typically elastic. Fine-grained deposits, such as clay or silt, generally do not possess a rigid framework, and typically both elastic and inelastic compression occur. For conditions that exist in Pahrump Valley, the quantity of water involved in inelastic compression of the aquifer is much greater than that involved in elastic compression. Consequently, for purposes of evaluating the current response to pumping in Pahrump Valley, it is satisfactory to assume that virtually all water yielded from storage by fine-grained materials is produced by inelastic compaction. Fine-grained materials form only a part of the total valley fill, and their aggregate thickness varies from place to place. Consequently, it is necessary to consider water released from or taken into storage per unit volume of a porous medium.

Specific storage is the volume of water released from or taken into storage per unit volume of the porous medium per unit change in head. There are no field data to describe specific storage of fine-grained deposits in Pahrump Valley; however, in adjacent Las Vegas Valley, areas underlain by fine-grained deposits generally required 20 to 80 ft of head decline to produce 1 ft of land subsidence. Comparison of these known magnitudes of land subsidence with measured head declines and the approximate thickness of the confining layer suggests that in Las Vegas Valley specific storage of the confining beds is on the order of 0.001 to 0.0001 per foot (Harrill, 1976, p. 19). Lofgren (1977, p. 30) states that compressible deposits may have an inelastic (largely nonrecoverable) virgin specific storage of about 0.0001 per foot. Compressible fine-grained deposits in Pahrump Valley probably have specific storage values of about the same magnitude.

In Pahrump Valley, the thickness of the saturated valley fill ranges from about 200 to 4,000 ft. If no appreciable fine-grained deposits were present, the storage coefficient for these thicknesses would be 0.0002 to 0.003. The percentage of fine-grained materials present ranges from

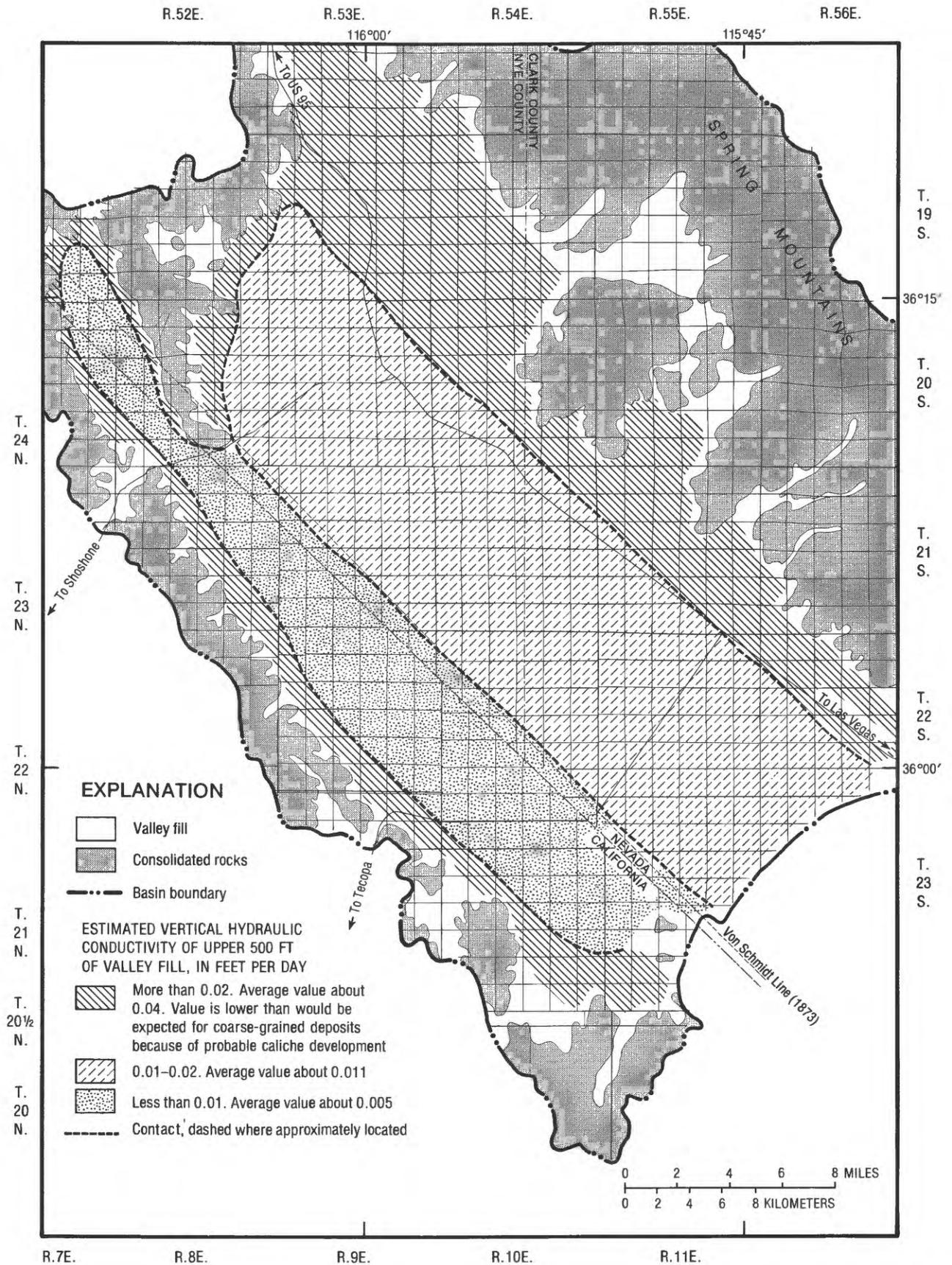


Figure 3. Estimated distribution of average vertical hydraulic conductivity in upper 500 ft of saturated valley fill.

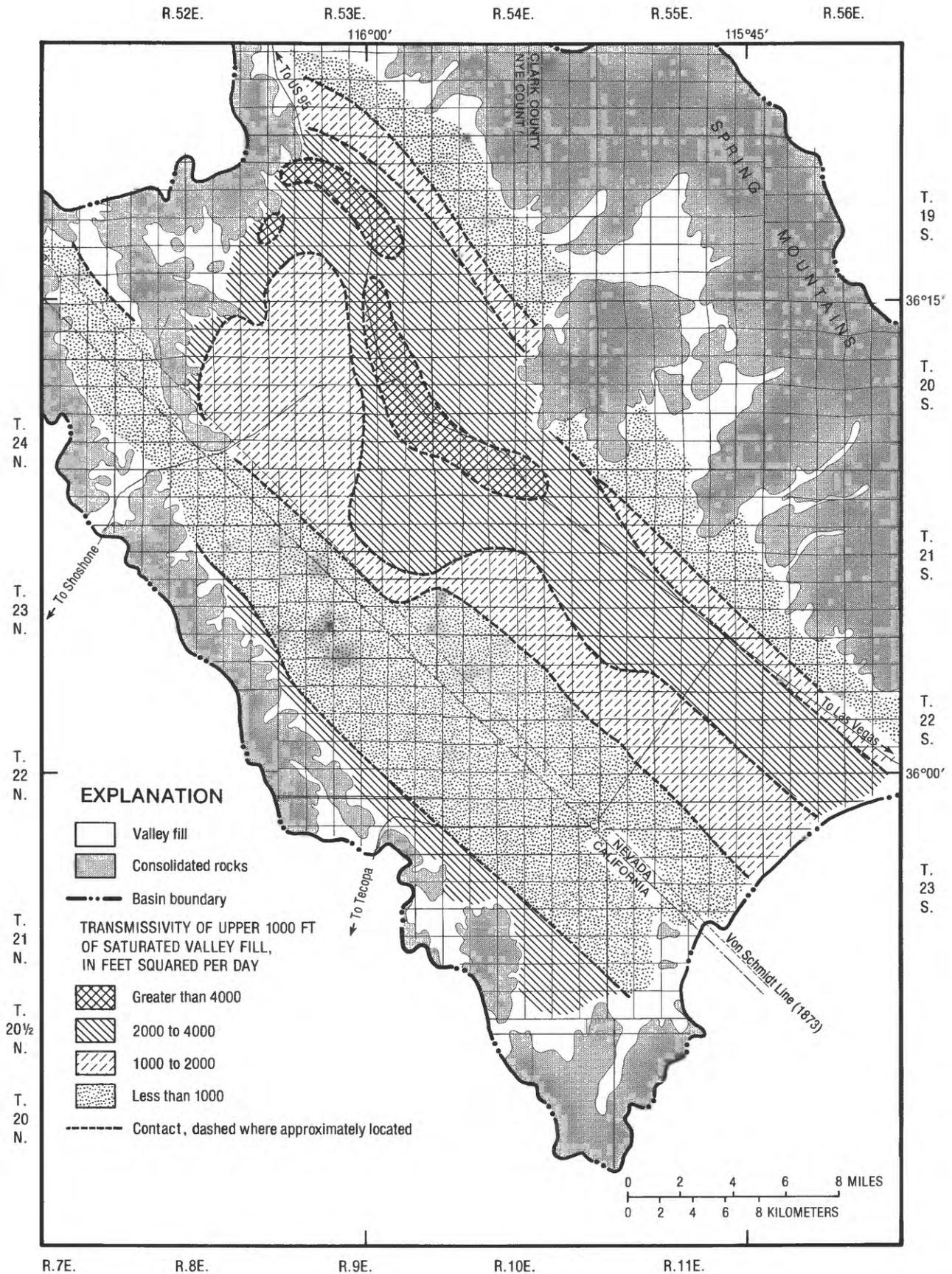


Figure 4. Estimated transmissivity of upper 1,000 ft of saturated valley fill.

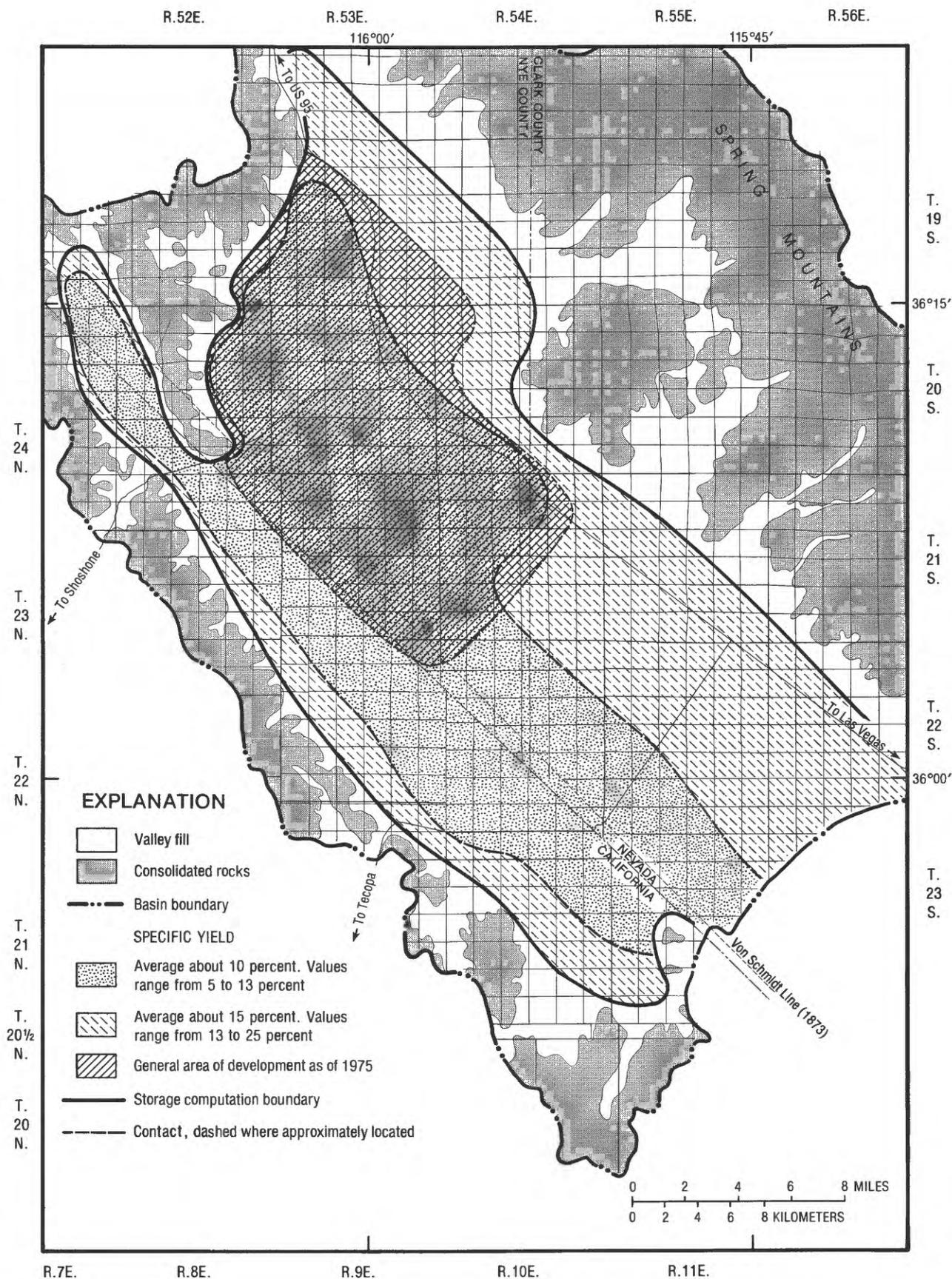


Figure 5. Estimated specific yield.

a very small amount around the margins of the valley to possibly as much as 80 in the central valley. If a change in head were uniformly distributed throughout the full thickness of the reservoir, the storage coefficient would be nearly 0.25. However, it is more probable that significant head changes would occur primarily in the most heavily pumped zones of the reservoir, for example, a 500-foot-thick interval in the upper part of the reservoir. In this case, the storage coefficient would be estimated to be about 0.04. In the quantitative parts of this study, values within the range 0.0002 to 0.003 were used for coarse-grained deposits around the margins of the valley and values within the range 0.001 and 0.04 were used for fine-grained deposits in the central part of the valley.

OUTLINE OF GROUND-WATER HYDROLOGY

Source, Occurrence, and Movement of Ground Water

Virtually all the ground water in Pahrump Valley is derived from precipitation that falls within the basin. Deep infiltration (recharge) occurs in the mountains, where percolating water moves through bedrock fractures to the zone of saturation, and on the upper slopes of the alluvial apron, where streamflow percolates through unsaturated valley fill to the zone of saturation.

Recoverable ground water is primarily in the saturated parts of the valley and in fill under both water-table and confined conditions. Confined conditions exist where saturated permeable deposits are overlain by less permeable strata and where the water at the top of the aquifer is under greater than atmospheric pressure. Water-table conditions exist where the water at the top of the zone of saturation, the water table, is at atmospheric pressure. Figure 6 shows the generalized depth to ground water as of March 1976.

Ground water moves along the path of lowest resistance from areas of high hydraulic head to areas of lower hydraulic head. The rate of movement depends on the hydraulic gradient and on the permeability and porosity of the material through which the water is moving. Typical rates in this area range from several feet per year to several hundred feet per year.

The general slope of the ground-water surface in Pahrump Valley under predevelopment conditions (prior to 1913) is shown in figure 7. This figure shows the approximate configuration of the potentiometric surface in that part of the valley-fill reservoir penetrated by most of the high-yield wells (generally the upper 200 to 1,000 ft of saturation). It was constructed with the earliest measurements available. Ground-water flow was generally from the principal recharge areas adjacent to the Spring

Mountains southwestward across the valley toward the Nopah Range. Water left the valley by evapotranspiration in areas of shallow ground water and by subsurface outflow beneath the Nopah Range. As drawn, the contours in figure 7 suggest that as water flowed across the northwest border of Pahrump Valley it moved into and through projections of consolidated rocks. The final disposition of this water is not known with certainty. Hydraulic gradients exist toward both the Ash Meadows discharge area (in the Amargosa Desert north and west of Pahrump Valley) and a discharge area along the Amargosa River between the towns of Shoshone and Tecopa (southwest of Pahrump Valley). Winograd and Thordarson (1975, p. C90-C92) evaluated the relation of the Ash Meadows ground-water basin to the Pahrump Valley ground-water basin and concluded that because a significant assemblage of rocks assigned to the clastic aquitards was exposed between Pahrump Valley and the Ash Meadows ground-water discharge area, at most only a small percentage of the Ash Meadows discharge can be derived from either Stewart Valley or western and northwestern Pahrump Valley.

Ground-Water Storage

The potentially recoverable water stored in the valley-fill reservoir can be estimated as the product of an area, a thickness, and a specific yield. The following procedures were used to compile estimates for Pahrump Valley:

1. The area underlain by valley fill was divided into a number of rectangular nodes identical to those used in the ground-water model that will be described in a later section of this report (see fig. 15).
2. For each node the thickness of saturated valley fill was determined, using total thickness of fill shown on plate 2C and depths to water shown in figure 6; the specific yield was determined from figure 5.
3. Recoverable storage for each node was calculated as the product of the area of the node, an interval of saturated valley fill, and a specific yield. Two intervals were used, the upper 200 ft of saturation and the remainder of the saturated valley fill. The yield of the interval below 200 ft was reduced by 5 to 15 percent (depending on the thickness of fill at each node) to account for lower yields in the older, more deeply buried deposits.
4. Values for nodes were summed to give the results listed in table 2. Computations were made for two general areas, the developed area as of 1975 (shown in fig. 5) and the remaining area of valley fill.

The estimated total amount of recoverable water stored in the valley-fill reservoir, 57 million acre-ft, illustrates the vast amounts of water stored in large

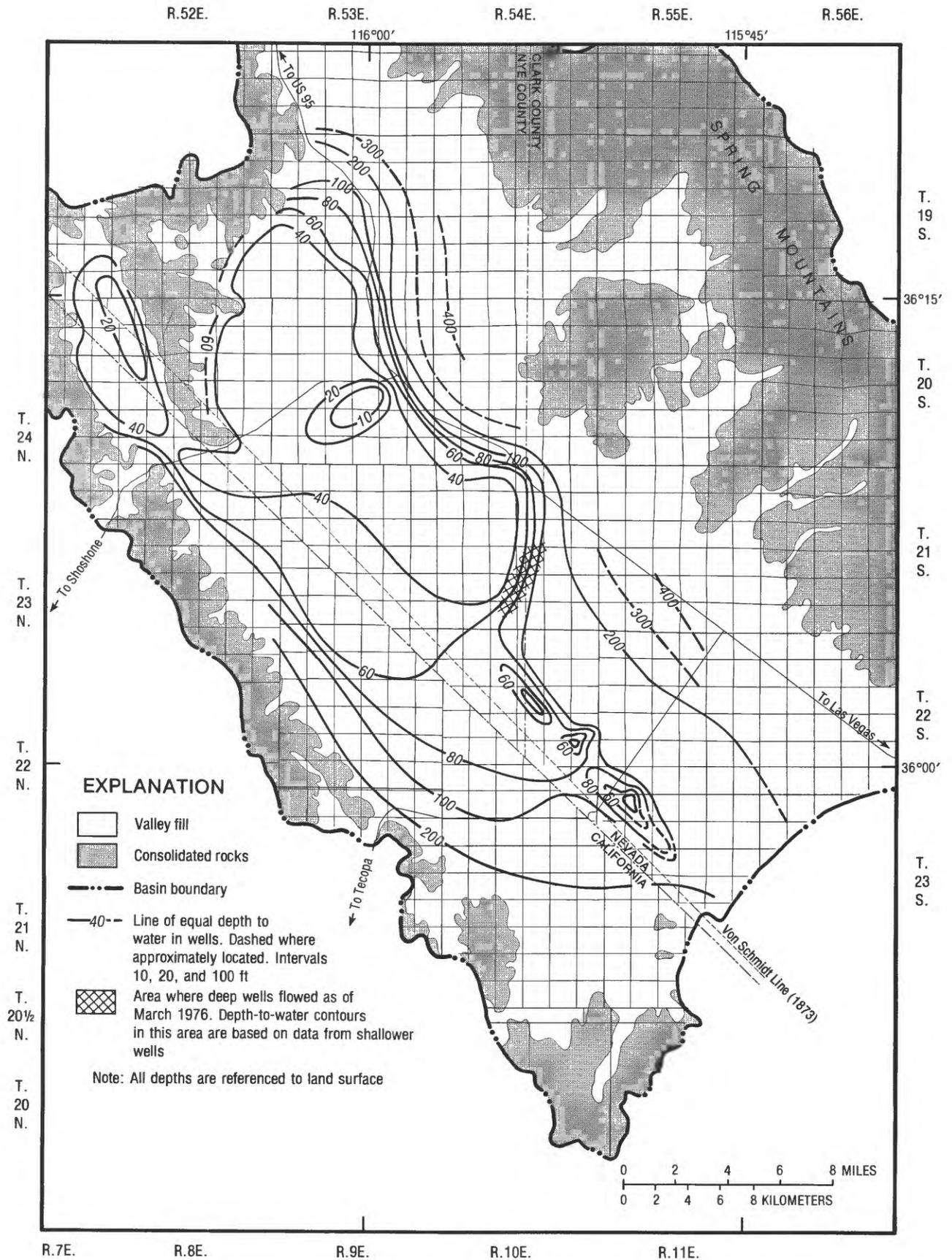


Figure 6. Depth to water, March 1976.

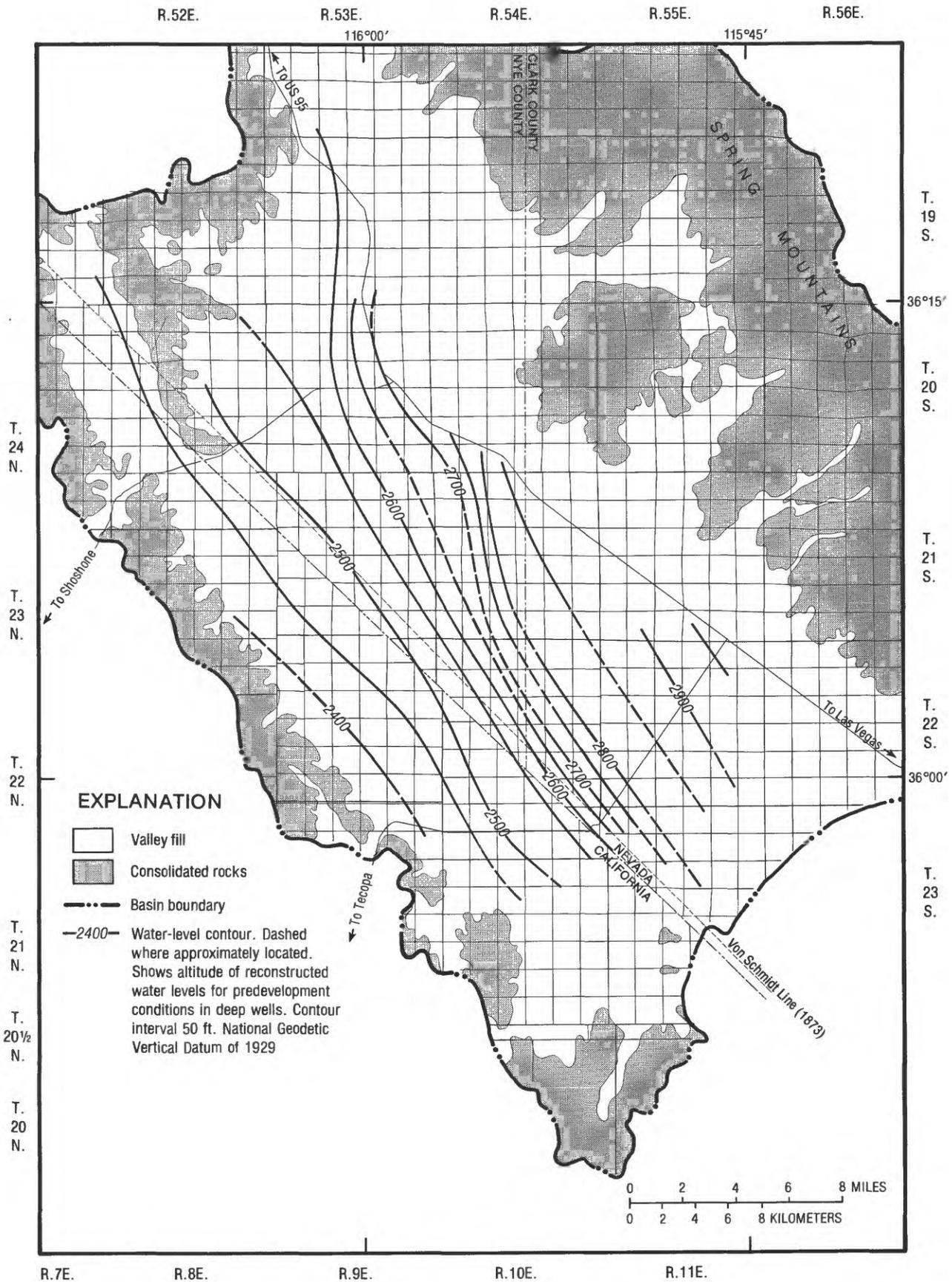


Figure 7. Water-level contours for deep wells under predevelopment conditions.

Table 2. Estimated recoverable ground-water storage

Location ¹	Recoverable ground-water storage (acre-feet, rounded)		
	Upper 200 feet of saturation	Saturated valley fill below 200 feet	Total valley fill
Developed area as of 1975	2,300,000	17,000,000	19,000,000
Area remote from 1975 development	5,500,000	32,000,000	38,000,000
Totals	7,800,000	49,000,000	57,000,000

¹ See figure 5 for location of areas.

valley-fill ground-water reservoirs in the Great Basin. However, much of this water cannot be practically recovered with our existing technology owing to economic factors, such as high pumping lifts, and environmental factors, such as land subsidence. Also, the quality of the deeper water is not known. The estimated 2.3 million acre-ft stored in the upper 200 ft of saturated valley fill in the 1975 area of development is probably within economic pumping lifts using the 1975 distribution of pumpage. Even so, depletion of this amount of storage would probably cause land subsidence in the central part of the valley.

Ground-Water Development

Development Prior to 1962

Pahrump Valley has supported agricultural development for many years. Two large springs (Bennetts Spring and Manse Spring, fig. 1) provided water to early travelers and were soon developed for irrigation. Mendenhall (1909, p. 91) described the level of development in Pahrump Valley shortly after the turn of the century as follows:

Pahrump, one of the oldest settlements in the southern part of Nevada, is about 7 miles northwest of Manse, on the road to Fairbanks Ranch. It is a large ranch in whose cultivation a number of Indians are employed. Here orchards, vineyards, and extensive fields of alfalfa flourish, and the water used in irrigation is supplied by a number of large, deep-seated warm springs similar to those at Manse. Travelers can obtain hay and grain here.

The springs at Manse have been known for years to travelers going northward from points in southern Nevada, and the place has long been the principal stopping point along this route. By the use of the water which the springs yield, this portion of the desert has been converted into a veritable oasis, and the 500 or 600 acres of alfalfa, orchards, and vineyards show the capabilities of the desert soil when water can be applied to it in sufficient quantity.

The springs described on the Pahrump Ranch were named Bennetts Spring and are reported to have flowed at about 7.5 ft³/s in the late 1800's. Manse Spring is reported to have flowed at about 6 ft³/s at that time (Maxey and Jameson, 1948, p. 10). The total average annual flow was about 9,800 acre-ft.

In 1910, the first well was drilled in Pahrump Valley in an attempt to obtain artesian water from wells. That attempt was unsuccessful; however, in 1913, three flowing artesian wells were successfully completed, and development of the area's ground-water resources had begun. In 1916, Waring (1921, p. 76-79) reported 28 wells in Pahrump Valley, 15 of which were flowing.

The number of new wells drilled and the annual pumpage increased slowly until the mid-1940's. At that time many wells were drilled and large-capacity pumps installed. From the mid-1940's through 1962, the annual discharge from wells increased from an estimated 10,000 acre-ft/yr to about 28,000 acre-ft/yr (Malmberg, 1967, p. 30-31). Thus, pumpage from the ground-water reservoir in 1962 was about three times greater than the reported natural flow from springs in the late 1800's.

Development 1962-75

The period 1962-75 was one of population growth and significant change in land use for Pahrump Valley. Population increased from about 250 in 1962 to nearly 1,500 in 1975. This increase in population was accompanied by conversion of land from agricultural use to real-estate development.

In the early 1960's Pahrump Valley was one of the most productive farm districts in southern Nevada. Cotton and alfalfa were the principal crops. The area remained primarily on an agriculture-based economy during most of the 1960's. In 1963, electrical power was introduced to the valley, followed by telephone service in 1965. In the late 1960's several large tracts of farmland were subdivided for real-estate development. Land sales soon became a major factor in the economy of the valley. The largest development in the valley, Calvada, is reported to have sold about 10,400 lots during the period 1970-74 and was selling an average of 300 lots per month in 1974 (Nevada West and Pahrump Valley Times, August 1974, p. 11).

Ground water provides the water supply for virtually all development in Pahrump Valley. Pumpage increased rapidly between 1962 and 1968. Pumpage decreased after 1968 when some land was taken out of agricultural production and subdivided for real-estate development. If this land is fully developed, pumpage will probably return to about the same level as in 1968.

Development during the period 1962-75 is summarized in table 3, which lists estimates of population, irrigated acreage, and ground-water withdrawal. In

Table 3. Summary of population, irrigated-land area, and ground-water withdrawals, 1962–75

[Populations and acreages rounded to nearest 10, withdrawals to nearest 100]

Year	Population ²	Irrigated land (acres) ¹			Ground-water withdrawals ¹ (acre-feet)		
		Cotton	Other ³	Total	Manse Spring	Pumpage	Total
1962	250	3,320	3,170	6,490	1,400	27,600	29,000
1963	280	3,360	4,480	7,840	1,300	31,200	32,500
1964	320	3,160	4,510	7,670	1,300	36,200	37,500
1965	430	2,950	5,300	8,250	800	35,700	36,500
1966	490	2,240	5,320	7,560	1,100	37,000	38,100
1967	510	2,230	6,000	8,230	1,100	40,400	41,500
1968	570	2,310	6,070	8,380	900	47,100	48,000
1969	750	2,220	6,180	8,400	700	40,200	40,900
1970	960	1,210	3,640	4,850	400	42,200	42,600
1971	1,050	1,370	3,180	4,550	800	37,200	38,000
1972	1,230	1,200	3,120	4,320	700	35,900	36,600
1973	1,390	2,070	5,100	7,170	600	38,800	39,400
1974	1,470	1,610	5,320	6,930	400	41,000	41,400
1975	1,480	1,530	5,010	6,540	200	40,600	40,800
Total for period (rounded)					12,000	530,000	540,000

¹From records of the Nevada State Engineer.²Populations for 1975 and 1970 reported in Nevada West and Pahrump Valley Times, May 1975, p. 4. Populations for other years

estimated by the author from data on home power and telephone hookups.

³Primarily alfalfa.

1975, irrigation remained the principal use of water, accounting for about 38,000 of the 40,800 acre-ft withdrawn for use. Of the remaining 2,800 acre-ft, about 800 acre-ft was used for self-supplied domestic purposes and about 2,000 acre-ft was used for public supply and commercial purposes. Part of the pumped water is recycled back to ground water. The percentage varies both with type of use and with individual systems. An average of about 25 percent of the agricultural pumpage, 70 percent of the self-supplied domestic pumpage, and 50 percent of the public supply and commercial pumpage was estimated to be recirculated back to ground water. The relative amount of water used for domestic, public-supply, and commercial purposes will probably increase substantially in the near future, and the amount of water recirculated will be affected accordingly. Also, agricultural water requirements could be affected by future changes in cropping patterns. For example, population increases in both Pahrump and Las Vegas Valleys could provide a significant market for certain vegetables and other diversified crops that require much less water per acre than alfalfa. A discussion of the effects of various cropping patterns on the area's water requirements and economy is beyond the scope of this study. However, this is an alternative that should be considered when evaluating means of dealing with the overdraft on the area's ground-water

resources. Figures 8 and 9 show the areal distribution of ground-water withdrawals in 1962 and 1975.

Effects of Development

As of 1975, a total of nearly 700,000 acre-ft of pumpage and about 550,000 acre-ft of spring flow had been discharged from the valley-fill reservoir in Pahrump Valley since pumping began in 1913. Of this, 530,000 acre-ft of pumpage and 12,000 acre-ft of spring flow occurred during the period 1962-75.

Response of the ground-water system to withdrawals was complex. The two most apparent effects were large water-level declines and cessation of most spring discharge. These will be discussed in the following paragraphs. Some of the more subtle responses, such as variations in ground-water evapotranspiration, probable land subsidence, and probable diminished subsurface outflow, will be discussed in later parts of this report.

Water-Level Changes

Water levels in wells generally have been declining since the first wells were constructed in 1913. The annual rate of decline and the net change between predevelopment and 1975 water levels vary at different locations,

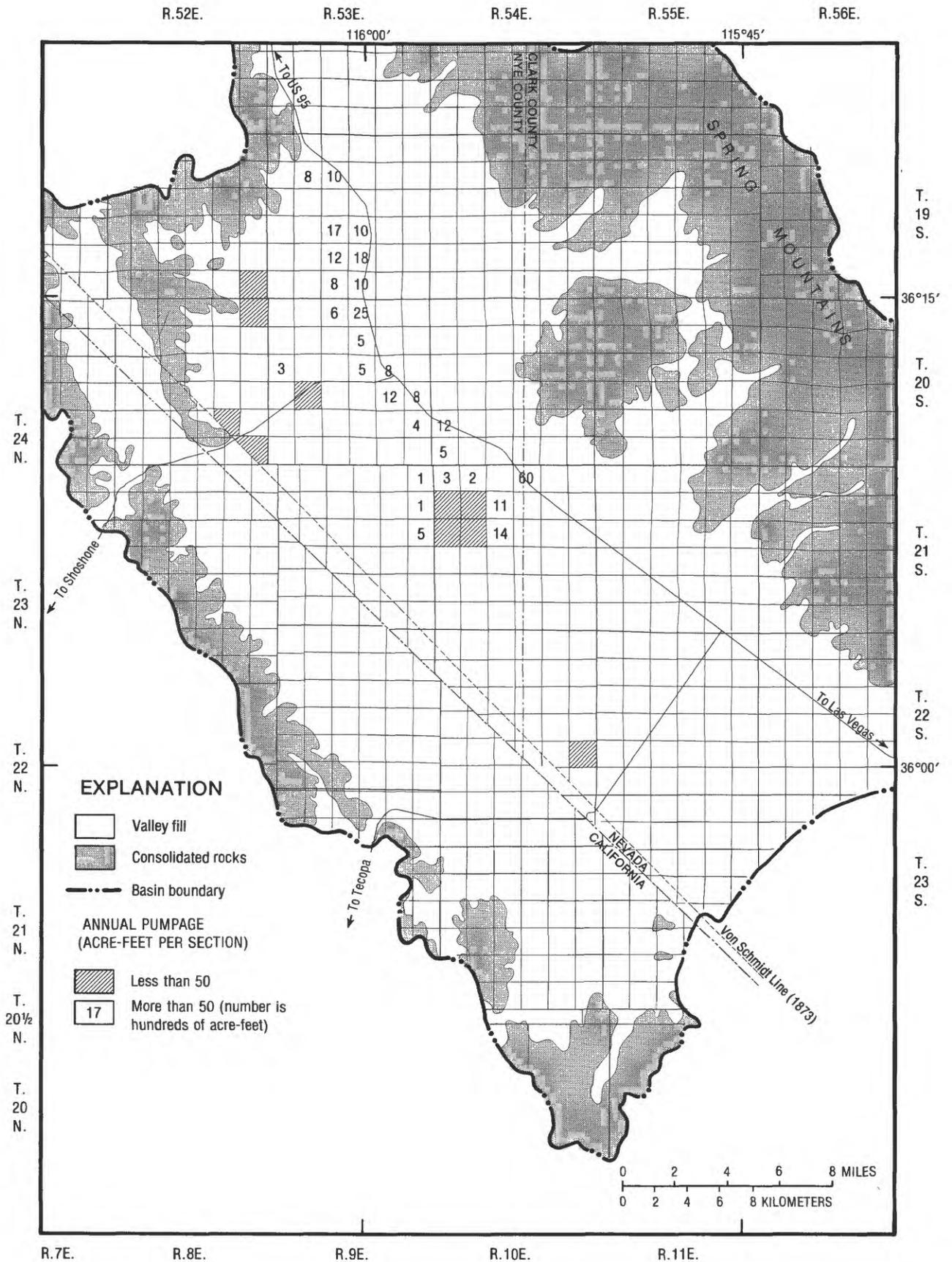


Figure 8. Distribution of pumpage in 1962.

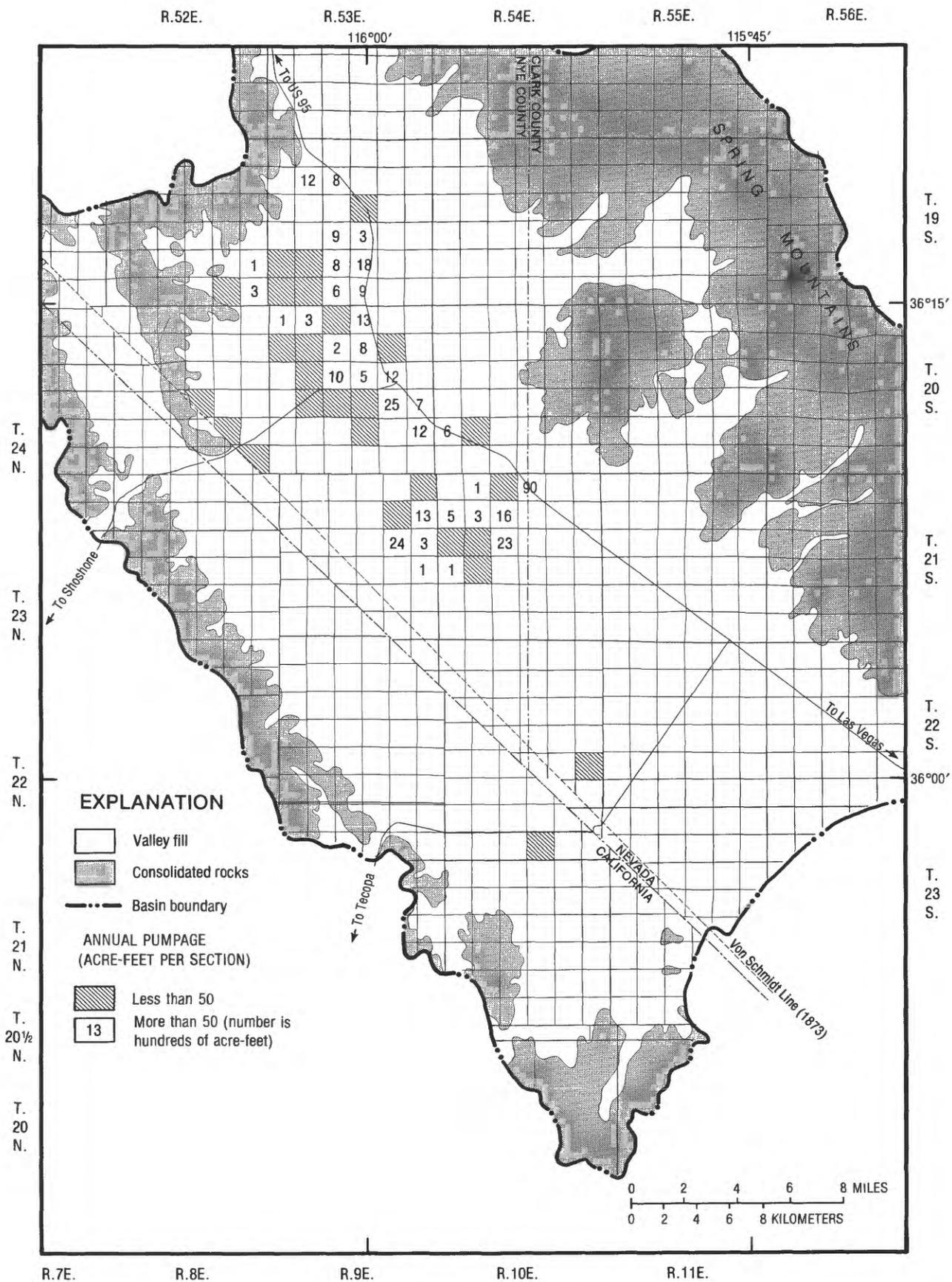


Figure 9. Distribution of pumpage in 1975.

depending on the distribution of pumping (figs. 8, 9), hydraulic properties of the valley fill (figs. 3-5), and the depth of the well being measured. Hydrographs of water-level changes in six wells were prepared to illustrate typical rates and magnitudes of change in various parts of the valley. Figure 10 shows locations of the six observation wells, and figure 11 shows the hydrographs. Generally, the greatest declines occurred along the base of the Pahrump and Manse fans, where maximum declines of about 100 ft were observed between predevelopment and February 1976 levels. The two wells located away from the fan in the central valley (162 S20 E53 06CDA1 and 162 S22 E53 01AAA1) exhibit substantially lesser rates of water-level decline. An exception to the generally declining trend occurs in some shallow wells located near irrigated areas. Some irrigation water recharges the shallow part of the valley-fill reservoir; consequently, water levels in some shallow wells on or near irrigated land may be higher than under predevelopment conditions. Additional information about the areal distribution of water-level changes is presented on net-change maps, located in a later section that deals with simulation of the response to pumping.

Declines in Spring Discharge

Pumping in Pahrump Valley is well situated to capture the discharge of Bennetts and Manse Springs. Consequently, spring flow began to decrease shortly after pumping began and continued to decrease until 1975, when it ceased during the pumping season. In 1959, Bennetts Spring ceased to flow. As of 1975, Manse Spring was dry during the summer irrigation season but discharged about 200 acre-ft during the winter months. Figure 12 is a graph illustrating changes in spring discharge through 1975. The amount by which spring discharge has decreased is also the amount of water captured by pumping. Thus, as of 1975, about 10,000 acre-ft per year of spring discharge had been captured by pumping.

GROUND-WATER RECHARGE AND DISCHARGE

Estimates of ground-water recharge and discharge for predevelopment conditions have been developed by Malmberg (1967, p. 36). In this study it was not necessary to develop completely new estimates but only to evaluate the existing ones to see if any revisions are warranted in light of other information and experience gained since the mid-1960's. In the Pahrump Valley area, virtually all inflow consists of recharge from precipitation that falls within the basin. Natural discharge consists of evapotranspiration and subsurface outflow. Spring discharge is

either consumed by evapotranspiration or returns to ground water to be discharged as subsurface outflow.

Malmberg (1967, p. 26) used a method described by Eakin and others (1951, p. 26, 27) to estimate recharge in Pahrump Valley to be about 22,000 acre-ft/yr. This method is based on the assumption that a fixed percentage of a given average annual rate of precipitation ultimately recharges the groundwater reservoir. However, during the 1960's and early 1970's this technique was applied to some other areas in Nevada where investigators used higher precipitation rates on the sides of mountains facing the prevailing storm tracks and also used higher percentages of recharge where there are significant areas of higher altitude. These variations could be roughly applied to Malmberg's estimates (1967, table 4) by changing average precipitation and assumed percentage of precipitation in the zone above 8,000 ft from 1.75 ft and 20 percent to 2.0 ft and 25 percent, respectively. The resulting revised estimate of recharge is about 26,000 acre-ft/yr.

There are insufficient data to determine which set of assigned values is best, so this technique will be considered to produce results ranging from 22,000 to 26,000 acre-ft/yr, depending on the set of assumptions and assigned values used.

Malmberg (1967, p. 29) estimated annual evapotranspiration by mapping areas and densities of phreatophytes present in 1961 and multiplying the areas by assigned use rates. Areas associated with spring discharge and irrigation tail water were separated from other areas of evapotranspiration. The total evapotranspiration estimated in this way was 10,000 acre-ft/yr (Malmberg, 1967, table 5). Estimates based on the 1961 distribution of phreatophytes include the assumption that there had been no significant change in areas or rates of evapotranspiration from the natural conditions. But, if pumping or clearing land for irrigated crops has reduced phreatophyte areas or discharge, then the estimate of discharge under natural conditions is too low. An alternate approach would be to assume that virtually all natural spring discharge was ultimately consumed by evapotranspiration. Total evapotranspiration could be estimated as the sum of estimated predevelopment spring discharge (10,000 acre-ft/yr) and natural evapotranspiration outside of areas where evapotranspiration is supported by spring discharge. The resulting total of 13,000 acre-ft/yr is larger than the original estimated 10,000 acre-ft/yr but is still of the same order of magnitude. Both approaches depend on assumptions that cannot be verified by existing data. The earliest estimates of discharge from Bennetts and Manse Springs were reported by the owners (Maxey and Jameson, 1948, p. 10). The earliest measurements were made in 1916 and were about 40 percent lower than the initial values reported by Maxey and Jameson. It could not be determined with

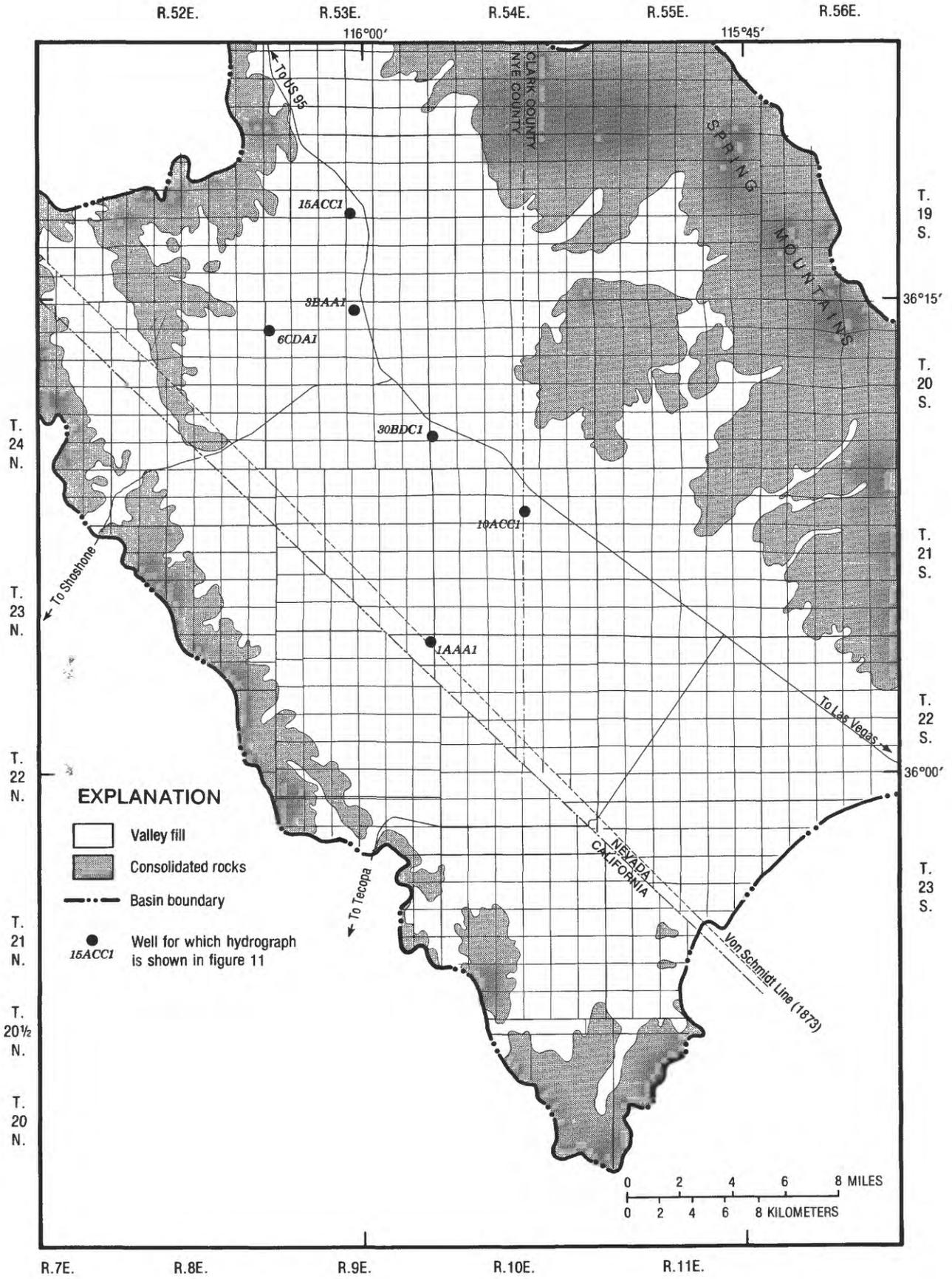


Figure 10. Location of selected observation wells.

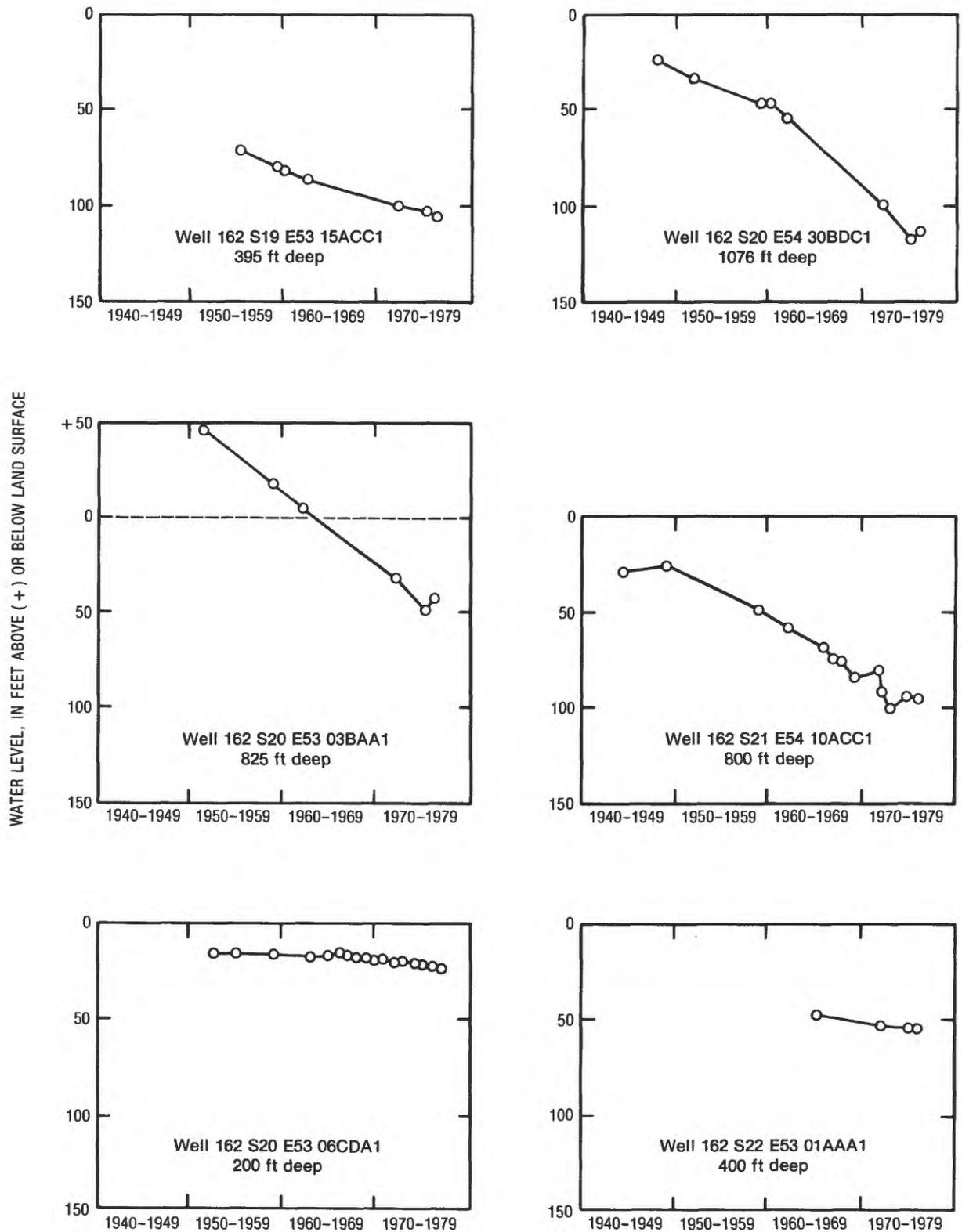


Figure 11. Water-level changes in six observation wells.

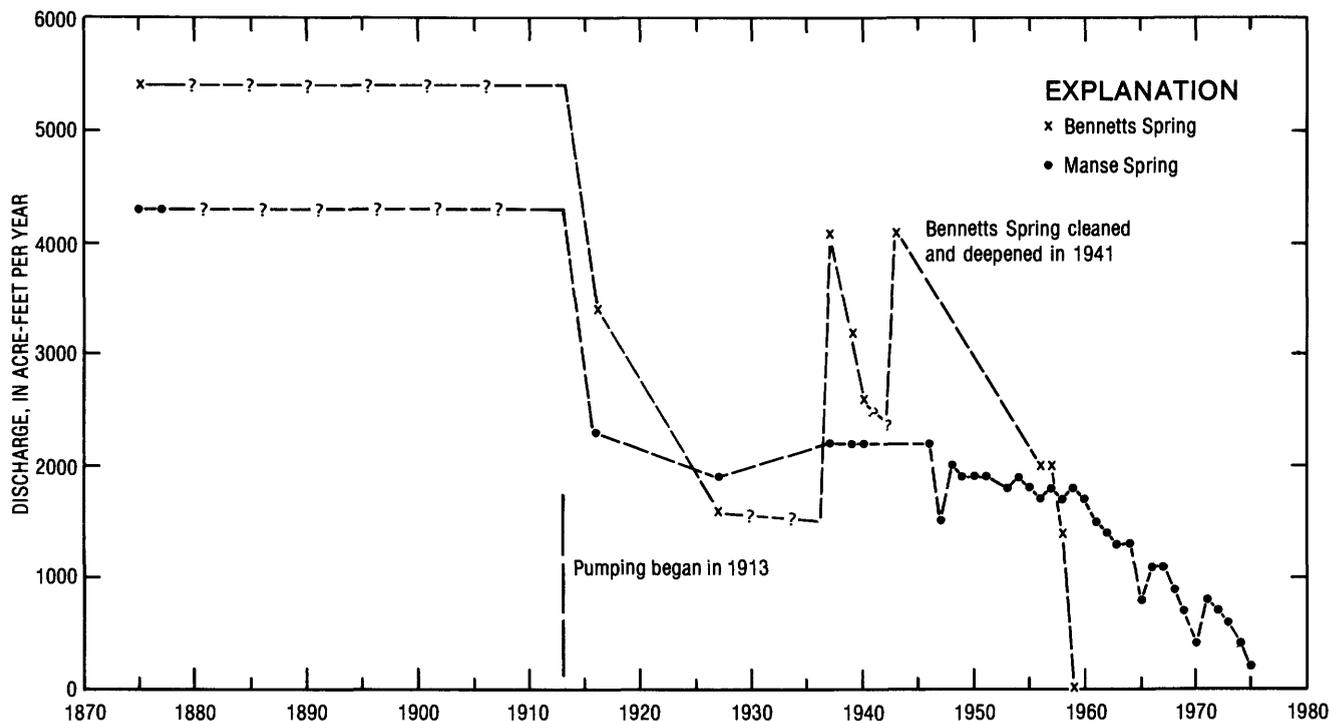


Figure 12. Annual discharge of Bennetts and Manse Springs, 1875-1975.

certainty if the earliest measurements represented reduced spring discharge caused by nearby flowing wells or if the earliest reported estimates were in error. Consequently, in this study, natural evapotranspiration is estimated to be between 10,000 and 13,000 acre-ft/yr.

During fieldwork conducted in 1975 and 1976, shad scale (atriplex) was observed growing in comparatively shallow ground-water areas near irrigated land in the north-central part of the valley. Some species of shad scale are phreatophytes and consume ground water. It was not determined if there were substantial stands of shad scale in the valley prior to development or if the shad scale seen today has developed as a result of the availability of irrigation tail water. If a significant amount of shad scale was present prior to development, then natural ground-water evapotranspiration probably is greater than the range indicated above.

Malmberg (1967, p. 30) estimated subsurface outflow from the southwest edge of the valley-fill reservoir on the basis of computations using transmissivity, ground-water gradients, and width of flow section. The range of transmissivity that he used (134 to 668 ft/d) gives a range of outflow estimates of 1,000 to 4,000 acre-ft/yr. Within this range, Malmberg chose 2,000 acre-ft/yr as his best estimate of the outflow. Because of the uncertainties involved in estimating transmissivity, the range of 1,000 to 4,000 acre-ft/yr will be used for this estimate of outflow.

It was not possible to make a credible direct estimate of subsurface outflow through the carbonate-rock reservoir. Malmberg (1967, p. 32) estimated this quantity as the difference between the other items of recharge and discharge. The same approach was used in this study and a range of 5,000 to 15,000 acre-ft/yr was obtained. Thus, total subsurface outflow through both valley fill and consolidated rocks is estimated to range from 6,000 to 19,000 acre-ft/yr.

Table 4 summarizes the various estimates of recharge and discharge. Ranges of estimates are given because of the uncertainties involved in assumptions for a given technique or because of varying results obtained when slightly different techniques were used to estimate the same parameter. Values estimated by Malmberg (1967, p. 36) are within the general range of estimates and generally fall in the lower part of the range. These estimates will be further evaluated in a later section of this report by using a computerized mathematical model of the flow system. The values listed in table 4 (which were based on field and empirical techniques) were used as input values for the initial computer runs, and where the model results differ they provide a basis for comparison.

Conceptualization of the Ground-Water System

The ground-water system, as described in the preceding sections of this report, is a thick reservoir of

unconsolidated deposits bounded on its sides and bottom by consolidated rocks, some of which are permeable enough to transmit significant regional ground-water flow. Water-bearing properties of the valley fill vary from place to place. Generally, the most productive deposits are along the lower parts of alluvial fans on the northeast side of the valley. Deposits in the central part of the valley are predominantly finer grained materials and are much less productive. Ground water in the valley-fill reservoir is both confined and unconfined. Water is unconfined at and near the upper surface of saturation (the water table). Interbedded silt and clay in the central valley and caliche horizons and cemented zones around the margins of the valley inhibit vertical movement, and ground water in most of the deeper valley-fill deposits is under leaky confining conditions. Water levels in the deeper wells generally are assumed to represent composite heads typical of conditions in the upper 1,000 ft of saturation. Heads in deeper parts of the valley-fill reservoir and underlying consolidated rocks are not known.

The ground-water reservoir underlying Pahrump Valley functions as a three-dimensional system. Generally, water flows from recharge areas in and near the Spring Mountains southwestward toward the Nopah Range, where it leaves the area as subsurface outflow. There is a downward vertical component of movement in the recharge areas and an upward vertical component of movement in the discharge areas. Consequently, head varies both areally and with depth, and a multiple-layer concept is required to give a reasonable representation of the system.

The ground-water system in Pahrump Valley is evaluated as a three-layer system. The top layer approximates the water table and the underlying adjacent material in which water is unconfined. It is assumed to be about 50 ft thick. The middle layer represents the part of the valley-fill reservoir most affected by pumping. This is assumed to be generally the zone from 50 to 1,000 ft

below the water table. The bottom layer consists of the valley fill not included in the overlying layer and the consolidated rocks that underlie the valley-fill reservoir and transmit significant subsurface flow.

Figure 13 is a conceptualization of the ground-water system in Pahrump Valley. The southwest edge of the system has been extended approximately 15 mi southwest of Pahrump Valley to include probable discharge areas of the subsurface outflow from the valley.

Development of the Mathematical Model

The preceding sections have developed qualitative and quantitative information that describes the ground-water system and its current state of development. A mathematical model is used in the following sections to simulate natural conditions and the response to development of the ground-water system. If a reasonable match between observed and simulated conditions can be obtained, the model can provide useful information about the available ground-water supply and probable responses to development.

Mathematical models are tools that increase an investigator's capability to formulate and test hypotheses about a ground-water system and to predict generalized responses to a given scheme of development.

Any attempt to simulate a ground-water flow system is subject to limitations inherent in the technique used. The model itself is essentially a set of equations that describe an idealized system having properties similar to a real ground-water system. If the model adequately describes a real ground-water system, then the response of the model to imposed stresses, such as ground-water pumpage, will be very close to the response of the real system if it were to undergo the same stress. The degree of exactness with which a model can describe a natural system is limited by characteristics of both the model used and the system being described. Examples of three types of limitations in most models are as follows:

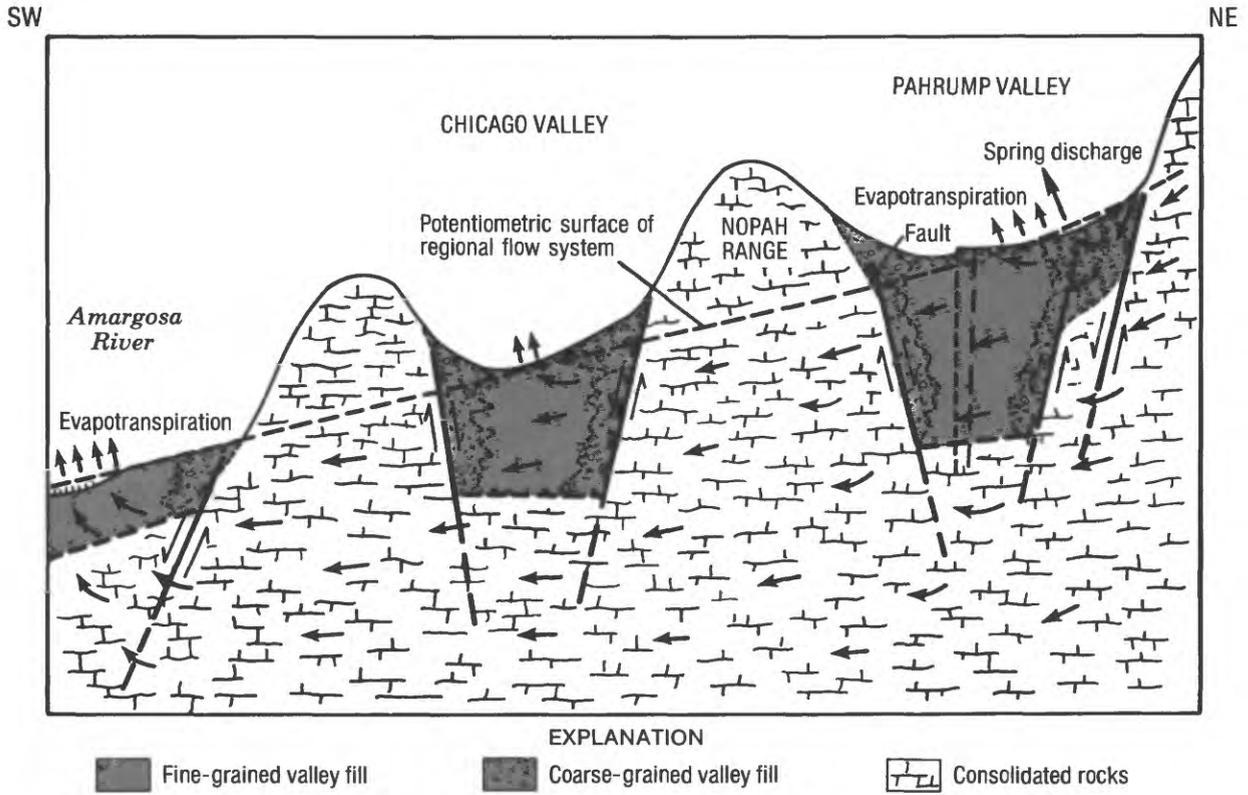
1. The inability of a model to handle all the complexities of a natural system. The simplifying assumptions and generalizations that are incorporated into a model affect the output. If a model is designed to perform a specific task, the simplifying assumptions can be made so that the effects on a particular type of prediction are minimal. If the model is used to make predictions other than those for which it was designed, the generalizations and assumptions used could significantly affect the results.
2. The inadequacy of existing data to describe the system. In most valleys, development is localized in a comparatively small area. Reasonably good data on water levels and aquifer properties in the vicinity of the development may be available; however, away

Table 4. Summary of estimates of recharge and discharge for natural conditions

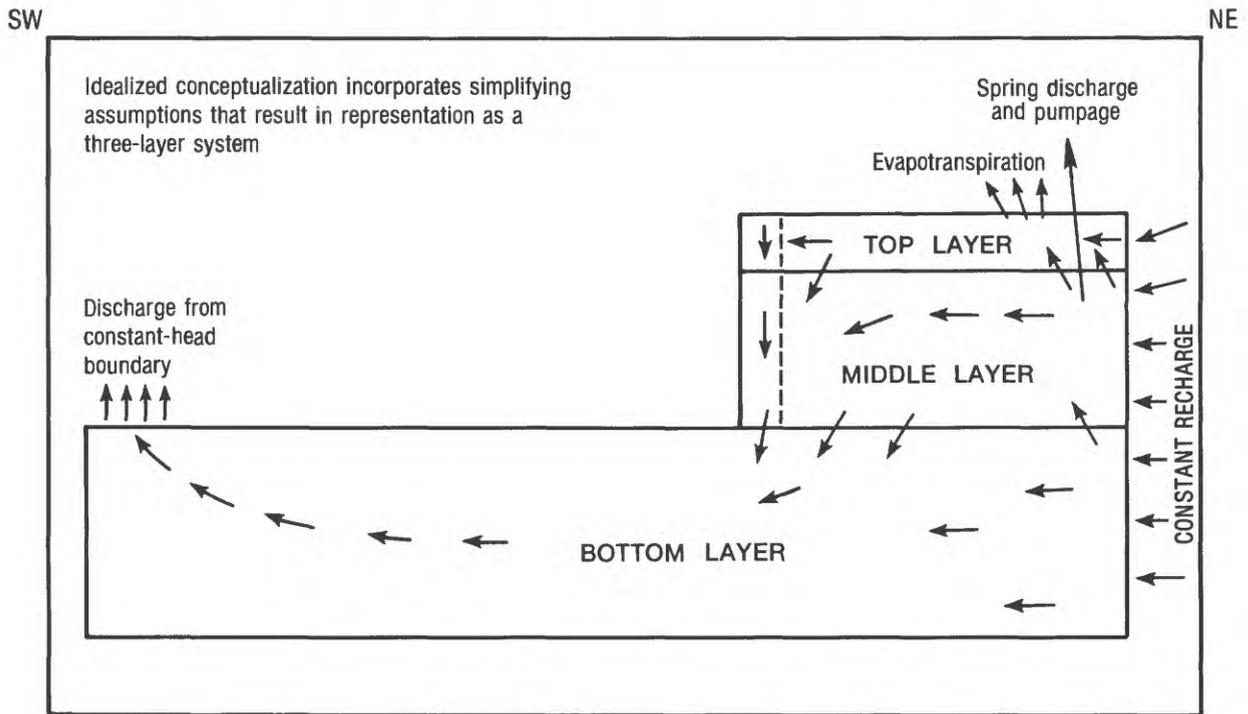
[Acre-feet per year]

Recharge	22,000-26,000
Discharge:	
Evapotranspiration	10,000-13,000
Subsurface outflow	
from valley fill	1,000- 4,000
Difference (recharge minus discharge)	¹ 5,000-15,000

¹Difference is assumed to be outflow through carbonate-rock reservoir. Calculated as maximum recharge minus minimum discharge for high end of range and minimum recharge minus maximum discharge for low end.



A. Generalized section across Pahrump Valley and basins to the southeast



B. Idealized ground-water flow

Figure 13. Conceptualization of the ground-water flow system in and downgradient from Pahrump Valley. Arrows show direction of ground-water movement.

from developed areas, information is generally sparse and aquifer properties and hydraulic heads must be estimated on the basis of what little information is available. Errors in these estimates may significantly affect the results. The severity of these adverse effects varies with the intended uses of the model. For some purposes, the probable errors associated with data deficiencies in areas remote from existing development may have little effect on the results. For other purposes, it may be necessary to collect additional data before an adequate model can be constructed.

3. The problem of nonunique solutions. Most ground-water models are calibrated by comparing model output with observed changes such as hydraulic heads or water-level changes and then adjusting model parameters, within limits, until a reasonable agreement between observed and computed values is obtained. However, in some cases it is possible to obtain identical water-level configurations with numerous different combinations of parameters. Consequently, computed solutions are not unique and a match between observed and modeled conditions does not guarantee that the model parameters and the parameters of the real system are identical. It guarantees only that the combination of parameters used will reproduce the observed conditions. If the parameters used are generally compatible with known information, the model will constitute a best fit of the data and errors caused by nonuniqueness are minimal.

These examples illustrate several factors that can limit the accuracy of model results. Generally, if the intended uses of a model are carefully considered prior to its formulation, it can be constructed so that the adverse effects of these and other factors will be minimal. It was not possible to determine the absolute accuracy of results obtained from the model used in this study. Few data were available to describe the materials underlying the valley fill, and, if the estimates used for these materials are reasonably accurate, the model results are considered by the author to be accurate to within about 30 percent of the real values.

Governing Equations of Ground-Water Flow

The flow of ground water in a porous medium in three dimensions (Jacob, 1950; Cooper, 1966) may be expressed as follows:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = \frac{S_s}{K} \frac{\partial h}{\partial t}, \quad (1)$$

in which

h is hydraulic head, in feet;

S_s is specific storage, per foot;

K is hydraulic conductivity, in feet per unit time;

and

t is time.

Permitting hydraulic conductivity to be heterogeneous and anisotropic and adding a source term, equation 1 becomes

$$\left[\begin{aligned} & \frac{\partial}{\partial x} \left(K_{xx} \frac{\partial h}{\partial x} + K_{xy} \frac{\partial h}{\partial y} + K_{xz} \frac{\partial h}{\partial z} \right) \\ & + \frac{\partial}{\partial y} \left(K_{yx} \frac{\partial h}{\partial x} + K_{yy} \frac{\partial h}{\partial y} + K_{yz} \frac{\partial h}{\partial z} \right) \\ & + \frac{\partial}{\partial z} \left(K_{zx} \frac{\partial h}{\partial x} + K_{zy} \frac{\partial h}{\partial y} + K_{zz} \frac{\partial h}{\partial z} \right) \end{aligned} \right] = S_s \frac{\partial h}{\partial t} + W(x, y, z, t), \quad (2)$$

in which $W(x, y, z, t)$ is a volumetric flux per unit time, K_{ij} is the hydraulic conductivity that produces flux along axis i caused by the component of hydraulic gradient on axis j , and i and j are x , y , or z . Assuming that the coordinate axes x , y , and z are aligned with the principal directions of the hydraulic conductivity tensor, the cross-product terms drop out of equation 2 and it becomes, in expanded form,

$$\frac{\partial}{\partial x} \left(K_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_{zz} \frac{\partial h}{\partial z} \right) = S_s \frac{\partial h}{\partial t} + W(x, y, z, t), \quad (3)$$

in which K_{xx} , K_{yy} , and K_{zz} are the principal components of the hydraulic conductivity tensor, in feet per unit time.

In the finite-difference simulator, it is often convenient to represent a hydraulic unit by one layer of nodes. For this approach, equation 3 is multiplied by b , the thickness of the hydraulic unit, giving

$$\frac{\partial}{\partial x} \left(T_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(T_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} b \left(K_{zz} \frac{\partial h}{\partial z} \right) = S \frac{\partial h}{\partial t} + bW(x, y, z, t), \quad (4)$$

in which T_{xx} and T_{yy} are the principal components of the transmissivity tensor, in feet squared per unit time, and S is the dimensionless storage coefficient.

Application of Flow Equations to a Finite-Difference Model

A computer algorithm for the model was developed by P.C. Trescott (1975) of the U.S. Geological Survey. The program is written to solve finite-difference approximations of the differential equations of ground-water flow (as expressed in eq. 4). The version used in this study allows for a multilayer heterogeneous aquifer with irregular boundaries, numerous wells, and evapotranspiration from the upper layer in areas of shallow ground water. Flow between layers is treated as vertical flow through confining layers using the quasi-three-dimensional option of the program where no horizontal flow or storage of water is allowed in the confining beds. Program output was modified to enable evaluation of the areal distribution of evapotranspiration. In this study, the ground-water system is represented by three layers of the variable-space finite-difference network shown in figure 14. A finite-difference representation for the ground-water-flow equation is written for each node in the network. This results in a series of simultaneous equations which are solved by the strongly implicit procedure. The reader is referred to Trescott (1975) and Trescott and Larson (1976) for detailed information about the model.

Parameter Values Used and Assumptions Made

Assumptions made and parameters used in this model are briefly outlined in the following paragraphs.

Boundary Conditions

The boundary condition of a model must be specified before satisfactory solution of the finite-difference flow equation can be obtained. When an area of interest is near model boundaries, the solution obtained is generally quite sensitive to the boundary conditions specified. Consequently, adequate evaluation and proper specification of appropriate boundary conditions is an important step in adjusting a mathematical model to be representative of a given area.

The northeast boundary of the model is recharged by inflow from the Spring Mountains and is treated as a constant-recharge boundary. The recharge is simulated by wells situated along the northeast margin of the model that inject water at a constant rate.

The northwest and southeast boundaries of the model are close to the ground-water flow lines under predevelopment conditions. Moreover, low-permeability bedrock belonging to the clastic aquitards is present just beyond the northwest edge of the model, and the southeast edge is remote from any heavy pumping. Consequently, these boundaries were specified as no-flow boundaries in the model.

The southwest boundary is assumed to be the discharge area of a multivalley flow system. Heads along this boundary are the lowest in the system. Discharge along this border is represented by flow into a series of constant-head nodes. Heads at these nodes have been set at altitudes comparable with the potentiometric surface in the vicinity of the Amargosa River. It was assumed, for the time periods and rates of pumping used in this simulation, that pumping in Pahrump Valley would have no significant effect on the water levels along the flood plain of the Amargosa River, some 25 mi away. The effects, if any, would most probably be small reductions in discharge. These changes would be roughly approximated by variations in flow to the constant-head nodes.

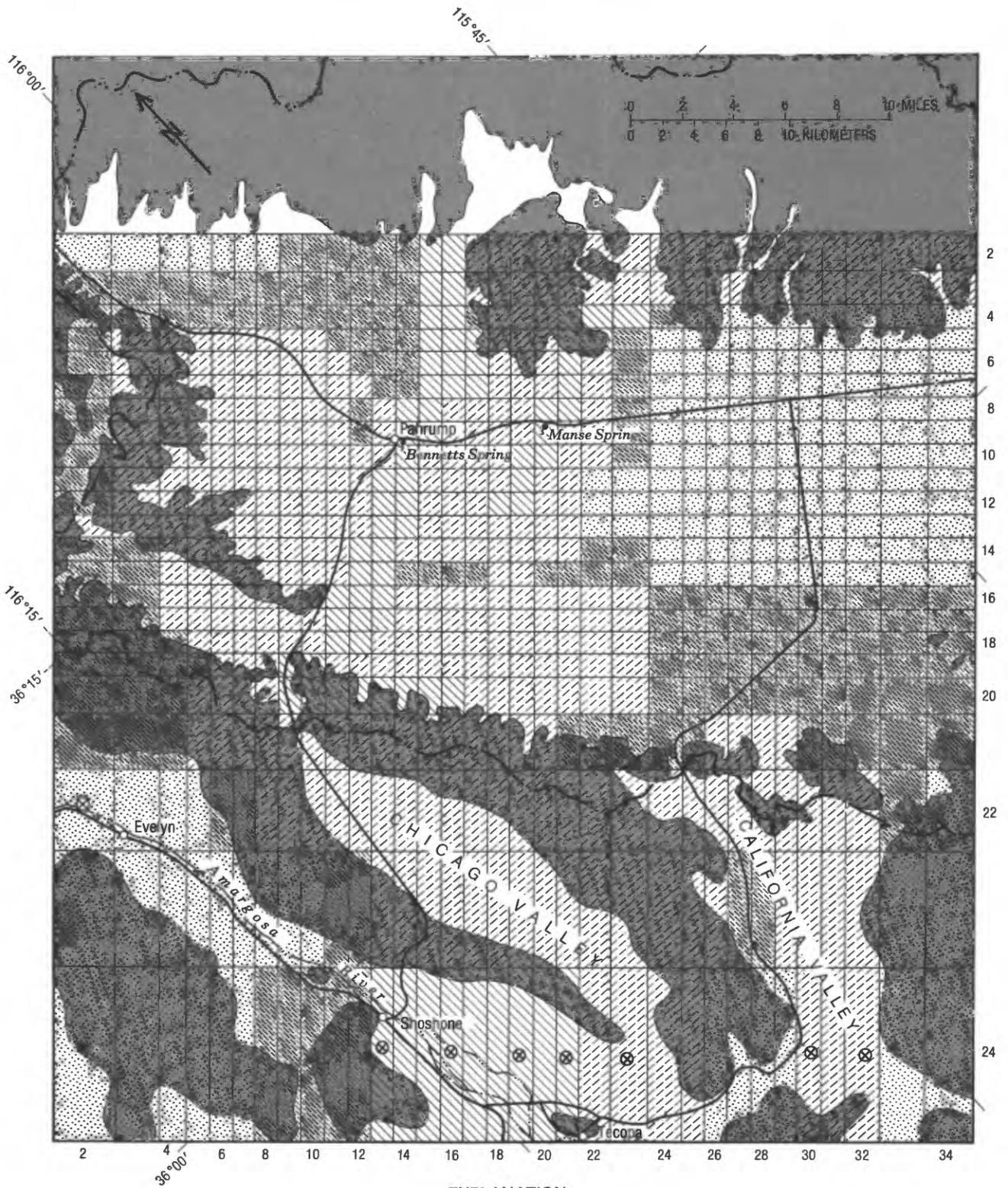
The lower part of the multivalley flow system also receives some inflow from the Amargosa Desert in the vicinity of the Amargosa River. Walker and Eakin (1963, p. 23) estimated that in the vicinity of Eagle Mountain there was subsurface flow of about 500 acre-ft/yr from the Amargosa Desert toward Shoshone. It is beyond the scope of this study to attempt to simulate the multivalley flow system; however, one constant-head node was placed along the northwest boundary of the model (fig. 14) where most of the inflow from the Amargosa Desert was assumed to occur. The head was varied until the amount of water added to the system from the node was about equal to the amount estimated by Walker and Eakin (1963). This same water was discharged from constant-head nodes near Shoshone, so there was little net effect on conditions in Pahrump Valley.

The bottom surface of the model was specified as a no-flow boundary. The upper surface was specified as a variable-flow boundary where discharge (if any) depends on the depth that the head in the upper layer is below land surface. This condition will be more fully described in the section on evapotranspiration.

Initial Conditions

For each simulation the model must have the head at each node set to an initial value. For transient-state simulations these values should represent a set of equilibrium conditions for the entire model; otherwise, simulated head changes may represent response to the initial conditions rather than to any imposed stress such as pumping.

The predevelopment water levels were assumed to represent equilibrium conditions. Figure 7 shows the predevelopment water levels representative of conditions in the middle layer of the model. Similar maps were prepared for the top and bottom layers. These values were used as the initial condition for the steady-state calibration of the model. The results of the steady-state calibration of the model produced a set of head values,



EXPLANATION

-  Valley fill
-  Consolidated rocks
-  Boundary of Pahrump Valley

-  Finite-difference grid used to model ground-water flow system. (Only bottom layer of model extends beyond Pahrump Valley)
-  Constant-head node used to simulate discharge from lower end of system
-  Constant-head node used to simulate inflow from Amargosa Desert

TRANSMISSIVITY USED IN BOTTOM LAYER OF MODEL, IN FEET SQUARED PER DAY

-  0 to 500
-  500 to 1500
-  1500 to 2500
-  More than 2500

recharge rates, and discharge rates that were at equilibrium. These values were used as the initial condition for the transient-state simulation runs which began with the year 1913.

Transmissivity

The distribution of transmissivity used for the top and middle layers of the model is similar to that in figure 4. It is apportioned between the two units on the basis of their relative thickness (5 to 10 percent to the top layer and 90 to 95 percent to the middle layer). Both the top and middle layers do not extend beyond Pahrump Valley. Consequently, vertical hydraulic conductivities along the downgradient margins of each layer were adjusted to ensure adequate continuity with the more extensive bottom layer.

There is no direct field information on which to base the exact distribution of transmissivity in the bottom layer of the model. It was assumed that rock types in an area overlain by valley fill would be generally the same as those exposed in adjacent mountains. Using this assumption and the transmissivity values listed in the section "Consolidated-Rock Reservoirs," a preliminary distribution of transmissivity was prepared. Adjustments were made to also allow for accumulations of saturated valley fill greater than 1,000 ft in parts of Pahrump Valley. This initial distribution was subsequently refined during calibration of the model. The final distribution used is shown in figure 14. One of the adjustments made during calibration was to assume two southwest-northeast-trending linear zones of higher permeability in the vicinity of Bennetts and Manse Springs (fig. 14). Orientation of the thrust faults shown on plate 1 and the steep gravity gradients shown on plate 2 provide some indirect support for this assumption. However, the principal reason these zones were added is that their presence was necessary to obtain an adequate model calibration. Additional information is needed to confirm or deny their existence.

Evapotranspiration of Ground Water

Evapotranspiration of shallow ground water is approximated as a linear relationship between a maximum, when depth to water in the top layer is at land surface, and zero, when the water table reaches the depth at which significant evapotranspiration ceases. The value used for maximum evapotranspiration, 6.3 ft/yr, is

slightly higher than the probable average annual lake evaporation in the area (Meyers, 1962, pl. 3) but less than the probable maximum of about 8 ft/yr that might occur if shallow ponds of water were maintained on a year-round basis. In actuality, the relationship between rate of annual ground-water evapotranspiration and depth to water table is probably not linear. The relation selected is considered to give a better approximation of the actual relationship at the depths to water table most commonly encountered in areas of evapotranspiration (generally between 10 and 20 ft). Under natural conditions, phreatophytes were not commonly found where depth to water table exceeded 20 ft. Consequently, that depth was selected as the maximum effective depth at which significant ground-water evapotranspiration occurred.

Vertical Hydraulic Conductivities

Vertical hydraulic conductivities used to represent confining beds between layers are those in figure 3. The model allows only vertical flow and no storage of water in the confining layers. Before being placed into the model, values were adjusted for thickness to represent more accurately the resistance to flow between midpoints of the various layers.

Storage Coefficient

The storage coefficients used for the upper layer approach the specific yield values shown in figure 5. They are generally 1 or 2 percent lower to allow for slow drainage and local retention of some water above impermeable clay beds and caliche layers. Storage coefficients used in the middle layer ranged between 0.0008 and 0.002 for coarse-grained valley-fill deposits around the margins of the valley. A higher storage coefficient was used for finer grained deposits in the central valley to account for water released by compaction associated with head declines. In reality, water yielded by compaction varies with time and is produced only during periods when water levels decline below the level that previously produced permanent deformation in the system. It is almost entirely a one-way process, and when water levels rise, the amount of water returned to the aquifer per unit of water level rise is much less than was originally released as a result of compaction. These refinements are beyond the scope of this study. The approximation made by increasing the coefficient of storage between 0.01 and 0.04 is satisfactory for the purposes of this study; however, the model cannot be used to accurately simulate the response to sustained cutbacks in pumping or other conditions that would result in rising water levels. The storage coefficient used for the bottom layer was 0.002.

Figure 14. Finite-difference grid and transmissivity used in bottom layer of the model (materials underlying upper 1,000 ft of saturated deposits).

Method of Analysis

The system and its response to development were simulated in three phases: (1) the natural condition prior to 1913, (2) the response through 1975, and (3) the probable future response assuming that pumpage remains the same as in 1975. Analysis of the first two phases provided insight about the nature of the system and was a means of evaluating parameters used in the model. The model was calibrated so that computed heads, water-level changes, and distribution of evapotranspiration agreed reasonably well with observed and estimated values. Transmissivity, vertical hydraulic conductivity, recharge, and subsurface outflow were adjusted mostly during the first phase of calibration, and distribution of storage coefficient and recirculation of pumpage was adjusted mostly during the second phase. Once a reasonable fit between observed and computed value was obtained, model output for the period 1962–75 was used to supplement the other analyses done during this study. Finally, a run was made for the period 1975–2040 to roughly determine the magnitudes of future change if the amount and distribution of pumping stays the same as in 1975.

Simulated Natural Conditions

Figure 7 shows the approximate predevelopment potentiometric surface in the part of the valley fill tapped by deep wells, and figure 15 shows the steady-state potentiometric surface generated for the middle layer of the model. These results were obtained using parameters already described and an average annual recharge of about 37,000 acre-ft/yr. The distribution of recharge and computed subsurface outflow (18,000 acre-ft/yr) is shown in figure 15. The area of most concentrated ground-water recharge (22,600 acre-ft/yr) is located upgradient from Bennetts and Manse Springs. Plate 1 shows this area to be underlain by carbonate sedimentary rocks that have been deformed by several thrust faults. The transmissivity of these rocks may have been substantially increased by this structural deformation. This, coupled with this area's location on the side of the Spring Mountains most exposed to major storms that move in from the southwest, may account in part for the exceptionally high recharge indicated.

Values of recharge and discharge developed by the model are higher than those estimated by using empirical techniques. However, they provide a reasonable fit with known information, and if assumptions about the deeper parts of the valley-fill reservoir and the underlying bedrock are adequate, the model should provide reasonably accurate quantitative results. Figure 16 illustrates the agreement obtained between "observed" and simulated head for all nodes in the model where there was adequate

information to make a reasonably accurate estimate of the head.

The quantity and distribution of evapotranspiration were one of the parameters evaluated by the model. Comparison of the modeled distribution of evapotranspiration and the mapped distribution of phreatophytes provides an additional check on the ability of the model to simulate the ground-water system. The mapped distribution of phreatophytes is shown on plate 3A, and the modeled distribution of evapotranspiration is shown on plate 3B.

Response Through 1975

Changes in the hydrologic system that occurred as a result of development prior to 1962 are not directly within the scope of this study; however, simulation of the entire period after 1912 provides additional information about the degree to which the model can reproduce changes in the natural system. The interval 1913 through 1975 was divided into 10 pumping periods. This was considered the minimum number of steps needed to approximate variations in pumpage that occurred during the 63-year period. Figures 8 and 9 show distribution of pumping in 1962 and 1975. A similar distribution of pumping was prepared for each period. All pumpage was assumed to be from the middle layer of the model. A percentage of the pumpage was assumed to be recirculated back to the water table (top layer of the model) by deep percolation of irrigation water. A value of between 20 and 30 percent was selected initially and then adjusted during calibration of the model. A comparatively high percentage of recirculation was used for the first pumping period for areas of pasture subirrigated by recirculated spring discharge. The lower percentage for periods 2, 3, and 4 allow for some recirculated water on newly irrigated land to become stored as soil moisture. Results from individual pumping periods were grouped for the longer periods, 1913–61 and 1962–75. Table 5 summarizes pumpage data used in each period of the simulation.

The model contains sufficient computational power to allow the response to development to be evaluated in terms of water-level changes, variations in natural discharge, and ground-water storage depletions. These items will be discussed in moderate detail in the following sections. One important item that was beyond the scope of this study, but should be considered, is possible changes in the chemical quality of ground water as a result of development activities.

Water-Level Changes

Figure 17 shows simulated net changes in the water table during the period 1913–76. There are not adequate data from shallow wells for a detailed comparison of

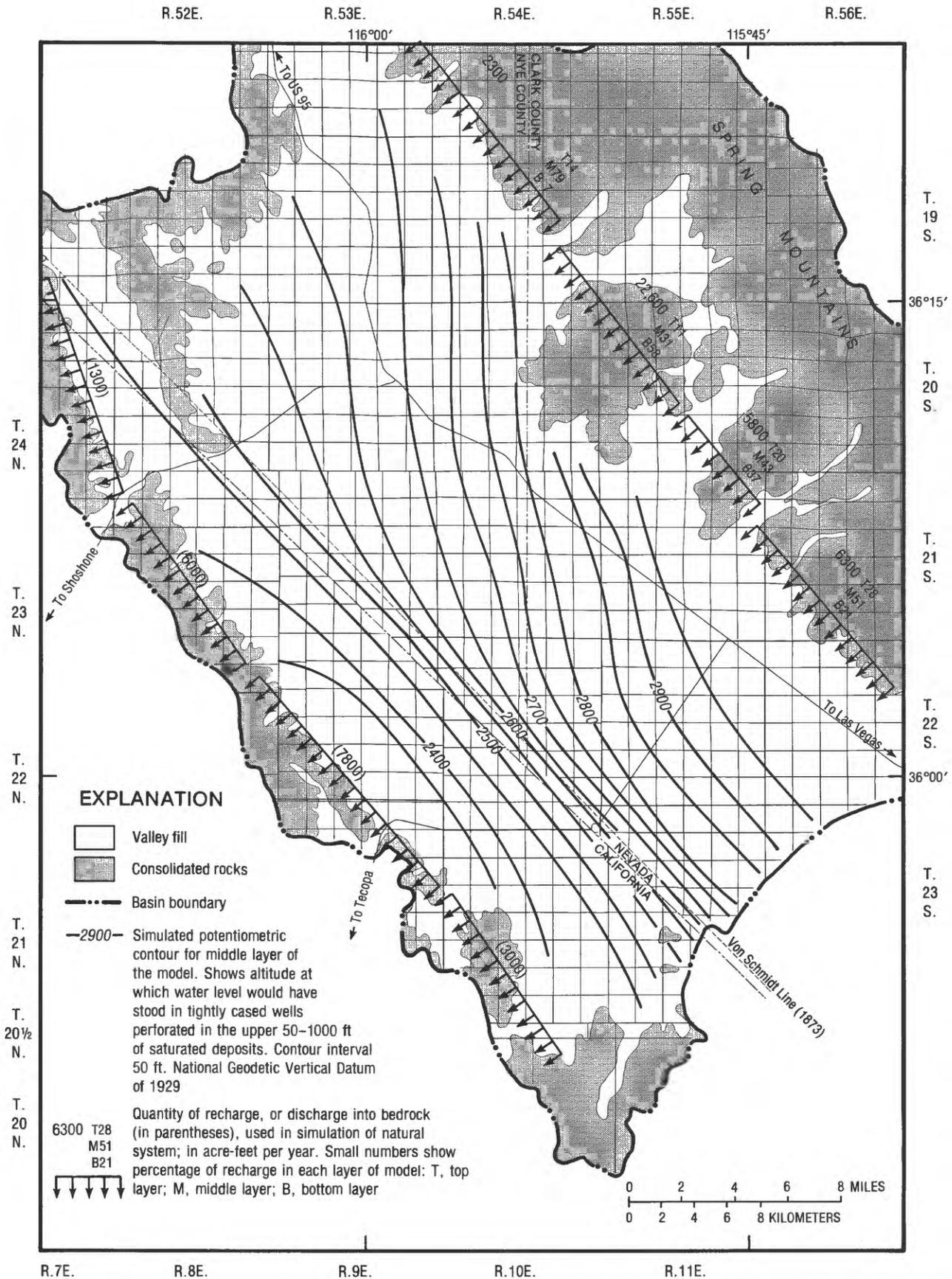


Figure 15. Contours of a simulated potentiometric surface for natural conditions.

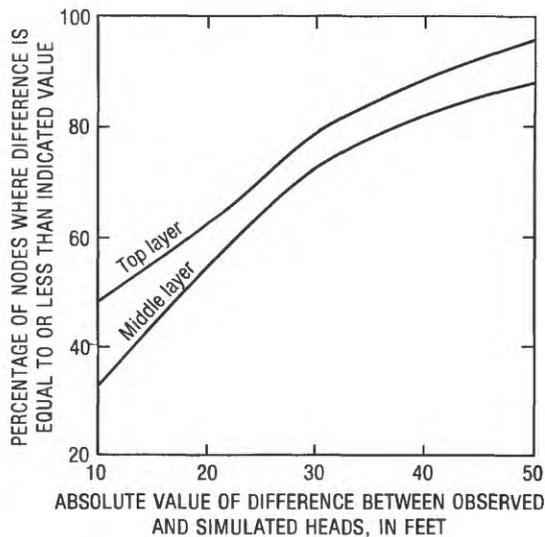


Figure 16. Relation between observed and simulated heads for natural conditions. Number of nodes used for calibration: top layer, 299; middle layer, 242; bottom layer, 0. Nodes used in calibration were those for which data were adequate to evaluate predevelopment heads.

observed and simulated water-table fluctuations. However, information available indicates changes of the same general magnitude as shown in figure 17. Also, water levels in some shallow wells near irrigated areas were reported to have risen slightly. The model produces similar results.

Water levels in deeper wells declined significantly more than those in shallow wells. Figure 18A shows the observed distribution of water-level declines in deeper wells and figure 18B shows the simulated head declines in the middle layer of the model during the period 1913–76. There is reasonable agreement between the observed and simulated distribution of water-level declines; however, there are two significant differences.

The first difference is that simulated declines along the base of the Pahrump fan were less than the observed values. The exact reason for this is not known; the three most probable causes are discussed here. (1) The amount of recharge assigned to nodes upgradient from this area may be more than that which occurs in the natural system. The resulting capture of discharge by pumping would cause water-level declines to be less than the observed values. (2) The assumption that the distribution

Table 5. Pumpage data used in simulation

Pumping period	Period	Number of nodes used as pumping centers	Average annual spring discharge and pumpage		Spring discharge and pumpage recycled back to ground-water system (acre-ft/yr)
			Spring discharge (acre-ft/yr)	Pumpage (acre-ft/yr)	
1	1913-44	2	6,000	4,000	4,300
2	1945-51	10	5,200	13,000	3,500
3	1952-58	26	4,000	23,000	5,000
4	1959-61	29	1,600	25,400	5,000
5	1962-63	35	1,200	29,000	7,600
6	1964-67	39	1,200	37,400	9,700
7	1968-68	39	900	47,900	12,600
8	1969-70	42	700	41,900	11,300
9	1971-72	41	600	37,600	9,900
10	1973-75	54	400	41,200	11,200
			Total acre-feet (rounded)		
Period 1913-61			260,000	460,000	210,000
Period 1962-75			12,000	1,540,000	140,000
Entire period 1913-75			270,000	1,000,000	350,000

¹Pumpage higher than 530,000 acre-feet shown in table 3 because of (1) minor increases made during model calibration and (2) rounding of values selected to represent average rates for each pumping period.

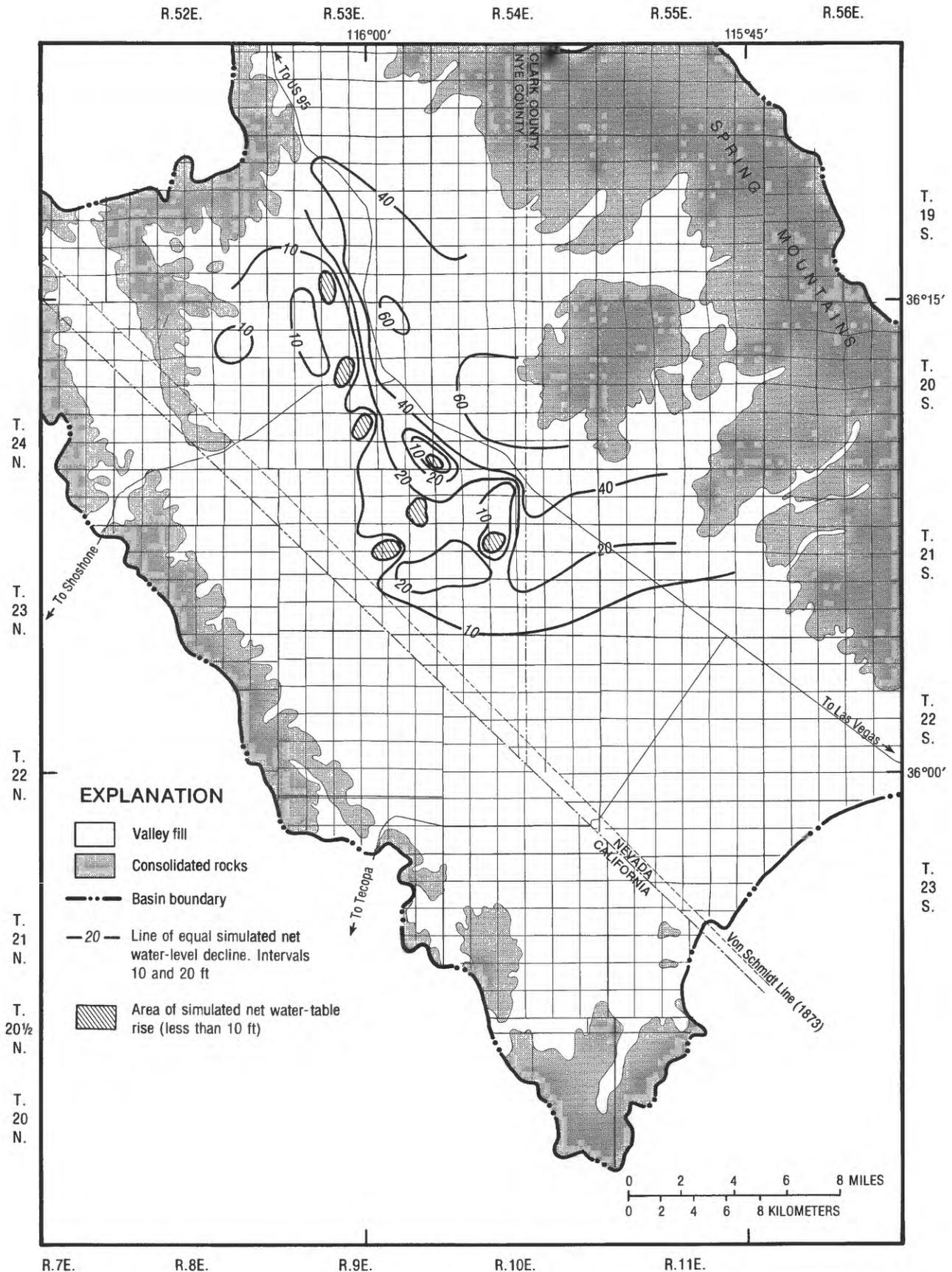


Figure 17. Simulated net changes in the water table, February 1913–February 1976.

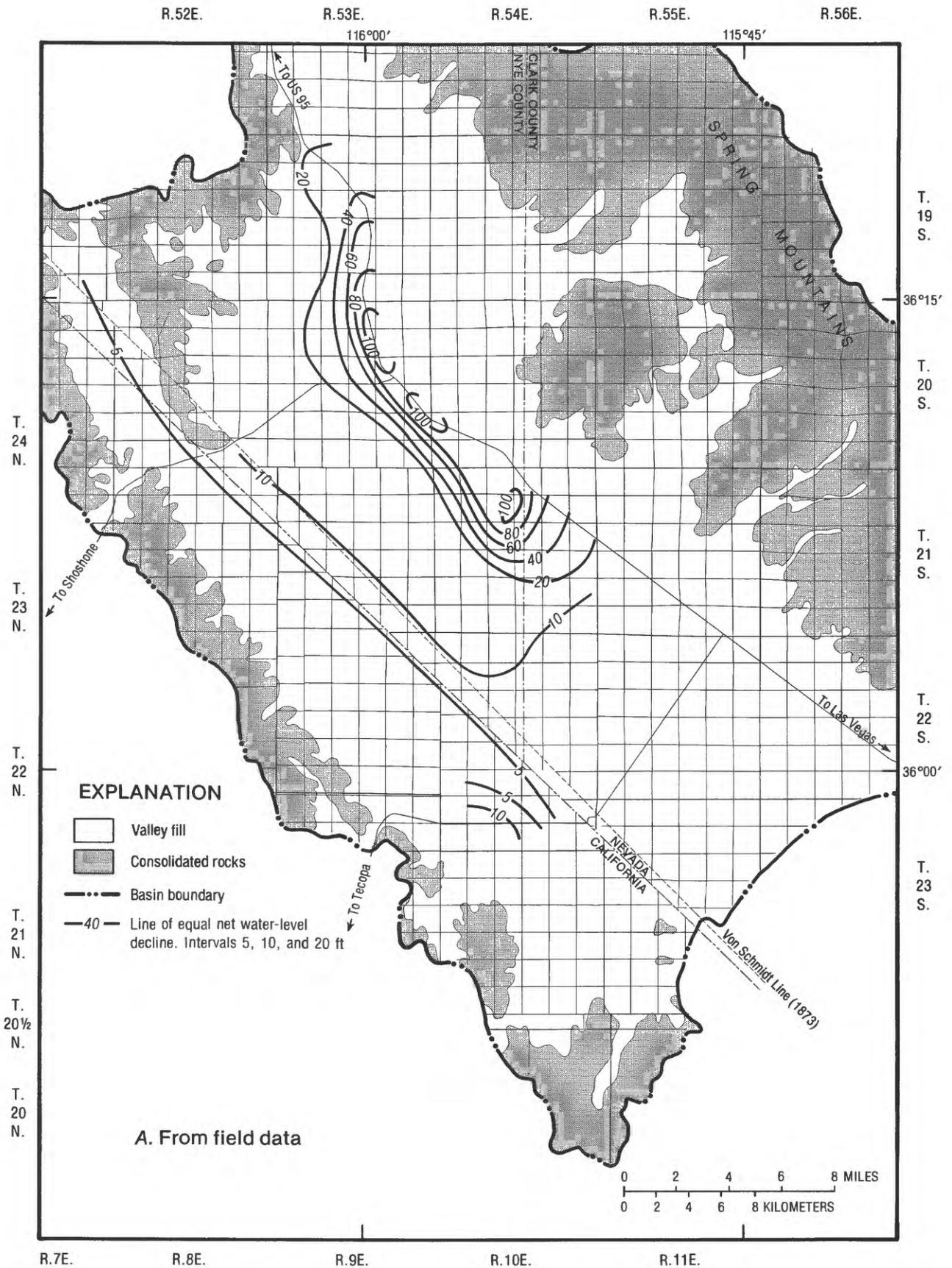


Figure 18A. Net water-level declines in deep wells, 1913-76, from field data.

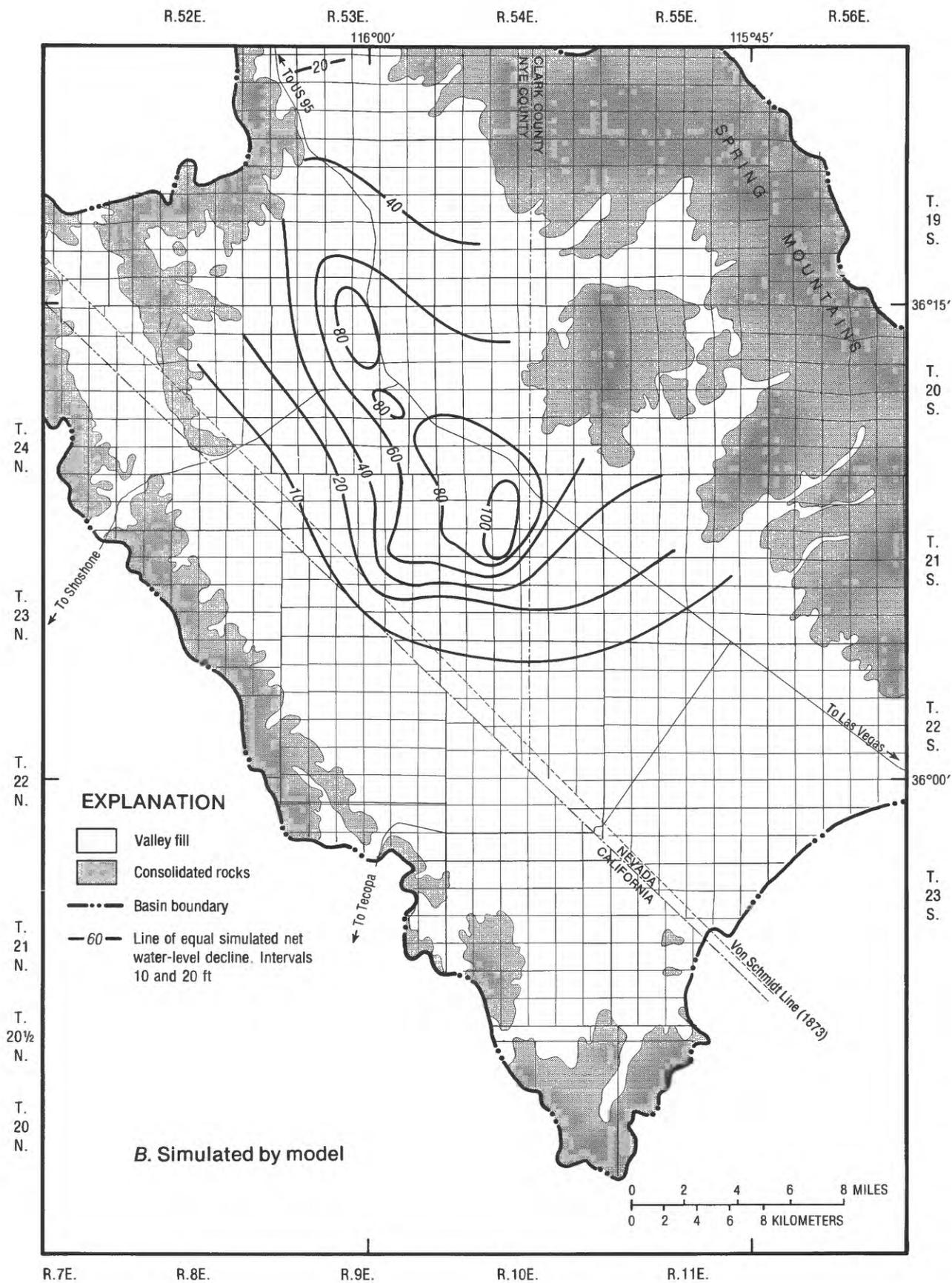


Figure 18B. Net water-level declines in deep wells, 1913-76, simulated by the model.

of recharge does not change may not be valid. Heavy pumping in the vicinity of Manse Spring may have altered heads in nearby carbonate rocks sufficiently to induce water that formerly flowed toward Bennetts Spring to move toward Manse Spring instead. During the last calibration run of the model a total of about 0.8 ft³/s (580 acre-ft/yr) of recharge was gradually shifted from a recharging node upgradient from Bennetts Spring to a recharging node upgradient from Manse Spring. The response was somewhat better agreement between the observed and simulated heads. (3) Modeled pumpage estimates may be smaller than the true values. Many pumpage estimates for individual wells were compiled by using an average discharge rate and an estimated or reported duration of pumping. More widespread use of meters and timing devices or site-specific determination of electrical consumption and wire-to-water pump efficiencies may be required before the absolute accuracy of existing pumping records can be determined.

The second significant difference between the observed and simulated distribution of water-level declines is that small areas with rapidly changing rates of decline tend to be smoothed out over a slightly larger area in the model. This is largely a result of the grid size selected for the model. A smaller grid size would produce more detailed results, but the larger number of nodes required would make the simulation more expensive. Results obtained with the existing grid are adequate for the purpose of this study; however, if there is a need to simulate detailed changes over localized areas of the valley, a much smaller grid size will be required.

Figure 19 shows the observed water-level declines in deeper wells and the simulated head declines in the middle layer of the model for the period 1962–76. There is general overall agreement, but the differences noted for the longer period are present in this shorter period also.

Variations in Natural Discharge

Changes in natural ground-water discharge include decreases in spring discharge, evapotranspiration of ground water by phreatophytes, and possible changes in subsurface outflow.

Spring discharge was located near areas where heavy pumping centers developed. Consequently, this type of natural discharge was most readily captured by pumping. Spring discharge decreased from nearly 10,000 acre-ft/yr under natural conditions to about 1,400 acre-ft/yr in 1962 (Malmberg, 1967, p. 31) and to about 200 acre-ft/yr in 1975.

Changes in ground-water evapotranspiration were evaluated by the model. Simulated ground-water evapotranspiration (not including direct evapotranspiration of about 5,000 acre-ft/yr of spring discharge from the soil or

open-water surfaces) declined from about 14,000 acre-ft/yr under natural conditions to about 4,500 acre-ft/yr in 1962 and to about 2,600 acre-feet in 1975. The capture of this amount of natural discharge has been a significant factor in limiting water-level declines to the values shown in figures 17, 18, and 19.

Plate 3 shows the simulated distribution of evapotranspiration of ground water by phreatophytes under natural conditions and in 1962 and 1975. Areas and rates of evapotranspiration near centers of heavy pumping (figs. 8, 9) have experienced the greatest changes, while there have been only minor changes in areas remote from pumping. Plate 3D indicates large areas where simulated evapotranspiration was eliminated when the water table declined to more than 20 ft below the land surface. In actuality, changes are not so clearly defined. Phreatophytes attempt to adjust to declining water levels by growing deeper tap roots, by developing a shallow root system to better use soil moisture, and by becoming established where they can use irrigation tail water. Consequently, residual stands of phreatophytes may survive for a number of years after declining water tables have virtually eliminated ground water as a source of supply.

Changes in subsurface outflow were evaluated by using the model. The amount of subsurface outflow captured by pumping was considered equal to the net decrease in flow to constant-head nodes along the southwest boundary of the model (fig. 14). As of 1976, only about 200 acre-ft/yr of the total outflow of 18,000 acre-ft/yr had been captured.

Ground-Water Storage Depletion

Ground-water storage depletion is primarily the result of drainage of unconsolidated porous materials as the water table is lowered. However, consolidation of fine-grained deposits and the elastic response of water and the aquifer also account for small but significant quantities of water. These processes are discussed in more detail in the following paragraphs.

Water derived from the drainage of unconsolidated materials is evaluated in the model as the product of a storage coefficient, a change in head, and an area. The storage coefficients used for the top layer of the model were generally 1 to 3 percent less than the specific yield values shown in figure 5, to allow for delayed drainage and impermeable lenticular deposits and caliche layers. The head changes used are those shown in figure 17, and the areas are the area of each node (fig. 14). The maximum water-table declines shown in figure 17 occurred along the lower parts of the Pahrump and Manse fans. This area also coincides with the area of highest specific yield shown in figure 5. Consequently, most of the ground-water storage depletion was derived from the

dewatering of deposits along the lower parts of the Pahrump and Manse alluvial fans.

The release of water from storage in confining beds causes consolidation of these deposits and commonly results in subsidence of the land surface. There are no data on reported leveling of benchmarks in critical areas of the valley to establish the magnitude and rate of land subsidence, if any, in the area. During the spring of 1972, a small ground fissure and some casing protrusion was observed in a localized part of NE¼ sec. 15, T. 20 S., R. 53 E. This suggests that land subsidence is active in at least parts of the area. Additional indirect arguments for the presence of active land subsidence were developed during calibration of the model.

During calibration, the storage coefficient of the middle layer was initially assigned values on the order of 0.001 or 0.002. These values are representative of the confined aquifer where water is derived mainly from the elastic response of water and the aquifer. Reasonable agreement between observed and computed values was obtained around the margins of the valley; however, where heavy pumping coincided with areas where significant fine-grained material was present in the valley fill, computed changes were much greater than observed changes. Attempts were made to improve agreement by increasing the vertical leakage, but this resulted in large head declines in the top layer that did not agree with available field data. The best agreement was obtained when the storage coefficient of the middle layer was increased to 0.02 or 0.03 in areas containing a significant amount of fine-grained material (see pl. 1). Theoretically, storage changes in a confined aquifer much in excess of the initial values used would have to be derived from the consolidation of fine-grained materials. Crude estimates of probable land subsidence were made by assuming that the amount by which the storage coefficient of the middle layer of the model exceeded 0.002 would represent water being derived from the consolidation of fine-grained materials. The volume of subsidence can be estimated as the residual of the storage coefficient times the drawdown times an area. The amount of land subsidence can be estimated as the product of the residual of the storage coefficient times the decline in a given area. Figure 20 shows areas of possible land subsidence estimated in this way. The total volume of subsidence was inferred to be about 68,000 acre-ft. This inference is based on adjustments made during calibration of the model and consequently is only an indicator of the possible extent and magnitude of land subsidence. However, it points out the need for additional field information.

Under confined conditions both the water and aquifer undergo small elastic changes in volume in response to changes in artesian head. Although the amount of change is small when evaluated on a unit basis, the total changes in confined systems cover large areas

and involve significant amounts of water. Both the middle and bottom layers of the model were considered to be under confined conditions. Storage depletions due to elastic response were evaluated as the product of change, area, and 0.002.

Table 6 summarizes estimates of storage depletion by all processes for the periods 1913-61 and 1962-75. The total storage depletion of about 375,000 acre-ft at the end of 1975 was equal to 38 percent of the total pumpage of about 1,000,000 acre-ft since 1913 (table 5).

Table 6. Summary of estimates of storage depletion [Acre-feet]

Period	Type of depletion			Total depletion
	Drainage of unconsolidated deposits	Consolidation of fine-grained deposits	Elastic response of aquifer and water	
1913-61	120,000	22,000	14,000	156,000
1962-75	155,000	46,000	18,000	219,000
1913-75	275,000	68,000	32,000	375,000

Future Response

It is difficult to predict future responses to pumping because magnitude, distribution, and use of the pumped water changes with time. However, generalized information about how the ground-water system is likely to respond in the future can be obtained by assuming that future pumping will remain at about the 1975 level. This assumption was incorporated in the model, and probable system response to the year 2040 was simulated. This long period was selected only to allow a crude quantitative evaluation of likely trends. Precise prediction is beyond the scope of this study, and this limitation should be kept in mind while evaluating the results presented in the following paragraphs.

Simulated future response is summarized in terms of two types of parameters. The first type comprises rates of flow that represent the total pumpage, spring discharge, ground-water evapotranspiration, and storage depletion at a given time. These factors provide insight as to the state of the system. The second type of parameter comprises water-level changes in different parts of the valley. Flow quantities listed as the first type of parameter tend to react with each other and the system in a complex manner. However, the net result is integrated into a simple change in water levels which provides an indication of the net response of the system. Three areas were selected, and computed water-level changes at nodes within each area were averaged to provide generalized indications of water-level trends. The areas are (1) a

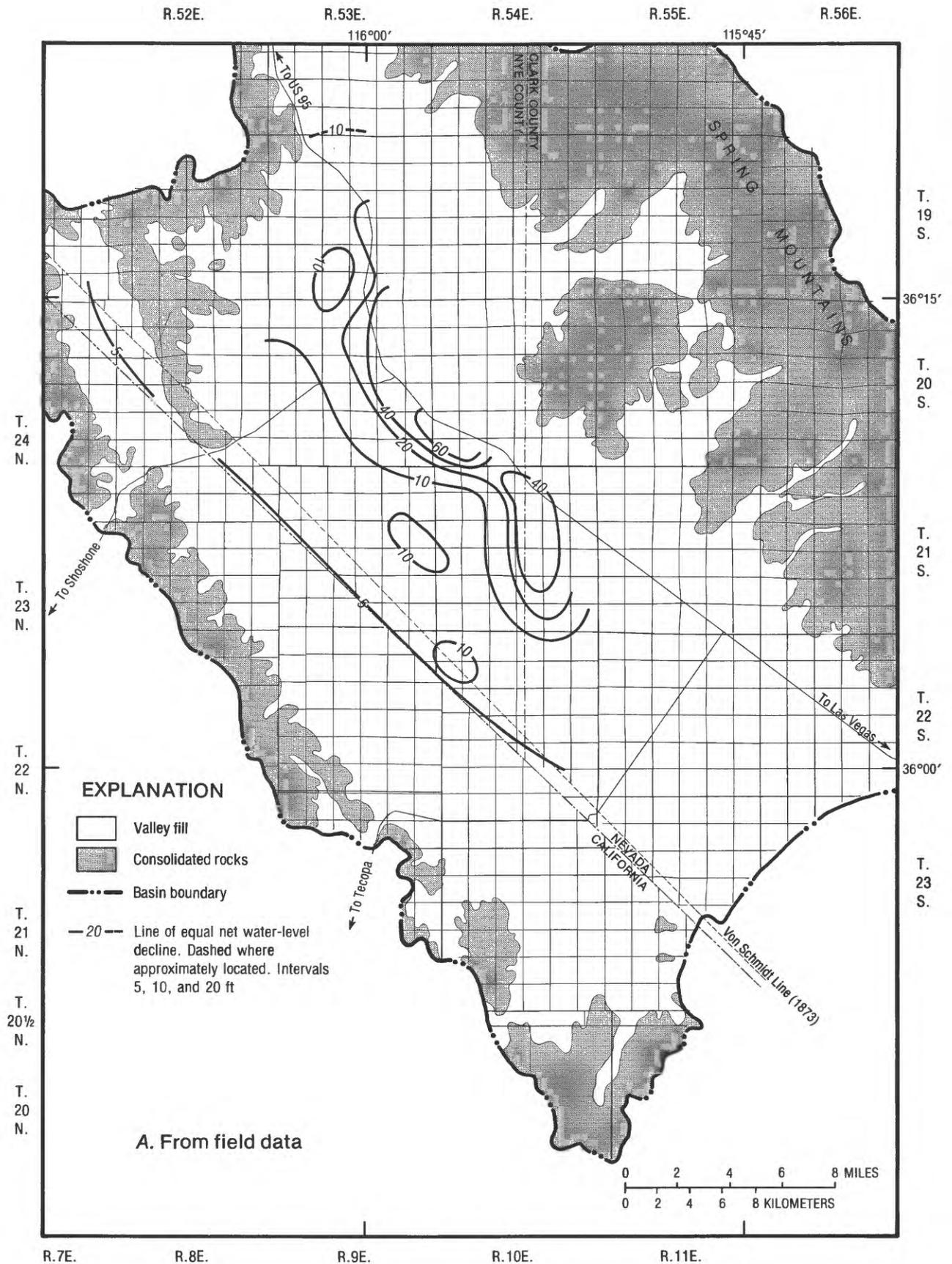


Figure 19A. Net water-level declines in deep wells, 1962-76, from field data.

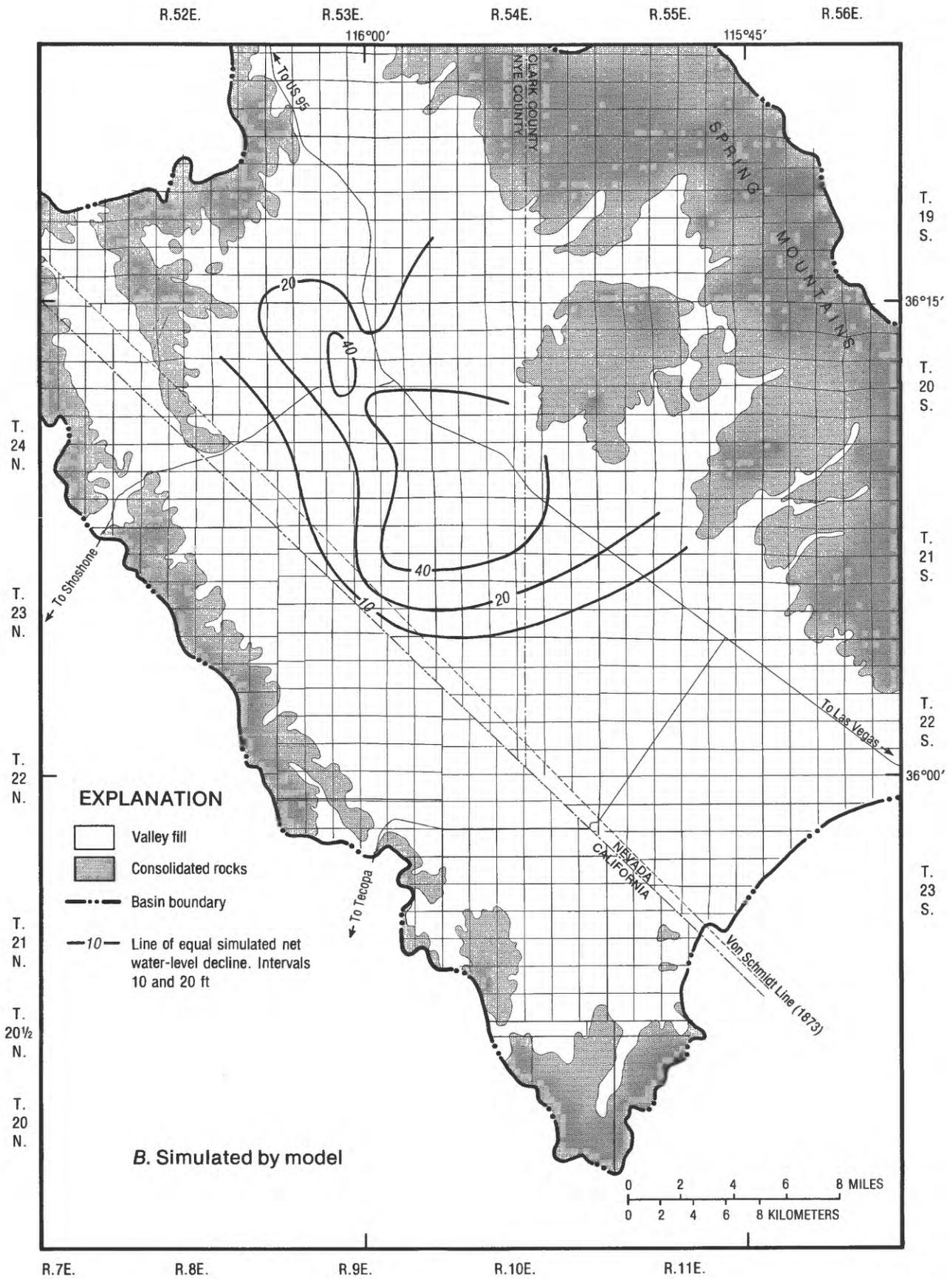


Figure 19B. Net water-level declines in deep wells, 1962-76, simulated by the model.

zone, C, along the base of the Pahrump and Manse fans where pumping historically has been concentrated, (2) a zone, B, along the axis of the Nevada part of the valley that contains some development, and (3) a zone, A, along the Nevada side of the State line that is southeast of any significant development. Location of these areas is shown in figure 21.

Figure 22 shows plots of the various parameters against time. The illustration shows results for the entire period of simulation (1913–2040). This was done because future trends tend to have more significance when viewed in terms of the perspective provided by historical information.

The following statements are based on information shown in figure 22:

1. Virtually all spring discharge was captured by pumping prior to 1976. Consequently, future water-level declines will not be moderated by additional capture of spring discharge.
2. Ground-water evapotranspiration was captured more slowly by pumping than was spring discharge. As of 1976, about 2,600 acre-ft/yr of ground-water evapotranspiration remained. Capture of all ground-water evapotranspiration by pumping probably will not occur in the foreseeable future because some remaining areas of active evapotranspiration are too remote from pumping.
3. It is very difficult to capture appreciable amounts of subsurface outflow from Pahrump Valley. As of 1976, only about 200 acre-ft/yr of the total of 18,000 acre-ft/yr had been captured. By the year 2040, a total of only 600 to 700 acre-ft/yr may be captured.
4. Ground-water storage depletion and water-level declines will continue at fairly constant rates until 2040, and the system will remain in nonequilibrium as long as pumping is maintained at the 1975 rate.

Accuracy of Model Results

Calculations performed by the model produce precise results. However, accuracy of the computer output depends on the validity of simplifying assumptions used in model formulation and the accuracy of the concept of the hydrologic system.

In Pahrump Valley, hydrologic conditions in the deeper valley fill and underlying bedrock must be inferred. Consequently, the assumptions made about these areas introduce a comparatively large degree of uncertainty into the model results. Moreover, because the boundary conditions and transmissivity of the lower layer are not precisely defined, the problem of nonunique solutions, which has already been mentioned in the section "Development of the Mathematical Model," also introduces uncertainty in results that give a reasonable

match to observed conditions. More specifically, the fact that a reasonably good fit between observed and simulated heads for natural conditions was obtained by using 37,000 acre-ft/yr of recharge and the distribution of transmissivity and vertical hydraulic conductivity shown in figures 3, 4, and 14 does not preclude that matches equally as good could be obtained by using other values of recharge and transmissivity. In theory, identical head distributions could be obtained by multiplying all the variables by a constant factor.

In this study the range of uncertainty of the final steady-state solution was evaluated by keeping the evapotranspiration function constant and multiplying other model parameters by a constant. When model parameters were increased by 30 percent (multiplied by 1.3), the agreement between observed and simulated heads was not as good as that shown in figure 16 (the difference was probably due to the increase in heads needed to cause additional evapotranspiration). However, when model parameters were decreased by 30 percent (multiplied by 0.7), the agreement between observed and simulated heads was almost as good as that shown in figure 17. The area of evapotranspiration was about the same as that shown on plate 3B but the rates were substantially less. The exact areas and rates of evapotranspiration that existed under natural conditions are not known, but further decreases probably would not produce representative results. Thus, analysis of the steady-state model results indicates a possible range in recharge of 37,000 to 26,000 acre-ft/yr.

It was necessary to evaluate the transient-state simulations where pumping was introduced into the model in order to determine a rate of recharge and the associated parameters that would give the best overall fit. Model parameters compatible with 37,000 acre-ft/yr of recharge produced the best fit between observed and simulated drawdowns. Consequently, 37,000 acre-ft is used as the best estimate of recharge generated by the model. When evaluating the accuracy of recharge estimates generated by the model, the possible range of 37,000 to 26,000 acre-ft/yr should be kept in mind.

THE AVAILABLE WATER SUPPLY

Ground-Water Budget

Under natural conditions, the ground-water flow system was in a state of dynamic equilibrium in which, over the long term, average annual recharge was equal to the discharge and there was no net change in ground-water storage. Pumping ground water has created an imbalance: the total discharge (natural discharge plus pumpage) exceeds the total recharge (natural recharge plus recirculated pumpage).

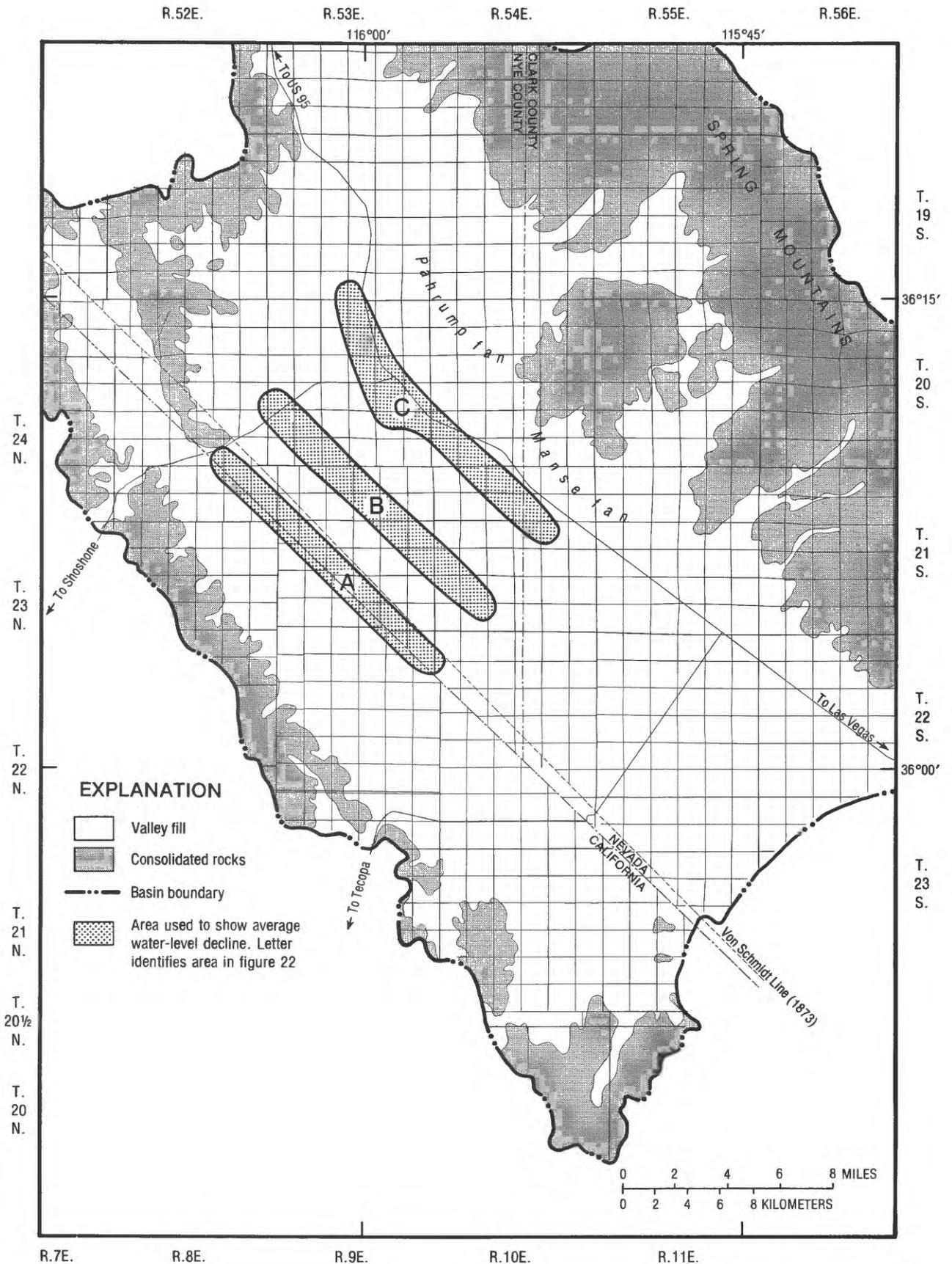


Figure 21. Areas used in figure 22 to indicate simulated long-term water-level declines.

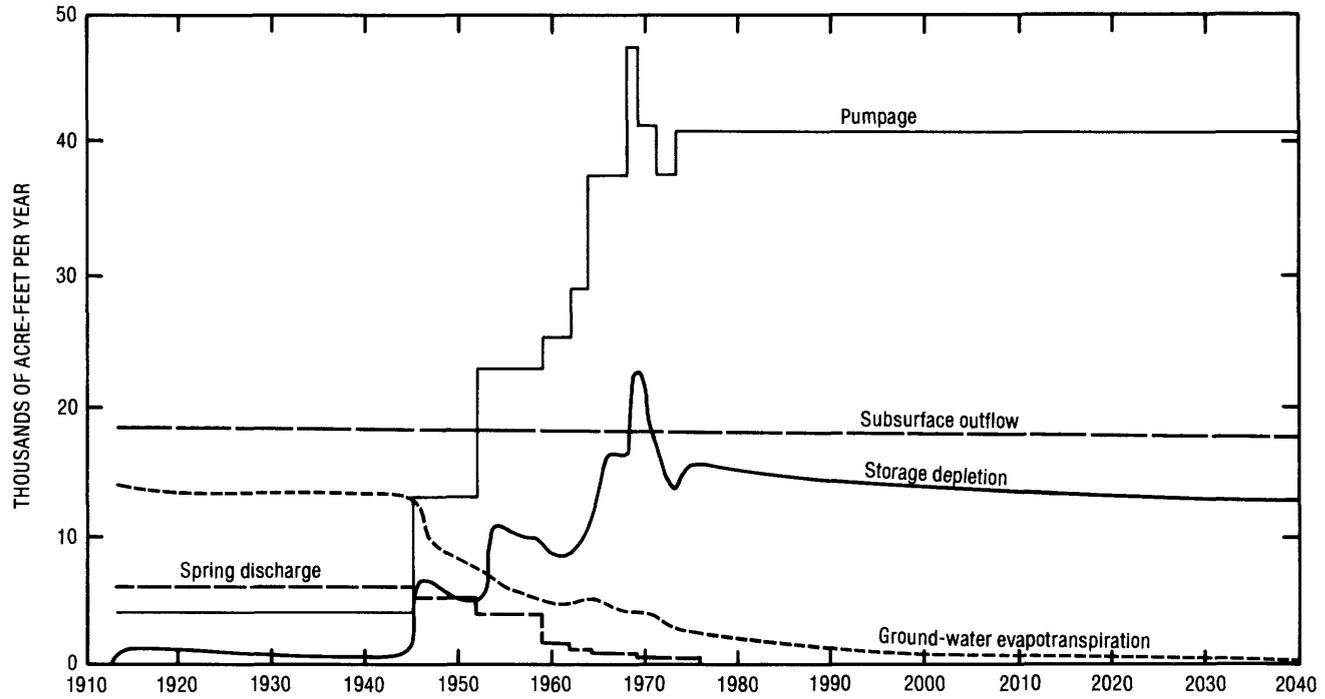
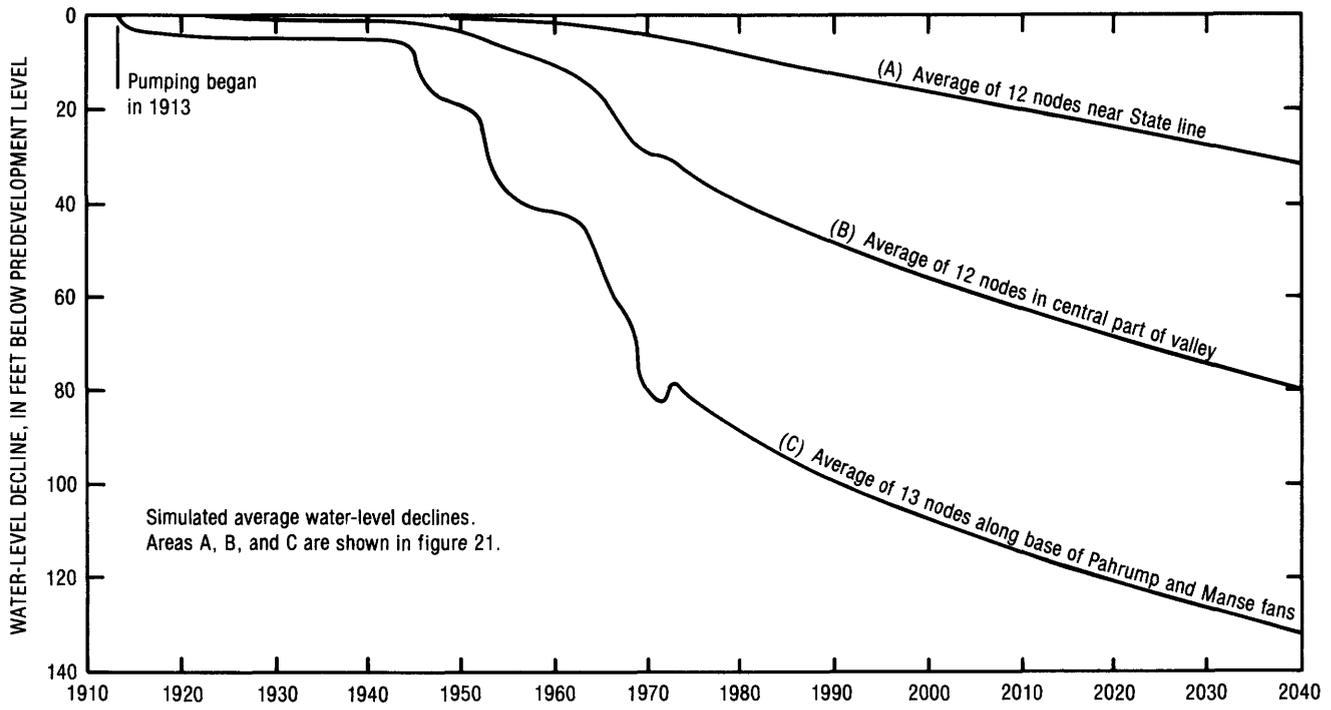


Figure 22. Simulated long-term trends in selected hydrologic parameters, 1910–2040.

The system responds to pumping by removing ground water from storage and subsequently capturing natural discharge in an attempt to establish a new equilibrium in which recharge (natural recharge plus recycled pumpage) again equals discharge (pumpage plus the reduced natural discharge). If pumpage exceeds the recharge to the system, a new equilibrium is not possible. Water will continually be withdrawn from storage, and ground-water levels will decline.

Table 7 lists a ground-water budget that summarizes the various items of inflow to and outflow from the ground-water system (1) under predevelopment natural conditions, (2) as of spring 1962, and (3) as of spring 1976. The varying quantities can be compared with the graphical information shown in figure 23 to get a feel for the state of the system at times other than the three times selected for a budget analysis. The simulated areal distribution of evapotranspiration for the three times for which budgets were formulated is shown on plate 3. Two budgets for natural conditions are shown in table 7. One is based on estimates derived by using field and empirical techniques and the other summarizes the items of inflow and outflow used in the calibrated steady-state version of the model. The estimates generated by field and empirical

techniques are less than those generated using the model. Determination of which of the two techniques provides the most accurate information is difficult. Credibility of the lower set of values is limited because of (1) the empirical nature of the techniques used, (2) the assumption that the distribution of evapotranspiration in 1962 was very close to that under natural conditions (see pl. 3), and (3) the need to estimate subsurface outflow by difference. On the other hand, credibility of the precise computations performed by the model is limited by the accuracy of the information entered in the model (see previous discussion on accuracy of model results). Budget values generated by the model are considered slightly better because they represent a set of data in which individual elements are internally compatible and because the assumptions used represent the best approximations that could be made at this time. However, the relatively wide range of results obtained by using both techniques, when the range of natural recharge is 37,000–26,000 acre-ft/yr, is an indication of the uncertainties in the estimates.

Under natural conditions the general level of net inflow to and outflow from the ground-water system is estimated by the model to be about 37,000 acre-ft/yr. In 1962 and 1976, when the system was not in equilibrium,

Table 7. Ground-water budgets

[Acre-feet per year, rounded to two significant figures]

	Natural conditions			
	Based on field and empirical techniques	Based on steady-state simulation	Spring 1962	Spring 1976
Inflow:				
Natural recharge	22,000–26,000	37,000	37,000	37,000
Recirculated pumpage and spring discharge	(¹)	² 4,600	5,900	11,000
Total inflow	22,000–26,000	³ 42,000	43,000	48,000
Outflow:				
Evapotranspiration	10,000–13,000	⁴ 14,000	4,900	2,600
Pumpage	0	0	27,000	42,000
Spring discharge	(¹)	9,800	1,400	200
Subsurface outflow	6,000–19,000	18,000	18,000	18,000
Total outflow	16,000–32,000	³ 42,000	51,000	63,000
Difference	6,000–10,000	0	8,000	15,000
Storage depletion	0	0	⁵ 8,600	⁵ 16,000

¹Spring discharge under natural conditions was about 9,800 acre-ft/yr. All of this quantity is included in the estimate of evapotranspiration and is not repeated in order to avoid double counting.

²Amount of spring discharge recirculated back to top layer of model to produce distribution of evapotranspiration shown on plate 3B.

³Includes 4,600 acre-feet of internal recirculation. Net inflow and outflow 37,000 acre-ft/yr.

⁴Does not include direct evapotranspiration of 5,200 acre-ft/yr of spring discharge not recirculated back to ground water.

⁵Average rates for periods 1959–61 and 1973–75, respectively.

the difference between inflow and outflow agrees closely with the calculated rates of storage depletion.

Table 8 presents a cumulative mass balance which summarizes cumulative values of the budget items listed in table 7 for the periods 1913-61, 1962-75, and 1913-75. As in table 7, the differences between cumulative values of recharge and discharge are about the same as the estimates of cumulative storage depletion. In theory, they should be in exact agreement. The observed differences are due to accumulating small consistent errors and to independent rounding of large numbers. During the period 1913-61, about 34 percent of the water pumped was derived from storage as opposed to about 40 percent during the period 1962-75.

Table 8. Cumulative mass balance
[Acre-feet, rounded]

	1913-61	1962-75	1913-75
Inflow:			
Natural recharge	1,800,000	520,000	2,300,000
Recirculated pumpage and spring flow	210,000	140,000	350,000
Total inflow (rounded)	2,000,000	660,000	2,700,000
Outflow:			
Evapotranspiration	540,000	60,000	600,000
Pumpage	460,000	540,000	1,100,000
Spring discharge	260,000	11,000	270,000
Subsurface outflow	880,000	250,000	1,100,000
Total outflow (rounded)	2,100,000	860,000	3,000,000
Difference	100,000	200,000	300,000
Storage depletion	156,000	219,000	375,000

Maximum Steady-State Pumping Rates

Ground water is the source of virtually the entire water supply in Pahrump Valley. Pumped water must be derived from the capture of natural discharge, from reuse of water recycled back to ground water, or from the depletion of ground-water storage. Depletion of ground-water storage will eventually be limited by the amount of storage economically recoverable or by environmental or legal constraints. Thus, the available water supply will ultimately be limited to the amount of natural discharge that can be captured by pumping.

The preceding analysis indicates that it will be very difficult to capture a significant amount of the subsurface outflow. Consequently, the maximum amount of natural discharge that feasibly can be captured by pumping is estimated as the total natural discharge (37,000 acre-ft/yr; table 7) minus subsurface outflow (18,000 acre-ft/yr), or about 19,000 acre-ft/yr. For practical purposes,

this represents the maximum amount of water that can be withdrawn and consumed annually on an indefinite basis without creating a continuing draft on ground-water storage.

Generally, when water is used some of it is not consumed and ultimately recirculates back to ground water as return flow. This water is usually degraded in quality but may be suitable for some uses. If it is assumed that water quality will not be a problem or that quality problems can be handled by treatment, the maximum steady-state pumping rate that can be sustained is a function of both the amount of natural discharge that can be captured and the amount of pumpage recycled back to ground water.

The amount of natural discharge that can be captured is virtually a fixed quantity; however, the amount of water recycled back to ground water varies with the type of use. The type of use may change as the valley develops; consequently, the maximum steady-state pumping rate may change with time. Arteaga and Durbin (1978, p. 29) described a technique for estimating maximum steady-state pumping rates in Eagle Valley, Nev., that allows for different rates of return flow from various uses. The relationship that they derived includes use of both surface water and ground water and is not directly applicable to Pahrump Valley. However, the procedures were applied to conditions in an arid desert basin with no surface supplies, and the following general relationship between the maximum steady-state pumping rate, capturable natural discharge, and net pumpage was obtained:

$$SPR = \frac{CND}{1 - [RFA(PCTA) + RFB(PCTB) + RFC(PCTC) + \dots + RFN(PCTN)]}$$

in which

SPR = maximum steady-state pumping rate;

CND = maximum amount of natural discharge that can be captured by pumping;

PCTA = fraction of the total pumpage used for purpose A;

PCTB = fraction of the total pumpage used for purpose B;

PCTC = fraction of the total pumpage used for purpose C;

PCTN = fraction of the total pumpage used for purpose N, where PCTA through PCTN total 1.0;

RFA = fraction of pumpage for purpose A that is return flow;

RFB = fraction of pumpage for purpose B that is return flow;

RFC = fraction of pumpage for purpose C that is return flow; and

RFN = fraction of pumpage for purpose N that is return flow.

Thus, $[RFA(PCTA) + RFB(PCTB) + RFC(PCTC) + \dots + RFN(PCTN)]$ is the total annual return flow for the entire valley expressed as a decimal fraction of the total annual pumpage.

For Pahrump Valley, A is agricultural use, B is self-supplied domestic use, and C is public-supply and commercial use. Under 1975 conditions,

CND = 19,000 acre-ft/yr (see section on "Simulated Natural Conditions"),

- PCTA = 0.93,
- PCTB = about 0.02,
- PCTC = 0.05,
- RFA = 0.25
- RFB = 0.70, and
- RFC = 0.50.

Substituting into the equation and solving,

$$SPR = \frac{19,000}{1 - [0.25(0.93) + 0.70(0.02) + 0.50(0.05)]}$$

$$= 26,000 \text{ acre-ft/yr.}$$

Thus, under 1975 conditions the maximum steady-state pumping rate for Pahrump Valley is 26,000 acre-ft/yr. This rate will undoubtedly change in the future as public supply and domestic use increase and the average return flow changes. Figure 23 shows the relation between the maximum steady-state pumping rate and the average return flow. It can be used to estimate the maximum steady-state pumping rate as types of water use and the resulting return flow change in the future.

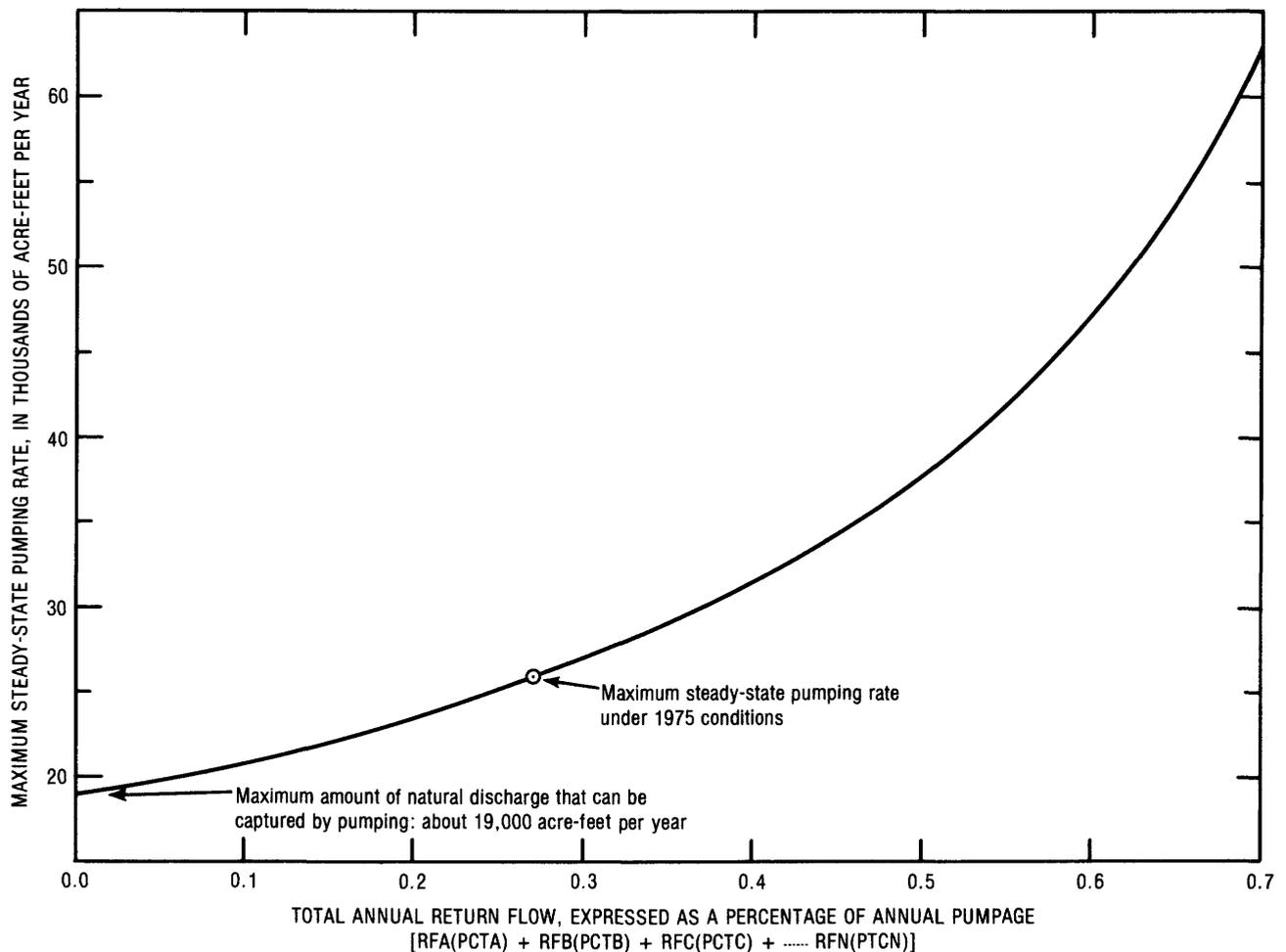


Figure 23. Relation between maximum steady-state pumping rate and average return flow.

Field conditions should be carefully evaluated before the general concept of a maximum steady-state pumping rate is applied to a specific area. Items such as the maintenance of suitable water quality, the areal distribution of pumping, the degree of continuity between shallow and deeper parts of the ground-water reservoir, and the possibility of localized overpumping in areas of low transmissivity should all be considered. Problems in any of these areas could cause adverse effects at pumping rates substantially less than the maximum steady-state pumping rate.

Overdraft

When an area having previously had a stable ground-water system is developed, water is withdrawn from storage until resulting water-level declines alter the flow system sufficiently to either reduce the discharge or induce additional inflow. Water levels stabilize when the system reaches a new equilibrium, that is when pumpage plus the reduced natural discharge (the quantity can be reduced to zero) equals the natural recharge plus any additional recharge induced as a result of development. If ground water is withdrawn from a source more rapidly than it is replenished, an overdraft develops. Ultimately resulting water-level declines cause pumping lifts to become prohibitive or lead to other undesirable results.

Two generalized types of overdraft are possible: basinwide and localized. Basinwide overdrafts occur when net ground-water pumpage exceeds inflow to the system over a sustained period of time. In this case, water levels will continue to decline as long as pumping exceeds recharge, although the rate of decline will decrease as natural discharge is captured by pumping. Thus, even though wells may be ideally located, the cumulative effects of gradual but sustained water-level declines will eventually result in excessive pumping costs or other undesirable effects. At this point, additional water must be imported or pumping must be reduced. A more common occurrence in Nevada valleys is localized overdraft, which results from pumping being concentrated in a localized area. Water-level declines in these areas are accelerated, and pumping lifts and associated detrimental effects may become intolerable before enough discharge is captured to stabilize water levels.

The analysis made in this report indicates that it will be very difficult to capture a significant amount of subsurface outflow by pumping from the valley-fill reservoir in the general vicinity of existing areas of development. This evaluation of overdraft assumes that future pumping will be primarily from the valley fill and, for the most part, will be concentrated in the same general areas as shown in figures 8 and 9. It is beyond the scope of this report to determine whether deep pumping located near

the Nopah Range could economically capture a significant amount of subsurface outflow.

A basinwide overdraft has existed in Pahrump Valley for many years. As of 1975 the general level of pumping of about 40,800 acre-ft/yr resulted in a net draft on the system of about 30,000 acre-ft/yr (total pumpage minus recirculation). The maximum amount of natural discharge that can be captured by pumping has been estimated as 19,000 acre-ft/yr. The difference between these two quantities (30,000-19,000, or 11,000 acre-ft/yr) is the magnitude of the existing overdraft. The magnitude of the overdraft can also be estimated from the maximum steady-state pumping rate by using the following relationship:

$$OD = \frac{(APR-SPR)(CND)}{SPR},$$

in which OD is the overdraft rate, APR is the actual pumping rate, SPR is the maximum steady-state pumping rate, and CND is the maximum amount of natural discharge that can be captured by pumping. Using 1975 pumping conditions:

$$\begin{aligned} OD &= \frac{(41,000-26,000)(19,000)}{26,000}, \\ &= 11,000 \text{ acre-ft/yr.} \end{aligned}$$

Eventually, either pumping in Pahrump Valley will have to be curtailed or additional water will have to be imported to alleviate the overdraft problem. However, at the present and probable future rates of water-level decline (fig. 23) considerable time may elapse before either action becomes necessary. One reason the present rates of water-level decline have been only moderate in terms of the level of pumping and the amount of overdraft on the basin is that the existing pumping is situated to capture spring discharge rather effectively. The consequent capture of about 10,000 acre-ft/yr of spring discharge and about 6,000 acre-ft/yr of other evapotranspiration by pumping has helped reduce the rate of water-level decline.

CONCLUSIONS

The principal conclusions regarding the ground-water resources of Pahrump Valley are as follows:

1. The ground-water system consists of two reservoirs: (1) the valley-fill reservoir, which consists of unconsolidated materials and occurs only within the study area, and (2) a consolidated-rock reservoir, which is composed primarily of carbonate-rock aquifers and extends beyond the boundary of Pahrump Valley to form a multivalley flow system that partly drains the ground-water resources of Pahrump Valley.

2. Although the scope of this study did not allow detailed delineation of the consolidated-rock reservoir, two statements are supported by the results of this evaluation: (1) the system, as conceived in this study, does not contribute appreciable subsurface inflow to the adjacent Amargosa Desert, and (2) the most probable discharge area for subsurface outflow from Pahrump Valley is along the flood plain of the Amargosa River between the towns of Shoshone and Tecopa, some 12 to 15 mi southeast of Pahrump Valley. Additional fieldwork is needed to confirm or disprove the latter hypothesis.
3. Analysis of the system suggests that natural ground-water recharge and predevelopment discharge are within the range of 37,000 to 26,000 acre-ft/yr. The value at the high end of the range was chosen because it provided the best fit to information available at the time of this study. About 18,000 acre-ft/yr of this quantity leaves the valley as subsurface outflow. Precise determination of these quantities is hindered by a lack of knowledge about hydrologic conditions in the consolidated-rock reservoir.
4. Ground water supplies virtually all the water used in Pahrump Valley. During the period 1962-75, ground-water withdrawals from springs or wells increased from about 29,000 acre-ft/yr in 1962 to a maximum of 48,000 acre-ft/yr in 1968 and then declined to about 41,000 acre-feet in 1975. The decrease was due primarily to the transition from agricultural to real estate development. Pumping may approach the maximum historical rate in the future when land taken out of agricultural production becomes fully developed for residential purposes. As of 1975, all but a few acre-feet of pumpage was from the Nevada part of the valley.
5. Substantial water-level declines have occurred in deeper wells along the lower parts of the Pahrump and Manse alluvial fans where heavy pumping has been concentrated. Maximum observed declines since development began have been slightly greater than 100 ft in localized areas. Maximum observed declines during the period 1962-75 were slightly more than 60 feet. Water-level declines were substantially less in the central part of the valley. During the period 1962-75, water levels along the fan generally declined at rates between 1 and 4½ ft/yr, while water levels in the central part of the valley declined less than 1 ft/yr. The rate of water-level decline was generally much less in shallow wells than in deeper wells. In some areas the water level in shallow wells rose as the result of local recharge from irrigated land.
6. There are no leveling data that will allow an accurate evaluation of the amount of land subsidence; however, the analysis made in this study suggests that land subsidence is active in the valley. A network of strategically located benchmarks should be established and periodically leveled to determine the extent and rate of subsidence.
7. Pumping during the period 1962-75 has resulted in a total ground-water storage depletion of 219,000 acre-ft, which was about 40 percent of the total pumpage. About 155,000 acre-ft of this storage depletion was derived from drainage of unconsolidated deposits, about 46,000 acre-ft was probably from the compaction of fine-grained sediments, and about 18,000 acre-ft was from the elastic response of the aquifer and the water.
8. Pumpage not derived from storage was supplied by the capture of spring discharge and natural ground-water evapotranspiration and from secondary recharge that consists mainly of infiltration from irrigated fields. During the period 1962-75, spring discharge declined from 1,400 to 200 acre-ft/yr, ground-water evapotranspiration declined from 4,900 to 2,600 acre-ft/yr, and recharge from recirculated pumpage and spring flow increased from 5,900 to 11,000 acre-ft/yr. Very little subsurface outflow had been captured by pumping.
9. The model analysis made during the study indicates that the maximum amount of natural discharge that might ultimately be captured by pumping is about 19,000 acre-ft/yr. This represents the amount of water that the valley could yield on a sustained basis without continually depleting ground-water storage. This amount is larger than the 12,000 acre-ft estimated by Malmberg (1967, p. 39). The difference in estimates is due primarily to different techniques used in the analysis.
10. The maximum amount of water that can be pumped on a sustained basis depends on both the amount of natural discharge that can be captured by pumping and the amount of pumped water that is recirculated back to ground water. Under 1975 conditions, about 27 percent of the pumpage was recirculated back to ground water. Under these conditions the maximum steady-state pumping rate is 26,000 acre-ft/yr. If the type of use and amount of water recirculated back to ground water change in the future, maximum steady-state pumping rate will change also.
11. There is significant uncertainty in estimates that attempt to quantify the ground-water budget in Pahrump Valley; however, all estimates indicate a substantial overdraft on the ground-water reservoir. Using the estimates generated by this study, overdraft on the system in 1975 was about 11,000 acre-ft/yr. Under these conditions, no new equilibrium is possible and water levels will continue to decline as long as this high level of pumping is sustained. Results from simulated pumping of the ground-

water model until the year 2040 also indicate this trend.

12. The valley-fill reservoir contains vast amounts of stored ground water. Geophysical techniques were used to estimate the total thickness of the valley fill. With this information, it was also possible to estimate that there may be as much as 57 million acre-ft of recoverable ground water stored in the valley-fill reservoir. Most of this cannot be economically recovered with existing technology because of high pumping costs. There is also the environmental factor of land subsidence to be considered. The amount of water stored in the upper 200 ft of saturated valley fill in and adjacent to the area of development, as of 1975, is about 2.3 million acre-ft. This quantity probably better represents the amount of ground water stored within economic pumping lifts, using the general distribution of pumping as of 1975. Depletion of even this amount of ground-water storage would probably cause significant land subsidence in the central part of the valley.
13. Ground water currently is the sole source for large-scale development in Pahrump Valley and will probably remain so for the foreseeable future. The overdraft that exists will result in a sustained depletion of stored ground water, and continuing water-level declines are anticipated. However, the amount of ground-water storage is large in relation to the magnitude of the annual overdraft, and pumping can remain at the 1975 level for many years before the reservoir of stored ground water is seriously depleted. If serious problems arise they will probably not be related to running out of water on a valleywide basis but, instead, to situations such as deteriorating water quality, land subsidence, or too closely spaced pumping.

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METRIC CONVERSION FACTORS

Only the inch-pound system of measure is used in this report. Abbreviations and conversion factors from inch-pound to International System of Units (metric) are listed below.

Multiply	By	To obtain
acre	4,047	m ² (square meters)
acre-ft (acre-feet)	1,233	m ³ (cubic meters)
ft ³ /s (cubic feet per second)	0.02832	m ³ /s (cubic meters per second)
ft (feet)	0.3048	m (meters)
ft/d (feet per day)	0.3048	m/d (meters per day)
ft ² /d (feet squared per day)	0.0929	m ² /d (meters squared per day)
gal/min (gallons per minute)	0.06309	L/s (liters per second)
mi (miles)	1.609	km (kilometers)
mi ² (square miles)	2.590	km ² (square kilometers)

