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THE EFFECTS OF PUMPING ON THE HYDROLOGY OF KINGS RIVER VALLEY, HUMBOLDT COUNTY, NEVADA, 1957-64

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THE EFFECTS OF PUMPING ON THE HYDROLOGY OF KINGS RIVER VALLEY, HUMBOLDT COUNTY, NEVADA, 1957-64

By G. T. Malmberg and G. F. Worts, Jr.

ABSTRACT

This, the second appraisal of the water supply of Kings River valley, was made 5 years after the first cooperative study. The first report by Zones (1963) described the ground-water flow system under near natural conditions and estimated that recharge and discharge were each about 15,000 acre-feet per year. That estimate agrees reasonably well with the 17,000 acre-feet per year derived in this report--the amount is also considered to be the perennial yield of the valley.

All pumpage and all applications to pump additional water are in the northern half of the valley, herein called the Rio King subarea. The yield of the subarea is about 12,000 acre-feet per year. The estimated net pumping draft in 1963 was about 3,000 acre-feet more than the estimated yield. If all permitted rights to pump water were exercised, the net pumping draft would be about 40,000 acre-feet per year, or more than three times the estimated yield.

During the period 1957-63, pumping in the Rio King subarea caused an estimated storage depletion of 65,000 acre-feet, which is only about 5 percent of the estimated water stored (1,400,000 acre-feet) in the upper 100 feet of saturation in the valley-fill reservoir. However, an overdraft of 25,000 to 30,000 acre-feet per year would deplete this stored water in less than 50 years.

The first approximation of transmissibility distribution in the Rio King subarea suggests that the values range from less than 50,000 gpd per foot around the margins of the valley-fill reservoir to about 100,000 gpd per foot in the central part. The long-term storage coefficient may average about 0.17.

The chemical quality of water generally has been satisfactory for irrigation, domestic, and stock use. However, over the long term, recycling of water pumped for irrigation could result in the deterioration of water quality.

INTRODUCTION

Development of Water for Irrigation

Prior to 1956, Kings River valley was largely a sheep and cattle ranching area. All principal streams and spring-flow in the valley had been appropriated for many years and used to irrigate the meadow lands along the flood plains and below the larger springs. Native grasses, growing on most of the irrigated areas, provided hay and winter pasture for livestock. Sagebrush, greasewood, rabbitbrush, and other indigenous species of vegetation covered most of the valley floor and provided brouse for livestock herds maintained by the local ranches.

Since 1956, however, private interests have acquired or filed entries for the agricultural development of public lands on about 15,000 acres, and farming has rapidly become the dominant activity in the valley. Farming on a large scale began in 1956. Since then about 12,000 acres of land has been cleared of brush and about 7,600 acres placed under cultivation. In 1963, 44 wells having high to moderate yields supplied most of the irrigation water to the farms. The cultivated area is devoted exclusively to irrigation farming and is dependent entirely on ground water for a water supply. The soils are well suited for cultivation; however, the erratic occurrence of late-spring and early-fall frosts limits agriculture to some degree to frost-tolerant grains, grasses, and legumes.

All farms and ground-water development are concentrated in the northern half of the valley north of Coyote Hills. Gross pumpage has increased annually since 1956 and by 1963 reached about 22,000 acre-feet. Pumpage each year since 1958 equaled or exceeded the preliminary estimate of average annual ground-water recharge of about 15,000 acre-feet made by Zones (1963).

The first report by Zones (1963) treated the valley as a single unit and described recharge to and discharge from the valley accordingly. Because recharge and pumping are localized in the northern half of the valley, questions were raised by the State Engineer regarding the effect of localized development on the basin as a whole. It was known that pumping was causing water levels to decline and that a large cone of depression was developing. The extent of the cone of depression was unknown, as was its rate of growth and its effect on the flow in Kings River. Increased infiltration resulting from lowering of the water table beneath the river would eventually decrease the surface-water flow. Infringement on prior appropriated surface-water rights in this part of Kings River valley would present the State Engineer with many problems.

As a result of declining ground-water levels and apparent local overdraft, the State Engineer invoked a temporary moratorium in 1962, which stopped the drilling of wells in an effort to prevent further overdevelopment of the ground-water reservoir. Action was initiated to have Kings River Valley declared a ground-water basin subject to the administrative jurisdiction of the State Engineer. Residents of the valley, concerned by the restrictions resulting from such action on future development of the ground-water reservoir, objected to the proposed declaration until the available water resources could be assessed.

Purpose and Scope of the Investigation and Report

The investigation on which this report is based is the second investigation of Kings River valley made by the U. S. Geological Survey under a cooperative program financed jointly with the Nevada Department of Conservation and Natural Resources. The first investigation (Zones, 1963) was a reconnaissance and included a cursory study of the nature and extent of ground-water aquifers, ground-water recharge, discharge, and chemical quality of ground water.

This study was directed toward the solution of problems related to development of the ground-water resources of the valley. The principal objectives of the study were to determine the effect that pumping during the period 1957-63 has had on the flow system in the Rio King subarea. Of particular concern is whether the net pumping draft exceeded the available supply, whether pumping has or soon will affect the surface-water rights, and insofar as possible to predict the probable effects of pumping on the flow system in the next several years.

To accomplish these objectives the scope of the report includes (1) a re-evaluation of the inflow and outflow estimates made by Zones (1963) with particular respect to the area of ground-water development; (2) an analysis of the amount and distribution of precipitation in the valley as related to the source and quantity of the available surface water and ground water; (3) an estimation of the average annual surface-water inflow to the valley, its disposition and routing, and its outflow; (4) a description of the ground-water reservoir; (5) an estimation of the magnitude of depletion of ground water in storage; (6) estimates of pumpage, perennial yield, and overdraft; and (7) an analysis of the chemical quality of ground water to establish a base for comparing changes in salt balance that probably will occur in the future.

Field work began in April 1963 and was completed by September 1964. It consisted of measuring surface-water inflow to the valley, drilling 18 small-diameter test wells in remote areas of the valley, measuring the high and low water levels in wells before and after an irrigation season, making pumping tests on wells, estimating the annual pumpage, and inventorying the chemical quality of the surface and ground water. This re-evaluation is consistent with the objectives of the long-range cooperative program (Shamberger, 1962, p. 14) for the orderly study of the water resources of Nevada, which provides for additional detailed studies in areas where moderate to substantial development has occurred and where records are available through a continuing inventory over a prolonged period of time.

Location

General Geographic Features

Kings River valley is in northern Nevada, about 50 miles northwest of Winnemucca. It is in north-central Humboldt County, Nevada, and includes about 2 square miles of mountainous terrane in the southwestern corner of Harney County, Oregon (pl. 1). It includes the entire drainage basin of Kings River valley, an area of about 420 square miles, lying approximately between lat 41°25' and 42°00' N.; long 118°00' and 118°25' W. The drainage basin has a north-south length of about 43 miles and an east-west width of about 12 miles.

Kings River is tributary to Quinn River, which forms the southern boundary of the study area. It heads near the juncture of the Bilk Creek and the Quinn River Mountains (Zones, 1959, p. 10; also called Montana, Trout Creek, and Double H Mountains) at the extreme northern end of the study area (pl. 1). The main stem of Kings River, downstream from the confluence of Kings River and Log Cabin Creek, flows southeastward about 2 miles across alluvial fans and dissected valley fill onto the floor of the valley. Below an altitude of about 4,380 feet the river flows generally southward.

Access to the valley is limited to two gravel roads, one crossing the Quinn River Mountains through Thacker Pass from Quinn River valley on the east and the other crossing the Bilk Creek Mountains on the west from Pine Forest Valley (pl. 1). Most points on the valley floor can be reached over unimproved roads and trails, usually passable with four-wheel drive vehicles.

Hydrologic Subareas

The Coyote Hills (pl. 1) extend eastward more than half way across the valley floor. All water development is north of these hills. Accordingly, for the purpose of describing the hydrology of Kings River valley, the area is divided into two parts: A northern part called the Rio King subarea, named after the Rio King Ranch; and a southern part, called the Sod House subarea, named after an old stagecoach stop at the southeast corner of the area.

Previous Investigations

Two reports of special historic, hydrologic, and geologic significance by Russell (1885) and Zones (1963) have been drawn upon extensively in the preparation of this report. The field work by Russell was done during 1881-82 as part of a study of Quaternary geology of the Great Basin. Russell discusses the history of Lake Lahontan, which once covered large areas of northern Nevada, including much of Kings River valley, and describes the topography, geomorphology, and stratigraphy of the Lake Lahontan sedimentary deposits.

The first report on the ground-water resources of Kings River valley contains the results of a reconnaissance made by Zones (1963) in 1958-59 under the cooperative program between the State of Nevada and the U. S. Geological Survey. That report gives a brief description of the geology, hydrology, and water quality of the valley and summarily concludes that the average annual recharge to and discharge from the ground-water reservoir under natural conditions was about 15,000 acre-feet.

A preliminary geologic map of Humboldt County by Wilden (1961) includes Kings River valley and adjacent mountains. The distribution of the principal lithologic units shown on plate 1 is after Wilden (1961).

Numbering of Hydrologic-Control and Sampling Points

Hydrologic-control and sampling points, including wells, springs, and permanent and miscellaneous streamflow measuring stations listed in this report, are numbered according to their location in the rectangular system for the subdivision of public lands. In this report, all hydrologic-control and sampling points are in Nevada. The numbers assigned to these points consist of three principal parts: First, the number of the township north of the Mount Diablo base line; second, a slant followed by the number of the range east of the Mount Diablo meridian; and third, a hyphen followed by the section number and series of letters used to designate the location within the section. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast subdivisions of the section. The first letter designates the quarter section; the second letter, the quarter-quarter section; and the third, where it was possible to make a determination, the quarter-quarter-quarter section.

Where more than one hydrologic-control or sampling point occurs within a quarter-quarter-quarter section, the points are numbered consecutively in the order in which they were recorded. For example, the first control point recorded in the NE 1/4 NE 1/4 NE 1/4 sec. 25, T. 46 N., R. 33 E., is numbered 46/33-25aaa1(pl. 1), the second point recorded is numbered 46/33-25aaa2, and so forth. Where the 40-acre and 10-acre tracts are unknown, the numbering system is modified to include only the designations for the subdivisions of the sections that are known.

Acknowledgments

Acknowledgment is made of the cooperation of the local residents of the valley in supplying data and permitting the use of their wells for pumping tests and water-level observations during the course of this investigation. The writer is grateful for the wholehearted assistance received from Federal, State, and local governmental agencies. Most of the drillers' logs and other pertinent data on well construction used in this investigation were furnished by the Nevada State Engineer.

Officials of the Harney Electric Company supplied records of power consumption, pump tests, and water-level measurements. Mr. Kirk Day, County Agent of Humboldt County, furnished records of irrigated farmland. Valuable records on precipitation and runoff were made available by the U. S. Bureau of Land Management for the Crowley Creek drainage basin, which is adjacent to Kings River valley and is one of the areas included in the Bureau's study of the hydrology of small watersheds.

CLIMATE

The climate of Kings River valley is influenced largely by movement of air masses coming chiefly from the Pacific Ocean. Orographic effects of the Sierra Nevada and Cascade Range cause most of the moisture in the inland-moving air masses to precipitate on those mountains; as a result, the Great Basin to the east is largely desert. As the relatively dry air masses move inland over the desert, orographic effects, similar to those caused by the Sierra Nevada and Cascade Range, but of smaller magnitude, cause more precipitation to fall on the desert mountain ranges than on the valley floors. The climate on the valley floors commonly is characterized by low precipitation and humidity, hot summers and cold winters, and wide extremes in daily temperature. In the adjacent mountains there is more precipitation and lower temperature.

Precipitation on the valley floor of Kings River valley averages about 9 inches annually. It is more abundant during the winter than in the summer. Winter precipitation on the mountains occurs as snow that usually remains until May or June before melting. Much of the precipitation that falls on the valley floor occurs as snow during the winter. It ordinarily melts within a few days.

Precipitation during the summer usually is meager and occurs as thundershowers of short duration and limited areal extent. U. S. Weather Bureau records indicate that the annual precipitation in Kings River valley during the 7 years of record since 1957 ranged from 8.08 inches in 1963 to 10.94 inches in 1959.

Table 1 shows that the mean annual temperature on the valley floor, which is at an average altitude of about 4,240 feet, is about 48°F, and the average minimum monthly temperature is about 16°F. Daytime temperatures in July and August frequently rise to 100°F or slightly higher. Lower temperatures in January and February commonly are 5 to 10°F below zero. A range of diurnal temperature fluctuation of 50°F is common. The frost-free growing season has ranged from 63 days in 1960 to 118 days in 1961, but for the period of record it averages about 88 days. It usually extends from about June 10 to about September 6.

The low relative humidity and prevalence of wind during most of the year cause evaporation to be high. At Rye Patch Dam on the Humboldt River, about 80 miles south-southwest of the study area, evaporation is on the order of 5 feet annually. It is somewhat less at Winnemucca, also on the Humboldt River, about 50 miles south-southeast of the study area. Although no data on evaporation in Kings River valley are available, the potential evaporation rate in the study area probably is somewhat less than that at Rye Patch Dam and Winnemucca, and is estimated to be about 4 feet during the growing season, or about 5 times the average annual precipitation on the valley floor.

Table 1.--Average monthly temperature data for Kings River valley and adjacent areas

(from published records of the U.S. Weather Bureau)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Years of records	Average annual temperature
KINGS RIVER VALLEY Altitude 4,240 feet														
Average monthly temperature	27.9	35.7	38.9	46.1	52.6	64.9	71.1	68.4	59.7	48.9	37.1	30.7	8	48.5
Average maximum temperature	53.4	59.4	66.1	76.7	86.6	95.1	101.5	100.3	92.6	83.5	68.2	56.8	8	78.4
Average minimum temperature	-10.4	7.9	13.5	14.8	23.0	30.7	39.2	33.2	26.5	15.0	3.8	-2.7	8	16.2
QUINN RIVER CROSSING Altitude 4,087 feet														
Average monthly temperature	24.4	33.8	38.1	48.3	55.2	61.9	69.9	66.7	58.2	46.1	36.9	29.3	13	47.4
Average maximum temperature	54.5	59.4	68.6	79.0	86.7	94.2	101.0	98.1	94.8	78.8	67.6	54.8	13	78.1
Average minimum temperature	-10.4	-.1	6.5	17.9	22.7	32.5	37.4	31.4	19.4	12.8	5.2	-3.3	13	15.1
OROVADA Altitude 4,300 feet														
Average monthly temperature	28.7	34.7	39.5	44.5	54.9	62.5	72.4	69.7	60.7	50.3	38.7	31.3	41	49.0
Average maximum temperature	53.8	59.2	69.0	78.7	88.2	96.6	101.9	100.2	94.2	83.5	67.6	56.3	41	79.1
Average minimum temperature	-3.3	5.1	11.8	18.2	25.6	32.1	39.7	37.0	26.3	18.9	9.0	.2	41	18.4

GEOLOGIC FEATURES

Landforms

Kings River valley is in the northern part of the Basin and Range physiographic province (Fenneman, 1931, p. 327). The topography of the Basin and Range, which is characterized by alternating north-trending mountains and valleys of approximate equal width and length, is largely the result of structural activity and is an expression of major geologic structure in the bedrock. Kings River valley is a structural depression between the Bilk Creek Mountains on the west and the Quinn River Mountains on the east.

The mountains form the topographic and drainage divides of the valley and impede movement of ground water to adjacent valleys. Stream erosion has deeply dissected the mountains, thereby modifying the topography and providing erosional debris that ultimately is transported to the valley. The structural depression between the mountain ranges, partly filled with detritus from adjacent highlands, is a broad lowland that throughout its late geologic history was occupied periodically by lakes. Topographic features of the valley floor related to the erosional and depositional history of the valley include a broad alluvial plain in the central part of the valley bordered by lake terraces, benches, beaches, bars, and related shoreline features. Between the shoreline features and the mountains the valley floor is a dissected surface of moderate relief that slopes upward to the bordering mountains. The alluvial plain is the agricultural area in the valley and is underlain by a thick sequence of unconsolidated highly porous detritus that contains an abundance of water that is readily obtainable from wells.

Mountains

The Bilk Creek and the Quinn River Mountains merge at the northern end of Kings River valley and form a continuous chain of mountains that separate this valley from adjacent valleys to the north, east, and west (pl. 1). The mountains attain their highest altitudes at the northern end of the valley where several peaks exceed 7,000 feet. The highest peak is an unnamed mountain at the northeastern end of the valley that rises to an altitude of 8,506 feet. From the juncture of these two ranges at the northern end of the valley, the mountains extend southward and southeastward at decreasing altitude to the southern end of the valley where they are breeched by the westward flowing Quinn River.

The Bilk Creek Range is part of an uplifted and upwarped fault block that is extensively dissected by erosion. The southern half of the range is a rolling upland characterized by relatively low sage-and-grass covered hills having steep to moderate slopes.

The most striking topographic feature of the mountains that border Kings River valley are the precipitous scarps of the Quinn River Mountains along the east side of the valley. The scarps form a nearly vertical cliff about 30 miles long that rises up to 2,000 feet above the valley floor. In contrast, the eastern slope of the range dips gently eastward toward the Quinn River valley.

Near the center of the valley a bedrock spur, called the Coyote Hills, extends eastward from the Bilk Creek Range more than half way across the valley. They rise to an altitude of 4,834 feet, or about 700 feet above the valley floor, and form a hydrologic restriction between the Rio King and Sod House subareas.

Valley Floor

Alluvial fans and talus slopes.--Alluvial fans and talus slopes occur along the margins of the valley at the base of the mountains. In the northern half of the valley the largest and best developed alluvial fans occur at mouths of canyons occupied by House, Rodeo, Granite, Flat, and Gold Hill Creeks (pl. 1). Alluvial fans formed by these creeks extend valleyward up to 3 miles from the mouths of the canyons. Along the Bilk Creek Mountains the alluvial fans form an apron generally less than a mile wide extending southward to the Coyote Hills. The apron forms an intermediate slope between the valley floor and the adjacent mountains.

Weathering of the precipitous cliffs along the front of the Quinn River Mountains has resulted in the accumulation of scree and the development of an extensive talus slope south of Horse Creek. The talus slopes rise steeply several hundred feet from the valley floor to the base of the cliff. North of Thacker Pass the base of the talus slopes in most areas is above 4,380 feet altitude and consequently was not modified in late Pleistocene time by Lake Lahontan. South of Thacker Pass the talus slopes extend below the maximum stage of the lake, and locally beaches and other shoreline features along the margin of the lake transect the talus slopes. Widespread deposition of tufa in the lake coated much of the talus material occurring below high lake level and locally cemented the talus into a highly resistant conglomerate.

Beaches, terraces, and related shoreline features.--Shoreline features including beaches, bars, and wave-cut and depositional terraces are common along the margins of the valley at altitudes ranging from 4,100 feet to about 4,380 feet. Wave-cut terraces are well developed around the Coyote Hills and the southern ends of the Bilk Creek and Quinn River Mountains. Depositional terraces and spits are common along the northeastern side of the Rio King subarea.

Alluvial plain.--The valley floor, lying below the shoreline features described above, is an alluvial plain underlain by lacustrine beds deposited on the bottom of Lake Lahontan and by alluvium laid down by the Quinn River. The plain is an elongate, slightly concave upward surface that slopes southward toward the Quinn River at an average gradient of about 8 feet per mile.

The width of the valley floor increases progressively southward to the north edge of Coyote Hills where it is about 7 miles wide. East of Coyote Hills it narrows to about 3 miles in width and to the south it broadens to about 11 miles.

South of Coyote Hills the valley floor is largely a clay flat covered by sparse vegetation that derives most of its water supply from ground water. Bare soil exposed between plants commonly is heavily salt encrusted due to evaporation.

North of Coyote Hills the alluvial plain dips gently toward the braided channel of the Kings River, which crosses the valley diagonally from northwest to southeast. Soil developed on lake-bed deposits consists largely of moderately permeable sandy loam, and consequently the potential surface-water infiltration is high. Most of the runoff from the mountains percolates into the soil after reaching the alluvial plain, and as a result the channel of the Kings River is not well defined south of about the Rio King Ranch.

Principal Lithologic Units

For purposes of this report the lithologic units in Kings River valley are divided into two highly generalized groups, based on their hydrologic properties: consolidated rocks, which have virtually no interstitial porosity or permeability and which occur in the mountains and at depth beneath the valley fill; and unconsolidated and partly consolidated deposits, which are highly porous and commonly transmit water readily.

The principal lithologic units and their stratigraphic relations are shown in table 2, which is compiled from the geologic reconnaissance by Wilden (1961). The consolidated rocks were not studied in detail, and as no known wells are drilled in them, their water-bearing character is largely inferred. Distribution of the principal units listed in table 2 is shown in plate 1.

Consolidated Rocks

The consolidated rocks exposed in the area consist of three principal units ranging in age from late Cretaceous to late Tertiary. The oldest rocks exposed in the area consist of granodiorite intrusives and associated plutonic rocks. They are overlain unconformably by rhyolite, dacite, andesite, and basalt, locally interbedded with some sedimentary rocks of Miocene and Pliocene age. Collectively the consolidated rocks are fractured by normal faults locally having relative vertical displacements of as much as 3,000 feet.

In the absence of wells, little is known of the water-bearing character of the consolidated rocks. However, the occurrence of water in some mines and numerous small perennial springs issuing from fractures and interflow

Table 2.--Principal lithologic units in Kings River valley

(After Wilden, 1961)

System and series			Lithologic unit	Lithology and occurrence	Thickness and water-yielding character
QUATERNARY	Pleistocene and Recent	Valley fill	Younger alluvium	Unconsolidated alluvial and colluvial deposits of gravel, sand, silt, and clay including younger alluvial-fan and talus deposits, river-channel deposits, and Lake Lahontan deposits, including beach-gravel and bar deposits and lake-bottom sedimentary deposits. Exposed extensively on the valley floor.	0-200 feet, occurring partly above zone of saturation. Low to high permeability. Lenses of sand and gravel within the zone of saturation may yield several hundred gpm to wells. Lake-bottom deposits of fine-grained sand, silt, and clay usually yield low to moderate amounts of water to wells.
	Pleistocene		Older alluvium	Largely unconsolidated alluvial and colluvial deposits of gravel, sand, silt, and clay; uplifted, faulted, and dissected by erosion. Principal exposures occur along the margins of the valley floor in the northern half of the valley.	0-600+ feet, occurring partly above the water table. Within the zone of saturation it contains most of the water-bearing zones and locally yields water to wells at rates up to about 2,000 gpm.

(Continued on next page)

Table 2.--Principal lithologic units in Kings River valley (Continued)

(After Wilden, 1961)

System and series				Lithologic unit	Lithology and occurrence	Thickness and water-yielding character
TERTIARY	Miocene and Pliocene	Consolidated rocks	Volcanic rocks	Rhyolite and dacite	Principally rhyolite and dacite but locally includes some basic rocks and some interbedded sedimentary rocks. Extensively exposed in the Quinn River Mountains, the southeastern third of the Bilk Creek Range, and the Coyote Hills.	0-2,500+ feet, commonly has little interstitial porosity and permeability. Transmits small amounts of water through fractures and along bedding planes.
TERTIARY	Miocene and Pliocene	Consolidated rocks	Volcanic rocks	Basalt and andesite	Predominately basalt and andesite but locally includes silicic rock types and sedimentary rocks. Exposed in the central and northern part of the Bilk Creek Range and the northern part of the Quinn River Mountains.	0-2,000+ feet, water-bearing character generally unknown but probably transmits some water through joints and along interflow zones.
CRETACEOUS OR TERTIARY	Upper Cretaceous or lower Tertiary	Consolidated rocks		Granodiorite	Principally granodiorite with compositional variations to quartz diorite and quartz monzonite. Exposed principally along the northeast margin of the valley in the Quinn River Mountains.	Crystalline rock having virtually no interstitial porosity or permeability. Unconsolidated residuum and joints locally contain small quantities of water.

zones in the volcanic rocks indicate that locally they are capable of absorbing and transmitting small quantities of ground water. The consolidated rocks, in overall aspect, have little or no interstitial permeability and in general are barriers to the movement of ground water. Where highly fractured rock occurs in the zone of saturation beneath the valley fill, it may yield small to moderate amounts of water to wells, but the consolidated rocks are not sufficiently productive to warrant exploration as a major source of water supply.

Valley Fill

The valley fill is composed of unconsolidated to moderately indurated detrital material derived chiefly from adjacent mountains. It includes the older alluvium of Pleistocene age and the younger alluvium of Pleistocene and Recent age. Valley fill underlies the floor of the valley and forms the principal ground-water reservoir in Kings River valley. The thickness of the valley fill generally is unknown; however, logs of several wells in the northern part of the valley indicate that locally it is more than 800 feet thick.

Older alluvium.--The older alluvium is composed of alluvial-fan deposits, uplifted and exposed by erosion, and channel, lacustrine, and perhaps playa and other deposits of continental origin occurring at depth beneath the valley floor. The older alluvium is exposed in a nearly continuous outcrop along the perimeter of the Rio King subarea. The channel, lacustrine, and other deposits were identified only in well logs and are considered to be equivalent in stratigraphic position and age to the older alluvium exposed along the margins of the valley. These deposits are believed to underlie most of the valley.

In the northeastern part of the valley the older alluvium is composed largely of weathered material derived from adjacent granitic intrusive rocks (pl. 1). Logs of wells drilled nearby indicate an abundance of clay in the valley fill. The high clay content probably is the result of the decomposition of feldspars derived from the adjacent outcrops of granodiorite. The occurrence of clay throughout most of the material decreases the permeability of the sedimentary deposits, and as a result water is not transmitted readily. Wells 46/33-35aab and 46/33-27 (destroyed), which were drilled to depths of about 800 feet, failed to produce sufficient water for irrigation and were destroyed or abandoned. The specific capacity of six wells tested in adjacent areas down-valley from the granodiorite outcrop had specific yields ranging from a maximum of 28 gpm per foot (gallons per minute per foot of drawdown) to a minimum of 5 gpm per foot, and averaged about 15 gpm per foot.

Throughout the north-central part of the valley, between Lewis Camp and Nine Mile Road, logs of approximately 35 wells indicate that the older alluvium is extremely variable in character, ranging from coarse gravel to clay. It is composed of alternating beds or lenses of gravel, sand, silt, and clay, some tightly compacted or cemented with calcareous cement and others relatively free of interstitial material. Most of the well logs indicate a high degree of heterogeneity of material throughout the depth penetrated by wells. However, a few beds of relatively clean, well-sorted and rounded sand and gravel are penetrated in most wells that yield water readily.

Where exposed along the sides of the valley, the older alluvium consists of a heterogeneous mixture of boulders, gravel, sand, silt, and clay. Structural deformation of the deposits in most areas has been obscured by erosion and usually is not readily apparent.

Younger alluvium.--The younger alluvium consists principally of alluvial and colluvial deposits of gravel, sand, silt, and clay, and includes lacustrine and associated material deposited in Lake Lahontan and the currently active alluvial-fan, flood-plain, talus, and river-channel deposits.

The younger alluvium, largely unaltered by uplift or structural deformation, in general rests unconformably on the older alluvium. The contact between Lake Lahontan deposits and older alluvium is clearly defined in most areas around the margins of the valley by nicks and strand line features at the high still-stand of the lake at an altitude of about 4,380 feet. Extensive erosion by the Kings River and its principal tributaries has removed most Lake Lahontan deposits or otherwise modified or eradicated the high still-stand features in the vicinity of the Kings River Ranch, thereby making the contact indistinct in that area. Lake Lahontan deposits are extensively exposed and underlie practically the entire central valley area below an altitude of 4,380 feet and include lake-bottom deposits of fine sand, silt, clay, and lakeshore deposits.

Although the thickness of Lake Lahontan deposits could not be determined from well logs, the total thickness probably does not exceed 200 feet, based on measured sections of similar deposits in the Winnemucca area (Cohen, 1963, p. 30, 31).

The clay, silt, and very fine sand beds of Lake Lahontan deposits have low permeability and do not yield water readily to wells. Deposits of beach gravel, formed by transgressing and regressing shorelines as the lake fluctuated, undoubtedly created highly permeable strand line deposits that interfinger with finer material deposited in the deeper part of the lake.

Alluvial-fan and flood-plain deposits, talus, and river-channel deposits usually are limited in areal extent and in general interfinger with or lie upon Lake Lahontan deposits. These deposits occur principally along the margin of the valley where the Kings River, Granite Creek, and other smaller streams emerge from the mountains and flow onto the valley floor. Alluvial material in most places is a heterogeneous mixture of detritus derived from older alluvial fans and bedrock. The mode of deposition suggests that the coarsest, most angular, and least sorted material occurs near the edge of the valley at the mountain front; farther away from the bedrock area the material becomes smaller in size, more rounded, and better sorted. Accordingly, porosity and permeability probably increase downslope.

The alluvial material deposited by perennial streams probably is less than 50 feet thick and generally is limited to the flood plain of the Kings River and its principal tributaries. Because of the high infiltration capacity of this material, it is highly significant to the water resources of the valley.

VALLEY-FILL RESERVOIR

Extent and Boundaries

The younger and older alluvium form the valley-fill reservoir, which is the principal source of ground water in Kings River valley. The reservoir encompasses an area about 30 miles long and 7 miles wide, or about 128,000 acres. The maximum thickness of the reservoir probably is more than 1,000 feet beneath the central part of the valley. The granodiorite yields only minor amounts of water to the valley-fill reservoir by subsurface flow through joints and fractures. The volcanic rocks locally may yield small to moderate amounts to the valley-fill reservoir by subsurface flow through interflow zones and fractures. Thus, the hydraulic boundaries of the reservoir, based on these qualitative observations, are considered to be slightly leaky along the contact with the granodiorite and moderately leaky along the contact with the volcanic rocks.

Recharge boundaries are formed principally by the live-stream segments of the Kings and Quinn Rivers and to a lesser extent by small perennial streams where they overlie the valley-fill reservoir and are in contact with the ground-water system. The recharge boundary formed by the Kings River is effective downstream only a few miles south of the Kings River Ranch (pl. 1), where the flow in most years becomes negligible as it sinks into the river-channel deposits. The flow of the Quinn River across the south end of the area usually is small to none.

The constriction formed between the Coyote Hills and the Quinn River Mountains is not a hydraulic boundary in the valley-fill reservoir. However, as of 1964 it provided a logical divide between the Rio King subarea of substantial water development to the north and the Sod House subarea of no water development to the south.

Coefficients of Transmissibility and Storage

The coefficient of transmissibility is a measure of the rate of ground-water flow in a reservoir or aquifer system. The coefficient of storage in a heterogeneous valley-fill reservoir is a measure of the amount of water that will drain from the deposits as the water level is drawn down by pumping. When utilized together in certain types of mathematical models or simulated in electrical models, the two coefficients define the hydraulic conductivity of the system; or in simpler terms, can be used to describe the distribution and amount of water-level decline that would result at specified future times under selected conditions of pumping and boundary conditions.

To determine the areal distribution of transmissibility, short-term tests were made at 27 selected irrigation wells. Individual results for wells

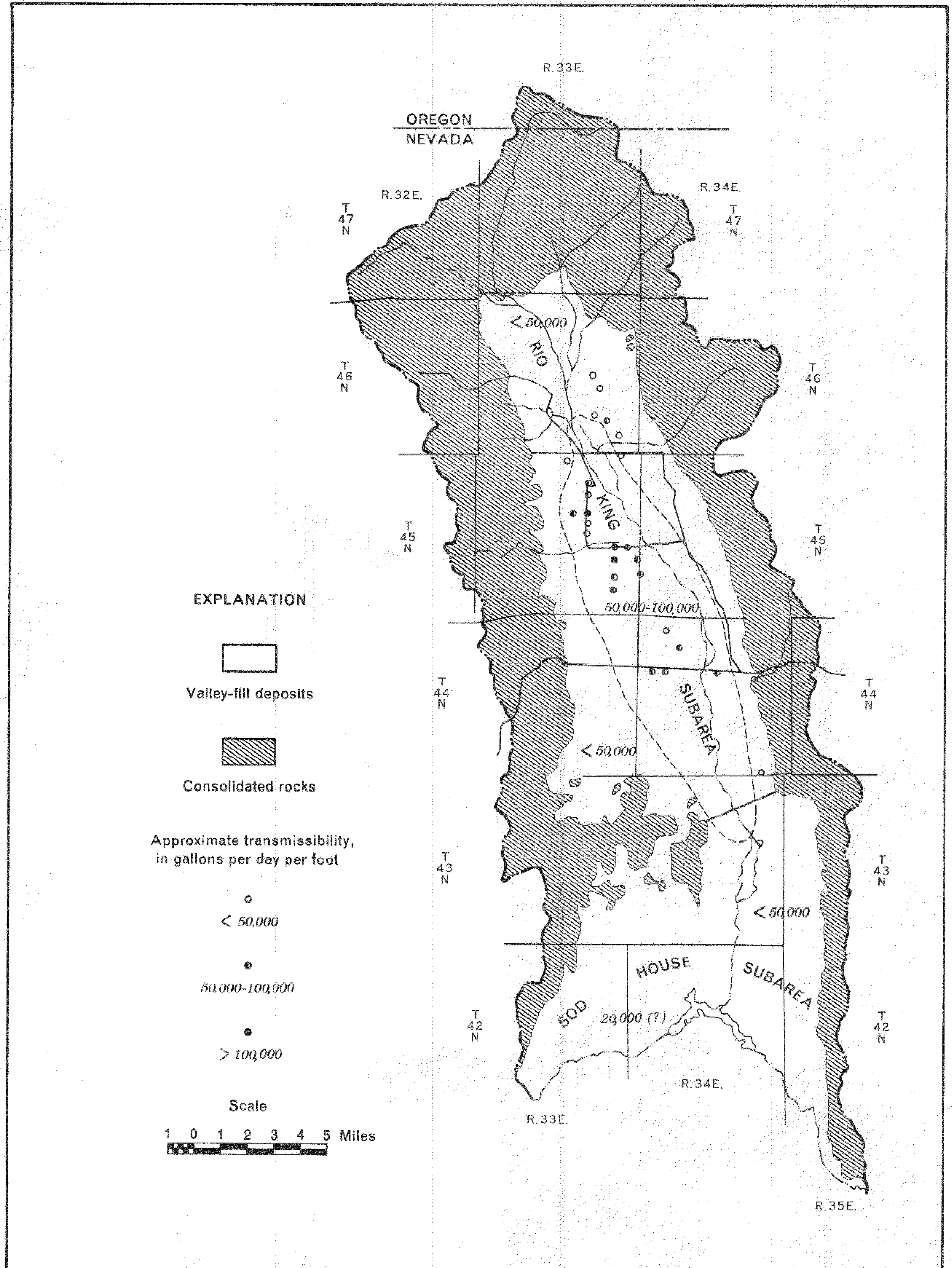

Figure 1.—Preliminary transmissibility map

500 feet or less in depth ranged between about 10,000 and 150,000 gpd (gallons per day) per foot. Figure 1 shows that the first approximation of the distribution of transmissibility is 50,000 to 100,000 gpd per foot in the central part of the Rio King subarea, less than 50,000 gpd per foot around the margins of the subarea, and probably decreasing southward to roughly 20,000 gpd per foot (Zones, 1963, p. 20) at the southwestern end of the Sod House subarea.

The specific-yield of the deposits, which over the long term may be nearly equal to the coefficient of storage, is computed from well logs to be about 17 percent, or equivalent to a storage coefficient of about 0.17 (table 9). Because the horizontal permeability of the valley-fill reservoir is many times the vertical permeability, the flow system for short-term periods responds to pumping stress much like an artesian system. Nevertheless, over the long term all the deposits will drain slowly in response to pumping; hence, the reservoir must be considered as a water-table system in analyzing long-term cause and effect relations.

Ground-Water Flow

The general direction of ground-water flow in the valley-fill reservoir is from areas of recharge around the sides of the valley to areas of discharge along the Quinn River and in areas of evapotranspiration and pumping. Plate 1 shows water-level contours for March 1964, and by constructing flow-lines normal to the contours and pointing down the hydraulic gradient, the direction of flow in the upper 500 to 600 feet of the reservoir can be determined. Not shown by this two-dimensional expression of flow are the downward component of flow in areas of recharge and the upward component of flow in areas of discharge along the Quinn River and in areas of evapotranspiration and pumping. This elementary concept of near vertical flow in the intake and discharge segments of an aquifer was recognized by Meinzer (1923) more than 40 years ago.

The water-level contours in plate 1 show that ground water is moving (1) generally southward for about 25 miles to the Quinn River, (2) westward into the area from Quinn River valley, (3) westward out of the area, (4) into two pumping depressions in the west-central part of the Rio King subarea, and (5) toward the north-trending pumping trough along the northeast side of the Rio King subarea.

INFLOW TO THE VALLEY-FILL RESERVOIR

The hydrology of the valley-fill reservoir is developed in two steps: first, inflow and outflow are estimated under natural conditions to determine the extent to which the estimates agree, which in turn is a rough measure of their reliability for application in subsequent analyses of the hydrology of the Rio King subarea; and second, utilizing the most reliable estimates for the area as a whole, a detailed hydrologic analysis of the effects of pumping on the Rio King subarea is made not only to describe the effects on the system as of 1964, but also to provide some reasonable projections of pumping effects in the next decade.

Precipitation

Distribution and Amount

The source of practically all water entering the hydrologic system of Kings River valley is derived from precipitation falling as rain or snow. The amount ranges from about 9 inches on the valley floor to as much as 30 inches on the highest peaks. Figure 2 shows the approximate relation between altitude and precipitation in and near the area. Using the altitude-precipitation graph and the areas of the altitude zones, the estimated precipitation within the drainage basin averages about 260,000 acre-feet per year (table 3).

The distribution of precipitation with time for Orovada, 25 miles southeast of this area in Quinn River valley, and for Kings River valley is shown in figure 3. The record for Orovada indicates the cyclic character of the precipitation: for the period 1915-33 a cumulative deficiency of more than 27 inches occurred; for the period 1934-45 an equal amount of excess precipitation occurred.

Ground-Water Recharge

Ground-water recharge to the valley-fill reservoir is principally by seepage loss from streams. Some occurs by ground-water flow across the bedrock-alluvial contact, which forms the leaky external hydraulic boundary of the reservoir, and a very minor amount occurs in wet years by direct infiltration of precipitation on the valley floor.

Eakin and others (1951, p. 79-81) devised a crude method of estimating total recharge to a ground-water reservoir by all the above processes, based on the relation between precipitation and altitude and an empirical relation between this calculated precipitation and recharge. The method is used in this report principally to obtain a rough approximation of total recharge; the principal element of recharge, seepage from streams, is derived separately (p. 27).

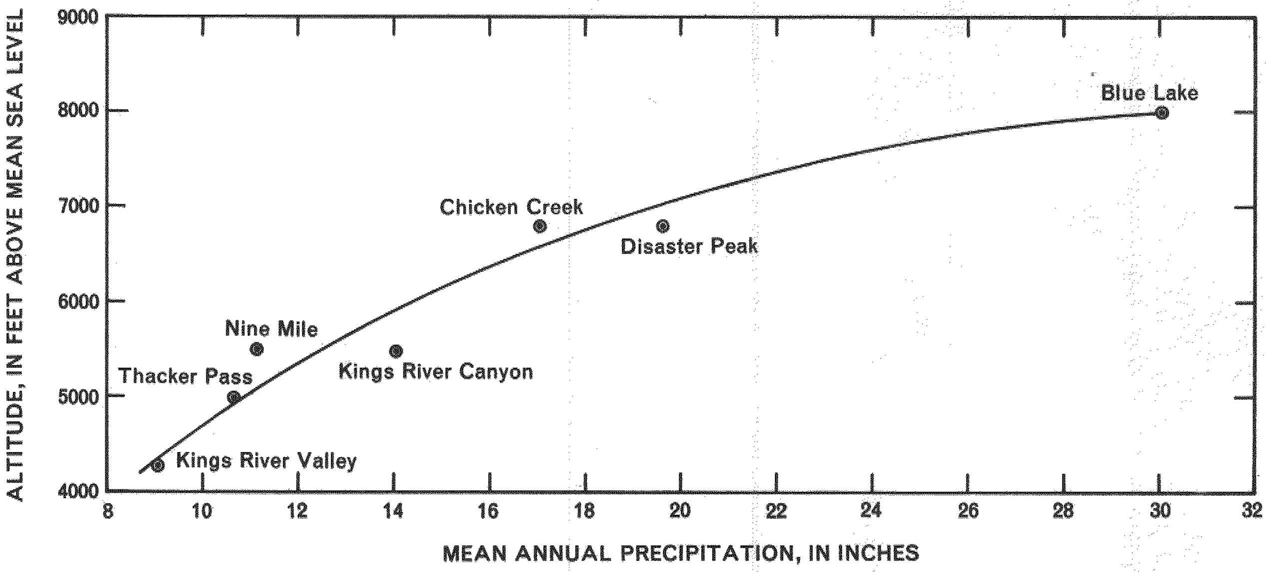

Figure 2.—Approximate relation between altitude and precipitation

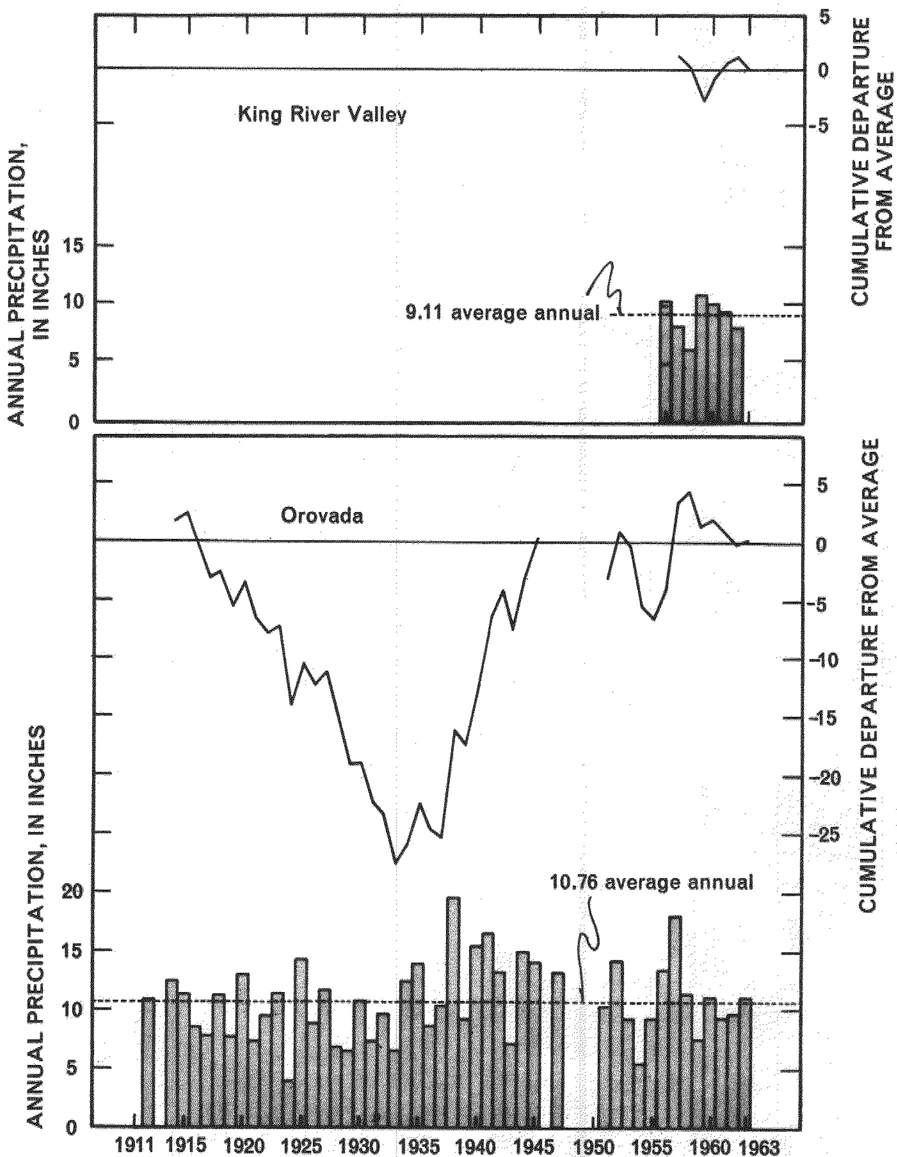

Figure 3.—Precipitation in Kings River Valley and vicinity

Using the relation of precipitation to altitude, shown in figure 2, precipitation rates were assigned to four altitude zones in the area. The estimated recharge is computed by applying a fixed percentage to the volume of precipitation in each zone. Table 3 shows that the estimated total recharge is about 15,000 acre-feet per year, which is roughly 6 percent of the estimated precipitation of 260,000 acre-feet per year. Of the total about 14,000 acre-feet per year occurs in the Rio King subarea and the remainder, about 1,000 acre-feet per year, occurs in the Sod House subarea.

Runoff

By

J. E. Parkes

The principal objectives of this part of the study were to determine the average annual surface-water inflow, surface-water outflow, and distribution and disposition of surface water within the valley. The techniques and hydrologic information used to develop these objectives are described below.

General Characteristics

Runoff to Kings River valley is derived from the streams, rills, and springs of the bordering mountains. The drainage basin as a whole includes the entire study area from the drainage divide along the crest of the Bilk Creek Mountains on the west to the crest of the Quinn River Mountains on the east. The drainage basin is composed of numerous small tributary drainages, some of which contain perennial streams. The tributary drainage basins are somewhat similar in physical character; however, in the northern end of the project area they are usually larger in areal extent and have greater relief than the tributary basins along the east and west sides of the valley.

Most of the runoff to the valley is contributed by an area of 134 square miles occurring above an altitude of 5,000 feet. Streamflow during the fall and winter normally is base flow caused by ground-water effluent, whereas streamflow during the spring and early summer is derived mainly from snowmelt. Snowmelt runoff forms the bulk of the year's total discharge.

Virtually all the main streams entering the valley are diverted for irrigation or dammed for stock ponds, and dependence on these streams is of considerable economic importance.

The major tributary streams in the project area are Granite and Log Cabin Creeks, which are in the northern end of the valley. The Kings River channel in the southern half of the valley is ill-defined, owing to channel

Table 3.--Estimated average annual precipitation and ground-water recharge

Precipitation zone (feet)	Area (acres)	Estimated average annual precipitation			Estimated recharge from precipitation	
		Range (inches)	Average (feet)	Average (acre-feet)	Percentage of precipitation	(acre-feet per year)
Above 7,000	8,000	More than 18	1.75	14,000	25	3,500
6,000-7,000	32,000	15 to 18	1.46	47,000	15	7,000
5,500-6,000	24,600	12 to 15	1.12	28,000	7	1,900
4,000-5,500	200,000	8 to 12	0.83	170,000	3	a 2,500
Total rounded	265,000	--	--	260,000	--	15,000
				Subtotal, Rio King subarea		14,000
				Subtotal, Sod House subarea		1,000

a. Does not include any recharge for about 100,000 acres of the valley floor where precipitation is presumed to be evaporated or retained as soil moisture and eventually discharged by evapotranspiration.

braiding and moderately dense growths of indigenous plants in the channel and along its banks.

Comparative studies indicate that from year to year runoff within the area is erratic. For example, runoff for a wet year may be 10 times the runoff for a dry year. Therefore, for the study year, the 1964 water year (from October 1, 1963 to September 30, 1964), records are adjusted to the long-term average, using the long-term records on McDermitt Creek and the East Fork of the Quinn River, which are outside this area.

Gaging Stations and Measuring Sites

Two gaging stations are within the project area: One, Kings River near Orovada (station 10-3536), in the northern end of the valley, at a point near maximum flow, records most of the surface-water inflow to the valley. The second station, Quinn River near Denio (10-3536.5), at the southwest end of the valley, about 8 miles below the confluence of the Quinn and Kings Rivers (fig. 6), records the surface-water outflow from the project area.

Records of streamflow are available for Kings River near Orovada for the water years 1963 and 1964, and Quinn River near Denio for water year 1964. Owing to the shortness of these records, average streamflow is estimated mainly from streamflow data that were collected at gaging stations outside the project area.

In addition to the gaging stations, miscellaneous current-meter measurements were made four or five times during the study on the principal tributary streams. The measurements were made near the contact between consolidated rocks of the mountains and the valley fill, which is at or near the point of maximum runoff to the valley. Also, periodic current-meter measurements, or observations of no flow, were made at four sites on the main stem of the Kings River on the valley floor. Table 4 lists streams for which miscellaneous measurements were made during this study and shows the data and magnitude of the streamflow.

Surface-Water Inflow to the Valley

Streamflow data for each miscellaneous measuring site in Kings River valley were synthesized for the 1964 water year, based on measurements and continuous streamflow data of the Kings River gaging station. The estimated runoff for each stream in 1964, except Kings River, is listed in table 5. Based on comparisons with nearby stream-gaging stations and cumulative departure from average precipitation at Orovada and Kings River valley (fig. 3), the streamflow in Kings River valley for the 1964 water year was somewhat less than the long-term average.

Table 4.--Streamflow data at miscellaneous measuring sites

(Measuring sites shown on fig. 6)

Stream	Measured discharge, in cfs				
	Sept. 1963	Jan. 1964	Apr. 1964	June 1964	Sept. 1964
Thacker Creek	0.27	0.39	0.45	0.39	0.46
Horse Creek	.10	.26	.99	.31	.05
China Creek	.05	--	1.41	.35	.02
Granite Creek	--	--	a 5.60	--	--
Log Cabin Creek	--	1.55	6.43	4.59	.38
House Creek	--	.54	1.42	.67	.12
Kings River 1/	dry	dry	3.40	4.51	dry
Kings River 2/	--	dry	dry	dry	dry
Kings River 3/	dry	dry	dry	dry	dry
Kings River 4/	--	--	dry	dry	dry

1. At Kings River Road crossing
2. At Rio King Ranch Road crossing
3. At Nine Mile Road crossing
4. At Old Hog John Road crossing

a. Measurement by Nev. Dept. Conservation and Natural Resources.

Table 5.--Estimated runoff of seven major streams in the 1964 water year

Name	Location (fig. 8)	Drainage area (sq. mi.)	Altitude of measuring site (feet)	Estimated runoff (acre-feet)
Thacker Creek	44/34-14ab	10.0	4,360	330
Log Cabin Creek	46/33-6ac	16.9	4,700	1,600
Granite Creek	46/33-10ca	10.9	4,480	a 1,300
House Creek	46/33-20bb	4.9	4,700	420
Horse Creek	46/34-28cb	10.1	4,700	280
Kings River	47/33-31dc	17.3	4,720	b 3,020
China Creek	47/33-36cc	6.7	4,830	350
Total (rounded)		76.8		7,300

a. Based in part on one current-meter measurement made April 21, 1964, by the Nevada Dept. of Conservation and Natural Resources.

b. Gaged flow at Kings River gaging station.

Figure 4 shows the relation between average annual runoff and altitude. The relation indicated by the curve is applied to tributary drainage basins to estimate runoff from remaining areas of Kings River valley. The procedure followed in this analysis is described by Eakin, Moore, and Everett (1965, p. 20-23) and Riggs and Moore (1965).

Physical characteristics of the drainage basin, such as vegetation, geology, orientation, and stream gradient, affect runoff. Differences in these physical characteristics from basin to basin require that median rating of runoff versus altitude be adjusted accordingly. This adjustment is made by comparing average synthesized discharge, based on discharge measurements, to discharge that would be obtained using the curve shown in figure 4. From this comparison, a departure from the curve is obtained. Drainages that have similar departures from the curve are grouped together and define similar zones of runoff. Three areas having different runoff characteristics are shown on figure 5.

Figure 6 is a map showing the distribution of average annual runoff, in inches. It was prepared from runoff estimates for seven streams (table 5), the runoff-altitude curve (fig. 4), and areas having similar runoff characteristics (fig. 5). Total surface-water inflow to the valley about at the bedrock-alluvium contact was computed from figure 6. Table 6 shows that, excluding the inflow from Quinn River Valley, the estimated surface-water inflow averages about 16,000 acre-feet per year. About 70 percent of the runoff is contributed from the northern mountains, which cover only a little more than 40 percent of the runoff area.

At the southeast corner of the area, Quinn River near Sod House is dry during average and dry years. It flows only during infrequent flood years. C. J. Huxel, U. S. Geological Survey, (oral communication, 1964) estimates that over the long term the discharge may range between 1,000 and 5,000 acre-feet per year. For the purposes of this report it is assumed to be 5,000 acre-feet per year. Thus, total surface-water inflow to the Kings River valley is the sum of locally derived runoff and the discharge of the Quinn River at Sod House, or on the order of 21,000 acre-feet per year (table 6).

The estimated runoff of 16,000 acre-feet generated wholly within Kings River valley seems somewhat low compared to the estimated recharge from precipitation of 15,000 acre-feet (table 3). It implies that nearly all the runoff becomes recharge and that little or no recharge occurs by subsurface inflow from the mountains across the bedrock-alluvial contact to the valley-fill reservoir. In other areas of Nevada, subsurface inflow has been computed by indirect methods to range between 5 and 20 percent of the recharge. For this valley, subsurface inflow is considered to be conservatively a little more than 5 percent of the estimated recharge from precipitation, or about

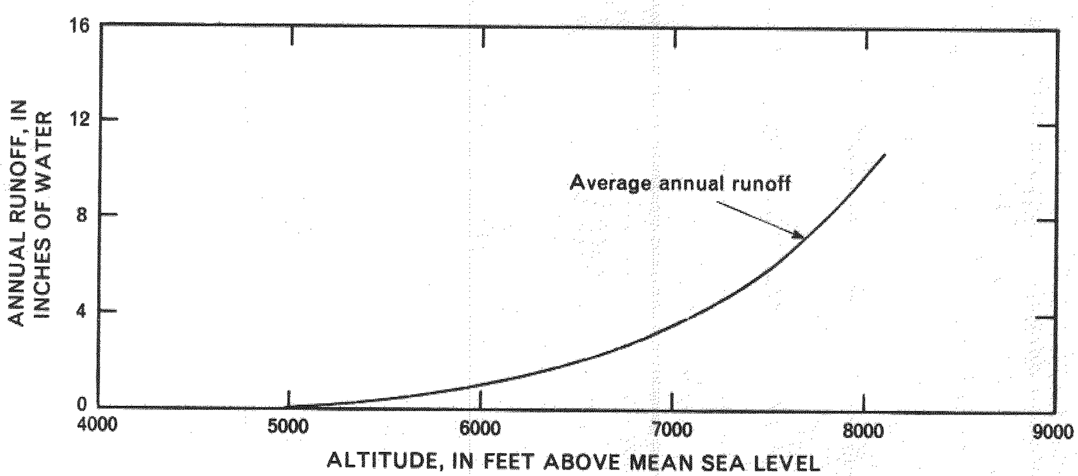

Figure 4.—Relation between runoff and altitude

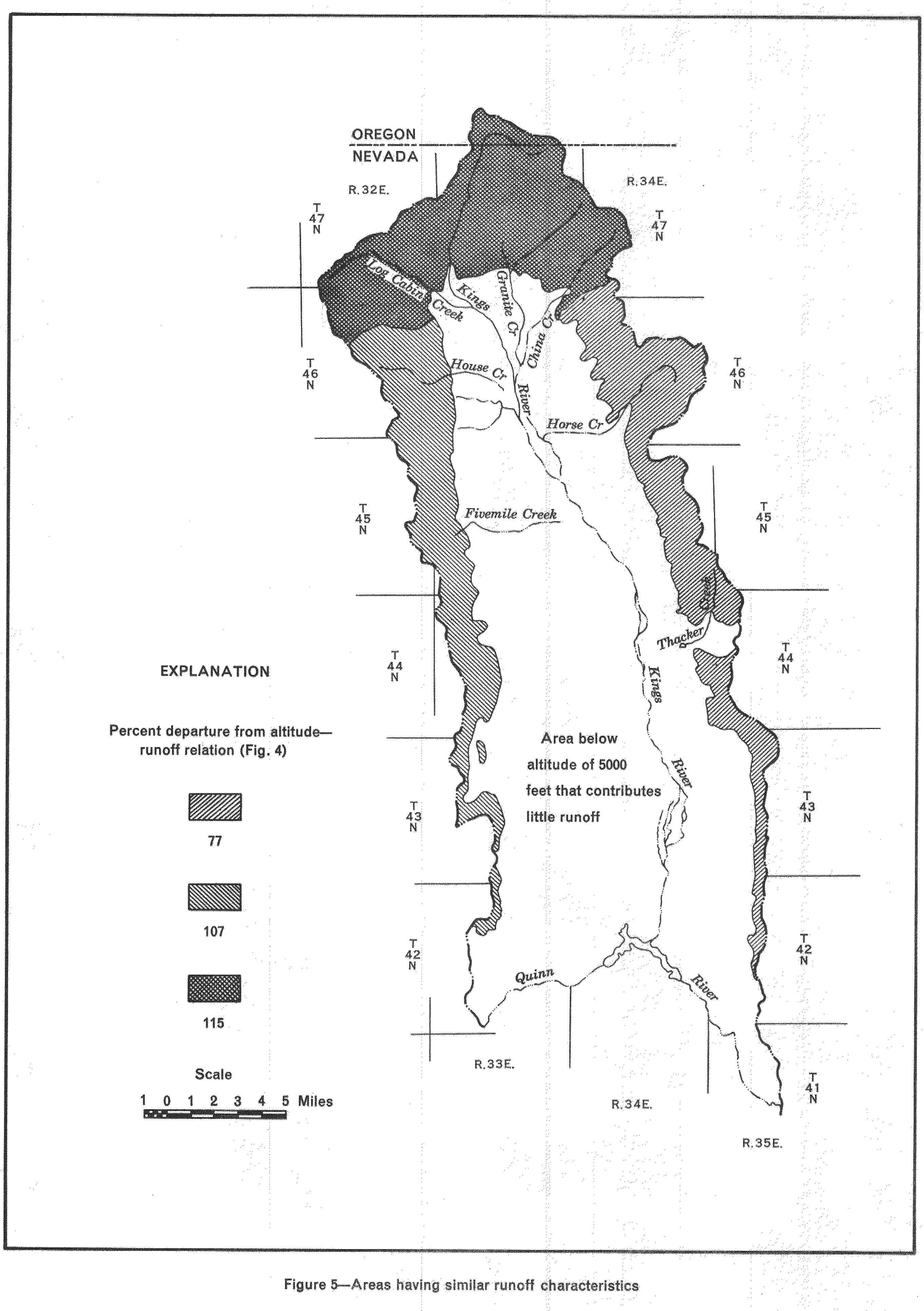

Figure 5—Areas having similar runoff characteristics

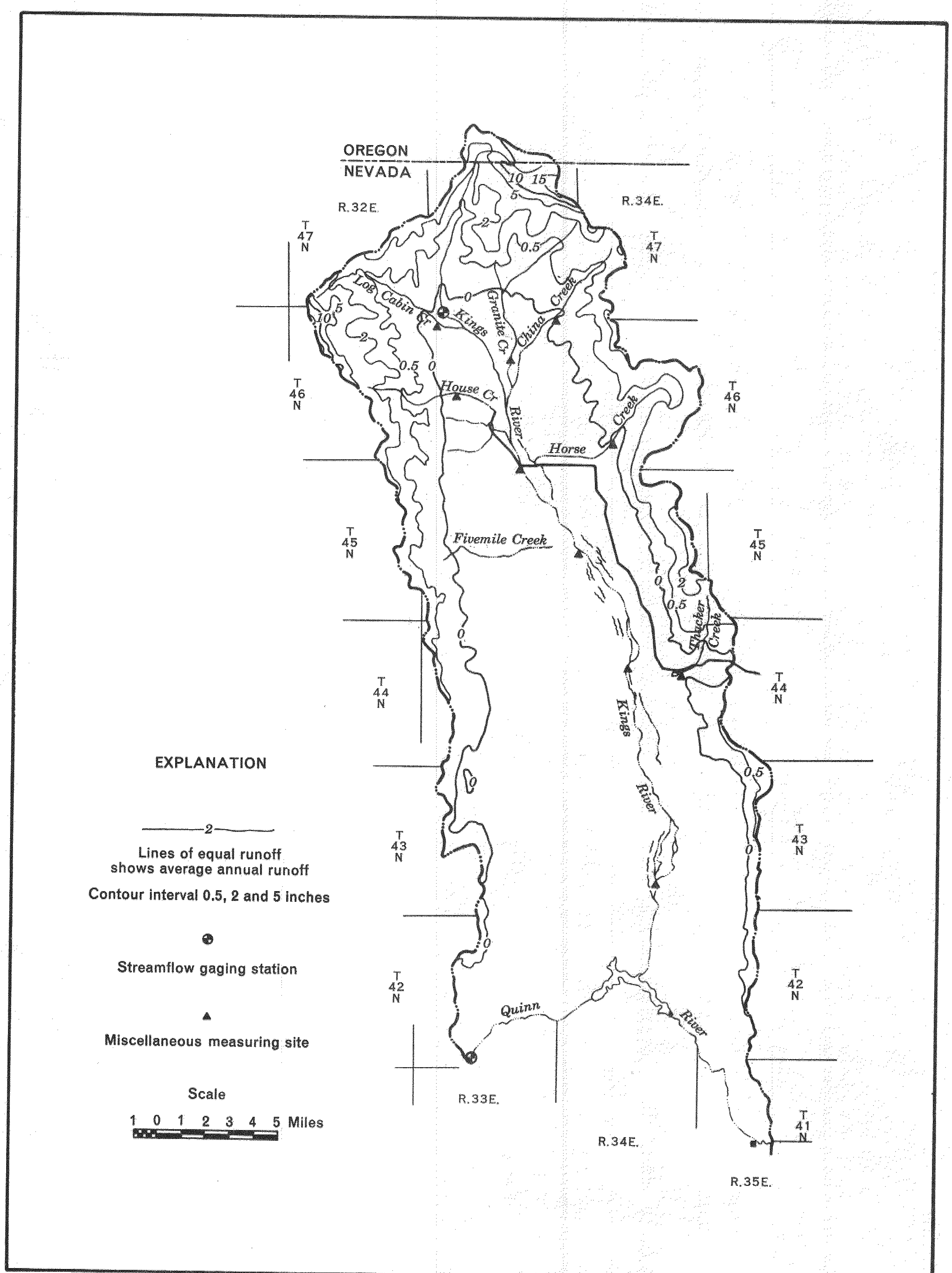

Figure 6.—Runoff distribution map

Table 6.--Estimated average annual runoff in Kings River valley

Mountains	Location	Area: Square miles	Area: Percentage of runoff area	Estimated runoff: Acre-feet per year	Estimated runoff: Percentage of total runoff
Western mountains (Bilk Creek Mountains)	Bilk Creek Mountains south of Log Cabin Creek drainage	36.1	27	2,600	16
Northern mountains (Bilk Creek and Quinn River Mountains)	The northern end of Bilk Creek and Quinn River Mountains	57.5	43	11,600	71
Eastern mountains (Quinn River Mountains)	Quinn River Mountains south of China Creek drainage	40.6	30	2,100	13
	Subtotal (rounded)	134.2	100	a 16,000	100
Inflow from Quinn River valley		--	--	5,000	--
Total				21,000	

a. Of the subtotal, only about 100 acre-feet per year is generated in the Sod House subarea; the remainder in the Rio King subarea.

1,000 acre-feet per year. Of this presumed subsurface inflow, about 900 acre-feet per year may occur in the Rio King subarea and 100 acre-feet per year may occur in the Sod House subarea. These values are used in the water budget (table 8).

Disposition of Streamflow

Most of the perennial streamflow is diverted for irrigation at the mouths of canyons. As a result, low flow is substantially depleted during the irrigation season before debauching onto alluvial fans. Practically all the low flow is dissipated before streams reach the lowest part of the valley floor.

During the 1964 water year, measured surface-water inflow to the head of the valley from China Creek, Granite Creek, Kings River, Log Cabin Creek, Rodeo Creek, and House Creek was nearly 7,000 acre-feet. Downstream from the confluence of these streams and about 2.5 miles below Kings River Road crossing only 760 acre-feet of surface water passed down the main stem of the Kings River. This represents a loss of almost 90 percent of the measured surface-water flow to the valley during the 1964 water year. From 9 miles south of Kings River Road crossing and throughout the remainder of its channel length the Kings River was dry. These findings are based on only one year of record, which was somewhat less than the long-term average. However, during flood years, surface-water outflow from the Rio King subarea to the Sod House subarea may be substantial. Over the long term it may average 1,000 acre-feet per year.

Recharge from streams can be roughly approximated as the difference between the surface-water inflow of 16,000 acre-feet per year (table 6) and the estimated surface-water outflow of roughly 1,000 acre-feet per year and the diversions on natural grass meadows. Most of the moderate to low flow in Kings River is diverted for irrigation on approximately 1,300 acres of grassland adjacent to the river. An additional 400 acres of predominately grassland is irrigated by tributary streams and springs. Assuming that the consumptive use of grassland is about 1.5 acre-feet per acre (Houston, 1950), the consumptive use of surface water for irrigation is computed to be about 2,500 acre-feet per year. Most of the remaining 12,000 to 13,000 acre-feet of surface water probably percolates to the ground-water system.

Direct evaporation from several small surface-water reservoirs, totaling less than 10 acres, and directly from streams is minor.

Ground-Water Inflow

Ground-water inflow, or subsurface inflow, occurs from Quinn River valley to Kings River valley in the vicinity of Sod House. C. J. Huxel, U. S. Geological Survey (oral communication, 1964), estimates that the inflow through the valley fill is on the order of 300 acre-feet per year. No attempt was made to estimate the inflow, if any, through volcanic rocks adjacent to the alluvium in the vicinity of Sod House.

Ground-water outflow from Desert Valley to Kings River valley occurs along the Quinn River. Sinclair (1962) estimated that the outflow probably was not more than 100 to 200 acre-feet per year. With no development in the Sod House subarea, this flow does not now contribute recharge to Kings River valley, but in part discharges into the river and in part leaves the area as ground-water outflow to Pine Forest Valley to the west (pl. 1).

NATURAL OUTFLOW FROM THE VALLEY-FILL RESERVOIR

The major component of natural outflow is evapotranspiration in areas of phreatophytes. Minor discharge occurs from springs and by surface and subsurface outflow at the southwest end of the area. The outflow from the Rio King subarea to the Sod House subarea, although small, is evaluated so that water budgets for each subarea can be compiled.

Evapotranspiration

Prior to the development of ground water for irrigation in 1956, about 64,000 acres of phreatophytes and bare soil were subject to evapotranspiration losses in the lowlands where ground-water levels were shallow. The principal phreatophyte is greasewood; minor amounts of saltgrass, native hay, and willows occur mostly at the north end of the Rio King subarea. Table 7 lists the estimated acreage of phreatophytes and rates of ground-water consumption by them, based on rates of use in other areas made by Robinson (1958) and Houston (1950). The table shows that the estimated average annual discharge in phreatophyte areas under natural conditions was about 16,000 acre-feet. The areal distribution of phreatophytes was shown by Zones (1963, pl. 1).

Some evapotranspiration occurs in the upper reaches of the streams, as shown by the diurnal fluctuation of streamflow recorded at the gaging station, Kings River near Orovada. The maximum recorded difference in discharge resulting from evapotranspiration is about 1 cfs, but the diurnal fluctuation averages about half as much; it is effective only during the growing season, which is about 88 days. Therefore, in the upper reaches of the Kings River, roughly 100 acre-feet is discharged annually by phreatophytes.

Surface-Water Outflow

Surface-water outflow from Kings River valley is measured as the combined flow of the Kings and Quinn Rivers at the station, Quinn River near Denio, which is at the southwest corner of the Sod House subarea. In 1964 only 50 acre-feet was gaged at the station. There was no flow of the Quinn River upstream near Sod House; similarly the flow of the Kings River at the confluence with the Quinn River was zero. Thus, the discharge of 50 acre-feet was entirely from ground water rising in the stream channel.

During flood years, moderate flows occur in the Kings River at the lower end of the Rio King subarea and moderately large flows probably occur in the Quinn River. Over the long term, the flood flows may average about 1,000 acre-feet per year at the lower end of the Rio King subarea, and possible average 1,000 acre-feet per year at the station, Quinn River near Denio.

Table 7.--Estimated ground-water discharge by evapotranspiration

(in part after Zones, 1963, p. 19)

Subarea	Phreatophyte	Area (acres)	Depth to water (feet)	Consumptive use (feet)	Estimated discharge[1] (acre-feet)
Rio King	Greasewood	25,000	10-25	0.2	5,000
	Saltgrass	2,800	2-10	1.0	2,800
	Willow and associated plants	200	5-20	3.0	600
	Native hay[2]	1,000	5-10	1.0	1,000
	Subtotal	29,000	--	--	9,400
Sod House	Greasewood	35,000	10-25	0.2	7,000
Total (rounded)		64,000	--	--	16,000

1. Includes evaporation from bare soil where water level is generally less than 10 feet.

2. Subirrigation of grassland largely in areas not irrigated with surface water.

Ground-Water Outflow

Ground-water outflow, or subsurface outflow, from the valley-fill reservoir occurs from the Rio King subarea to the Sod House subarea east of Coyote Hills and from the southwest corner of the Sod House subarea where the Quinn River leaves the area. The ground-water flow at these two lines of section can be computed by use of a form of Darcy's law:

$$Q = 0.00112TIW$$

in which Q is the quantity of flow, in acre-feet per year; T is the coefficient of transmissibility, in gallons per day per foot; I is the hydraulic gradient, in feet per mile; W is the width of the flow section, in miles; and 0.00112 is a factor for converting gallons per day to acre-feet per year.

Zones (1963, p. 20), using this equation, estimated that the outflow from the southwest corner of the area was only 200 acre-feet per year. This estimate was based on a transmissibility of roughly 20,000 gpd per foot, a hydraulic gradient of 3 feet per mile (the same as in 1964; pl. 1), and an effective width of about 3 miles. This estimate agrees reasonably well with that made by Sinclair (1962a) for the inflow to Pine Forest Valley.

For the ground-water outflow from the Rio King subarea to the Sod House subarea, the following values are used: transmissibility, 50,000 gpd per foot (fig. 1); hydraulic gradient, about 5 feet per mile (pl. 1); and an effective width of 3 miles (pl. 1). When substituted in the above equation, the computed subsurface outflow is nearly 1,000 acre-feet per year.

Springs

Most of the discharge from major springs is used for irrigation of pasture or is consumed by evapotranspiration. These losses are included in the estimates of evapotranspiration and water diverted to irrigated lands.

WATER BUDGET FOR NATURAL CONDITIONS

Water budgets generally are based on the premise that over the long-term and for natural conditions, the total inflow to and total outflow from an area are equal. In other words, a water budget for natural conditions expresses the quantity of water flow in a hydrologic system under equilibrium conditions. A water budget that balances reasonably well also lends confidence to the reliability of the individual elements of inflow and outflow, which in turn are depended upon for estimating such critical factors as the perennial yield of an area.

For the Kings River valley, equilibrium conditions existed up to the time that man began to develop the area agriculturally. Surface-water diversions from the principal streams and springs for irrigation of native meadowgrass began more than 50 years ago and has continued to date. However, this change modified only slightly the natural water balance of the hydrologic system.

Table 8 summarizes the several estimates of inflow and outflow made in the preceding sections of the report and shows the water balance achieved. The overall imbalance is about 10 percent, which is reasonable in view of the several rough estimates of inflow and outflow. The imbalance for the Rio King subarea is large--nearly 20 percent. The imbalance in the Sod House subarea is less than 10 percent. Imbalances of the magnitude shown for the Rio King subarea could only be accounted for by errors in the larger elements of inflow and outflow. The most likely error is in the runoff, which might be too large, and evapotranspiration, which might be too small.

Table 8.--Water budget, in acre-feet per year, for near natural conditions in the Kings River valley

Budget element	Total	Rio King subarea	Sod House subarea
INFLOW:			
Runoff:			
Within valley (table 6)	16,000	15,900	100
Quinn River valley (table 6)	5,000	--	5,000
Rio King to Sod House subarea (p. 27)	--	--	1,000
Ground water:			
Across bedrock-alluvial contact (p. 27)	1,000	900	100
Quinn River valley (p. 28)	300	--	300
Desert Valley (p. 28)	200	--	200
Rio King to Sod House subarea (p. 31)	--	--	1,000
Total (1):	22,500	16,800	7,700
OUTFLOW:			
Surface water:			
Diversions for irrigation (p. 27)	2,500	2,500	0
Springs (p. 27)	(a)	(a)	(a)
Rio King to Sod House subarea (p. 31)	--	1,000	--
Quinn River to Pine Forest Valley (p. 27)	1,000	--	1,000
Ground water:			
Evapotranspiration (table 7)	16,400	9,400	7,000
Rio King to Sod House subarea (p. 31)	--	1,000	--
Outflow to Pine Forest Valley (p. 31)	200	--	200
Total (2):	20,100	13,900	8,200
IMBALANCE: (1) - (2)	2,200	2,900	- 500

a. Discharge either diverted for irrigation or consumed by evapotranspiration losses, which are included above.

GROUND WATER IN STORAGE

The amount of recoverable ground water stored, or more precisely in transient storage, in the valley-fill reservoir to any selected depth below the water table is the product of the area, the selected depth, and the specific yield of the deposits. The selected depth for this study is the uppermost 100 feet of saturation, which in most of the area probably is within economic reach.

The specific-yield of a deposit with respect to water 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 (Meinzer, 1923, p. 28). The average specific yield of the materials in the upper 100 feet of saturation was estimated from drillers' logs. The materials recorded in the logs were grouped into five general lithologic categories, using the method described by Davis and others (1959, p. 202-206) in estimating the specific yield of similar alluvial deposits in the San Joaquin Valley, Calif.

Table 9 shows the assigned specific-yield values and the computations used to estimate the amount of recoverable stored water in the uppermost 100 feet of saturation in the valley-fill reservoir. The average specific yield of the deposits in the Sod House subarea, where meager well data are available, is believed to be somewhat less than that in the Rio King subarea, because more lake deposits and fine-grained stream-laid deposits are present.

Table 9.--Estimated ground water in storage in the valley-fill reservoir 1/

	Lithologic categories: Gravel	Coarse to medium sand	Fine sand	Cemented: sand, silt	Clay	Totals	Recoverable water (acre-feet)
RIO KING SUBAREA							
(1) Thickness of material sampled (feet)	167	93	6	222	178	666	
(2) Do (percent)	25	14	1	33	27	100	
(3) Assigned specific yield (percent) 2/	25	30	15	10	5	--	
(4) Specific yield, entry (2)x(3) (percent)	6.2	4.2	1.5	3.3	1.4	17	

Area (acres)	Selected thickness (feet)	Volume of deposits (acre-feet) (1)	(2)	(1) x (2)
80,000	100	8,000,000	0.17	1,400,000
SOD HOUSE SUBAREA				
48,000	100	4,800,000	a 0.15	700,000
Total (rounded)				2,000,000

1. Uppermost 100 feet of saturation below prepumping water levels.
2. Values based on studies and tests by the Hydrologic Laboratory, U.S. Geological Survey, Denver.
a. Assumed value of specific-yield.

CHEMICAL QUALITY OF WATER

By

D. E. Everett

Thirty-seven water samples were analyzed as part of the present study to make a general appraisal of the suitablility of the water for domestic and agricultural use and to help define potential water-quality problems. Sampling sites were chosen to achieve the widest possible areal coverage. Detailed analyses are shown in table 10, and field analyses in table 11.

Suitability for Agricultural Use

According to the U. S. Department of Agriculture (1954, p. 69), the most significant factors with regard to the chemical suitability of water for irrigation are dissolved-solids content, the relative proportion of sodium to calcium and magnesium and the concentration of elements and compounds that are toxic to plants. Dissolved-solids content commonly is expressed as "salinity hazard", and the relative proportion of sodium to calcium and magnesium as "alkali hazard."

The Salinity Laboratory Staff suggests that salinity and alkali hazards should be given first consideration when appraising the quality of irrigation water, then consideration should be given to boron or other toxic elements and bicarbonate, any one of which may change the quality rating. The above properties of water were described by Zones (1963, p. 22-25).

Samples were collected from wells, streams, and one spring. All the streams and all but three wells yield water which probably is suitable for irrigation. Well 42/33-32bad (pl. 1), just downstream from the Sod House subarea, yields water with a high salinity hazard, a very high alkali hazard, and a high residual sodium carbonate (RSC) value. Although this well is not in the project area, the water quality probably is representative of ground-water outflow from the valley. Water from wells 43/33-26ddd, 42/33-10ddb, and 41/35-17abb has a high RSC value, and must be considered marginal on this basis. Spring 44/33-10cac yields water with a high salinity hazard. This water, however, has proved to be suitable for irrigation, because it is used under favorable conditions of drainage and plant tolerance, In general, water in the Rio King subarea probably is suitable for irrigation, whereas water in the Sod House subarea is marginal or unsuitable.

With adequate drainage, water in the northern part of the valley will continue to be suitable for irrigation. However, as the cones of depression continue to expand in the Rio King subarea, adequate downstream drainage cannot be maintained. Accordingly, the recirculation of ground water through

Table 10.--Detailed chemical analyses, in parts per million, of water from selected wells

[Analyses by the U.S. Geological Survey]

Location (well or spring number)	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Dissolved solids (calculated)	SAR	RSC	Specific conductance (micromhos at 25°C)	pH[1]
41/35-17abb	6-23-59	--	69	0.17	22	3.9	104	12	200	64	54	1.0	0.8	0.3	70	0	431	5.4	1.86	622	7.0
42/33-32bad	10- 5-54	76	39	.04	32	5.2	416	11	885	184	59	.9	.2	1.7	102	0	1,180	18	12	1,820	--
43/35-31cdd	11- 5-60	--	--	--	26	6.8	39	5.1	147	--	22	--	--	--	93	0	--	1.8	.55	357	8.0
44/33-10cac (spring)	6-22-59	79	54	.14	25	5.8	27	6.3	117	20	22	.1	.2	.1	86	0	219	1.3	.19	303	8.0
44/33-10dbb	6-22-59	--	55	.63	99	33	78	12	228	107	152	.0	56	.2	382	198	705	1.7	.00	1,130	7.5
44/33-12bbb	6- 2-64	59	60	.02	28	9.2	25	3.7	148	19	18	.3	3.5	.0	108	0	240	1.0	.27	325	7.5
44/33-25cca	6-22-59	--	45	.13	29	7.1	21	3.2	145	13	13	.2	.7	.1	102	0	204	.9	.35	291	7.6
44/34-5bcc	6- 2-64	60	52	.02	29	12	13	3.4	158	9.0	12	.1	1.4	.0	123	0	210	.5	.13	294	8.0
44/34-9bbb	6-22-59	--	4.9	2.4	28	18	57	4.2	208	28	50	.2	.0	.1	145	0	298	2.1	.53	530	8.1
44/34-18abb	6-22-59	--	59	.10	27	13	15	4.1	156	10	9.5	.2	2.6	.0	120	0	218	.6	.14	285	7.8
45/33-3ddb	6-22-59	--	48	.18	28	11	17	3.0	164	9.7	8.6	.1	.4	.1	115	0	208	.7	.39	293	7.5
45/33-14ccc	6- 2-64	56	51	.10	29	12	20	4.1	156	14	20	.1	2.2	.0	121	0	229	.8	.14	332	7.5
45/33-15bad	6- 7-64	61	55	.11	28	12	23	5.2	158	15	20	.2	2.2	.1	121	0	239	.9	.17	239	7.3
45/33-24bcc	6- 2-64	56	57	.53	40	18	23	5.1	154	32	49	.1	2.1	.0	176	50	302	.8	.00	460	8.1
45/33-24ccc	6-22-59	--	49	.05	30	12	17	3.0	171	11	9.9	.2	.6	.1	126	0	218	.7	.31	309	7.5
45/33-26bbc	6-22-59	--	64	.03	30	9.2	28	5.8	156	22	21	.1	1.7	.1	113	0	259	1.1	.30	353	7.5
45/34-7aaa	6- 2-64	61	40	.08	47	14	32	4.3	183	43	30	.4	.8	.1	174	24	302	1.1	.00	476	7.4
46/33-23bba	6-22-59	--	42	.05	31	11	26	2.9	157	22	19	.1	2.6	.1	122	0	235	1.0	.12	352	7.4
46/33-23caa	11- 2-60	--	46	--	28	12	21	2.4	175	11	6.0	.1	6.1	.1	120	0	219	.8	.47	331	7.5

1. Because all samples had pH values less than 8.2, the carbonate content is 0 ppm.

Table 11.--Field chemical analyses, in parts per million, of water from selected wells and streams

[Field analyses by the U.S. Geological Survey]

Location (well number)	Date of collection	Temperature (°F)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) plus Potassium 1/ (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	SAR	RSC	Specific conductance (micromhos at 25°C)	pH
42/33-10ddb	2-13-64	59	27	6.0	101	186	22	44	55	92	0	4.6	1.21	646	8.6
43/33-35aca	2-13-64	58	17	7.7	87	168	12	35	49	74	0	4.4	1.67	559	8.6
43/34-35	2-13-64	--	38	10	79	157	16	88	45	138	0	2.9	.34	650	8.5
44/33-25cca	2-13-64	--	40	7.5	49	161	14	32	35	131	0	1.9	.49	484	8.5
44/34-8bbc	2-13-64	--	76	31	56	216	0	75	131	318	141	1.4	.00	939	8.2
44/34-16bbb	2-14-64	--	33	12	31	184	0	20	20	133	0	1.2	.36	390	8.2
45/33-10bdc	2-14-64	--	35	13	24	130	8	21	36	140	20	.9	.00	404	8.5
45/33-24add	2-14-64	--	51	18	30	232	8	24	25	199	0	.9	.09	529	8.3
45/33-24bcc	2-14-64	--	33	11	33	150	11	24	22	126	0	1.3	.31	384	8.5
46/33-21ddc	2-14-64	54	33	14	10	140	0	15	23	140	26	.4	.00	397	8.2
46/33-34dda	2-14-64	--	26	9.7	24	160	0	12	10	105	0	1.0	.52	306	8.2
Streams															
China Creek	9-29-64	65	31	12	32	178	3	20	18	128	0	1.2	.46	379	8.4
Horse Creek	9-29-64	57	42	13	27	176	0	40	23	160	0	.9	.51	477	8.2
House Creek	9-29-64	69	19	11	12	120	0	8.0	8.0	92	0	.6	.13	228	7.9
Kings River	9-29-64	63	16	6.3	11	96	0	4.8	3.8	66	0	.6	.25	172	7.8
Log Cabin Creek	9-29-64	70	18	7.1	17	96	8	8.0	8.0	74	0	.9	.36	213	8.4
Thacker Creek	9-29-64	60	37	11	40	200	0	27	22	136	0	1.5	.56	407	8.2

1. Computed by difference.

several cycles of irrigation will increase the dissolved-solids content and in time may render the water unsuitable for irrigation.

Suitability for Domestic Use

The limits recommended by the U.S. Public Health Service (1962, p. 32) for water used on interstate carriers for drinking purposes commonly are cited as standards for domestic use. Most of the ground water and all the surface water sampled meet these requirements. Listed below are some of the chemical substances which should not be present in water in excess of the listed concentrations where more suitable supplies are available.

Substance	Concentration in ppm (parts per million)
Chloride (Cl)	250
Iron (Fe)	0.3
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Fluoride (F)	1.7
Total dissolved solids	500 (1,000 permitted)

Of the elements and compounds listed in table 10, only iron and nitrate occur in amounts significantly larger than those recommended by the U.S. Public Health Service. Wells 44/33-10dbb, 44/34-9bbb, and 45/33-24bcc yield water which contains 0.63, 2.4, and 0.53 ppm iron, respectively. Iron in excess of 0.30 ppm may impart a bitter and astringent taste to water and a brownish color to laundered goods. Water from well 44/33-10dbb contains 56 ppm nitrate, which is above the limits recommended by the U.S. Public Health Service. Methemoglobinemia, or "blue baby" disease, seems to be a possible hazard with water containing more than 45 ppm nitrate. This disease, however, is associated almost entirely with infants.

Excessive hardness of water, which is caused principally by calcium and magnesium, adversely affects its suitability for domestic use, especially for cooking and washing. The U.S. Geological Survey uses the following classification of water hardness:

Hardness range (ppm)	Classification
0-60	Soft
61-120	Moderately hard
121-180	Hard
Greater than 180	Very hard

As shown in tables 10 and 11, water in Kings River valley ranges from moderately hard to very hard. The range was from 66 ppm in Kings River to 382 ppm in well 44/33-10dbb.

Relation to the Flow System

Ground water in the Rio King subarea is derived largely from precipitation on the Bilk Creek and the Quinn River Mountains. The runoff from these mountains generally is a calcium bicarbonate type and is low in dissolved-solids content; dissolved solids range from 204 ppm in well 44/33-25cca to 302 ppm in wells 45/33-24bcc and 45/34-7aaa (pl. 1). As the water moves downgradient from north to south, the water changes to a sodium bicarbonate type, and the dissolved-solids content increases; dissolved solids range from 431 ppm in well 41/35-17abb to 1,180 ppm in well 42/33-32bad. This increase in dissolved solids probably is due to the greater distance the water has traveled from the recharge area. The change from calcium bicarbonate type water to sodium bicarbonate type water probably is due in part to base exchange, because the hardness content decreases from an average of about 127 ppm in the northern part of the valley to 70 ppm in water from well 41/35-17abb. However, as the water moves downgradient, an increase in sodium occurs by some process other than by base exchange. The increase may be caused by water moving through clay and silt deposits, which contain sodium soluble compounds.

Very little change was noted in the quality of water from wells which were sampled in 1958 (Zones, 1963, table 2) and 1964 (tables 10 and 11). This suggests that little or no recycling of return irrigation water has occurred as of 1964.

DEVELOPMENT IN THE RIO KING SUBAREA

The preceding sections of the report described the flow characteristics of the valley-fill reservoir under near natural equilibrium conditions. The large-scale development of ground water by pumping in the Rio King subarea upset this natural equilibrium by depleting storage in and near the area of development. The clearing of lands in phreatophyte areas for irrigation of crops and the decline of water levels in phreatophyte areas have reduced somewhat the natural discharge. As a result of the continued storage depletion, a nonequilibrium condition has developed in this part of the valley. Water levels will continue to decline as a new equilibrium is approached; the natural discharge by phreatophytes will decrease, and streamflow will be intercepted. If the net pumping draft exceeds the salvable discharge, the new condition of equilibrium will not be reached, and water levels eventually will decline to the economic limit. The simple hydrologic equation of non-equilibrium is:

$$\text{Inflow} = \text{Outflow} \pm \text{change in stored water}$$

The several elements of this equation are estimated and evaluated in the following sections of the report.

Pumpage

Prior to 1956, when the drilling of irrigation wells began, pumping was limited to a few domestic and stock wells. Between 1956 and 1963 approximately 100 irrigation wells were drilled, and most are shown on plate 1. Zones (1963, p. 20) estimated that the pumpage in 1956 and 1957 amounted to a few thousand acre-feet per year, but that in 1958 the pumpage from 23 wells increased substantially to about 17,000 acre-feet.

For 1963 most of the wells were powered electrically, and estimates of pumpage were based on the calculated number of kilowatt-hours required to pump 1 acre-foot of water. The annual pumpage was computed by dividing the total annual kilowatt-hours consumed at each pump by the kilowatt-hours required per acre-foot of pumpage. Of the wells tested, the number of kilowatt-hours per acre-foot ranged from 129 to 350 and averaged about 250. Electrical energy consumed in 1963 was about 4,200,000 kilowatt-hours, enough to pump about 17,000 acre-feet of water. Estimated pumpage by pumps driven by internal-combustion engines was between 4,000 and 5,000 acre-feet. Total pumpage in 1963 was about 22,000 acre-feet. Total pumpage for the 7-year period 1957-63 was about 110,000 acre-feet (table 12). Figure 7 shows the areal distribution of the gross pumpage for the same period.

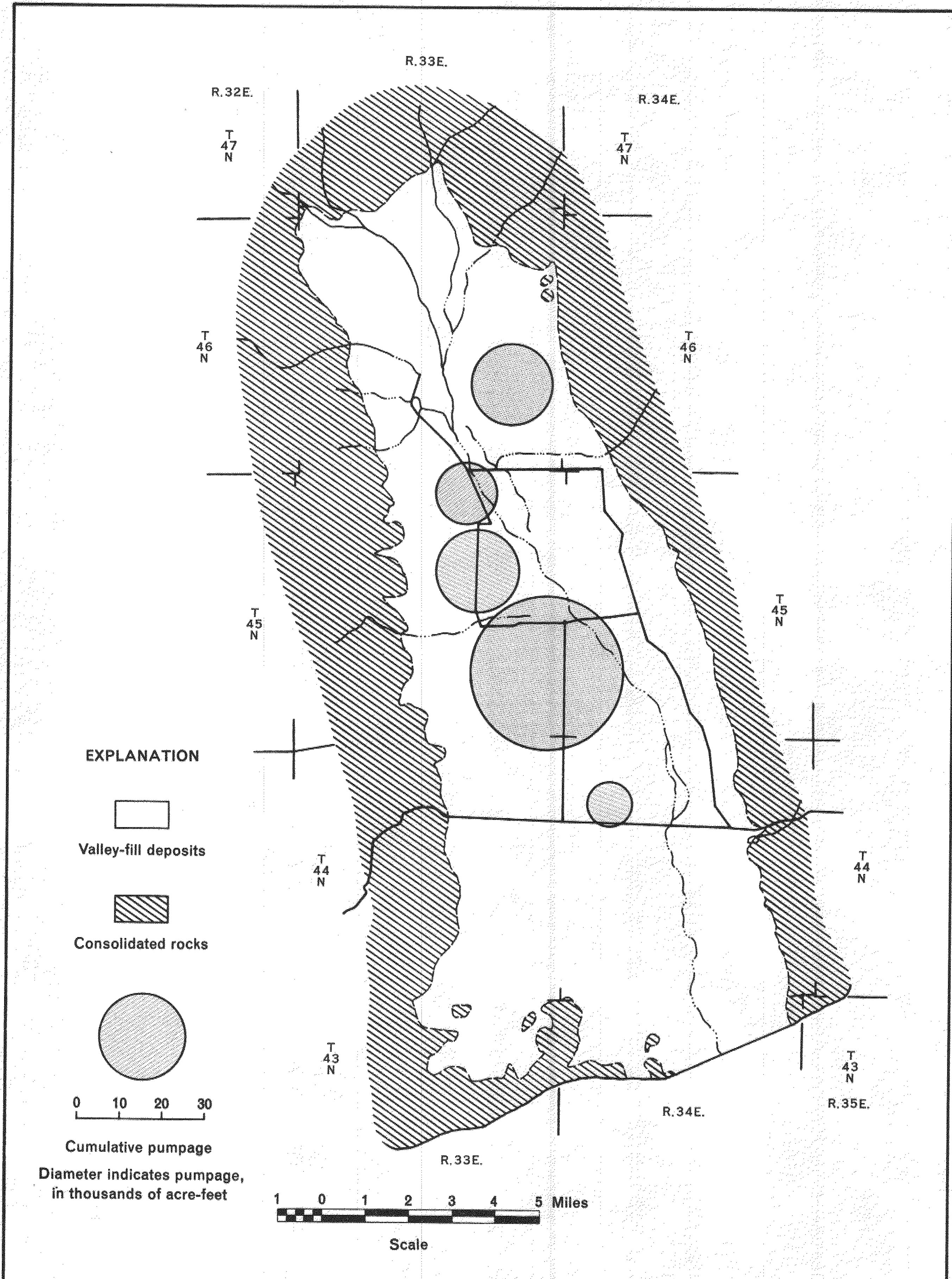

Figure 7.—Approximate cumulative pumpage in the Rio King subarea, 1957-63

Pumpage for domestic and stock use was only about 100 to 200 acre-feet per year, which is well within the probable limits of error of the estimated pumpage for irrigation. Thus, the annual pumpage shown in table 12 can be considered to be the total pumpage for the Rio King subarea.

In other areas the amount of the pumped water that returns to ground water by deep percolation below the roots of crops commonly ranges from 25 to 40 percent of the gross pumpage (Thomasson and others, 1960). Accordingly, for this area, where most crops are flood or ditch irrigated, the net pumping draft, or water permanently removed from the valley-fill reservoir, is assumed to be two-thirds of the gross pumpage. Thus, net pumpage for the 7-year period 1957-63 was about two-thirds of 110,000 acre-feet, or roughly 75,000 acre-feet (table 12).

Figure 8 shows the irrigated cropland and land cleared for irrigation in 1964. Eighteen farms, ranging in size from 320 to more than 15,000 acres, irrigated about 9,300 acres from ground and surface water in 1963. This is the gross acreage, which includes the area occupied by ranch houses, barns, work areas, access roads, and head ditches. The net acreage would be about 5 percent less. Principal crops and approximate acreages irrigated by ground water include hay, 4,300 acres; seed alfalfa, 1,200 acres; grain, 1,650 acres; and corn, 400 acres; the total was about 7,600 acres. The gross pumpage was about 22,000 acre-feet, which suggests an average duty of water of about 3 acre-feet per acre. As previously mentioned, the remaining 1,700 acres is native grassland irrigated from streams and springs.

The lands having the best soils in the northern part of the area have been developed. Most of the remaining land suitable for cultivation lies along the margins. Development of these lands is continuing together with the development of more water; more wells are being drilled each year.

The Nonequilibrium Condition

Water-Level Decline, 1957-64

Water-level fluctuations over a period of time are the result of an imbalance between recharge to and discharge from the ground-water reservoir and represent changes of ground water in storage. This is the physical result of the nonequilibrium condition. If recharge to the ground-water reservoir exceeds discharge, the surplus water goes into storage, causing water levels to rise. On the other hand, if discharge exceeds recharge, the deficit is made up by the removal of ground water from storage, causing water levels to decline.

The water levels over an ever-increasing area in the Rio King subarea have been declining since the beginning of large withdrawals in 1958, and the

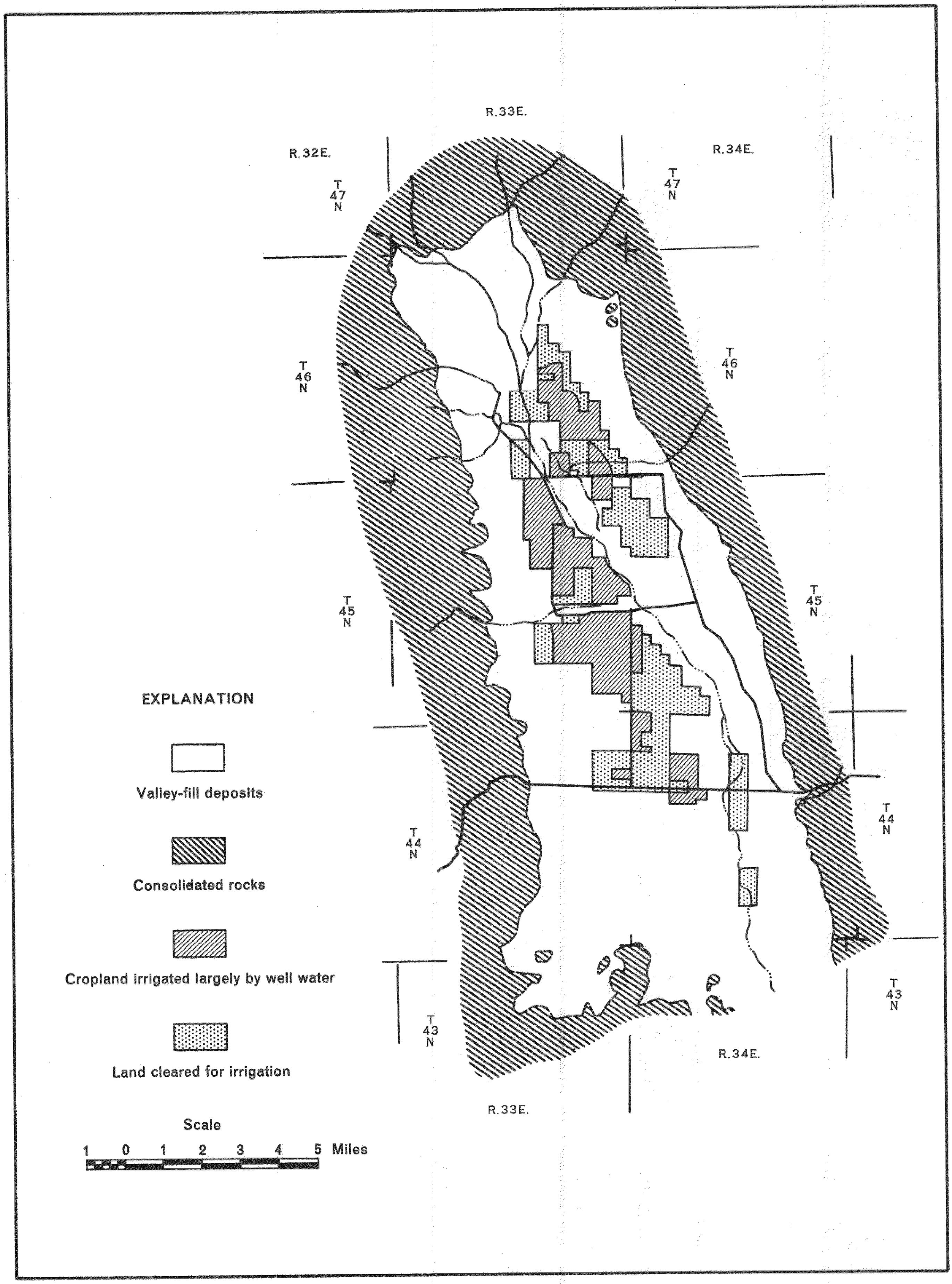

Figure 8.—Irrigated cropland and land cleared for irrigation, 1964

Table 12.--Estimated pumpage for irrigation, in acre-feet, in the Rio King subarea

Year	Gross pumpage	Net pumping draft [1]
1957	a 3,000	2,000
1958	a 17,000	11,000
1959	b 17,000	11,000
1960	b 19,000	13,000
1961	b 14,000	9,000
1962	b 18,000	12,000
1963	c 22,000	15,000
Total (rounded)	110,000	75,000

1. Assumed to be about two-thirds of the gross pumpage.

a. From Zones (1963, p. 20).

b. Estimates based largely on information provided by local ranchers.

c. Estimated largely from electric power consumption.

greatest declines are in the areas where the largest withdrawals have occurred. Using the data compiled by Zones (1963, figs. 2 and 3), maximum water-level declines between near natural conditions in the spring 1958 and early pumping conditions in 1959 were about 10 feet in the central and northeastern parts of the Rio King subarea. Comparison of the 1958 and 1964 water-level surfaces (Zones, 1963, fig. 2, and pl. 1 of this report) indicates that a moderate net decline in water levels had occurred. Because pumpage in 1957 was small (Zones, 1963, p. 20), the net change for the period 1958-64 is considered to be about the same as for the period of this analysis, spring 1957 to spring 1964.

Figure 9 is a net-change map for the period 1957-64 and shows the area and magnitude of the water-level decline in the Rio King subarea caused by pumping. The maximum declines in and near the centers of pumping are 30 to 40 feet. The smallest net declines in the area of pumping, not much more than 10 feet, occurred beneath the Kings River channel, which during times of flow, forms a line source of recharge, or a recharge boundary. The weighted average areal net decline for the Rio King subarea was between 10 and 11 feet.

Storage Depletion

The amount of the storage depletion in the Rio King subarea from the time pumping began through the 1963 irrigation season is the product of the volume of the valley-fill reservoir dewatered and the specific yield of the deposits. From figure 9 the volume dewatered can be computed as the area inside the zero net-change contour, which is about 37,000 acres, times the average weighted areal water-level decline, which is about 10 1/2 feet, or nearly 400,000 acre-feet. This volume times the estimated specific yield of 17 percent (table 9) provides an estimate of storage depletion of about 65,000 acre-feet for the period spring 1957 to spring 1964, which spans the 7 pumping seasons in the years 1957-63.

The estimated net pumping draft during the same period was 75,000 acre-feet (table 12). When compared to the storage depletion of 65,000 acre-feet, most of the pumpage was derived from ground water stored in the valley-fill reservoir.

The effects of pumping locally have extended to and possibly beyond the boundaries of the valley-fill reservoir. Figure 9 shows that the net decline for the period 1957-64 along the northeastern boundary amounted to a maximum of about 25 feet; along the western boundary, to more than 10 feet. Thus, some additional storage depletion may have occurred in the volcanic rocks along the sides of the valley, but the amount of this depletion is not evaluated at this time.

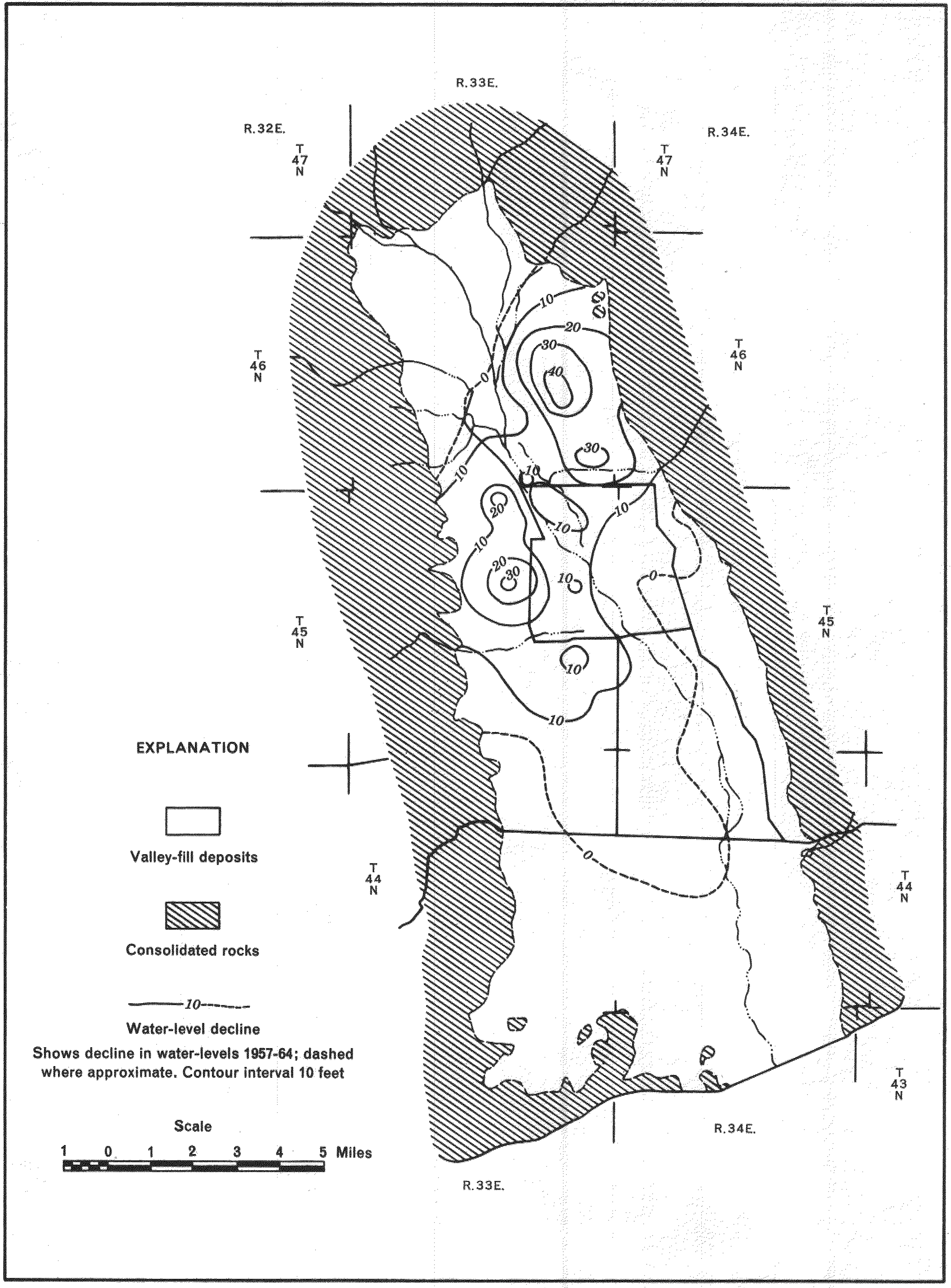

Figure 9.—Approximate net decline of water levels in the Rio King subarea, 1957-64

Decrease in Evapotranspiration

Table 7 shows that for the Rio King subarea under near-natural conditions the estimated ground-water discharge by evapotranspiration from 29,000 acres of phreatophytes amounted to about 9,400 acre-feet per year. In the period 1957-63, nearly 4,000 acres of phreatophytes were eliminated by land clearance and replaced by irrigated crops. In addition, the water level beneath roughly 20,000 acres of phreatophytes declined an average of about 10 feet. Assuming nearly 100 percent transfer of natural evapotranspiration losses to consumptive use by crops in the irrigated areas and assuming a 20 percent reduction of evapotranspiration losses in the remaining area of water-level decline, the salvage in 1963 amounted to between 1,200 and 1,500 acre-feet. Thus, evapotranspiration losses in 1963 probably were about 8,000 acre-feet compared to 9,400 acre-feet under natural conditions from the same area.

Ground-Water Budget, 1957-64

The ground-water budget for the period 1957-64 compares the inflow and outflow estimates, except runoff, for the seven years 1957-63 to the estimated net change in stored water from spring 1957 to spring 1964. Thus, the difference (3) in table 13 is for a slightly different period than the storage depletion (4).

A water budget for a selected period of time should utilize the measured or estimated elements of inflow and outflow for each year of the budget period. For the period 1957-63, annual estimates of most budget elements have been made for the Rio King subarea. However, none could be made for the runoff to the valley-fill reservoir, except an estimate of the long-term average, which is used in table 13.

Rainfall during the period 1957-63 at Orovada averaged 11.33 inches, or about 5 percent above the long-term average of 10.76 inches (fig. 3). Thus, the runoff to the valley-fill reservoir probably was somewhat larger than the long-term average shown in table 13.

Table 13 shows the ground-water budget for the Rio King subarea for the 7-year period 1957-63. During this period of ground-water development and storage depletion, the estimated discharge exceeded recharge by about 53,000 acre-feet. The estimated storage depletion, computed independently, was 65,000 acre-feet. If all estimates of inflow, outflow, and storage change were accurate, values (3) and (4) in table 13 should agree. The imbalance of 12,000 acre-feet, which averages about 1,700 acre-feet per year, is due to errors in the estimates. The most likely errors are in the larger estimates, principally runoff, evapotranspiration, and net pumpage. For the reason given above, runoff for the budget period probably is low, which would make the budget even more in error.

Table 13.--Ground-water budget, in acre-feet, for the Rio King subarea, 1957-64

Budget element	7-year period
INFLOW:	
Runoff to valley-fill reservoir (table 8)	a 110,000
Ground-water inflow across bedrock-alluvial contact (p. 26)	6,000
Total (1):	116,000
OUTFLOW:	
Evapotranspiration (table 7 and p. 42) 1/	62,000
Net pumping draft (table 12)	75,000
Surface-water diversions (table 8)	18,000
Springs (table 8)	(b)
Surface-water outflow (table 8)	7,000
Ground-water outflow (table 8)	7,000
Total (2):	169,000
DIFFERENCE (3): (1) - (2)	- 53,000
STORAGE DEPLETION (p. 42) (4):	- 65,000
IMBALANCE BETWEEN METHODS: (3) - (4)	12,000

1. Based on an average annual loss of 8,900 acre-feet.

a. Based on long-term average rather than on runoff during the period 1957-63.

b. Included in evapotranspiration and surface-water diversions.

PERENNIAL YIELD

Basic Concepts

The perennial yield of a ground-water reservoir may be defined as the maximum amount of water of usable chemical quality that can be withdrawn and consumed economically each year for an indefinite period of time. If the perennial yield is continually exceeded, water levels will decline until the ground-water reservoir is depleted of water of usable quality or until the pumping lifts become uneconomical to maintain. Perennial yield can not exceed the natural recharge to or discharge from an area. Most pertinent is the fact that the perennial yield ultimately is limited to the maximum amount of natural discharge that can be economically salvaged for beneficial use.

The concept of perennial yield in the development of a ground-water basin is three-fold: (1) In a state of nature before pumping begins, the hydrologic system is in an equilibrium condition--recharge equals natural discharge and over the long term no change in stored water occurs; (2) after pumping starts, the system is in a nonequilibrium condition--natural discharge plus pumpage exceed recharge; the deficit over the years is made up by a substantial depletion of stored water; and (3) if the net pumping draft is held to a rate about equal to the salvable natural discharge and most critical, if the distribution and amount of the pumpage are strategically situated so as eventually to reduce the salvable natural discharge to zero, then the system attains a new equilibrium--recharge equals net pumping draft, natural discharge is virtually zero, and over the long term no change in storage occurs.

The amount of time that it takes to make the full transition from equilibrium under natural conditions to the new equilibrium under pumping conditions is largely a function of the annual pumping rate and the amount of stored water that must be removed to terminate the salvable natural discharge. Ordinarily the time involved is measured in decades, provided that the annual net pumping draft is maintained at a rate roughly equal to the perennial yield.

What has happened in Kings River valley is typical of most ground-water basins in the west: In developing the area, the conditions set forth in item (3) above are disregarded. As estimated in quantitative terms in table 8, evapotranspiration and other natural water losses occur in both the Rio King and Sod House subareas. Yet all the pumpage is concentrated in the Rio King subarea where pumping never will affect materially the natural discharge in the southern part of the Sod House subarea. This type of concentrated development commonly leads to a paradox where local overdraft occurs in one part of the valley while at the same time an excess, or water available for development by pumping, goes to waste in another part of the same valley.

Valley-Fill Reservoir

For Kings River valley, the estimated total natural outflow averages about 20,000 acre-feet per year (table 8). As mentioned, the perennial yield is limited to the maximum amount of natural discharge that can be economically salvaged. The estimated maximum salvage over the long term, if pumpage were strategically distributed throughout the valley, would include most of the evapotranspiration losses, roughly half the surface-water diversions, possibly half the surface-water and ground-water outflow at the southwest corner of the area, and little or none of the spring discharge (table 8). Thus, the estimated perennial yield of the entire valley-fill reservoir is computed to be about 17,000 acre-feet, or about 85 percent of the estimated discharge.

About half the surface-water diversions are included in the yield, because these diversions are on the valley floor. As water levels are drawn down by pumping, much of the moderate to low flows of the streams would sink into the stream channels before reaching the points of diversion. In other words, those ranchers now depending on streamflow to irrigate crops in areas that will be affected by pumping probably would have to drill wells and pump water. Moreover, some of these lands now in part are subirrigated by ground water, but in the future as water levels are drawn down, more irrigation water would be required to raise the same crops. Similarly, about 1,000 acres of native hay almost wholly supported by subirrigation would require irrigation from wells (table 7). On the other hand, spring flow probably would remain unaffected by the development.

If the 17,000 acre-feet were to be developed in proportion to where the salvable discharge occurs and more or less concurrently throughout the valley, the approximate distribution would be 10,000 acre-feet in the Rio King subarea and 7,000 acre-feet in the Sod House subarea. However, as of 1964, development in the Sod House subarea does not seem imminent.

The substantial development near Orovada in the adjacent Quinn River valley may in time reduce the ground-water and surface-water outflow to the Sod House subarea, estimated to total about 5,300 acre-feet per year (table 8). The yield of the subarea would be reduced in about the same proportion as the reduction in outflow from Quinn River valley.

Rio King Subarea

Because ground-water development has not been ideally distributed throughout the valley-fill reservoir, as just described, the available supply in the Rio King subarea is critical to the agricultural growth and economy of the area. Nearly all rights to pump additional water have been granted in this subarea. The estimated yield of 10,000 acre-feet per year under conditions of valley-wide development would be somewhat less than the yield if nearly all the future pumpage continues to be concentrated in this part of the valley. Assuming that future development is limited to the Rio King subarea, the yield would be increased by the additional amount of natural discharge (outflow) that could be salvaged.

Although the extent and magnitude of future pumping effects are difficult to predict, the water-level change between 1957 and 1964 provides a guideline to the future (fig. 9). Pumping effects have already reached the sides of the valley-fill reservoir. As pumping continues, the area affected will extend farther northward and southward. In time, the effects probably will extend southward several miles into the Sod House subarea. Although the additional amount of natural discharge that would be salvaged is also difficult to foretell, the preliminary estimate is on the order of 2,000 acre-feet per year. This would be largely by reduced evapotranspiration loss in the northern part of the Sod House subarea and in small part by reduced subsurface outflow from the Rio King subarea to the Sod House subarea.

The above analysis and assumptions suggest that the yield of the Rio King subarea, with no development in the Sod House subarea, is roughly 12,000 acre-feet per year. In other words, by concentrating all the pumping in this part of the valley, only about two-thirds of the potential yield of Kings River valley will be realized.

Overdraft in 1963

Overdraft of a ground-water reservoir may be defined as the amount by which the net pumping draft exceeds the perennial yield. Similarly, local overdraft is the amount by which the net pumping draft in a given part of a ground-water reservoir, such as the Rio King subarea, exceeds the local yield. If pumping were ideally distributed throughout the Kings River valley so as eventually to salvage most of the natural discharge, as previously described, no overdraft would occur until the net pumping draft exceeded about 17,000 acre-feet per year. Similarly, if pumping were limited only to the Rio King subarea, which it has been, no local overdraft would occur in the subarea until the net pumping draft exceeded about 12,000 acre-feet per year.

In 1963 the estimated net pumping draft in the Rio King subarea was roughly 15,000 acre-feet (table 12), or roughly 3,000 acre-feet more than the estimated local yield of 12,000 acre-feet. Moreover, the local yield probably was equaled or slightly exceeded in 1960 and 1962 (table 12).

FUTURE DEVELOPMENT

Exercise of Existing Water Rights

Rights to pump about 60,000 acre-feet per year of ground water in the Rio King subarea have been granted by the State of Nevada. Exercise of all these rights would result in a net pumping draft of roughly 40,000 acre-feet per year. This is more than three times the estimated yield of the Rio King subarea.

If an overdraft of this magnitude should occur, a new equilibrium between inflow and net pumping draft never could be achieved. A continued net pumping draft that exceeds inflow by nearly 30,000 acre-feet per year would cause a continued and moderately rapid depletion of stored ground water, water levels would become progressively deeper, and pumping lifts and hence costs would increase.

At the same time, water levels and natural discharge in the Sod House subarea would be only slightly affected by the local overdraft in the Rio King subarea. Thus, in the Sod House subarea, approximately 5,000 to 6,000 acre-feet per year would waste in the future as it does today.

Storage Depletion in the Rio King Subarea

Pumping during the period 1957-63 resulted in a net decline of water levels of more than 30 feet in the pumping center along the west side of the Rio King subarea and more than 40 feet in the pumping center along the east side. Storage depletion totaled about 65,000 acre-feet for the period.

If all the permitted rights to pump about 60,000 acre-feet per year were exercised by 1973 (10 years hence) and if the increase in pumpage between 1963 and 1973 were reasonably uniform, storage depletion (1957-73) could be on the order of 250,000 acre-feet. This estimate is based on several major factors: (1) evapotranspiration losses would continue to decrease and would become negligible by 1973; (2) ground-water and surface-water outflow would decrease to about one-half their present average amount; (3) surface-water diversions would be decreased to about half the 1963 rate; and (4) inflow during the 10-year period would be about the same as the long-term average. Obviously, storage depletion would be considerably greater if the 10-year period were of below-average wetness, and of course the converse would be true.

In terms of water-level decline, a storage depletion on the order of 250,000 acre-feet is equivalent to a subarea-wide decline of nearly 20 feet, based on the estimates in table 9. However, in the centers of pumping, the actual declines probably would be more than 100 feet below the March 1964 levels (pl. 1) and less than 20 feet in those parts of the subarea remote from pumping.

Economic Effects

Pumping costs increase in about the same proportion as pumping lifts. In 1963 the average number of kilowatt-hours required to pump one acre-foot was about 250; the average pumping lift was about 125 feet. If the average lift should double by 1973, the average number of kilowatt-hours required to pump an acre-foot of water also would about double, provided that well and pumping plant efficiencies were to remain about the same as in 1963.

Pumping in the Rio King subarea results in the mutual interference among the water-level drawdowns in adjacent pumped wells. This will happen in any area where substantial development has occurred. However, the magnitude of the interference in large part is controlled by the distance between pumped wells; that is, the closer together the wells the greater the interference drawdowns and, of course, pumping costs.

CONCLUSIONS

This second water-resources appraisal of Kings River valley has developed several pertinent conclusions with respect to the adequacy of the supply and leads to several additional conclusions regarding the kinds and types of data needed to refine the flow system and response characteristics of the valley-fill reservoir:

1. All the development to date and all the applications for future development are in the Rio King subarea, or northern half of the valley, where the ground-water supply over the long term is estimated to average about 12,000 acre-feet per year.

2. The net pumping draft in the Rio King subarea in 1963 exceeded this estimated yield by about 3,000 acre-feet. If all the permitted rights to pump ground water are exercised, about 60,000 acre-feet per year of gross pumpage (roughly 40,000 acre-feet net draft), the yield would be exceeded by between 25,000 and 30,000 acre-feet per year.

3. Pumping eventually will affect the surface-water rights in areas where shallow ground water occurred in 1963 in the valley-fill reservoir. As water levels are drawn down in Rio King subarea, all or part of the streamflow and stream diversions in these areas will seep into the channels before reaching the irrigated lands. Of the total diversions of about 2,500 acre-feet per year, possibly half will become ground-water recharge in the future.

4. In the Rio King subarea nearly all the estimated net pumping draft of 75,000 acre-feet from 1957 through 1963 was supplied from stored ground water (table 12). A small amount, probably less than 5,000 acre-feet, was by the salvage from phreatophyte use.

5. Much of the future pumpage will be derived from stored ground water --on the order of 250,000 acre-feet for the period 1957-73, if pumpage should increase steadily to 60,000 acre-feet per year by 1973 Should this occur, pumping lifts and hence costs might be about double those of 1963.

6. The first approximation of transmissibility distribution is shown in figure 3. For storage coefficient, the use of a value of 0.17 (or a specific yield of 17 percent), when applied to the volumetric depletion, provided reasonably good agreement with the water-budget method.

7. It is obvious that the continued growth of pumpage will lead to an increasing overdraft and accelerated rates of water-level decline in and near the large areas of substantial ground-water withdrawals.

Because the increase in pumpage for irrigation is widespread rather than localized, general projections of the cause-and-effect relations in the Rio King subarea could be approximated when needed by those concerned with administration and management of water resources.

8. Future refinement of the cause-and-effect relations will require reasonably accurate records of the annual pumpage, periodic water-level measurements in most wells, preferably in the spring before pumping begins, streamflow measurements on the major streams, magnitude of and change in the spring and stream diversions, and quality of ground water in the irrigated areas. A reappraisal, possibly in 1973, would need these data to determine the extent of the overdraft and storage depletion in the Kings River valley.

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Table 14.--Records of selected wells in Kings River valley

Use: D, domestic; I, irrigation; O, observation; S, stock.
Yield: In gallons per minute (gpm).
Altitude: Land-surface datum interpolated from U.S. Geol. Survey topographic maps.
Water-level measurements: Depth to water in feet below land-surface datum; a few may be pumping levels.
Log number: Number in files of the State Engineer; L, log of U.S. Geol. Survey test well.

Well number	Owner or lessee	Year drilled	Depth (feet)	Diameter (inches)	Use	Yield(gpm)/ drawdown (feet)	Altitude (feet)	Water-level measurement Date	Water-level measurement Depth	State log number
41/33- 3bba	U.S. Geol. Survey, test well 19	1963	102	2	O	- -	4118	9-19-63	14.53	L
4baa	- -	1949	350	6	O	- -	4103	do.	2.70	1204
10bbb	U.S. Geol. Survey, test well 17	1963	45	2	O	- -	4115	do.	12.04	L
41/34- 6bb	do. do. 18	1963	43	2	O	- -	--	do.	14.91	L
13d	Nev. Highway Dept. (?)	1949	160	8	-	100/--	4121	do.	9.56	1202
41/35-17a	P. Lueder	1950	80	16	I	80/3	4126	do.	11.60	1597
20a	do.	1951	112	16	I	- -	--	--	- -	--
42/33-10dd	Bur. Land Management	--	220	6	S	- -	4143	9-19-63	31.68	5668
21d	U.S. Geol. Survey, test well 1	1963	52	2	O	- -	4120	do.	19.99	L
32bad	do. do. 21	1963	88	2	O	- -	--	do.	21.18	L
42/34- 4bab	do. do. 4	1963	102	2	O	- -	4113	do.	.34	L
12dd	do. do. 7	1963	34	2	O	- -	4120	do.	14.20	L
26dd	Bur. Land Management	--	229	6	S	- -	--	do.	11.92	--
42/35-19a	Cleto	--	--	10	O	- -	4132	do.	12.98	--
43/33-35a	Bur. Land Management	1962	--	6	S	- -	--	do.	41.98	--
43/34- 1c	U.S. Geol. Survey, test well 9	1963	69	2	O	- -	4144	do.	15.52	L
10c	do. do. 6	1963	23	2	O	- -	4144	do.	16.15	L
13b	Bengoa Bros.	--	76	6	S	- -	4135	do.	11.31	--
28db	Coyote Point well	--	--	-	S	- -	4125	do.	.48	--
35a	U.S. Geol. Survey, test well 5	1963	102	2	O	- -	4123	do.	9.93	L

Table 14.--Continued

Well number	Owner or lessee	Year drilled	Depth (feet)	Diameter (inches)	Use	Yield (gpm)/ drawdown (feet)	Altitude (feet)	Water-level measurement Date	Water-level measurement Depth	State log number
43/35-30bc	U.S. Geol. Survey, test well 8	1963	23	2	O	- -	4131	9-19-63	11.82	L
31cdd	Bengoa Bros.	--	236	8	S	- -	4131	do.	9.51	--
44/33-10cac	Dan Ugoldi	--	60	16	I	- -	--	1- -59	11.18	--
10dbb	do.	--	--	6	S	- -	4324	do.	15.57	--
12bbb	Homer Tyler	1961	590	16	I	2640/70	4225	do.	56.30	6492
12cbb	Barbara Gildersleeve	1961	500	16	I	3000/82	4220	do.	51.93	6486
12ddd	U.S. Geol. Survey, test well 14	1963	72	2	O	- -	4188	do.	28.50	L
25cca	Bur. Land Management	--	--	6	S	- -	4171	do.	30.13	--
44/34- 5bcc	June Braidy	1959	358	16	I	3000/72	4190	9- 5-62	20.95	5739
6abb	Hazel Till	1961	395	16	I	3410/93	4196	9-19-63	23.52	6491
6bbb	Leonard Olson	1960	370	16	I	3000/70	4203	--	--	5199
7bbb	Warren Scott	1961	347	16	I	1440/141	4195	do.	27.73	6484
7cbb1	Norma J. Scott	1960	425	16	I	1860/109	4191	do.	29.18	6485
7cbb2	do.	1960	--	-	-	- -	4191	--	--	--
8abb	Helen Pettibone	1959	210	16	I	2050/--	4185	9-19-63	21.63	4909
8bbb	Pettibone	--	--	-	-	- -	4188	--	--	--
8bbc	do.	1959	222	16	I	2000/70	4187	9-19-63	22.82	4946
9aaa	Gladys Scott	1962	346	18	I	4040/74	4178	do.	20.07	7202
9bbb	Drake	--	--	16	I	- -	4179	do.	13.14	--
16aaa	Carolyn Hobbs	1962	415	16	I	4000/120	4178	do.	26.10	7195
16bbb	M. H. Pettibone	1959	250	16	I	2000/70	4175	do.	19.09	4856
17abb	Ralph Johnson	1959	215	16	I	2000/70	4179	do.	22.47	4965
17bbb	do.	1959	224	16	I	1700/35	4179	4- 4-63	20.46	4818
18abb	Rose M. Frank	1958	335	18	I	2000/59	4182	do.	21.98	4271
19cad	U.S. Geol. Survey, test well 13	1963	102	2	O	- -	4170	9-19-63	24.60	L

Table 14.--Continued

Well number	Owner or lessee	Year drilled	Depth (feet)	Diameter (inches)	Use	Yield (gpm)/drawdown (feet)	Altitude (feet)	Water-level measurement Date	Water-level measurement Depth	State log number
44/34-20aab	Lee Eliss	1958	217	16	I	- -	4171	9-19-63	20.09	4544
27acc	U.S. Geol. Survey, test well 12	1963	44	2	O	- -	4168	do.	21.94	L
27bab	John Scott	1962	360	18	I	4000/79	4164	do.	21.85	7203
32dcd	U.S. Geol. Survey, test well 11	1963	23	2	O	- -	4156	do.	17.99	L
34ccc	Bengoa Bros.	1948	62	2	O	- -	4152	do.	17.52	381
35dd	do.	--	76	6	S	- -	4156	9- -59	21.10	--
45/33- 1dad	Ed Fox	1961	422	16	I	2420/108	4279	9-19-63	48.48	6488
3bbd	Rio King, well 13	1958	595	16	I	2200/105	4320	do.	109.17	4561
3cba	L. D. Alcorn & Lewis, well 6	1960	600	16	I	- -	4318	do.	125.80	5226
3ddb	Belle Curtis & Lewis, well 7	1959	710	16	I	3700/110	4239	9- -59	50.24	4560
10bdc	Ed Lewis, well 8	1959	880	16	I	- -	4316	9-19-63	119.75	4581
11bbb	Rio King, well 25	1959	400	16	I	3000/55	4277	do.	74.86	7195
12bcb	- -	--	--	6(?)	-	- -	4258	do.	27.55	--
13bcb	Bengoa Bros, well 2	1961	505	16	I	- -	4249	do.	pumping	6443
14bbc	C. M. Rocca, well 8	1957	400	16	I	1500/33	4272	4- 4-63	71.40	3811
14cbb	Archie L. Till, well 6	1957	410	16	I	1000/21	4275	9-19-63	94.24	3812
14ccc	Clifford V. Scott, well 15	1958	400	16	I	2600/120	4271	do.	86.10	4823
15bad	Belle Curtis, well 23	1959	500(?)	16	I	- -	4303	do.	93.27	4559
23cbd	Rio King, well 14	1959	323	16	I	- -	4265	do.	pumping	4564
24acc	do. well 1	1956	748	16	I	2000/22	4229	do.	34.78	3714
24ada	Bengoa Bros.	--	--	6	S	- -	4225	do.	22.00	--
24adc	H. Scott	--	--	14	S	- -	--	1- -59	2.36	--
24add	do.	--	--	16	D	- -	--	9-19-63	32.14	--
24bcc	Rio King, well 2	--	410	16	I	- -	4236	do.	45.24	3714
24ccc	do. well 3	1956	466	16	I	2500/62	4236	do.	61.15	3715
24ddd	do. well 26	--	--	-	-	2340/--	4220	do.	32.64	--
25/cbb	do. well 16	1958	470	16	I	3100/110	4236	do.	66.88	4303
26acb	do. well 17	1958	557	16	I	2700/76	4257	4- 4-63	74.50	4588

Table 14.--Continued

Well number	Owner or lessee	Year drilled	Depth (feet)	Diameter (inches)	Use	Yield(gpm)/ drawdown (feet)	Altitude (feet)	Water-level measurement Date	Water-level measurement Depth	State log number
45/33-26bbc	Rio King, well 18	--	601	16	I	- -	4289	9-19-63	120.20	4589
36bbb	Grace Harwood	1959	400	16	I	2580/--	4232	do.	70.02	4847
45/34- 7aaa	J. Diana Rocca, well 28	1960	478	16	I	- -	4275	do.	46.63	6487
7daa	Helen Cauley, well 36	1961	595	16	I	- -	4249	do.	20.77	7200
29abb	G. Kidd	1955	150	6	S	- -	4204	do.	14.22	3125
30bcc	Rio King, well 7	--	282	16	I	- -	4217	do.	29.87	--
31ab	Joseph Brady, well 27	1960	345	16	I	2500/--	4205(?)	do.	20.06	7197
31bbb	Stanley D. Scott, well 30	1960	395	16	I	- -	4209	do.	29.13	6490
46/33-15cc	Bengoa Bros.	1949	122	12	I	50/5	4391	do.	7.10	1103
21ddc1	do.	1960	460	16	I	600/79	4360	do.	23.08	6440
21ddc2	do.	1960	25	6	D	- -	4352	9- -59	3.82	--
23bba	Rio King, well 21	1959	670	16	I	1250/--	4373	9-19-63	100.70	4562
23caa	Marilyn Knaub, well 20	1958	580	16	I	3000/150	4361	do.	103.30	4558
25bca	Bengoa Bros.	--	--	16	I	- -	--	do.	116.73	--
26aba	J. Steckle, well 22	1957	800	16	I	- -	4342	do.	84.83	3966
26cab	Fred Van Dyke, well 10	1957	400	18	I	- -	4321	4- 4-63	47.90	3962
26dac	Rio King, well 19	1958	585	16	I	3000/100	4311	9-19-63	54.83	4557
27aaa	Jake Steckle, well 11	--	800	18	I	- -	4337	do.	48.77	4805
27bbc	Bengoa Bros.	--	72	6	D	15/--	4337	do.	13.99	--
34aac	do.	--	--	-	-	5/--	4307	9- -59	16.66	--
34bda	U.S. Geol. Survey, test well 15a	1963	--	-	O	- -	4310	9-19-63	70.58	L
34dda	Rio King	1960	--	-	I	2240/88	4294	4- 4-63	54.27	6439
34dda2	Bengoa Bros.	--	42	3	D	- -	4294	10- 2-47	22.10	--
35acb	- -	--	--	-	-	- -	4299	9-19-63	65.37	--
35ccd	do.	--	--	-	-	- -	4290	do.	24.75	--
36bca	Rio King, well 9	1958	580	16	I	3000/--	4310	do.	68.32	4556

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF NEVADA
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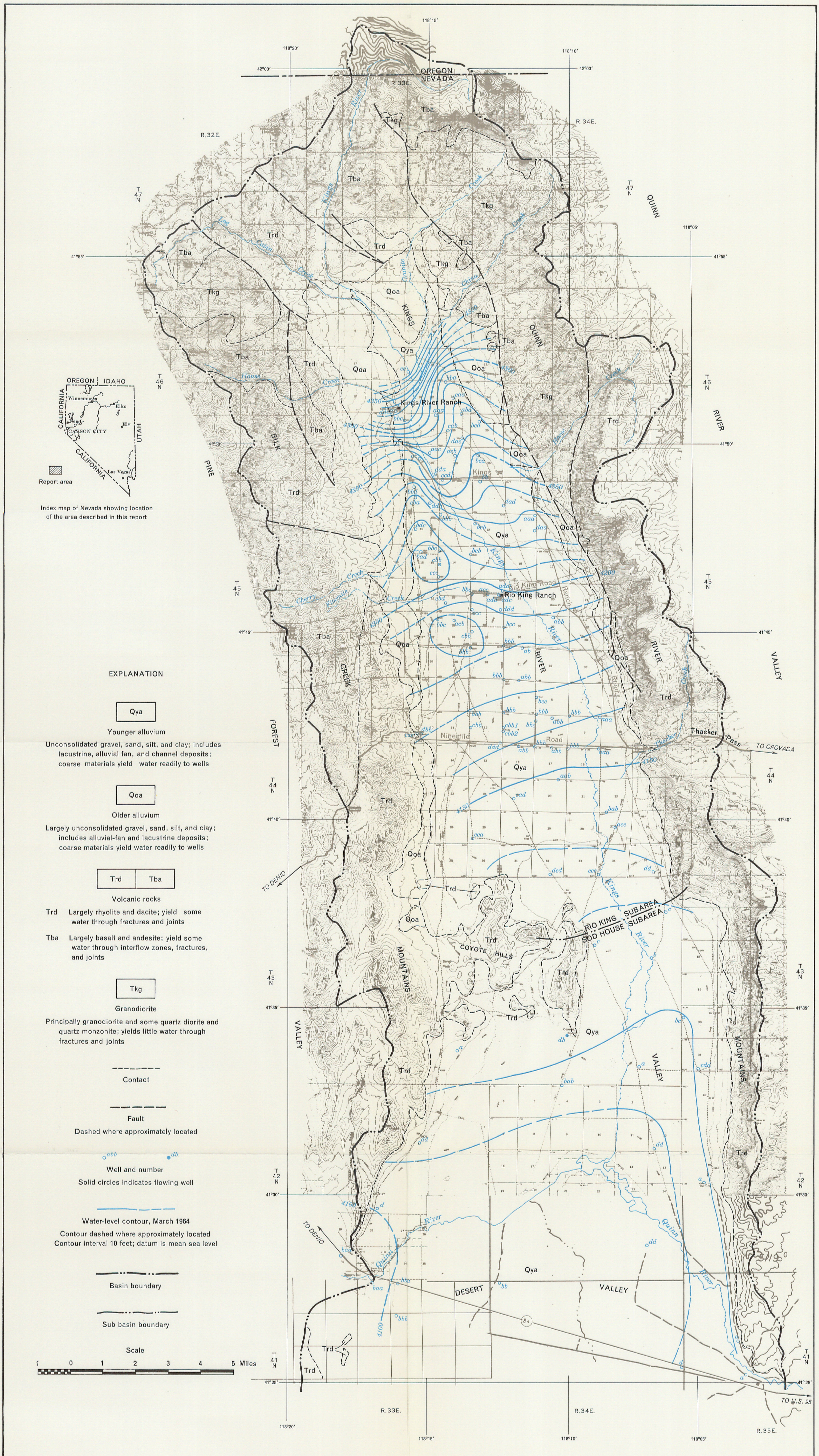

PLATE 1.—GENERAL GEOLOGY, WATER WELLS AND WATER-LEVEL CONTOURS FOR MARCH 1964