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HYDROLOGIC RESPONSE TO IRRIGATION PUMPING IN HUALAPAI FLAT, WASHOE, PERSHING, AND HUMBOLDT COUNTIES, NEVADA, 1960-67

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With section on Surface Water

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Prepared cooperatively by the

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HYDROLOGIC RESPONSE TO IRRIGATION PUMPING IN HUALAPAI FLAT, WASHOE, PERSHING, AND HUMBOLDT COUNTIES, NEVADA, 1960-67

By James R. Harrill

ABSTRACT

This second appraisal of the water supply of Hualapai Flat was made five years after an initial reconnaissance study. The first report by Sinclair (1962) described the ground-water flow system under near natural conditions and estimated recharge and discharge to be on the order of 5,000 acre-feet per year. This is lower but in reasonable agreement with the estimated perennial yield of 6,700 acre-feet derived in this report.

All ground-water development to date and all proposed future development is in the northern half of the area. Pumping during the period spring 1960 to spring 1967 has resulted in an estimated storage depletion of 22,000 acre-feet. Net pumpage during the 1967 irrigation season was estimated to be 7,400 acre-feet, which exceeds the estimated perennial yield by about 10 percent.

Pumping is both localized and asymmetrically distributed with respect to natural discharge; consequently, a large quantity of water must be withdrawn from storage before the perennial yield can be salvaged. A first approximation shows that before all natural discharge in the valley could be salvaged by pumping from the approximate 1967 area of development, water levels at the northern end of the development may decline 150 feet or more, depending on the long-term barrier effects of bedrock boundaries on the valley-fill reservoir and fault barriers within the reservoir. Thus, even though pumping is limited to the perennial-yield rate, a local overdraft could develop before all the natural discharge of Hualapai Flat is salvaged. The amount of natural discharge that can be profitably salvaged by future pumping from the same general area as in 1967 is dependent on both economic and hydrologic factors and cannot be precisely determined at this time. The salvage probably would be at least 4,000 acre-feet but less than the perennial yield.

A first approximation of the distribution of transmissibility suggests that values range from less than 50,000 gallons per day per foot in the central and southern part of the area to more than 100,000 gallons per day per foot in parts of the developed area. The long-term storage coefficient for the entire area

may average 12 to 13 percent, but locally may be as high as 20 percent in parts of the developed area. However, the small size of the valley-fill reservoir and barrier effects caused by alluvial faults in the valley fill must be evaluated in greater detail before meaningful predictions of water-level changes can be made using these coefficients.

Chemical quality of the water in 1967 was generally satisfactory for irrigation, domestic, and stock use, except in the vicinity of the playa. Over the long term, recycling of pumped water and the possibility of migration of poor quality water from beneath the playa could result in a gradual deterioration in water quality in areas of use. The reported decrease in yields of a few irrigation wells could be caused by chemical encrustation of the casing perforations, mechanical failure of the well, or mutual pumping interference among wells.

INTRODUCTION

Purpose and Scope

This is the second report on the hydrology of Hualapai Flat prepared by the U.S. Geological Survey in cooperation with the Nevada Department of Conservation and Natural Resources. The first report (Sinclair, 1962) was a reconnaissance and provided preliminary estimates of recharge to and discharge from the valley.

The need for the present study was expressed by the State because of the extensive development of ground water for irrigation since 1962. All development has occurred in the northern part of the valley and water-levels have declined rapidly in the area most heavily pumped. It was feared that concentrated pumping might lead to conditions of local overdraft at the north end of the valley. A potential overdraft for the entire valley was possible because permits to pump ground water exceeded the preliminary estimate of perennial yield. Furthermore, the continued lowering of the water levels might ultimately induce underflow of poor quality water from beneath the playa and from the adjacent Black Rock Desert into the area of development. Therefore, the principal purposes of this report are: (1) to reappraise the hydrology of the valley with special emphasis upon the effects of the existing development; (2) to predict the possible future effects of this development; (3) to appraise the chemical quality of the water in order to provide a basis for comparison in the future; and (4) to evaluate the structural basin and, if possible, better define the outer hydraulic boundaries of the system.

To accomplish these objectives, this report includes: (1) a reappraisal of the main elements of the natural hydrologic system, including precipitation, recharge, subsurface outflow, and natural evapotranspiration; (2) an estimate of the average annual surface-water inflow to the valley and its distribution within the valley; (3) a description of the ground-water reservoir; (4) an estimate of the magnitude of depletion of ground water in storage for the period of development, 1960-67; (5) estimates of pumpage (1960-67), the available water supply, potential overdraft, and effects of future development; and (6) an analysis of the chemical quality of the ground water to establish a base for evaluating changes in salt balance that probably will occur in the future.

Field work began in November 1966 when all wells in the area were canvassed. Intensive field work began in April 1967 and was completed by November 1967. This consisted of measuring the

water levels in wells before and after the 1967 irrigation season, making pumping tests and discharge measurements on wells, estimating the annual pumpage and natural evapotranspiration, collecting water samples to determine the chemical quality, and drilling 11 small-diameter test wells in undeveloped parts of the valley. Surface-water inflow to the valley was estimated from periodic streamflow measurements made during the course of this study and from 11 months of record (February 1967 to December 1967) at a temporary gage installed on Red Mountain Creek.

This reevaluation 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 detailed studies in areas covered by reconnaissance reports where moderate to substantial development has occurred and where records are available through a continuing inventory over a prolonged period of time.

Location and General Features

Hualapai Flat is a topographically closed embayment on the west side of the Black Rock Desert, about 20 miles north of Gerlach (pl. 1). The area is principally in Washoe County but also includes parts of Humboldt and Pershing Counties. It is bordered on the south and west by the Granite Range and on the north and northeast by the Calico Mountains. A low bedrock ridge and alluvial divide along the east side of the area separates Hualapai Flat and the Black Rock Desert.

The highest points in the Granite Range are Granite Peak, altitude 9,056 feet, and Fox Mountain, altitude 8,222 feet. The highest point in the Calico Mountains is Division Peak, altitude 8,491 feet. The lowest point in the area is the small playa in the southern end of the valley, altitude about 4,000 feet. The altitude of the playa surface in the Black Rock Desert, 4 miles east of the alluvial divide separating the areas, is about 3,905 feet. The total drainage area is about 315 square miles, 50 of which are moderately flat valley lowland.

Nevada route 34, a graded and graveled road, passes through Gerlach, crosses the southern end, traverses the west side of the valley, and extends on to northeastern California.

Economic Development

Hualapai Flat, although small, is developing into a productive agricultural area. Ranching was the principal occupation before land was irrigated by pumping ground water. Cattle and sheep were grazed on the mountain slopes and some alfalfa and hay were irrigated by streamflow and spring discharge. An unsuccessful attempt

at dry farming was made by several families who settled in the valley in the 1920's.

Large-scale development by pumping ground water began in about 1961. By 1967 there were about 28 large-diameter irrigation wells in the valley; about 20 were pumped for irrigation that season. Alfalfa was the principal crop grown in 1967. About 6,500 acres of cropland and about 400 acres of meadow and pasture have had permits issued for irrigation by ground water. As of the 1967 growing season, about 3,400 acres of cropland were in production. Figure 1 shows the location of wells and test holes, areas for which permits to irrigate by pumping ground water have been issued, and approximate acreages in production. Wells are numbered as described in the section at the end of the report.

Lead-silver ore was mined from the Leadville mine from 1910-28. About 3,717 tons of ore produced a gross yield of $541,671 during the period 1910-25 (Overton 1947, p. 58). The mine was closed in 1928 and has remained closed since. Some prospecting has occurred on the west flank of Division Peak in the Donally District where small amounts of gold occur in the quartz veins which cut exposures of granodiorite and metamorphic rocks. Vanderburg (1938) states that the total production from the area is said to have been about $90,000.

Interest in the potential geothermal resources of the area has resulted in several exploratory wells being drilled in the vicinity of thermal springs in sec. 1 and 2, T. 34 N., R. 23 E., and on the Granite Ranch at the southwest end of the valley. No sources of steam suitable for power generation had been developed as of 1967.

Previous Studies

The earliest descriptions of rock types and structures in the vicinity of the report area are by King (1878) in his report on the exploration of the 40th parallel. Russell (1885) presents maps of generalized structural features and a chemical analysis of water from Wards Springs (sec. 1, T. 34 N., R. 23 E.). Most of the area has been geologically mapped at reconnaissance level. Bonham (1962) mapped the Washoe County portion of the area as part of a master's thesis for the University of Nevada, and Wilden (1964) mapped the Calico Mountains as part of a study of the mineral deposits of Humboldt County. The southwestern part of the area is being mapped at reconnaissance level by Mr. Donald Tatlock of the U.S. Geological Survey, who is preparing a geologic map of Pershing County. Overton (1947) describes the geology in the vicinity of the Leadville Mining District, and the generalized geology of the whole area is shown on a progress geologic map of

Nevada by Webb and Wilson (1962). L. D. McGinnis and W. W. Dudley (1964) made a seismic profile along the alluvial divide which separates Hualapai Flat from the Black Rock Desert.

The only previous hydrologic study of the area is a reconnaissance by Sinclair (1962) which describes the hydrologic system under near equilibrium conditions and gives preliminary estimates of recharge to and discharge from the valley. Reconnaissance hydrologic studies of the adjacent areas were made by Sinclair (1963a, b) and Glancy and Rush (1968).

Climate

The climate in Hualapai Flat is similar to that of other valleys in west-central Nevada at altitudes of about 4,000 feet. Precipitation is controlled largely by topography. Airmasses which move eastward across the State are generally deficient in moisture, and areas at low altitudes commonly receive less moisture than areas at higher altitudes. This results in semiarid conditions in the valleys and subhumid conditions in the surrounding mountains. Winter precipitation generally falls as snow from regional storms, whereas summer precipitation is localized as thunderstorms of short duration and high intensity.

No precipitation stations are in the area. The average annual precipitation at Gerlach (altitude 3,940 feet) for the period 1913-66 is 5.46 inches (1952-57 precipitation measured at Empire; no record 1958-62). Short-term records at nearby Soldiers Meadows (altitude 4,550 feet, 4-year average 1963-66, 6.74 inches), and Pahute Meadows Ranch (altitude 4,375 feet, 3-year average 1964-66, 5.53 inches) suggest similar values; however, longer records must be obtained before significant averages can be obtained. Average annual precipitation in Hualapai Flat probably ranges from less than 8 inches on the valley floor to 20 inches or greater in the Granite Range, which receives the most precipitation of any part of the area.

Much of the precipitation at the south end of the valley falls on the northwest flank of the Granite Range. Potential evapotranspiration there is less than at the north end of the valley, where the mountain slopes generally have a southerly exposure.

Freeze data published by the U.S. Weather Bureau for Gerlach, Empire, Pahute Meadows Ranch, and Soldiers Meadows are shown in table 1. They may be used to estimate the approximate length of the growing season in the study area, which is determined largely by temperature and varies with the type of crop grown. For example, a crop which experiences a

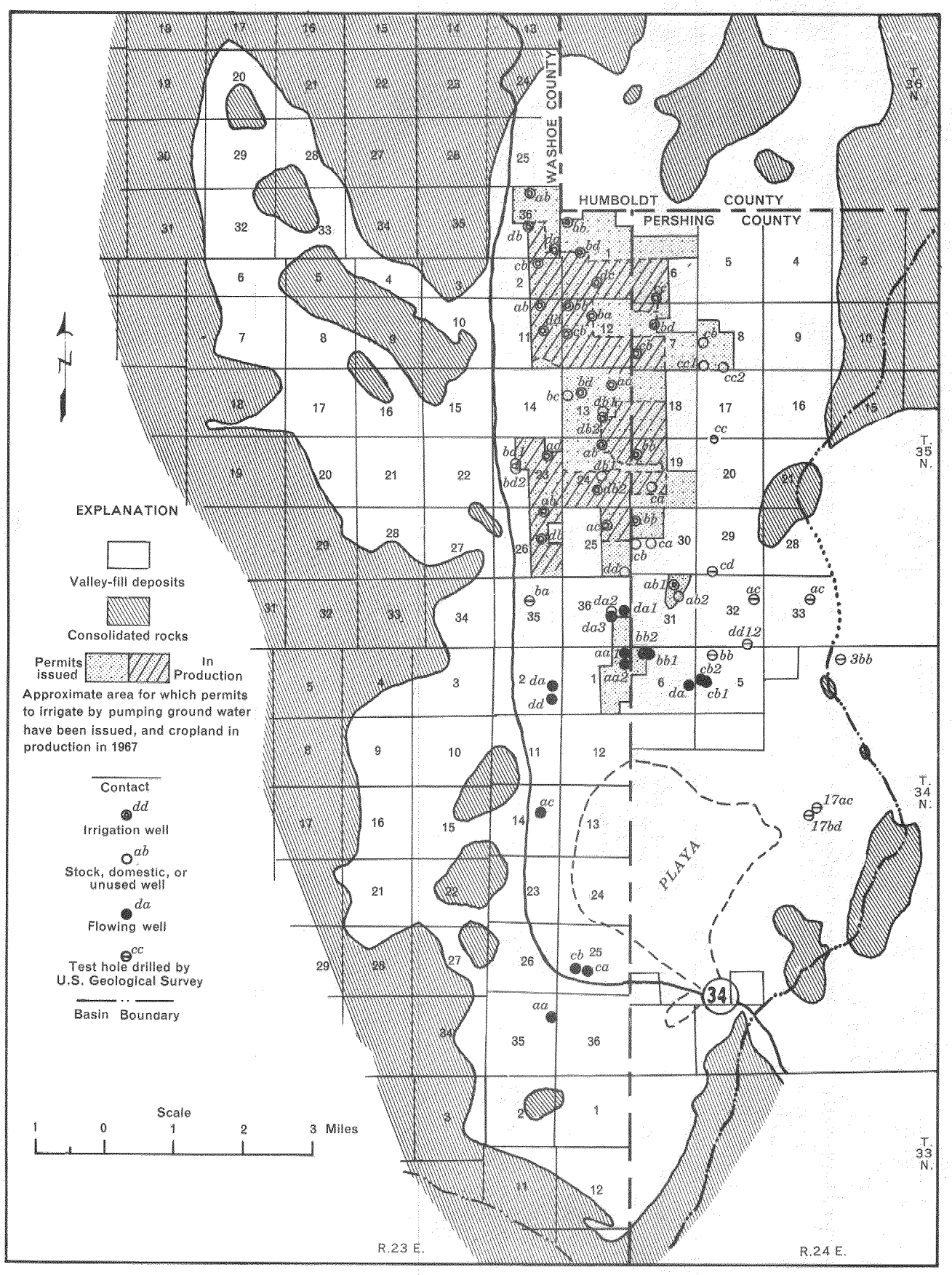


Figure 1.—Location of wells, test holes, land for which permits to irrigate by pumping ground water have been issued, and approximate acreage in production in 1967

Table 1.--Longest period, in days, in which temperatures did not go below the indicated values at four stations in northwestern Nevada

[From published records of the U.S. Weather Bureau]

Year	Empire[1]			Gerlach[2]			Pahute Meadows Ranch[3]			Soldiers Meadows[4]		
	24°F	28°F	32°F	24°F	28°F	32°F	24°F	28°F	32°F	24°F	28°F	32°F
1948	--	--	--	202	139	137	--	--	--	--	--	--
1949	--	--	--	199	199	145	--	--	--	--	--	--
1950	--	--	--	187	146	144	--	--	--	--	--	--
1951	228	205	147	--	--	--	--	--	--	--	--	--
1952	227	225	--	--	--	--	--	--	--	--	--	--
1953	189	162	129	--	--	--	--	--	--	--	--	--
1954	219	175	115	--	--	--	--	--	--	--	--	--
1955	187	181	146	--	--	--	--	--	--	--	--	--
1956	204	201	181	--	--	--	--	--	--	--	--	--
1957	--	--	--	--	--	--	--	--	--	--	--	--
1958	--	--	--	--	--	--	--	--	--	--	--	--
1959	--	--	--	--	--	--	--	--	--	--	--	--
1960	--	--	--	--	--	--	--	--	--	--	--	--
1961	--	--	--	--	--	--	--	--	--	--	--	--
1962	--	--	--	--	--	--	--	--	--	--	--	--
1963	--	--	--	188	187	165	--	--	--	192	183	117
1964	--	--	--	204	169	164	181	164	164	154	154	104
1965	--	--	--	217	163	131	134	127	123	205	124	111
1966	--	--	--	177	177	167	--	--	121	177	169	131
Average	209	192	144	196	169	150	157	145	136	182	158	116

1 Altitude 3,980.
2 Altitude 3,940.
3 Altitude 4,375.
4 Altitude 4,550.

killing frost at 28°F should have a growing season of 130 to 170 days in the study area while crops which are killed by the first 32°F freeze should have growing seasons of only 110 to 150 days.

The low topographic divide on the east side of the area allows cool air to drain to the Black Rock Desert. Consequently, thermal inversions which may significantly effect growing seasons in the lower parts of many valleys in the State, have limited effects on development in Hualapai Flat.

Acknowledgments

Acknowledgment is made of the gracious cooperation of the local residents of the valley in supplying data and permitting use of their wells for pumping tests and water-level observations during the course of this investigation. Wholehearted assistance was also 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 State Engineer of Nevada.

GENERALIZED GEOLOGY

Physiography

Land forms in Hualapai Flat are transitional to those found in the Great Basin and those in the Columbia Plateau. Physiographically, the valley may be divided into three major parts, the mountains, the alluvial apron, and the playa. Shoreline features of Lake Lahontan Pleistocene lakes are developed largely on the alluvial apron.

Mountains

The mountains that border the southern part of Hualapai Flat are composed principally of granitic rocks and those that border the northern part are composed principally of extrusive volcanic rocks. The overall size and shape of the mountains has been determined largely by uplift and warping associated with large scale normal faults. Subsequent weathering and erosion has produced characteristic topographic forms for each of the two principal rock types.

Granitic rocks generally have weathered to a rugged topography Internal structures, joints, and fault zones locally have had pronounced effects on the topography. Drainages are typically short with steep gradients. Volcanic rocks typically exhibit less rugged topography with the upper surfaces rounded in a convex shape. Talus slopes and columnar volcanic palisades are prominent locally. Drainages generally are longer, and have more fully developed dendritic patterns and flatter gradients than in the granitic rocks.

Alluvial Apron

The alluvial apron is the area of intermediate slope between the mountains and the comparatively flat playa. It is composed principally of coalescing alluvial fans, but also contains pediments, or areas in which the bedrock is covered by a veneer of alluvium. Prominent outcrops of bedrock protrude through the alluvial apron along the west side and at the north end of the valley. Much of the alluvium upslope from these outcrops probably forms a comparatively thin mantle over underlying bedrock.

Slopes on the alluvial apron decrease from greater than 300 feet per mile at the mountain fronts to only a few feet per mile near the playa. Local relief may be as much as 25 feet, due principally to stream entrenchment on the higher slopes and to bars, spits, tuffa deposits, and eolian deposits on the intermediate and lower slopes.

Lake Features

That part of the area below an altitude of about 4,380 feet was intermittently covered by the waters of Lake Lahontan (Russell, 1885) during Pleistocene time. Many of the resulting shoreline deposits and features have subsequently been destroyed or buried by the action of recent intermittent streams; however, high-level shoreline features are prominent in protected areas at the north end of the valley. A gravel-covered bar was formed between the main mass of the Calico Mountains and the prominent bedrock outcrop about one mile to the south (pl. 1). Bars and spits have also formed between smaller bedrock outcrops along the low divide on the east side of the area.

Playa

The playa occupies the southern part of the valley floor. Its surface is nearly flat and covers an area of about 3,500 acres. Fine windblown material from the playa and lower slopes of the alluvial apron locally forms small dunes and phreatophyte mounds along the margins of the playa. The large sand dunes just east of the alluvial divide between Hualapai Flat and the Black Rock Desert and the phreatophyte mounds at the northeast end of the playa have orientations which indicate that they were formed by material blown in from the Black Rock Desert.

Principal Lithologic Units

For the purpose of this report, the lithologic units in Hualapai Flat are divided into two major groups on the basis of their hydrologic properties: (1) unconsolidated deposits, which form the valley fill, are highly porous, and commonly transmit water readily; and (2) consolidated rocks which occur in the mountains and at depth beneath the valley fill, commonly have low porosities and permeabilities and, except where high fractured or altered by other secondary features, do not readily transmit appreciable quantities of water.

The six principal lithologic units used in this report are presented in table 2, which was compiled largely from the work of Bonham (1962) and Wilden (1964). The six units are: metavolcanic and metasedimentary rocks, granitic rocks, volcanic rocks, older alluvium, younger alluvium, and playa deposits. Distribution of the units listed in table 2 is shown on plate 1.

Structural Features

Bonham (1962, p. 48) states that at least four episodes of deformation are recognizable in the northern part of Washoe County. The last period of deformation, which commenced in late Pliocene or early Pleistocene time and is still in progress, is the most

Table 2.--Principal lithologic units

Age		Unit designation	Estimated thickness (feet)	Lithology	Occurrence	General hydrologic properties
QUATERNARY	Pleistocene and Holocene	VALLEY FILL: Playa deposits	0-100±	Silt, clay, and evaporites, includes some eolean deposits	Occurs beneath playa in southern part Hualapai Flat	High interstitial porosity and low permeability
		VALLEY FILL: Younger alluvium	0-200±	Unconsolidated alluvial and colluvial deposits of interbedded sand, gravel, silt, and clay. Materials generally moderately to well sorted and form lenticular bodies.	Occurs primarily as Lake Lahontan and associated deposits near the center of the valley and as slope wash, flood-plain, channel, or reworked lake deposits along the margins of the valley.	Sand and gravel deposits are highly permeable and may yield large quantities of water to wells. Buried alluvial channels and shallow-water lake deposits form the most productive aquifers. Lake-bottom deposits of fine-grained sand, silt, and clay are less capable of yielding water to wells.
	Pleistocene	VALLEY FILL: Older alluvium	0-1000±	Alluvial and colluvial deposits of sand, gravel, silt, and clay. Some interbedded flow rock and pyroclastic material. Materials range from well sorted to poorly sorted. Partially consolidated (cemented) in localized areas and at depth. Deposits at depth in center of the valley generally moderately to well sorted.	Occurs primarily as alluvial-fan deposits, also slope wash, talus deposits, upland alluvial surfaces and high-level shoreline deposits. Fan deposits have locally been uplifted, faulted, dissected by erosion and marked by shoreline features of high-level lake stages. Occurs at depth in the center of the valley as lake and interlake deposits which locally may overlie valley-fill deposits of older age not exposed in the area.	Permeability ranges from low to high. Zones of high permeability generally associated with buried channel deposits.

Table 2.--Continued

Age		Unit designation	Estimated thickness (feet)	Lithology	Occurrence	General hydrologic properties
TERTIARY	CONSOLIDATED ROCKS	Volcanic rocks	--	Primarily rhyolite, andesite, and basalt, some associated diatomite and tuffaceous mudstone. Includes undifferentiated Tertiary rocks as mapped by Wilden (1964) and the Canyon Rhyolite of Bonham (1962), Miocene (?) andesite sequence, upper Miocene and Pliocene sequence, and Pliocene and Pleistocene (?) olivine basalt as mapped by Bonham (1962).	Occur in the mountains which border the west-central and northern part of the valley as flows, lahars, agglomerates, welded tuff and domes, with some dikes and pyroclastic material.	Commonly have little or no interstitial porosity except where highly vesicular. May transmit some water through joints and zones between flows.
CRETACEOUS(?)		Granitic rocks	--	Principally granodiorite	Occur as intrusive body of batholithic dimensions in the Granite Range and as a smaller fault-bounded intrusive body on the west flank of Division Peak in the Calico Mountains.	Virtually no interstitial porosity and permeability, may transmit small quantities of water through fractures and weathered zones.
PERMIAN(?)		Meta-volcanic and meta-sedimentary rocks	--	Metamorphosed andesite and basalt flows, breccia, and tuff intercalated with some recrystallized limestone, pebble conglomerate, and other fine-grained sediments.	Exposed in the Granite Range between Rock Creek and Cottonwood Creek. Also occurs on the east side of the area as isolated exposures along the divide between Hualapai Flat and the Black Rock Desert.	Low interstitial porosity and permeability. May transmit some water through areas where fractures have not been sealed by secondary minerals or where solution features have developed in the carbonate rocks.

significant with regard to the hydrology of Hualapai Flat. During this time, high angle block faulting, uplift, and tilting disrupted the then existing surface of low relief and formed the present day structural basin. This basin was then intermittently occupied by Pleistocene lakes and has been filled by alluvial deposits to the extent that they now overlap the lowest part of the bedrock closure and locally are continuous with alluvial deposits in the Black Rock Desert.

The persistence of this period of deformation into Holocene time is evidenced by faults in both the younger and older alluvium at the north end of the valley (pl. 1). These faults may affect the hydrologic character of the valley fill by (1) imposing some structural relief on the lower surface of the valley-fill material, (2) forming fracture zones in some of the bedrock that underlies valley fill, and (3) forming near-vertical zones of poorly sorted material along fault planes in the valley fill as a result of movement. These zones may then act as relative barriers to water movement across the fault and as such may significantly effect the response to pumping.

The direction of relative movement was determined along three faults and is indicated on plate 1. Relative movement shown on the fault crossing the alluvial divide was inferred from bedrock displacement shown in an interpretative profile of seismic findings by McGinnis and Dudley (1964, p. 32).

VALLEY-FILL RESERVOIR

The valley-fill reservoir is composed of younger and older alluvial deposits that partly fill the structural depression underlying Hualapai Flat. Locally, these deposits overlap the lowest parts of the bedrock closure and are continuous with alluvial deposits in the Black Rock Desert. These deposits contain the most productive aquifers in the area of study and are considered to be the only ones feasible for the large-scale development of ground-water supplies. Consequently, the elements of the hydrologic system are discussed in terms of their relation to the valley-fill reservoir.

Extent and Boundaries

The valley-fill reservoir is approximately 15 miles long, 4½ miles wide, and has a surface area of about 68 square miles. Bedrock surfaces of the adjacent mountains and their subsurface extensions form the lateral boundaries of the reservoir, except along parts of the east side of the area where alluvium provides a conduit for some subsurface outflow to the Black Rock Desert.

The exact configuration of the lower surface of the valley fill cannot be determined, but several deductions may be made from existing data. Wells 36/23-36ab and 35/23-1bb encountered "shale" at 450 feet and 441 feet, respectively. Wells 35/23-1bd, 35/23-23ad, and 35/23-26db encountered "hard black rock" at depths of 368 feet, 301 feet, and 319 feet, respectively. These wells are along the west side of the valley, which suggests that there much of the valley fill is less than 500 feet thick. This contention is further supported by the numerous fault traces in the alluvium along the west side of the valley and the relative upward movement on the west side of the fault in secs. 1, 11, and 14, T. 34 N., R. 23 E. (pl. 1). The thickness of fill in the north-central part of the valley is probably greater than on the west side. Reflection shots made near the northeast edge of the playa by McGinnis and Dudley (1964, p. 33) indicated a thickness of 755 feet of unconsolidated material. The maximum thickness of valley fill may be less than 1,000 feet.

The alluvium along the divide between Hualapai Flat and Black Rock Desert probably is underlain by bedrock at shallow depth. A seismic profile by McGinnis and Dudley (1964, p. 31) in secs. 28 and 33, T. 35 N., R. 24 E. and sec. 4, T. 34 N., R. 24 E. indicates that there the maximum thickness of alluvium is about 175 feet. This seismic work also indicated that Hualapai Flat is a closed bedrock basin and that hydrologic continuity with the Black Rock Desert is maintained by water moving through unconsolidated deposits overlying a bedrock "lip." During Pleistocene

time Hualapai Flat probably was intermittently drained by a stream that flowed through this area to Black Rock Desert.

Coefficients of Transmissibility and Storage

The coefficients of transmissibility, T, and storage, S, express certain water-bearing properties of the valley fill. Transmissibility is a measure of the capability of an aquifer or reservoir system to transmit water. It is dependent upon the permeability of the material involved and the thickness of the aquifer. The coefficient of storage is a measure of the amount of water that will be released from storage, within a unit area, as water levels are lowered. These coefficients may be used for computing drawdowns and storage changes caused by pumping, or in the determination of subsurface flow.

Coefficients of transmissibility may be estimated from specific capacities of wells, which are usually expressed as yield in gallons per minute per foot of drawdown. Properly designed wells in deposits with high transmissibilities have higher specific capacities than wells in deposits with low transmissibilities.

Two pumping tests, 70 minutes and 175 minutes in duration, were made during this study. The values of transmissibility determined were slightly more than 200,000 gpd (gallons per day) per foot of aquifer in the vicinity of well 35/23-13aa, and nearly 100,000 gpd per foot of aquifer in the vicinity of well 35/23-25ac. Transmissibility values were also estimated from nine specific capacities measured during the course of this study and 18 commercially determined specific capacities. These values provide the basis for the approximate distribution of transmissibility in northern part of Hualapai Flat (fig. 2). The transmissibility values shown are representative only of that thickness of the valley fill affected by pumping. Additional refinement may be required because of barrier effects caused by near-vertical zones of poorly sorted material along alluvial faults and the proximity of bedrock masses to the northern part of the developed area.

No coefficients of storage were calculated; however, flowing wells in the southern part of T. 35 N., Rs. 23 and 24 E. indicate that there the horizontal permeability of the valley fill is much greater than the vertical permeability and that the flow system, for short periods, will respond to pumping stress as an artesian system. Artesian coefficients of storage typically have values of less than 0.001. Short-term artesian coefficients probably would also be obtained in some localities at the north end of the development where semiconfined conditions predominate. Over

the long term, however, all deposits will drain slowly in response to pumping, and the coefficient of storage will be nearly equal to the specific yield. Thus, in analyzing long-term cause-and-effect relations, the valley-fill reservoir must be considered as a water-table system. Storage coefficients may be approximated from the specific-yield values, discussed in the next section.

Specific Yield

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 to gravity to (2) its own volume, usually expressed as a percentage (Meinzer, 1923, p. 28). Estimates of specific yield of the upper 50 feet of saturated deposits (pre-pumping water levels) were made from descriptions in drillers' logs. The deposits described were grouped into five lithologic categories, which are listed in table 3. Specific-yield values were assigned to each category, based on values determined by Morris and Johnson (1966) for similar deposits. Some interpretation is involved when working with drillers' logs; however, comparable results were usually obtained in adjacent wells. Observations made while drilling 11 small-diameter test holes in undeveloped parts of the area were used to supplement information obtained from drillers' logs.

The estimated specific-yield distribution is shown in figure 3. The zone having the highest specific yield underlies the same general area of the alluvial apron as that traversed by the most recent stream channels. Also, it is slightly east of the area of highest transmissibility shown in figure 3. This suggests that permeable sand and gravel deposits beneath the upper 50 feet of saturation are more extensive on the west side and at the north end of the valley.

Storage depletions caused by water-level declines may be estimated as the product of an area, a depth of lowering, and the specific-yield values shown in figure 3. Some of the alluvial areas shown adjacent to consolidated rocks in figure 3 probably contain only a small thickness of saturated material; discretion must be exercised when estimating storage changes in these areas.

Source, Occurrence, and Movement of Ground Water

Virtually all ground water in the valley-fill reservoir is derived from the infiltration of precipitation that falls within the drainage basin. Most deep infiltration is from runoff and occurs on the upper slopes of the alluvial apron; however, some deep infiltration also occurs in the mountains where percolating water moves through bedrock fractures to the zone of saturation. During exceptionally wet years, significant amounts of moisture

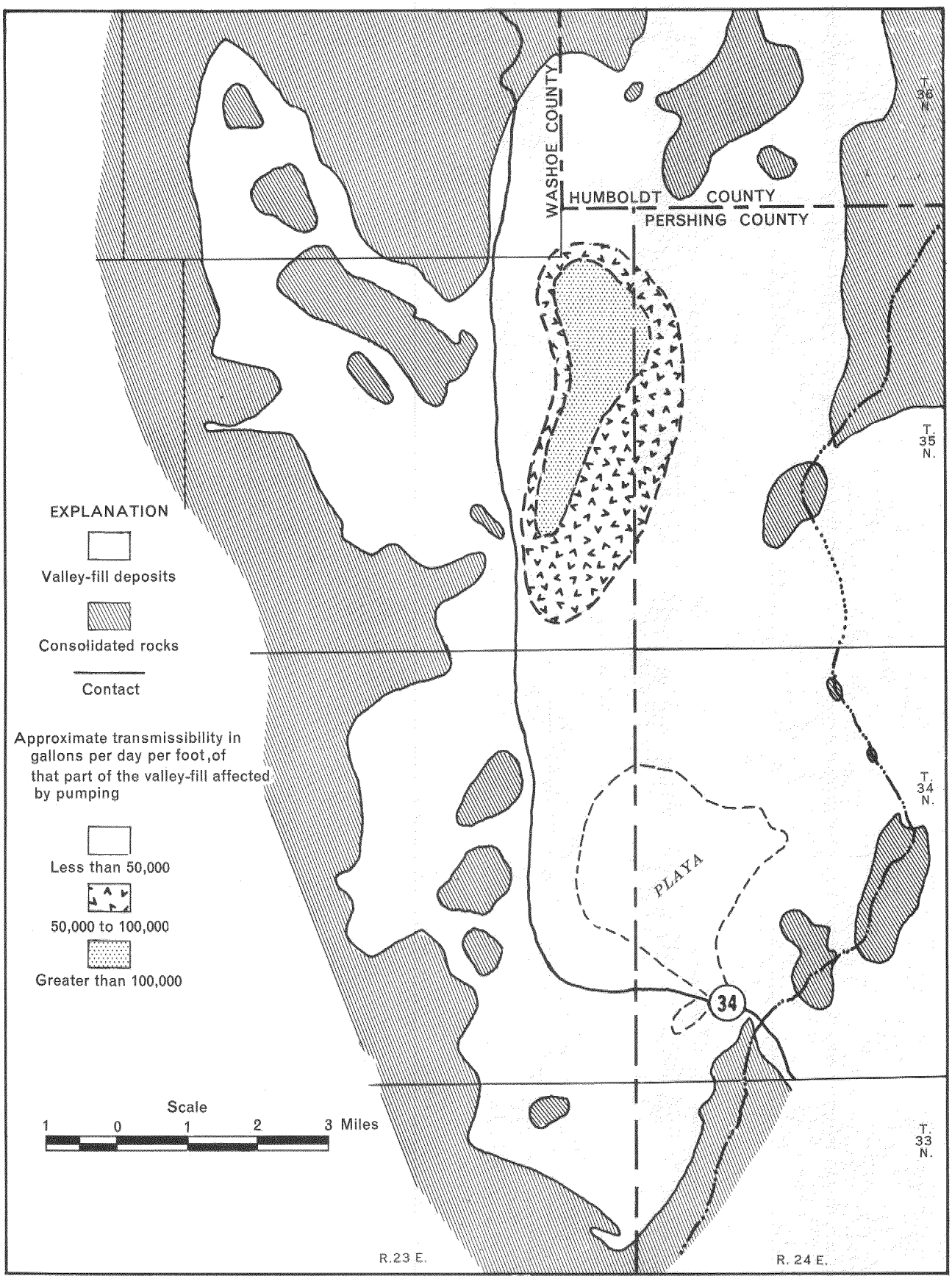


Figure 2.—Preliminary transmissibility map

Table 3.--Specific yields of materials described in drillers' logs

Lithologic category (based on drillers' descriptions)	Assigned specific-yield value[1] (percent)
Medium and coarse sand	30
Gravel, sand and gravel	25
Sand, gravel, and clay, gravel and clay	15
Fine sand, sand and clay, sandy clay, cemented gravel	10
Clay, silt, mud, muck	5±

1. Assigned specific-yield values based on Morris and Johnson (1966).

may also infiltrate to the zone of saturation directly from precipitation on the upper slopes of the alluvial apron and in the mountains.

Ground water occurs in the saturated parts of the valley fill where it occupies the interstices present in the granular clastic deposits and chemical precipitates. It is present under both water-table and artesian conditions. Artesian conditions occur where the saturated permeable deposits are overlain by less permeable strata and where the water at the top of the aquifer is under greater than atmospheric pressure. Water-table conditions exist where the saturated deposits are not confined by poorly permeable strata and where the water at the top of the zone of saturation, the water table, is under atmospheric pressure.

Artesian conditions were encountered in the southern part of T. 35 N., Rs. 23 and 24 E., and around the margins of the playa in T. 34 N., Rs. 23 and 24 E. Most wells flow in this area and springs are present in the NE cor. T. 35 N., R. 23 E. Artesian conditions also occur locally to the north where lenses of silt and clay partially confine the water in underlying deposits.

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

The horizontal movement of ground water in the valley fill generally is parallel to the slope of the water surface. A downward component of movement occurs in areas of recharge, and an upward component occurs in areas of evapotranspiration. The slope of the water surface is indicated on plate 1, which shows contours of the approximate altitudes of spring water levels in 1960 prior to any extensive withdrawal of ground water by pumping. Therefore, the contours indicate the general direction of ground-water movement under natural conditions. The direction of movement is perpendicular to the contours. In general, ground water moves eastward from the principal areas of recharge in the mountains and upper parts of the alluvial apron toward the bare soil and surrounding phreatophyte-covered discharge areas in the south-central part of Hualapai Flat and the adjacent Black Rock Desert. The water-level ridge in secs. 29, 30, 31, and 32, T. 35 N., R. 24 E. may be due to a combination of artesian conditions in the general area and zones of less permeable material or offset masses of unexposed bedrock along the planes of alluvial faults.

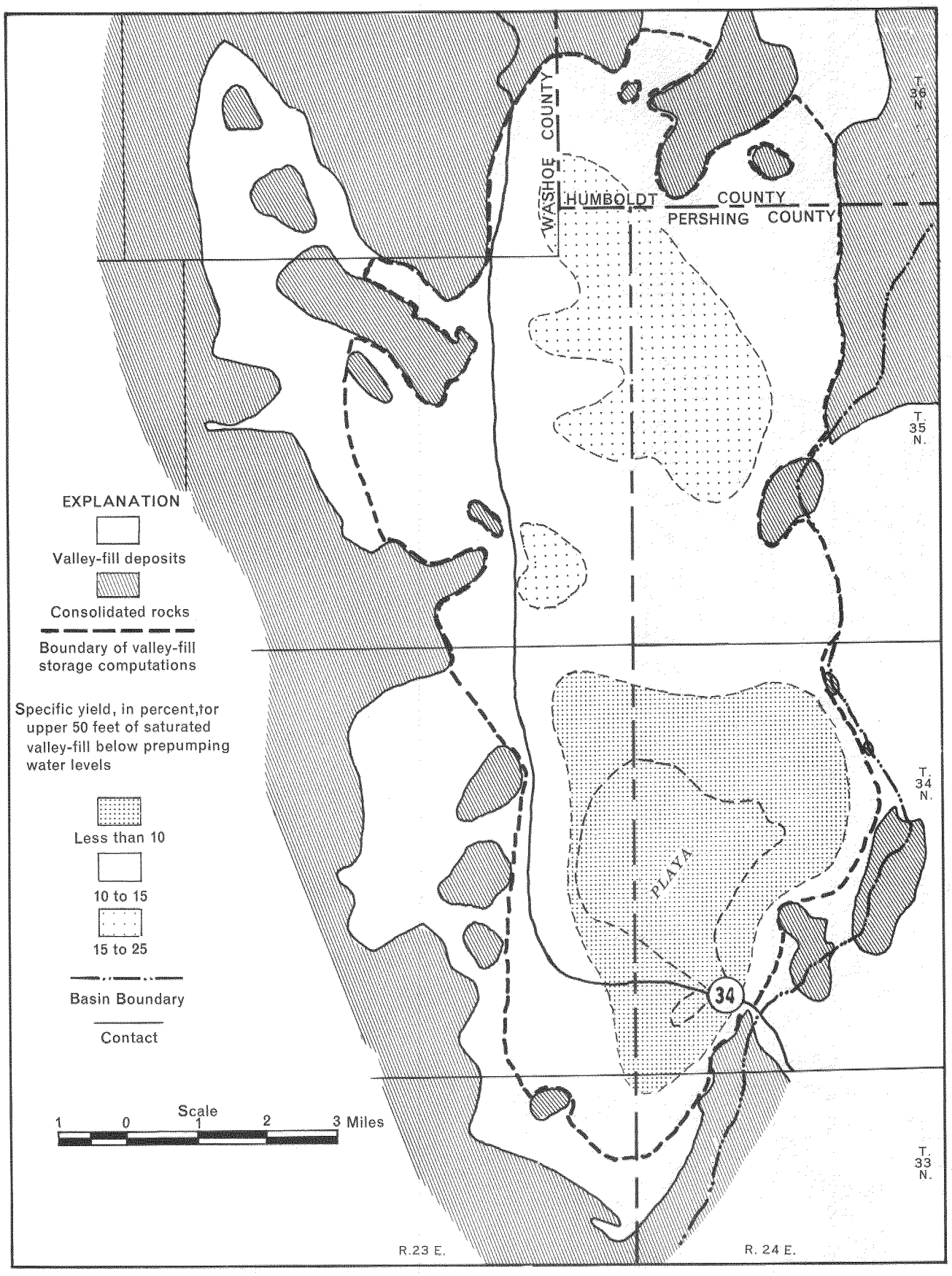


Figure 3.—Estimated distribution of specific yield

The markedly steeper gradients along the eastern boundary of the area are attributed to a local decrease in transmissibility rather than to large quantities of underflow. The steep gradients are thought to represent movement of ground water through a cross-sectional area of valley fill that is appreciably reduced by the presence of bedrock at relatively shallow depth.

Figure 4 shows the approximate depths to water in the spring of 1967. Depths ranged from more than 100 feet at the northwest end of the development to within a few feet of land surface around the playa in the southern part of the valley. Deeper wells in areas of natural discharge near the playa commonly flowed; however, shallow wells in the same vicinity generally had depths to water of 5 to 10 feet.

INFLOW TO THE VALLEY-FILL RESERVOIR

Precipitation

Precipitation is the source of virtually all the water entering the hydrologic system in Hualapai Flat. Of the precipitation that falls within the basin, part is directly evaporated from vegetation or the ground surface, part runs off as surface flow, part infiltrates to shallow depths where it replenishes soil moisture, and part eventually infiltrates to the zone of saturation where it recharges the ground-water system.

Ground-Water Recharge

Observations made during the course of this study suggest that, as in many other valleys in the State, much of the ground-water recharge occurs on the alluvial apron and is derived principally from runoff generated in the adjacent mountains. Recharge also occurs in the mountains and moves as underflow across the bedrock-alluvial contact to the valley-fill reservoir. During wet years additional recharge may be generated on the alluvial apron from high-intensity precipitation or snowmelt.

Average annual recharge may be estimated as a percentage of the average annual precipitation within the basin (Eakin and others, 1951, p. 79-81). Hardman (1965) demonstrated that in gross aspect, the average annual precipitation in Nevada is related closely to the altitude of the land surface and that it can be estimated with a reasonable degree of accuracy by assigning precipitation rates to altitude zones. Thus, the recharge may be estimated as a percentage of the precipitation within each zone.

Estimates of recharge for Hualapai Flat are summarized in table 4. Altitudes of the various precipitation zones were approximated from a 1965 revision of the Nevada precipitation map (Hardman, 1936) and are the same as those used by Sinclair (1962) in his reconnaissance study of the area. Total estimated recharge from precipitation within the basin is approximately 7,000 acre-feet, or about 4 percent of the total precipitation. This estimate may be slightly high because during most years some streamflow, which is potential ground-water recharge, flows down the alluvial apron to areas of shallow ground water where it is consumed by evaporation instead of infiltrating to ground water. This is especially true during high runoff years when some streamflow ultimately reaches the playa.

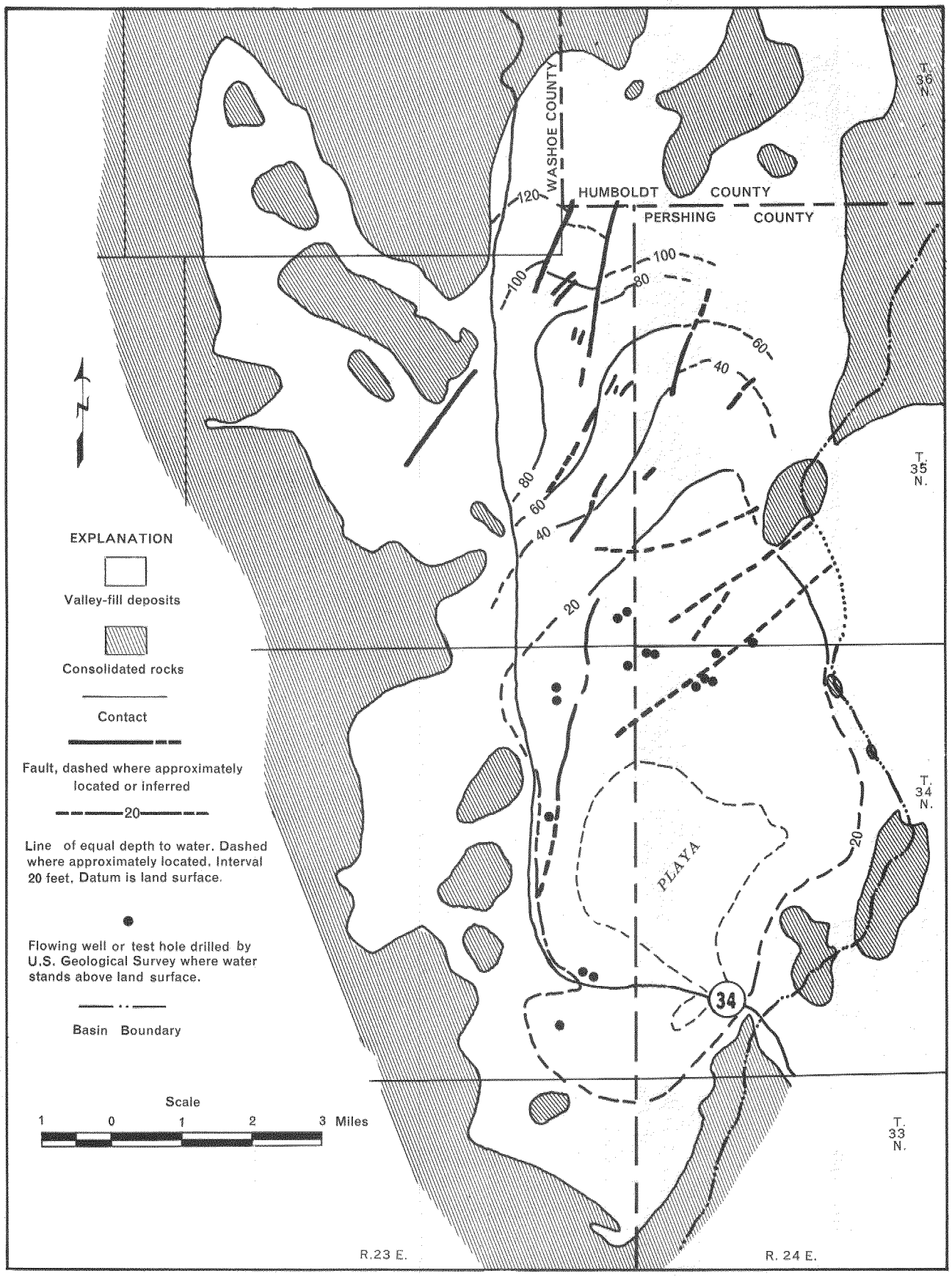


Figure 4.—Approximate depths to water, spring 1967

Table 4.--Estimated average annual precipitation and ground-water recharge from precipitation

Precipitation zone (altitude, in feet)	Area (acres)	Estimated annual precipitation: Range (inches)	Estimated annual precipitation: Average (feet)	Estimated annual precipitation: Average (acre-feet)	Estimated recharge from precipitation: Percent of precipitation	Estimated recharge from precipitation: Acre-feet per year
Above 8,000	1,200	>20	1.8	2,200	25	550
7,000 to 8,000	9,800	15 to 20	1.5	15,000	15	2,200
6,000 to 7,000	44,700	12 to 15	1.1	49,000	7	3,400
5,000 to 6,000	50,300	8 to 12	.8	40,000	3	1,200
Below 5,000	96,300	<8	.6	60,000	0	--
Total (rounded)	202,000			170,000		7,000

Runoff

By P. L. Soule

The principal objectives of the surface-water section of the study were to determine the amount of surface-water inflow to the valley, the distribution of this runoff, and its seasonal variation.

Streamflow in the project area is derived directly or indirectly from storm runoff or snowmelt. The drainage system consists of several major streams (pl. 1) and a number of small tributaries. The higher sustained (perennial) flows are derived from the high mountains in the western and northwestern part of the valley and are the direct result of snowmelt that runs off in the spring or that portion of the snowmelt that infiltrates into the soil mantle and appears later as a lower sustained flow.

Runoff Characteristics

Runoff is that residual of precipitation that drains from the land after the infiltration and evaporation demands are met. Runoff is defined as "that part of the precipitation that appears in streams." Most of the runoff in Hualapai Flat is produced directly or indirectly from the melting snow from orographic precipitation occurring on the mountains. Some runoff occurs as a result of thermal convection storms, or thunderstorms, that occur periodically in most arid areas, such as this, but the significance of these events probably is small insofar as total runoff is concerned.

The mountains to the north and west of the valley are generally the higher yield areas, because of (1) the greater precipitation and snow accumulations commonly associated with altitudes above 5,000 feet; (2) comparatively low infiltration rates through the commonly thin soil mantle that overlies low permeability bedrock; and (3) steep mountain slopes. Some runoff also originates on the alluvial apron but is of minor significance. Thus, nearly all runoff in the basin is generated in the 106,000-acre area lying above an altitude of 5,000 feet.

The runoff from the northern and eastern parts of the project area is very meager as a result of lower mountains and extensive piedmont slopes with southerly exposures.

Gaging and Measuring Sites

There has been no previous systematic collection of surface-water data in the project area except for one crest-stage gage, South Willow Creek near Gerlach (10-3537.7), installed October 1962.

One gaging station, Red Mountain Creek near Gerlach (10-3537.25), was installed and records collected from February 16, 1967, to December 11, 1967. Additional periodic streamflow measurements, or observations of no flow, were made at seven miscellaneous streamflow measurement sites and 20 supplemental miscellaneous streamflow measurement sites throughout the 1967 water year (pl. 1). Table 22 (at end of report) summarizes these observations.

Streamflow

The mountain tributaries are gaining streams (increasing in flow) until they near the bedrock-alluvium contact at the mountain front. The low base flow is quickly depleted as it flows down the alluvial fans. Higher flows are diverted for irrigation as they reach the developed areas of the valleys. The mountain front thus commonly represents the point of maximum flow of the stream, and the average annual flow at this point is an index to the amount of water potentially available for development. Most of the analysis presented is based on runoff data collected at or near this point of maximum flow. Because streamflow varies in areal and seasonal distribution from year to year, the pattern for the 1966-67 (fig. 5) water year provides only a rough indication of the seasonal and areal distribution that might occur any one year or over any period of years.

Streamflow at each streamflow measurement site in Hualapai Flat was synthesized for the 1967 water year using discharge measurements made at that site, continuous records collected at Red Mountain Creek near Gerlach, streamflow records collected at gaging stations adjacent to the project area, and weather records collected at Gerlach. These streamflow data were adjusted to the reference period 1950-67, on the basis of records of nearby gaging stations in Nevada, Oregon, and California, and expressed as average annual streamflow (table 5).

Measurements were made at several points along the streams to determine longitudinal variations in flow. Figure 6 shows that for Red Mountain Creek the point of maximum flow migrates during the year. It is farthest downstream during the seasonal runoff maximum, then moves upstream as flow diminishes. This generally is characteristic of the streams in the report area.

Table 5.--1967 water-year adjustment to reference period 1950-67, for stations adjacent to study area

Station number	Station name	Flow, 1967 water year (acre-feet)	Reference period 1950-67: Average annual flow (acre-feet)	Reference period 1950-67: Adjustment to 1967 water year
10-3536	Kings River nr. Orovada, Nev.	4,130	3,400	0.83
10-3537	Leonard Creek nr. Denio, Nev.	3,584	2,800	0.79
10-3583	Willow Creek nr. Susanville, Calif.	31,360	23,000	0.73
10-3609	Bidwell Creek below Mill Creek nr. Fort Bidwell, Calif.	17,300	18,000	1.04
10-3660	Twenty Mile Creek nr. Adel, Calif.	37,150	39,000	1.06
	Average			0.89

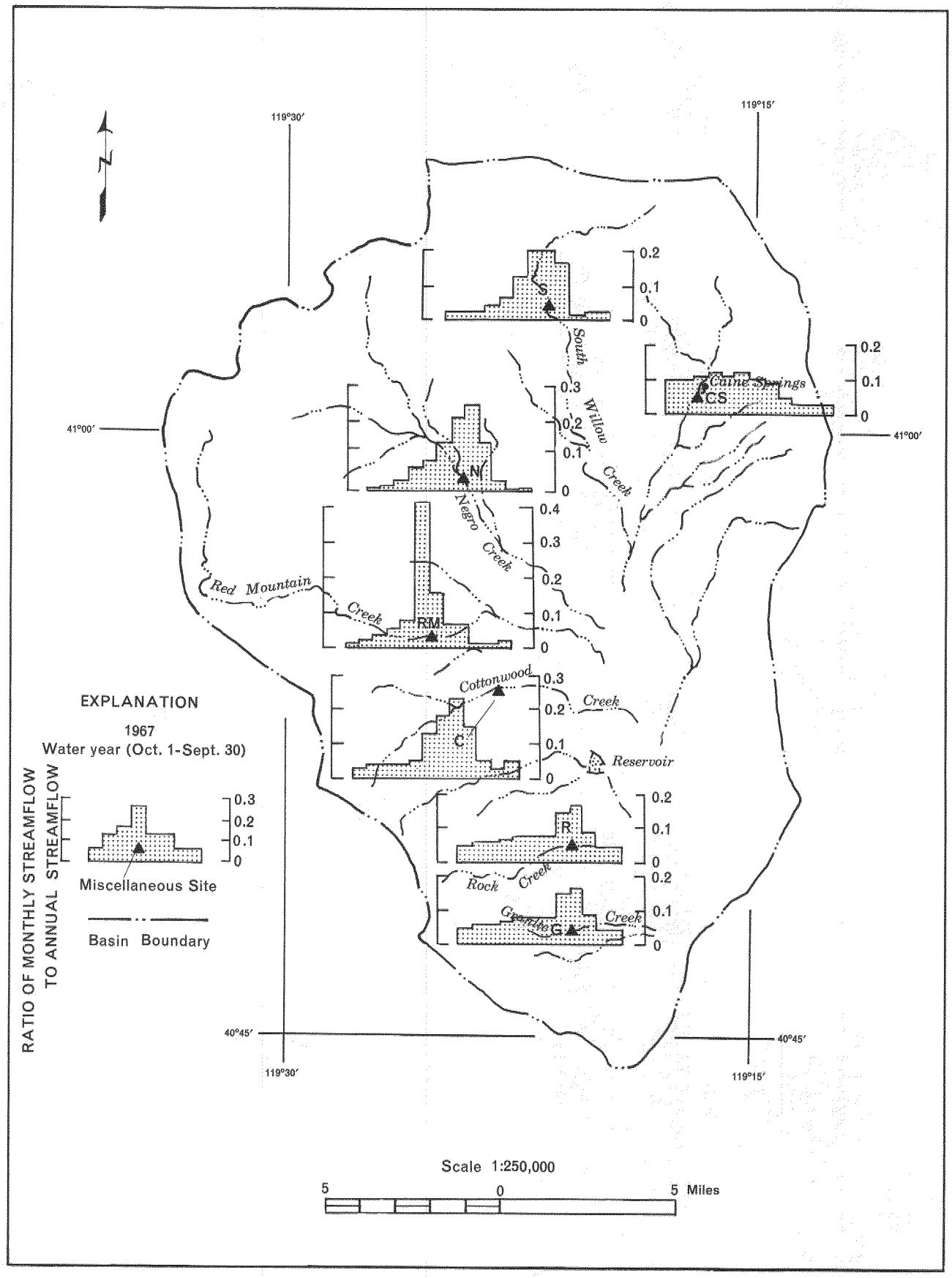


Figure 5.—Seasonal pattern of streamflow at miscellaneous sites in 1967.

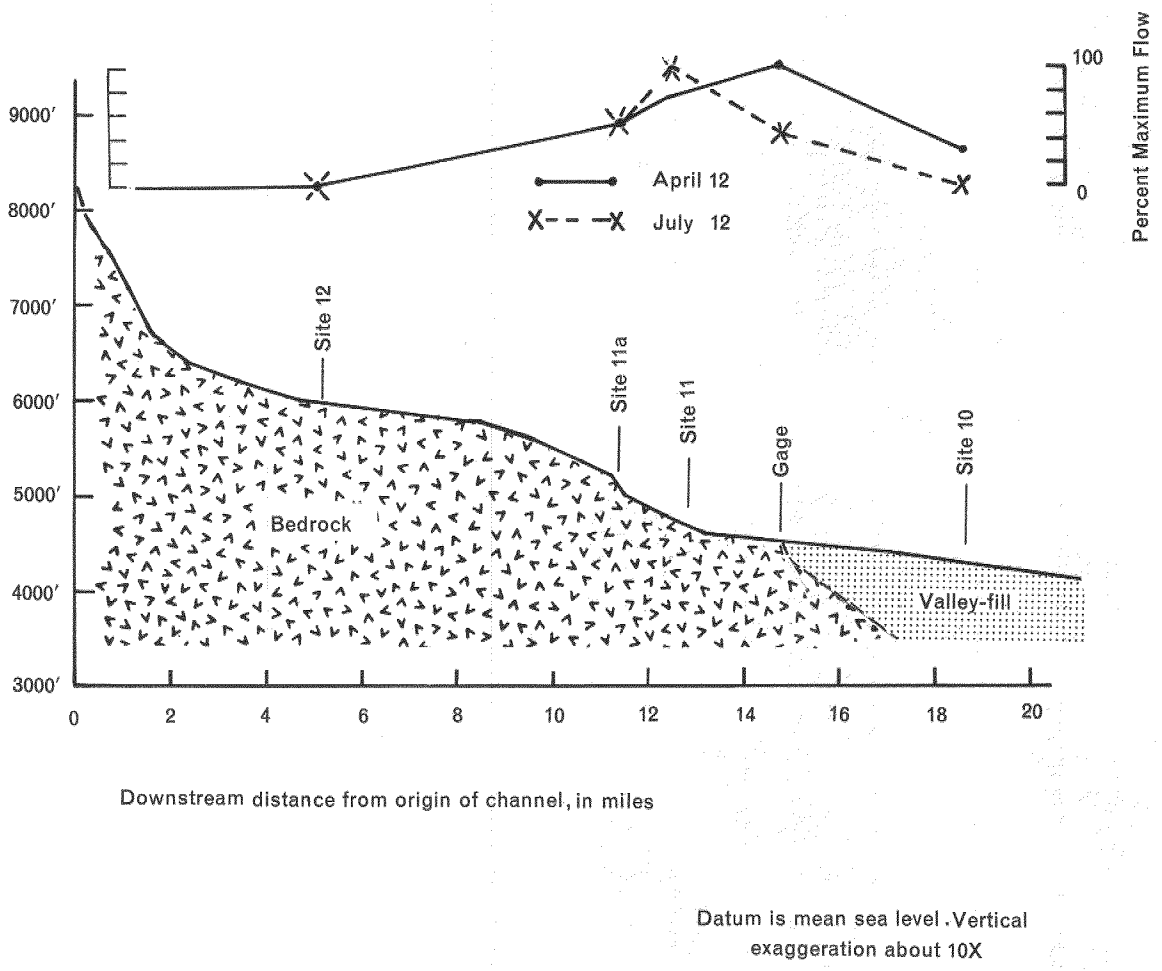


Figure 6.—Variations in the distribution of flow in Red Mountain Creek during April and July 1967

Estimated Runoff

The method used to estimate runoff at the mountain front is described in detail by Moore (1968). In this method, altitude-runoff relations for general areas are developed on the basis of long-term records of streamflow and precipitation.

The altitude-runoff relation used for this report is illustrated by table 6. The runoff estimated on the basis of the above method was compared on an area basis (fig. 7) with computed streamflow for subareas that were monitored by miscellaneous measuring sites. A correction factor was then used to determine runoff from remaining ungaged parts of the subareas. The synthesized average annual discharge at the mountain front for Granite Creek, Rock Creek, Cottonwood Creek, Red Mountain Creek, and Negro Creek, was 3,300 acre-feet (table 7). Flow of these streams has been appropriated for irrigation of 913 acres in Hualapai Flat, according to the files of the State Engineer.

Table 8 is a summary of estimated average annual runoff in Hualapai Flat. Because of (1) the seasonal distribution of flow, (2) infiltration to the ground-water reservoir, and (3) evapotranspiration, only an estimated 500 acre-feet of the total flow is being used for flood-type irrigation.

Table 6.--Runoff-altitude relation used for Hualapai Flat

Altitude	Runoff in cfs per sq mi
4,000-5,000	Trace
5,000-6,000	0.037
6,000-7,000	0.089
7,000-8,000	0.222
8,000-9,000	0.407

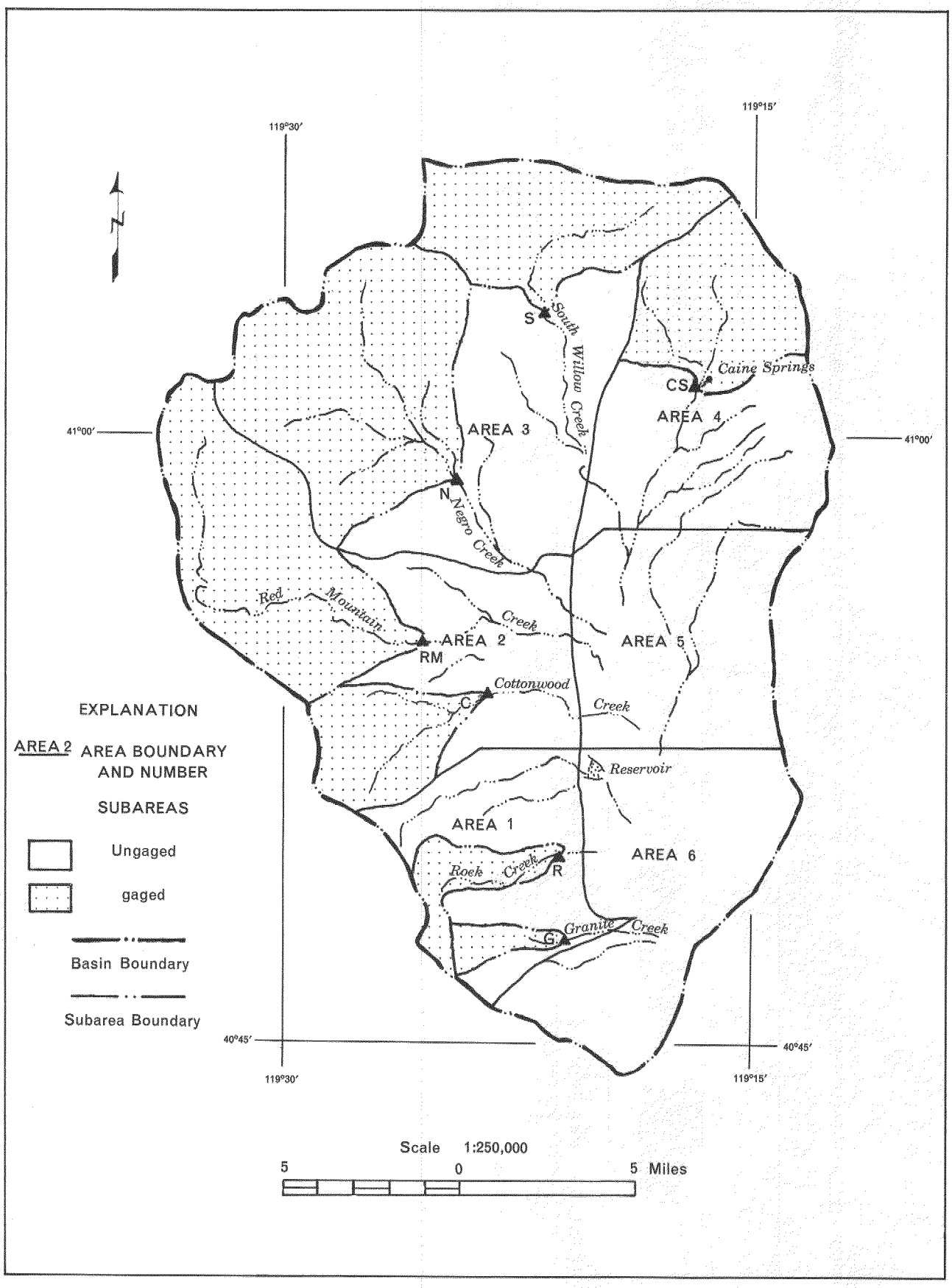


Figure 7.—Runoff areas

Table 7.--Estimated runoff of five major streams at mountain front in Hualapai Flat for water year 1967

Name	Estimated runoff at mountain front (acre-feet)	Acreage having surface water rights[1] (1966-67)
Granite Creek	290	248
Rock Creek	960	
Cottonwood Creek	540	528
Red Mountain Creek	1,300	
Negro Creek	230	137
Total	3,300	913

1. Files of State Engineer, 11-15-67.

Table 8.--Average annual runoff to Hualapai Flat

Area	Subarea	Drainage area (acres) Gaged	Drainage area (acres) Not gaged	Drainage area contributing to runoff[1] (acres)	Percent of total drainage area contributing to runoff	Estimated average annual runoff (acre-feet)
1	Granite Creek	1,541				290
	Rock Creek	3,068				960
	Remaining		14,980	9,894	4.9	1,400
	Subtotal					2,600
2	Cottonwood Creek	9,070				540
	Red Mountain Creek	21,890				1,300
	Remaining		14,150	29,800	14.7	70
	Subtotal					1,900
3	Negro Creek	26,710				230
	South Willow Creek	14,410				120
	Remaining		23,190	47,510	23.5	350
	Subtotal					700
4	Caine Springs Wash	11,670				80
	Remaining		18,780	16,810	8.3	40
	Subtotal					120
5	All	--	19,330	438	0.2	2
6	All	--	23,670	1,565	6.6	8
	Total	88,360	114,100	106,000	57.5	5,300

1. That area above 5,000-foot altitude.

NATURAL OUTFLOW FROM THE VALLEY-FILL RESERVOIR

Natural outflow from the valley-fill reservoir is accomplished by evapotranspiration in areas of shallow ground water and by subsurface flow to the Black Rock Desert.

Evapotranspiration

Natural discharge of ground water occurs where the saturated part of the valley fill is at shallow depth. Discharge is accomplished principally in three ways: (1) by evapotranspiration in areas of phreatophytes; (2) by direct evaporation from bare soil where the capillary fringe extends to within a short distance of the land surface; and (3) by evaporation of spring discharge where the water table intersects the land surface, or where artesian conditions cause ground water to rise to the surface.

The principal phreatophytes, as shown on plate 1, are greasewood, rabbitbrush, saltgrass, and meadowgrass or native hay. Some buckbrush, shadscale, and wild rye grows in localized areas and has been mapped in with the saltgrass, rabbitbrush, greasewood assemblage. Some meadowgrass and native hay is supported in part by discharge from flowing wells. Well 34/23-2dd, drilled in 1962, flows about 440 gpm. All other flowing wells in this area have flowed for longer periods. The concentration of discharge by these flowing wells probably is partly compensated for by local reduction in seepage and spring discharge. About one-third to one-half of the annual water requirement of the meadowgrasses and native hay is assumed to be supplied by precipitation and surface-water flow.

Estimates of the natural evapotranspiration of ground water are given in table 9. These estimates are based on rates of consumption of ground water, as described by Lee (1912), White (1932), Young and Blaney (1942), Houston (1950), and Robinson (1965). The rates are about the same as those used by Sinclair (1962). Little information is available concerning the rate at which ground water is evaporated from bare soil on the playa. The depth to water is generally less than 5 feet, and the surface typically has a porous, fluffy texture. Salt encrustations are formed readily, and during hot dry summer months the ground remains moist to within several inches of the surface. An estimated average rate of evaporation of ground water of 0.1 foot per year is used for both the playa and the sparsely vegetated area of greasewood mounds and bare soil on the northwest side of the playa where depth to water is generally greater than 5 feet.

Table 9.--Estimated evapotranspiration of ground water

Phreatophyte assemblage or type surface	Areal density	Depth to water (feet)	Area (acres)	Annual evapotranspiration: Acre-feet per acre	Annual evapotranspiration: Acre-feet
Principally greasewood and rabbitbrush, some shadscale and sparse saltgrass	Low to moderate	5 to 35	13,600	0.2	2,700
Principally saltgrass, rabbitbrush, greasewood, some buckbrush, wild rye, and shadscale	Moderate to low	<5 to 10	2,300	0.4	920
Principally meadowgrass and native hay, some saltgrass and rabbitbrush	--	<5	2,100	a 1.0	2,100
Bare soil (playa) and adjacent area of bare soil, sparse greasewood, and greasewood mounds	--	<5 to 30	5,600	0.1	560
Total (rounded)			23,000		6,300

a. Annual consumption of water may range from 1.5 to 2 acre-feet per acre. About 1 foot is assumed to be supplied by ground water (including spring discharge); the remainder is supplied by surface water and precipitation.

The estimated annual evapotranspiration of ground water is 6,300 acre-feet, of which about 560 acre-feet is evaporated from the playa and adjacent area of bare soil and low density greasewood. These figures, although slightly higher, are in reasonable agreement with the estimate of 5,000 acre-feet by Sinclair (1962), which did not include evapotranspiration from the playa and adjacent bare-soil, low-density phreatophyte area.

Subsurface Flow to the Black Rock Desert

Underflow to the Black Rock Desert may be estimated by assuming that most of the water moves through alluvial deposits that have hydraulic continuity with the Black Rock Desert. McGinnis and Dudley (1964, p. 32) show that the width of saturated alluvial deposits along the divide is about 0.8 mile and that the average thickness of the deposits is about 120 feet. The transmissibility of these deposits is estimated to be about 15,000 gpd per foot on the basis of their thickness, the probability that a stream once drained Hualapai Flat through this part of the divide (McGinnis and Dudley, 1964, p. 31), and the logs of U.S. Geological Survey test holes 35/24-32dd2 and 35/24-33ac1 (table 21). Plate 1 shows the hydraulic gradient across the divide to be about 30 feet per mile. Using the formula $Q = 0.00112\ TIW$, where Q is underflow in acre-feet per year, 0.00112 is a factor to convert gallons per day to acre-feet per year, T is the coefficient of transmissiblity of the alluvial deposits in gallons per day per foot, I is the ground-water gradient in feet per mile, and W is the width of section in miles, underflow to the Black Rock Desert is computed to be about 400 acre-feet per year.

The magnitude of the underflow may also be estimated from the quantity of natural discharge that occurs directly downgradient from the divide and above the Black Rock Desert playa. Depth to water in this area ranges from about 10 to 30 feet and greasewood and rabbitbrush are the principal phreatophytes. The overall areal density is low because sand dunes are prevalent locally. About 4,500 acres of phreatophytes consume ground water at an estimated annual rate of about 0.1 acre-foot per acre, or about 450 acre-feet per year, which is in reasonable agreement with the above estimate. Undoubtedly, some of the discharge is supported by locally derived recharge; however, it is also probable that some of the underflow from Hualapai Flat moves beneath the phreatophytes and is discharged from the surface of the Black Rock Desert playa.

Subsurface flow to the Black Rock Desert thus is estimated to be about 400 acre-feet per year. Because the ground-water gradient across the divide may in part represent the upward component of flow west of the divide and because some additional water may leak through fractured bedrock at the south end of the Calico Mountains, this estimate may be conservative. Additional information is required before a more accurate estimate can be made.

EQUILIBRIUM CONDITIONS OF THE NATURAL SYSTEM

Prior to the development of ground-water supplies, the hydrologic system of the valley-fill reservoir, for practical purposes, was in a state of dynamic equilibrium. Over the long term, recharge equaled discharge and no net change occurred in the quantity of ground water stored in the system.

Water Budget

Table 10 is a ground-water budget which lists the several estimates of recharge to and discharge from the valley-fill reservoir under natural conditions. The estimated total average annual recharge to the valley-fill reservoir of 7,000 acre-feet is approximately 300 acre-feet more than the estimated average annual discharge. Ideally, these estimates should be equal. The minor imbalance is attributed to inaccuracies in the assumptions made and to unresolved hydrologic factors as well as the previously mentioned possibility that estimated recharge (table 4) may be slightly high because some potential recharge is evaporated in areas of shallow ground water.

The estimated annual runoff of 5,400 acre-feet (table 8) appears slightly low when compared with the estimates of recharge and discharge. This implies, provided all estimates are reasonably correct, that although much of the recharge is derived from runoff, a significant part occurs in the mountains and moves laterally as underflow from the consolidated rocks to the valley-fill reservoir.

Table 10.--Ground-water budget, in acre-feet per year, for equilibrium conditions in Hualapai Flat

Budget item		Acre-feet per year
RECHARGE:		
From precipitation (table 4)	7,000	
Total (rounded) (1)		7,000
DISCHARGE:		
Evapotranspiration (table 9)	6,300	
Subsurface flow to the Black Rock Desert (p. 29) .	400	
Total (rounded) (2)		6,700
IMBALANCE: (1) - (2)		300

CHEMICAL QUALITY OF WATER

Waters from 16 wells were analyzed during this study to determine the quality of ground water as of 1967, to relate variations in quality to the ground-water flow system, and to determine suitability of the water for use. These analyses are listed in table 11 along with nine others made prior to this study.

Relation to the Flow System

The chemical quality of ground water in Hualapai Flat changes as water moves from recharge areas near the mountains to discharge areas near the playa. Water near the mountains is typically a sodium bicarbonate or calcium bicarbonate type with a comparatively low dissolved-solids content. Dissolved solids tend to increase as the water moves downgradient toward the playa and Black Rock Desert. In these downgradient areas, water in shallow deposits is generally a sodium sulfate-chloride type with a comparatively high dissolved-solids content. Locally, where ground water is rising toward the surface, accumulations of the more concentrated water may overlie sodium bicarbonate water of better quality.

In some places the above-mentioned trends are overshadowed by local variations. For example, samples on the northeast side of the valley indicate that the water there is a sodium chloride-sulfate type with a comparatively high proportion of sodium. The exact reason for this was not determined; however, the anomaly may reflect the differing composition of nearby bedrock.

Suitability for Use

Agricultural Use

The dissolved-solids content, the amount of sodium relative to calcium and magnesium, and the concentration of substances that may be toxic to plants are the most significant factors affecting the suitability of water for irrigation. Four factors used by the U.S. Salinity Laboratory (1954, p. 69-82) to evaluate the suitability of irrigation water are listed in table 11, and are discussed briefly in footnote 5 of that table. Boron, though essential to plant nutrition in minor amounts, is highly toxic to some plants when it exceeds certain limits. The recommended limits for boron in water irrigating sensitive, semitolerant, and tolerant crops are about 1, 2, and 3 mg/l (milligrams per liter, which are equivalant to parts per million; see footnote 2, table 11), according to Scofield (1936).

Table 11.--Chemical analyses of water from wells, springs, and streams

Part I.--Detailed analyses by the U.S. Geological Survey

Location[1]	Date sampled	Temperature °F	Temperature °C	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)[3]	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved-solids content[4]	Hardness as $CaCO_3$	Specific conductance (micromhos per cm at 25°C)	pH (lab. determination)	Salinity hazard	Sodium-adsorption ratio (SAR)	Sodium hazard	Residual sodium carbonate (RSC)
				Milligrams per liter (upper number) and milliequivalents per liter (lower number)[2]																Factors affecting suitability for irrigation[5]			
34/23-1aa	5-12-67	66	19	67	0.02	30 1.50	8.4 0.69	46 2.00	9.5 0.24	178 2.92	18 0.37	34 0.96	0.1 0.01	0.5 0.01	0.1	302	110	435	7.6	Medium	1.9	Low	0.73
-2da	5- 3-61	--	--	76	--	18 .90	4.6 .38	386 15.60	16 .41	336 5.51	205 4.27	250 7.05	7.9 .42	0.2 .00	2.1	1,170	64	1,840	9.0	High	20	Very high	4.36
-10a	12-13-61	72	22	89	--	72 3.59	21 1.71	54 2.35	10 .26	223 3.65	67 1.39	93 2.62	.1 .01	.3 .00	.1	516	265	755	7.2	High	1.4	Low	.00
-25ca	12-13-61	55	13	36	--	30 1.50	9.5 .78	109 4.74	2.2 .06	220 3.61	41 .85	86 2.43	.1 .01	1.5 .02	.4	424	114	703	7.3	Medium	4.4	Low	1.33
-34	12-13-61	--	--	18	--	19 .95	3.8 .31	18 .78	3.5 .09	84 1.38	9.0 .19	21 .59	.1 .01	1.1 .02	.1	135	63	229	7.5	Low	1.0	Low	.12
34/24-6bb	12-12-61	61	16	69	--	30 1.50	10 .82	38 1.65	8.8 .23	176 2.88	20 .42	27 .76	.1 .01	.4 .01	.1	290	116	409	7.9	Medium	1.5	Low	.56
35/23-11da	5-12-67	63	17	65	.22	21 1.05	8.8 .72	43 1.87	7.8 .20	159 2.61	22 .46	29 .82	.2 .01	.1 .00	.1	275	88	380	7.1	Medium	2.0	Low	.84
-13db	5- 3-61	--	--	61	--	25 1.25	9.0 .74	32 1.39	4.7 .12	148 2.43	16 .33	23 .65	.2 .01	.5 .01	.1	245	100	339	7.8	Medium	1.4	Low	.44
-25ac	5-12-67	70	21	60	.02	44 2.20	14 1.15	35 1.52	8.9 .23	178 2.92	42 .87	46 1.30	.1 .01	1.2 .02	.0	339	168	509	7.3	Medium	1.2	Low	.00
35/24-31ab	5- 3-61	62	17	66	--	26 1.30	9.7 .80	33 1.44	7.1 .18	159 2.61	20 .42	25 .71	.2 .01	.5 .01	.2	266	104	366	7.7	Medium	1.4	Low	.51
36/23-18	12-13-61	--	--	64	--	8.4 .42	4.1 .34	21 .91	7.0 .18	73 1.20	12 .25	13 .37	.1 .01	.8 .01	.1	166	38	188	7.4	Low	1.5	Low	.44
-36dd	5-12-67	55	13	42	.02	46 2.30	20 1.65	40 1.74	5.1 .13	205 3.36	69 1.44	33 .93	.1 .01	.4 .01	.1	357	198	559	7.2	Medium	1.2	Low	.00
36/24-16a	12-12-61	70	21	74	--	23 1.15	8.4 .69	74 1.13	10 .26	107 1.75	22 .46	32 .90	.1 .01	1.8 .03	.0	250	92	323	7.3	Medium	1.2	Low	.00

1. Samples are from wells, except: 34/23-10a, unnamed spring; 34/23-34, Granite Creek; 36/23-18, Negro Creek; and 36/24-16a, Caine Spring.

2. Milligrams per liter and milliequivalents per liter are metric units of measure that are virtually identical to parts per million and equivalents per million, respectively, for all waters having a specific conductance less than about 10,000 micromhos. The metric system of measurement is receiving increased use throughout the United States because of its value as an international form of scientific communication. Therefore, the U.S. Geological Survey recently has adapted the system for reporting all water-quality data. Where only one number is shown, the number is milligrams per liter.

3. All carbonate (CO_3) values 0 mg/l except: 34/23-2da, 40 mg/l (0.13 me/l).

4. Calculated, with HCO_3 expressed as CO_3.

5. Salinity hazard is based on specific conductance (in micromhos) as follows: low, 0-250; medium, 251-750; high, 751-2,250; very high, >2,250. Sodium adsorption ratio (SAR) provides an indication of what effect an irrigation water will have on soil-drainage characteristics. SAR is calculated as follows, using milliequivalents per liter: $SAR = Na/\sqrt{(Ca + Mg)/2}$. Sodium hazard is based on an empirical relation between salinity hazard and sodium-adsorption ratio. Residual sodium carbonate (expressed in milliequivalents per liter) is tentatively related to suitability for irrigation as follows: safe, 0-1.25; marginal, 1.26-2.50; unsuitable, >2.50. The several factors should be used as general indicators only, because the suitability of a water for irrigation also depends on climate, type of soil, drainage characteristics, plant type, and amount of water applied. These and other aspects of water quality for irrigation are discussed by the U.S. Salinity Laboratory Staff (1954).

Part II.--Field-office analyses by the U.S. Geological Survey

Location[6]	Date sampled	Temperature °F	Temperature °C	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) plus potassium (K)[8]	Bicarbonate (HCO_3)[9]	Sulfate (SO_4)	Chloride (Cl)	Hardness as $CaCO_3$	Specific conductance (micromhos per cm at 25°C)	pH (lab. determination)	Salinity hazard	Sodium-adsorption ratio (SAR)	Sodium hazard	Residual sodium carbonate (RSC)
				Milligrams per liter (upper number) and milliequivalents per liter (lower number)[7]									Factors affecting suitability for irrigation[10]			
34/23-35aa	8- 2-67	57	14	41 2.05	13 1.03	140 6.11	244 4.00	76 1.58	128 3.61	154	840	8.2	High	4.9	Low	0.92
34/24-3bb	8- 3-67	59	15	18 .90	17 1.38	870 37.82	548 8.98	390 8.12	762 21.50	114	4,200	8.4	Very high	35	Very high	8.20
-5bbT	6-15-67	57	14	22 1.10	11 .90	87 3.80	194 3.18	70 1.46	41 1.16	100	480	8.1	Medium	3.8	Low	1.18
35/23-23ad	7-25-67	75	24	34 1.70	13 1.10	61 2.67	174 2.85	61 1.27	48 1.35	140	440	8.2	Medium	2.3	Low	.05
-24db	9-28-67	77	25	31 1.55	13 1.09	59 2.55	172 2.82	56 1.17	38 1.07	132	420	8.3	Medium	2.2	Low	.31
-26db	7-25-67	--	--	39 1.95	14 1.13	66 2.87	202 3.31	62 1.29	48 1.35	154	480	8.2	Medium	2.3	Low	.21
-35baT	8- 3-67	--	--	36 1.80	12 .96	120 5.22	262 4.29	81 1.69	71 2.00	138	730	8.2	Medium	4.4	Low	1.53
35/24-6cc	6-16-67	78	26	1.8 .09	.9 .07	124 5.40	166 2.72	77 1.60	44 1.24	8	480	8.1	Medium	19	High	2.56
-17cc	10/27/67	57	14	7.4 .34	.9 .07	177 7.71	237 3.88	67 1.39	102 2.88	22	790	7.5	High	16	High	3.44
-32dd1T	8- 3-67	55	13	10 .50	4.1 .34	163 7.07	314 5.15	73 1.52	44 1.24	42	670	8.0	Medium	11	Medium	4.31
-32dd2T	6-15-67	58	14	30 1.50	12 .98	83 3.60	196 3.21	82 1.71	41 1.16	142	480	8.2	Medium	3.2	Low	.73
-33acT	8- 3-67	64	18	6.4 .32	2.4 .20	263 11.44	284 4.65	160 3.33	141 3.98	26	1,100	8.2	High	22	Very high	4.13

6. All samples are from wells. Location numbers followed by "T" indicate shallow test holes augered by the U.S. Geological Survey.

7. See footnote 2 in Part I.

8. Computed as the milliequivalent-per-liter difference between the determined negative and positive ions; expressed as sodium. Computation assumes that concentration of undetermined ions--especially nitrate--are small.

9. All carbonate (CO_3) values 0 mg/l except: 35/23-24db, 4.0 mg/l (0.13 me/l); 34/24-3bb, 45 mg/l (1.50 me/l).

10. See footnote 5 in Part I.

Table 11 shows that all samples from large-diameter irrigation wells, except that from well 35/24-6cc, had low sodium hazards, medium salinity hazards, and residual-sodium-carbonate values less than 1.25. The sample from well 35/24-6cc had a high sodium hazard, a medium salinity hazard, and an unsuitably high RSC, which suggests that some future treatment of the soil or the water may be necessary to alleviate the accumulation of excessive amounts of sodium in the soil.

The boron content of all sampled irrigation waters from Hualapai Flat was less than the amount that might be harmful to semitolerant crops. Water from well 34/23-2da in the thermal spring area had a boron content of 2.1 mg/l and is thus classified as doubtful for purposes of irrigating semitolerant crops.

Most animals are more tolerant of poor water than man. Although available data are somewhat conflicting, dissolved-solids contents below 4,000-7,000 mg/l apparently are safe and acceptable (McKee and Wolf, 1963, p. 112-113). Thus, all sampled water within the study area is sufficiently dilute for livestock. However, the high fluoride concentration in water from well 34/23-2da, in the thermal spring area, suggests that some undesirable effects might result from sustained use of this water as stockwater.

Domestic Use

The U.S. Public Health Service (1962, p. 7-8) has formulated drinking-water standards that are generally accepted as a guide-line for public supplies. The standards, as they apply to data listed in table 11, are as follows:

Constituent	Recommended maximum concentration (milligrams per liter)
Iron (Fe)	0.3
Sulfate (SO_4)	250
Chloride (Cl)	250
Fluoride (F)	1.2a/
Nitrate (NO_3)	45
Total dissolved solids	500

a. The optimum concentration is about 0.9 mg/l. Water containing more than about 1.8 mg/l should not be consumed regularly, especially by children.

Most of these are only recommended limits, and water therefore may be acceptable to many users despite concentrations exceeding the given values.

Among the listed constituents, excessive iron causes staining of porcelain fixtures and clothes while large amounts of chloride and dissolved solids impart an unpleasant taste, and sulfate can have a laxative effect on persons who are drinking a water for the first time. Excessive fluoride tends to stain teeth, especially of children, and large amounts of nitrate are dangerous for infants and pregnant women because of the possibility of "blue-baby" disease.

The hardness of a water is important to many domestic users. Therefore, the U.S. Geological Survey has adapted the following rating:

Hardness range (milligrams per liter)	Rating and remarks
0-60	Soft (suitable for most uses without artificial softening)
61-120	Moderately hard (usable except in some industrial applications; softening profitable for laundries)
121-180	Hard (softening required by laundries and some other industries)
More than 180	Very hard (softening desirable for most purposes)

The bacteriological quality of drinking water also is important, but is outside the scope of this report. If any doubt exists regarding the acceptability of a drinking-water supply, contact the Nevada Bureau of Environmental Health, Reno.

At the present time (1967) less than 10 families use water obtained from the valley-fill reservoir. The chemical constituents of all samples from irrigation and stock wells sampled during the course of this study are within the permitted limits for domestic use. Water from well 34/23-2da in the thermal spring area had a fluoride content of 7.9 mg/l, which substantially exceeds the recommended limit.

Possibility of Chemical Encrustation

A reported decrease in yield of several wells may be due in part to the formation of encrustations on the casing perforations. The term "encrustation" is used to describe any undesirable substance deposited on well parts. This includes corrosion products,

minerals precipitated from the water, adhering materials from the geologic formation, or bacterial growths (Clarke, 1966, p. 371). Changes in chemical equilibrium resulting from flow of water through screen openings and up the casing can cause separation of minerals such as calcium carbonate and iron carbonate if the necessary constituents are present in critical concentrations. Even a slight change in concentrations or pH can trigger deposition reactions in waters that are saturated or supersaturated with troublesome minerals. Precise and detailed field measurements are required to determine whether corrosion or encrustation is occurring in a given well. These measurements were beyond the scope of this study. If future decreases in yield cannot be satisfactorily explained by mechanical failure of the well, mutual interference among wells, or declines in water levels, a detailed field study of possible encrustation may be warranted.

IRRIGATION DEVELOPMENT

History

Initially, grazing of sheep and cattle was the principal occupation in the area. Some hay and meadowland was irrigated by streamflow and spring discharge. An unsuccessful attempt at dry farming was made in the 1920's by a number of families that settled in the valley. During that period and in the 1930's hay and alfalfa were grown intensively and with some success on the Granite and Fly Ranches in conjunction with cattle grazing operations.

The first large diameter irrigation well (35/23-24ab) was drilled in 1951 in the northern part of the valley. No additional irrigation wells were drilled until 1960 when intensive efforts to develop land were begun. By the summer of 1967 about 28 large diameter irrigation wells had been drilled in the northern part of the valley and 20 wells were pumped for irrigation during some part of the 1967 growing season. Several flowing wells have been drilled in the hot spring area and about 10 flowing wells, which are used for stock, domestic, and limited irrigation purposes, have been drilled in the northern part of T. 34 N., Rs. 23 and 24 E., and the southern part of T. 35 N., Rs. 23 and 24 E. Virtually no attempt has been made to develop ground-water supplies in the southern part of the valley where much of the acreage suitable for cultivated crops can be irrigated by surface water.

As of November 1967, permits to pump about 26,500 acre-feet per year from the subsurface have been issued by the State Engineer. All of these permits are for areas in the northern part of the valley.

Crop Types, Acreages, and Consumptive Use

The principal crops that have been grown commercially are alfalfa, small grains (wheat, barley, and rye), hay, and sugar beets. A small acreage of sunflowers was planted one year but did not prove successful. The principal crop types and approximate acreages that have been irrigated by pumping ground water since 1960 are shown in table 12. Sugar beets have proved less successful than alfalfa; consequently, sugar beets have not been raised since 1965. Alfalfa was grown on about 85 percent of all land irrigated by pumping in 1967. This percentage probably will increase in the future.

The consumptive-use rates shown in table 12 are based on information in Houston (1950) and Blaney and Hanson (1965). The use rate for alfalfa is slightly higher than that shown by

Table 12.--Approximate acreages and seasonal consumptive use for major crops irrigated by pumping ground water

Crop	Approximate growing season	Consumptive use requirement (acre-feet per acre)1/	Approximate acreage2/							
			1960	1961	1962	1963	1964	1965	1966	1967
Alfalfa3/	5 to 5½ months	2.5	140	a 640	b 910	630	c 780	d 1,400	e 2,600	f 2,900
Small grains and hay	3 months	1.3	--	250	250	250	250	260	400	500
Sugar beets	4 months	1.5	0	0	0	760	880	240	0	0
Total acreage (rounded)			140	900	1,200	1,600	1,900	g 1,900	3,000	3,400

1. Based on information in Houston (1950) and Blaney and Hanson (1965).

2. Based largely on information furnished by local residents; 1966 figures based in part on information supplied by Mr. William Hunt, Soil Conservation Service, U.S. Dept. of Agriculture; additional information furnished by personnel of the Water Resources Division of the Nevada Dept. of Conservation and Natural Resources.

3. Includes alfalfa-grain mixtures and seed alfalfa.

a. About 500 acres of new alfalfa used about two-thirds seasonal water requirement.

b. About 300 acres of new alfalfa used about two-thirds seasonal water requirement.

c. About 150 acres of new alfalfa used about one-half seasonal water requirement.

d. About 500 acres of new alfalfa used approximately one-half seasonal water requirement.

e. About 300 acres of new alfalfa used approximately one-half seasonal water requirement.

f. About 400 acres of alfalfa not irrigated until late spring, used approximately two-thirds seasonal water requirement. About 120 acres of new alfalfa used approximately one-half seasonal water requirement.

g. Some sunflowers were grown in addition to the listed acreages.

Houston for the northwestern desert area, because a consumptive-use coefficient of 0.5 was used for periods of relatively slow growth before and after the frost-free period (Blaney and Hanson, 1965, p. 25). In an average year, three cuttings of alfalfa are obtained.

Estimated Pumpage 1960-67

Estimates of pumpage for the 7-year period 1960-67 were made from pumpage inventories, crop acreages, and number of wells considered to have been pumped in a given year. Approximate crop acreages are available for 1960-67. A pumpage canvass was made in 1967 as a part of this study, and information concerning 1966 pumpage was obtained from the State Engineer. Partial reports of pumpage in other years were obtained from local residents.

That part of the total pumped water that is consumed by crops or lost by surface or spray evaporation and that part that is recirculated (returned to ground water) varies with each field, depending on the method used to distribute water, the degree of efficiency with which the method is used, soil texture and permeability, land slope, and other factors. The principal methods used to distribute water in Hualapai Flat are by gated pipes and by sprinkling. During the 1967 growing season, seven wells pumped through sprinkler systems, several wells pumped into open ditches, and the remainder pumped water through gated pipes. In general, as compared to other methods, sprinkling tends to reduce the percentage of the total pumped water that is recirculated and to increase the percentage of the total pumped water that is lost to spray and surface evaporation. For purposes of computation, roughly two-thirds of the total water pumped is assumed to be consumed by crops or lost by spray and surface evaporation. The remaining one-third is assumed to be recirculated, or returned to ground water.

Table 13 lists the estimated gross pumpage, net pumpage, and cumulative net pumpage for the 8-year period 1960-67 inclusive. The estimated net pumpage for this period is 28,000 acre-feet, one-half of which was pumped during 1966 and 1967. The gross pumpage is about 42,000 acre-feet of which an estimated 14,000 acre-feet has been recirculated. The estimated cumulative net pumpage for the seven growing seasons of the study period, beginning spring 1960 and ending spring 1967, was 21,000 acre-feet.

Table 13.--Estimated pumpage, 1960-67

[All estimates, in acre-feet, rounded to two significant figures]

Year	Gross pumpage	Net pumpage[1]	Cumulative net pumpage[2]
1960	520	350	350
1961	2,200	1,500	1,800
1962	3,400	2,300	4,200
1963	4,500	3,000	7,200
1964	5,100	3,400	11,000
1965	5,400	3,600	14,000
1966	9,900	6,600	a21,000
1967	11,000	7,400	28,000
Totals (rounded)	42,000	28,000	28,000

1. Net pumpage is assumed to be roughly two-thirds of gross pumpage.

2. At end of growing season.

a. Cumulative net pumpage for study period spring 1960-spring 1967 (see tables 16 and 17). Because virtually no pumpage occurred during winter months, cumulative net pumpage at the close of 1966 pumping season remained about the same through spring 1967.

EFFECTS OF PUMPING ON THE GROUND-WATER SYSTEM

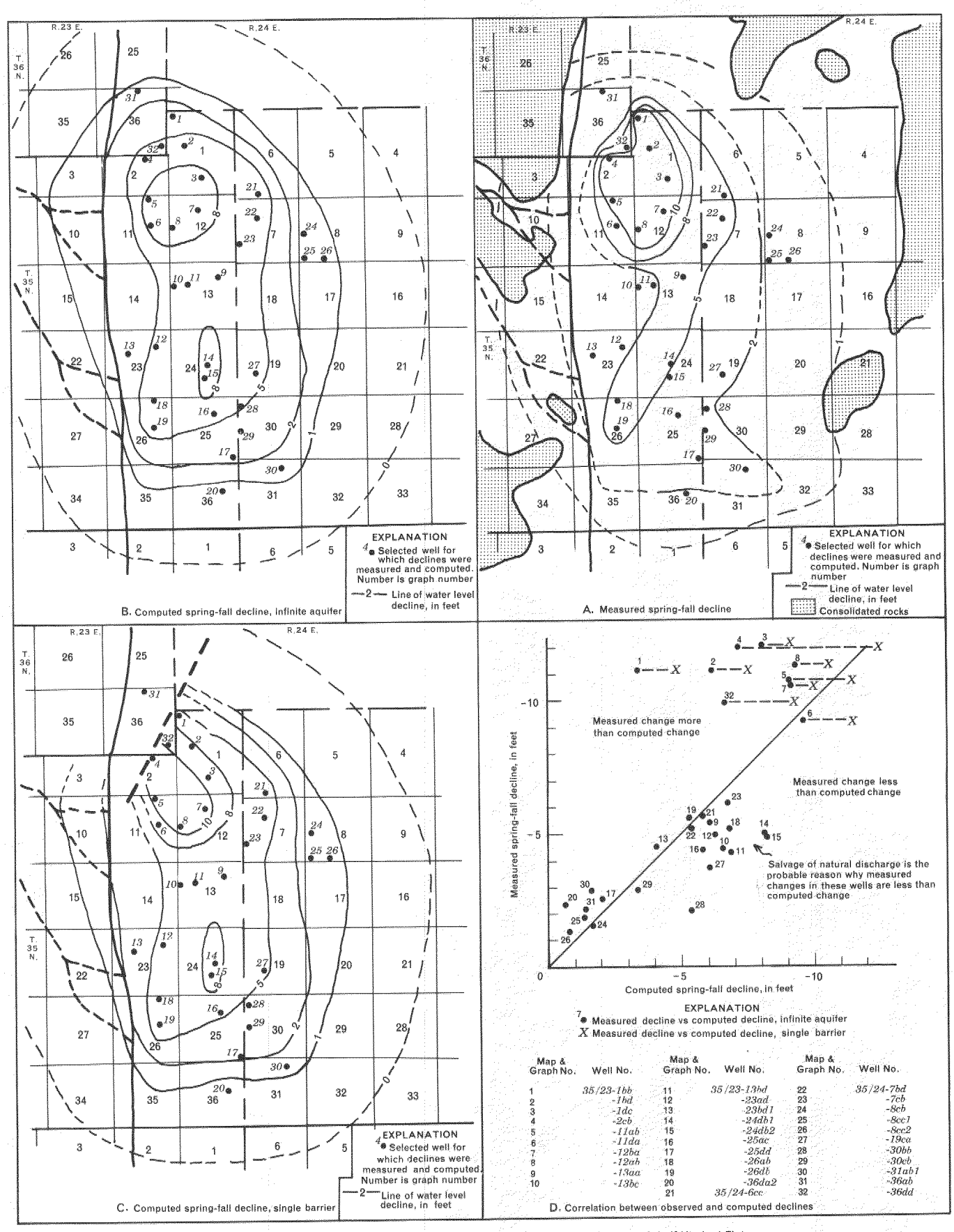
As mentioned before, prior to any pumping and over the long term the ground-water system was in a state of dynamic equilibrium where recharge equaled discharge and the quantity of water in storage remained constant. Pumping creates an imbalance in the system where total discharge (natural discharge plus pumping) exceeds the recharge. Consequently, water is withdrawn from storage and water levels decline until natural discharge is reduced sufficiently to bring the system to a new equilibrium where recharge equals a reduced natural discharge (sometimes to zero), plus net pumpage. However, if net pumpage plus natural discharge continually exceeds recharge, water levels will decline indefinitely and a new equilibrium will never be reached.

Irrigation pumping in Hualapai Flat occurs in a cyclic pattern. Virtually all pumping occurs between April and October with heavy pumping concentrated from June to early September. Cyclic pumping produces seasonal water-level fluctuations which are superposed on the above-mentioned long-term trend of storage depletion and water-level decline. Water levels typically decline during the pumping season, reach their lowest points in the late summer, and when pumping ceases recover (rise) during the fall, winter, and early spring to a level slightly below that for the preceding spring. These fluctuations are most pronounced in the well field and diminish as distance from pumping increases. Generally, in other areas having properly spaced wells, extensive aquifers, and moderately high transmissibilities, the seasonal response to pumping is much less significant than the cumulative changes that occur over the long term.

However, in Hualapai Flat, localized close-well spacing and areas of low transmissibility, limitations in the areal extent of the aquifer, and other factors may induce comparatively large summer drawdowns in heavily pumped areas. In time, as water levels gradually decline in response to the long-term trend, these summer drawdowns may become significant economic factors.

Seasonal Response

At the start of each pumping season, water levels in the north-central part of Hualapai Flat are drawn down. By the end of the pumping season, a substantial decline has occurred. Figure 8 (map A) shows the magnitude of the net decline for the 1967 pumping season. To evaluate these short-term effects of concentrated pumping in an aquifer of limited areal extent,



Map & Graph No.	Well No.	Map & Graph No.	Well No.	Map & Graph No.	Well No.
1	35/23-1bb	11	35/23-13bd	22	35/24-7bd
2	-1bd	12	-23ad	23	-7cb
3	-1dc	13	-23bd1	24	-8cb
4	-2cb	14	-24db1	25	-8cc1
5	-11ab	15	-24db2	26	-8cc2
6	-11da	16	-25ac	27	-19ca
7	-12ba	17	-25dd	28	-30bb
8	-12ab	18	-26ab	29	-30cb
9	-13aa	19	-26db	30	-31ab1
10	-13bc	20	-36da2	31	-36ab
		21	35/24-6cc	32	-36dd

Figure 8.— Computed and measured 1967 spring-fall water-level declines north half Hualapi Flat

the actual water-level declines are compared to two mathematical models--one showing the response in an infinite aquifer; the other an infinite aquifer with a single barrier, which partially simulates the conditions in Hualapai Flat.

Seasonal drawdown scales were prepared for each pumped well in the valley. They were constructed from a chart for the computation of drawdown in the vicinity of a discharging well (Theis, 1963, p. C10-C15), following a procedure similar to that outlined by Conover and Reeder (1963, p. C38-C44).

The following assumptions were made and procedures followed:

(1) The scales were designed to represent the residual drawdown (below spring levels) around each pumped well and nonpumped well after the 1967 irrigation season. Provision was made for periods of recovery between cuttings of hay and before the fall water-level measurement so that the periods used in the computation would nearly equal the observed pumping periods.

(2) The distribution of transmissibility used is shown in figure 2.

(3) A uniform storage coefficient of 0.1 was used instead of the slightly higher specific-yield values shown in figure 3, because some water probably was still draining from partly dewatered material at the time fall water-level measurements were made.

(4) Residual drawdowns were computed with both measured discharge rates and estimated net pumping rates (two-thirds of the measured rate, table 13) which allows for recirculation of some water to the ground-water reservoir. The best correlation with observed values was obtained using net pumping rates; thus, for purposes of computation, it was assumed that most recirculation of irrigation water to the ground-water reservoir had occurred by the time the fall water-level measurement was made and that residual drawdowns could be more accurately computed using net pumping rates.

(5) Because of the many assumptions and partly resolved variables involved, observed and computed values for water-level decline within 1 foot of agreement were considered reasonable for this first approximation.

(6) The total residual drawdown at pumped and nonpumped wells throughout the area was computed by adding the drawdowns resulting from mutual interference, and maps were prepared showing computed spring-fall changes.

Figure 8 shows (A) the measured spring-fall net water-level decline; (B) the computed spring-fall net water-level decline, assuming a homogeneous aquifer of infinite extent; (C) the computed spring-fall net water-level decline, assuming a single barrier in the valley fill, and (D) the correlation between measured and computed water-level declines.

Measured residual drawdowns in secs. 1, 2, 11, and 12, T. 35 N., R. 23 E., were generally greater than computed values. Values shown on map B indicate that heavy pumping and comparatively close well spacing caused greater drawdowns there than in other parts of the well field; however, these factors alone are not sufficient to account for the measured water-level declines (map A). Better correlations are obtained when the computed values are corrected for a single barrier (map C), but some wells still exhibit large deviations. The large residual drawdowns observed in this part of the well field probably result from the combined effects of heavy pumping from relatively closely spaced wells in the proximity of several hydrologic barriers (the alluvial faults shown on pl. 1). Bedrock barriers that bound the valley-fill reservoir apparently have had only small effects on water-level declines during this one season but may have considerable effect on cumulative declines caused by the overall long-term trend.

Measured residual drawdowns in the southern part of the well field are generally less than computed values. Part of this difference is interpreted to represent some salvage of natural discharge that would cause a lessening in the rate of water-level decline.

Long-Term Response

Water-Level Decline and Salvage of Natural Discharge

The ultimate amount by which water levels will decline in any given case is dependent on the quantity of water pumped in relation to the quantity of natural discharge (or recharge), the distance from the area of pumping to the area of natural discharge, the degree to which pumping is localized, the coefficients of transmissibility and storage, and barrier effects posed by bedrock boundaries or by internal structures of the valley-fill reservoir. Development in Hualapai Flat is

distributed asymmetrically with respect to the area of natural discharge, and heavy pumping is localized in the northwest end of the well field; however, the southern end of the well field is in the area of natural discharge (pl. 1). Figure 9 shows the long-term effects of three rates of pumping on the natural system. The distribution of pumping in relation to the area of natural discharge as shown is similar to that which exists in Hualapai Flat.

The above-mentioned distribution of pumping suggests that, regardless of the pumping rate, some natural discharge should be readily salvaged after a comparatively short period of pumping. Salvage was occurring in 1967, as previously described by the deviations between the measured and computed spring-fall water-level declines and also by the fact that several wells that formerly flowed (35/23-36da1, 35/23-36da2, 35/23-36da3, 35/24-31ab1, and 35/24-31ab2) did not flow during the 1966 or 1967 pumping season. A seepage area in the SE¼ sec. 36, T. 35 N., R. 23 E. was reported to be much drier than in previous years and the pressure (head) in flowing wells 35/23-1aa1, 35/23-1aa2, 34/24-6bb1, and 34/24-6bb2 was less in 1967 than in previous years. Some discharge was also salvaged when about 1,500 acres of land in the discharge area was cleared for development.

Assuming that prior to development phreatophytes on the cleared land consumed ground water at an annual rate of 0.2 acre-foot per acre (table 9), and upward leakage was reduced by about 100 acre-feet during 1967, natural discharge probably was only reduced by about 400 acre-feet during 1967. The total quantity salvaged prior to the 1967 pumping season was probably only about 600 acre-feet.

The relative ease with which natural discharge may be salvaged by pumping from existing wells, as of 1967, is illustrated by the estimates in table 14. For example, most of the estimated 4,500 acre-feet per year of discharge in T. 35 N., Rs. 23 and 24 E., is within about 2 miles of the southernmost pumped well and about 6 miles from the area of maximum water-level decline. At least 4,000 acre-feet of this discharge probably can be salvaged by pumping without excessive water-level declines occurring in the existing well field.

Salvage of all evapotranspiration (6,300 acre-feet per year, table 9) would require that pumping induce water-level declines of about 50 feet in the area of phreatophytes (pl. 1). This might not be accomplished by pumping the existing well field without undue drawdown, and hence excessive pumping costs. A drawdown of about 50 feet might salvage one-half the subsurface outflow to the Black Rock Desert, which totals about 400 acre-feet per year.

Table 14.--Distribution of natural discharge with respect to existing well field

Area	Approximate distance south of: Southernmost pumped well in 1967 (35/24-32ab1)	Approximate distance south of: Area of maximum water-level decline in 1967 (secs. 1, 2, 11, and 12, T. 35 N., R. 23 E.)	Estimated annual natural discharge (acre-feet)	Estimated natural discharge cumulative to the south (acre-feet)
T. 35 N., Rs. 23 and 24 E.	In discharge area	2 to 3 miles	a 2,200	2,200
N 1/3 T. 34 N., Rs. 23 and 24 E.	2 miles	6 miles	2,300	4,500
Middle 1/3 T. 34 N., Rs. 23 and 24 E.	4 miles	8 miles	1,000	5,500
S 1/3 T. 34 N., Rs. 23 and 24 E.	6 miles	10 miles	1,100	6,600
T. 33 N., Rs. 23 and 24 E.	7+ miles	11+ miles	100	6,700

a. Includes an estimated 400 acre-feet per year of underflow to the Black Rock Desert.

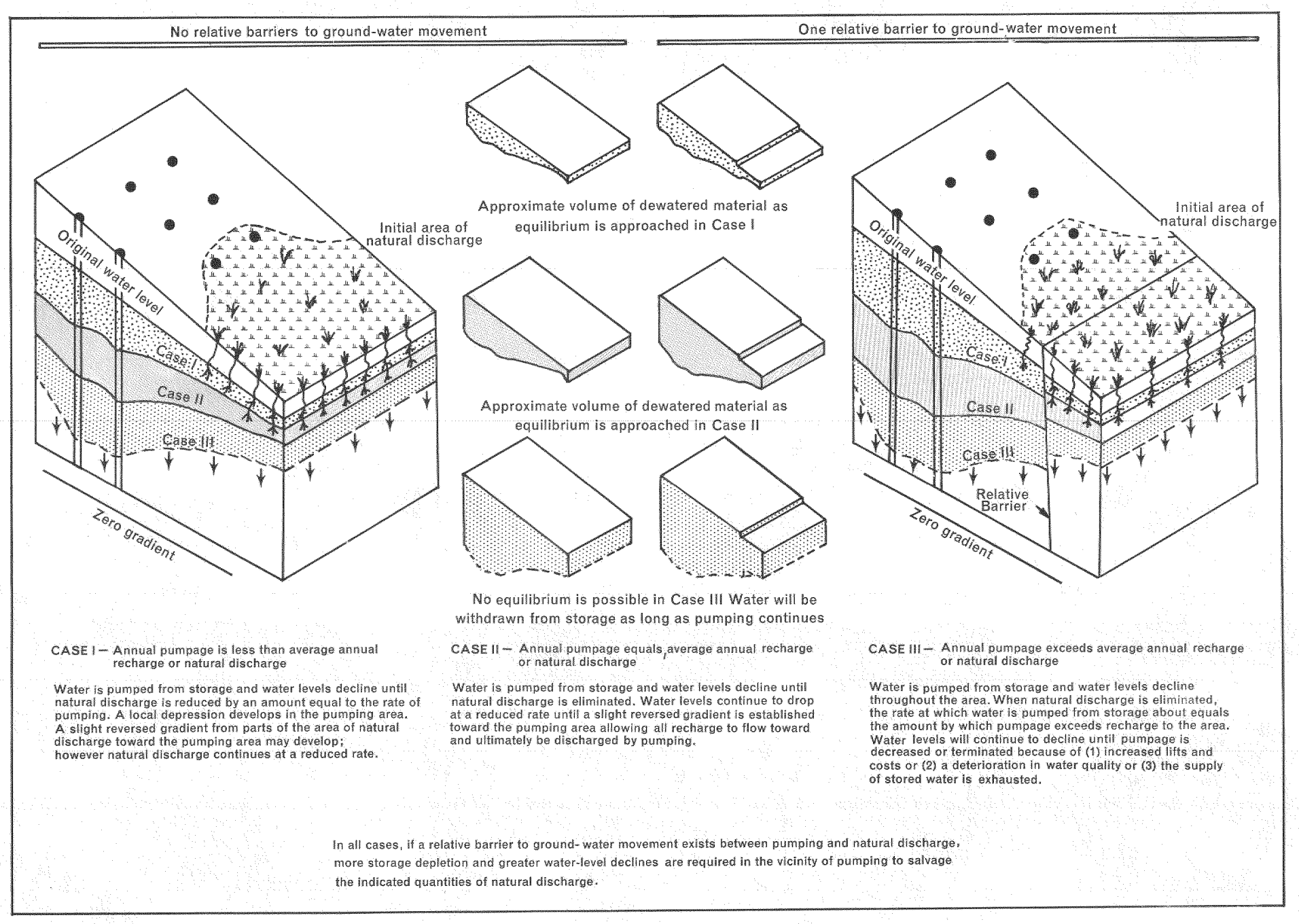


Figure 9.— Long term effects of three rates of pumping on the ground-water systems

Decreases in Transmissibility

As mentioned before in the section on coefficients of transmissibility and storage, the transmissibility of the valley-fill reservoir is dependent upon both the permeability of the material involved and its thickness. Consequently, long-term water-level declines which cause permeable deposits to be dewatered also cause the transmissibility of the valley fill to decrease. Thus, pumping lifts in wells where water levels are steadily declining may be expected to increase faster than the rate at which nonpumping water levels decline. Table 15 shows the relation between long-term decline of static water levels, percentage of the aquifer dewatered, and resulting decline in pumping levels in three hypothetical wells. Because actual conditions vary with each well encountered in the field, only the relative magnitudes of difference and the trends exhibited in the table are significant.

Generally, the additional increases in pumping lifts caused by decreased transmissibility are so small in relation to the cumulative water-level decline through spring 1967 that they are of little economic significance. However, in areas of moderate to low transmissibility that are experiencing accelerated rates of water-level decline for other reasons, decreased transmissibility may become a significant additional factor in causing economic limits to be approached sooner than would otherwise occur.

Changes in Water Quality

In hydrologically closed basins, the chemical quality of pumped water generally deteriorates with time. This change is attributed to (1) the reversal of natural gradients, which may cause water of poor quality to flow into the pumping area from beneath the playa and adjacent discharge area, and (2) an unfavorable salt balance caused by the recycling of irrigation water in the area of pumping. The effects of both of these processes are lessened by natural mixing with locally derived water of good quality, so that considerable pumping usually is required to bring about economically significant changes.

The problem of an unfavorable salt balance may in time pose a threat to the future of the existing ground-water development. As pointed out by Hem (Halpenny and others, 1952, p. 149):

"It has long been recognized that if an irrigation project is to be permanently successful it must be so designed and operated that the drainage leaving the area of irrigation carries off the accumulating soluble salt from the whole area. Ideally, the amount of mineral matter that must be removed should at least

Table 15.--Relation between long-term decline in nonpumping water-levels, percentage of the aquifer dewatered, and resulting long-term decline in pumping level in three hypothetical wells

Long-term decline in nonpumping water level (feet)	Percentage of the aquifer dewatered	Resulting long-term decline in pumping level (feet)1/		
		Well in aquifer (1) Initial T = 150,000, gpd/ft	Well in aquifer (2) Initial T = 75,000, gpd/ft	Well in aquifer (3) Initial T = 30,000, gpd/ft
25	8.3	26	27	30
50	16.7	52	54	60
75	25	78	82	91
100	33.3	105	110	119

1. Resulting long-term decline in pumping level computed as: Long-term decline in nonpumping level plus (resulting drawdown minus original drawdown). Drawdowns determined from a chart by C. V. Theis (1963) on the basis of the following assumptions:

1. All three wells drilled in aquifers 300 feet thick.
2. All aquifers have a coefficient of storage of 0.15.
3. The initial transmissibilities shown will decrease in direct proportion to the percentage of the aquifer dewatered.
4. All drawdowns were determined at a radius of 1 foot after 20 days of pumping at 1,000 gpm.

be equivalent to the amount entering the area in the irrigation water supply and from other sources. This is essentially the principal of salt balance."

Drainage from the north half of Hualapai Flat under natural conditions was accomplished principally by subsurface flow toward the playa and, to a minor extent, by underflow into the Black Rock Desert. As natural gradients are reversed by pumping, natural drainage from the area is reduced and ultimately eliminated, and salts that are not removed by crops or wind action remain either in the soil or in that part of the irrigation water that returns to the zone of saturation. Soluble salts are continually being brought into the area, either in ground water or in fertilizers. This results in an unfavorable salt balance and, over the long term, a gradual but cumulative deterioration in the quality of the pumped water.

Deterioration in the quality of the pumped water may also be caused by an influx of highly mineralized water from beneath the playa and from the adjacent Black Rock Desert area. The quantity of undesirable water that might move in from the Black Rock Desert would probably be small in relation to the quantity of water that might migrate northward from beneath the playa. Furthermore, fault barriers in the alluvium between the playa and the main area of development may significantly impede the northward migration of large quantities of undesirable water from both areas.

Net Change in Water Levels, 1960-67

Contours drawn for the high water levels in the spring of 1967 in the north half of Hualapai Flat are shown in figure 10. In the developed area, water levels are substantially lower than those shown for the spring of 1960 on plate 1. Figure 10 also shows the net decline in water levels from the spring 1960 to spring 1967. The areas in which water levels have declined and the amount of the decline were determined from the water-level contour maps for 1960 and 1967 and extrapolated from changes observed in individual wells having shorter records. Many of the early water levels were based on observations made by drillers.

Maximum water-level declines were in excess of 20 feet and occurred in secs. 1 and 2, T. 35 N., R. 23 E. This is also the area where the maximum decline in water levels occurred from spring to fall 1967 (fig. 8). Thus, the hydrologic barriers and concentrated pumping that produced the maximum seasonal change are apparently also causing localized accelerated rates of long-term water-level decline.

In figure 10, the zero net-change line is approximately the limit of measurable change and therefore also represents the approximate lateral limit of storage depletion. Pressure changes may have caused slight declines in head outside of this area. Also, water levels may have risen slightly in localized areas on the southeast side of the development where waste irrigation water is collected in a ditch and flows southward toward sec. 31, T. 35 N., R. 24 E. This area is small and the water-level rise minor; therefore it is not shown in figure 10.

Storage Depletion as of Spring 1967

Water which has been removed from storage as a result of pumping during the 7-year period spring 1960 to spring 1967 is estimated as the sum of the products of (1) areas of dewatered material, (2) net declines of water levels, and (3) specific-yield values. For purposes of computation, the specific yields for the upper 50 feet of saturation shown in figure 3 are considered to be roughly equivalent to those of the thinner, uppermost interval dewatered during the 7-year period. The volume of dewatered material in each specific-yield zone (fig. 3) was determined from the area and net water-level declines shown in figure 10.

Table 16 lists net changes, areas, volume of the dewatered interval, specific yield, and estimated storage depletion. The estimated storage depletion of 22,000 acre-feet is slightly larger than the estimated total net pumpage of 21,000 acre-feet for the seven pumping seasons 1960-67 (table 13). Under ideal conditions, the storage depletion should be slightly less than the net pumpage because although most pumped water has come from storage some natural discharge has been salvaged. The difference in estimates is attributed to inaccuracies in the assumptions made, to water-level declines in some wells that may represent changes in pressure head rather than actual storage depletion, to a possible time lag in the draining of some finer grained deposits, and to a possible time lag in the return of some of the recirculated water to the zone of saturation. This last possibility may be of minor significance as it was previously mentioned that the best correlation between computed and measured spring-fall water-level changes was obtained when it was assumed that most of the recirculation had occurred before the fall water-level measurement was made.

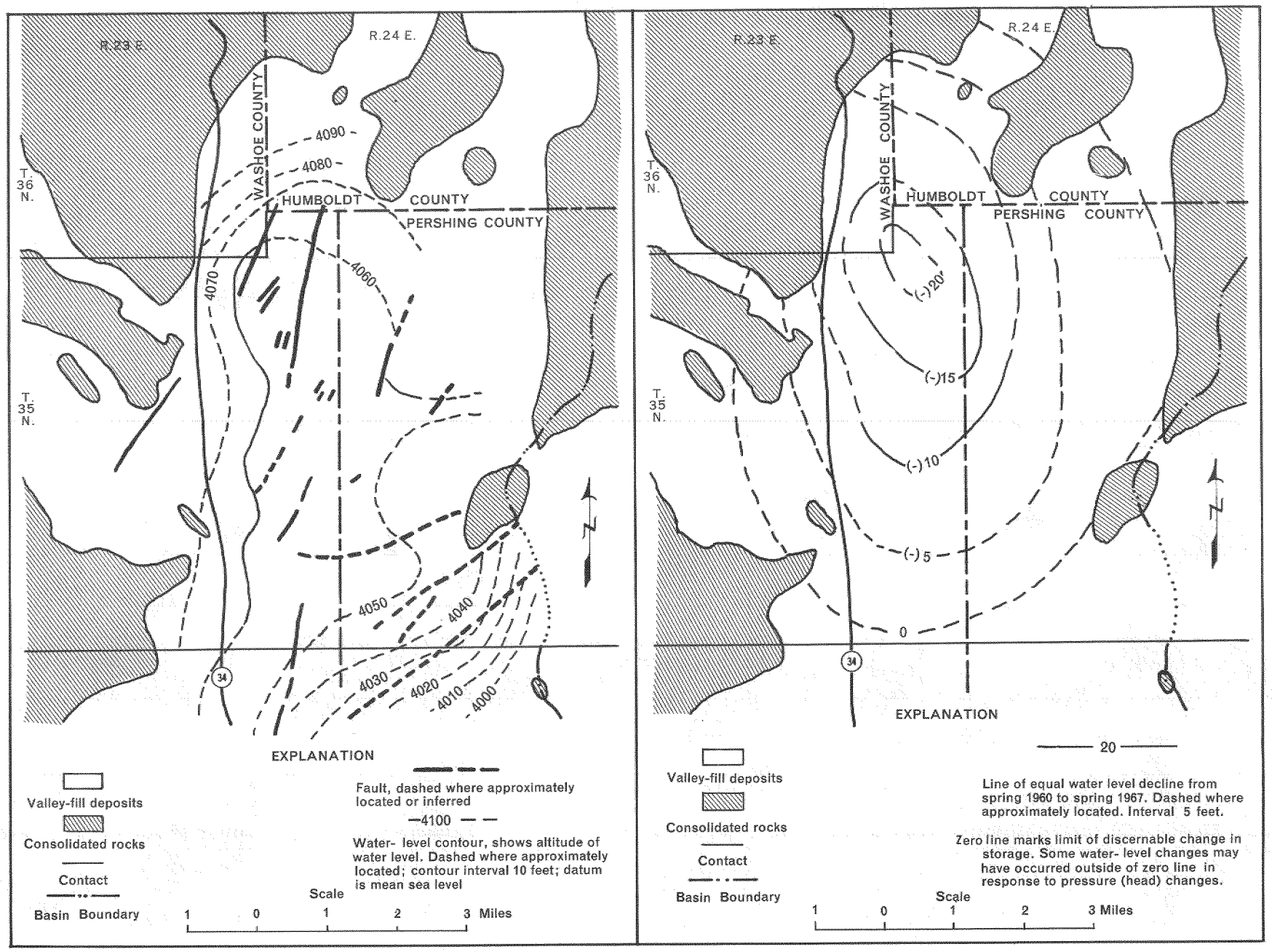


Figure 10.—Water-level contours for April 1967 and net decline in water levels spring 1960 to spring 1967, north half Hualapai Flat

Table 16.--Estimated net storage depletion for the 7-year period spring 1960-spring 1967

Net water-level decline (feet) Range	Average (1)	Area (acres) (2)	Volume dewatered (acre-feet) (1)x(2)=(3)	Average specific yield (percent) (4)	Storage depletion (acre-feet) (3)x(4)
0 to 5	1.5	1,300	2,000	17.5	350
	1.5	8,700	13,000	12	1,600
5 to 10	7	2,000	14,000	17.5	2,400
	7	4,200	29,000	12	3,500
10 to 15	12	1,800	22,000	17.5	3,800
	12	2,600	31,000	12	3,700
15 to 20	17	1,400	24,000	17.5	4,200
	17	890	15,000	12	1,800
Greater than 20	21	220	4,600	17.5	800
	21	120	2,500	12	300
Totals (rounded)	a 7	23,200	160,000	b 14	22,000

a. Average weighted water-level decline.

b. Average weighted specific yield.

Ground-Water Budget, Spring 1960-Spring 1967

Table 17 summarizes the effects of 7 years of pumping on the hydrologic system--a period of nonequilibrium conditions. Virtually all the change has occurred in the north half of Hualapai Flat. During the 7-year period the estimated total discharge exceeded recharge to the valley-fill reservoir by approximately 18,000 acre-feet, or 2,600 acre-feet per year. If all estimates are correct, this deficiency of 18,000 acre-feet (budget item 3) should equal the estimated net storage depletion of 22,000 acre-feet (budget item 4), which was computed independently. The imbalance between methods of 4,000 acre-feet, is less than 10 percent of the recharge or discharge. The most likely errors are in the larger estimates, principally recharge from precipitation and discharge by evapotranspiration and net pumpage.

Table 17.--Ground-water budget, in acre-feet, for nonequilibrium conditions in Hualapai Flat, spring 1960-spring 1967

(All values, in acre-feet, estimated as described in text)

Budget item[1/]	7-year period	Average annual
RECHARGE:		
Precipitation (table 4)	49,000	7,000
Total (rounded) (1):	49,000	7,000
DISCHARGE:		
Natural evapotranspiration (table 9)	44,100	6,300
Salvaged discharge (p. 45)	- 600	- 100
Subsurface flow to the Black Rock Desert (p. 31)	2,800	400
Net pumpage (table 13)	21,000	3,000
Total (rounded) (2):	67,000	9,600
IMBALANCE (3) = (1) - (2):	-18,000	-2,600
STORAGE DEPLETION (table 16) (4):	-22,000	-3,100
DIFFERENCE BETWEEN METHODS: (3) - (4)	4,000	500

1. All items except pumpage and storage depletion based on long-term average rather than for period 1960-66.

THE AVAILABLE WATER SUPPLY

The available water supply in Hualapai Flat is discussed in the following sections in terms of both the available surface-water supply and the available ground-water supply. The available surface-water supply represents that portion of the total runoff that is concentrated as streamflow in major drainages. The available ground-water supply is discussed in terms of: (1) the perennial yield, or the maximum amount of salvable natural discharge; and (2) storage depletion, which is sometimes referred to as the "one time reserve" and is evaluated in terms of both a transitional storage reserve for the entire valley and the storage depletion necessary before equilibrium could be approached with the existing distribution of pumping. The possible future development and its relation to the available supply is also discussed.

Streamflow

About 60 percent of the total runoff in Hualapai Flat occurs as streamflow in the major drainages and is potentially available for use. However, because of the seasonal distribution of flow and evapotranspiration and infiltration losses between points of maximum flow in the mountains and points of use in the valleys, only about 10 percent (about 500 acre-feet, table 8), of the total annual runoff arrived at points of use during the 1967 growing season. Improvements, such as upstream storage facilities and lined ditches or pipes, would be required before much of this potentially available water could be used for irrigation in the valley. Determination of whether or not such improvements are economically feasible is beyond the scope of this study.

Utilization of a substantial part of the surface-water resources would increase the total available water supply only by the quantity of water that would otherwise have been consumed by native vegetation and evaporation in the canyons and on the alluvial fans. This is due to the fact that much of the streamflow infiltrates to ground water where it is potentially available for use by pumping. However, in the event that sustained heavy pumping ultimately causes excessive water-level declines at the north end of the valley, development of some of the available surface water for use in conjunction with pumping is an alternative that might be considered.

Perennial Yield

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 pumping lifts become uneconomical to maintain. Perennial yield cannot exceed the natural recharge to or discharge from the reservoir. Moreover, the perennial yield ultimately is limited to the maximum amount of natural discharge that can be economically salvaged for beneficial use.

Table 10 shows that the estimated average annual recharge to the ground-water reservoir is 7,000 acre-feet, and that the estimated natural discharge of ground water is 6,700 acre-feet. Possibly half of the subsurface outflow of 400 acre-feet per year could be salvable by pumping (p. 45). As was previously mentioned, the estimated recharge may be slightly high because some streamflow which is potential recharge is evaporated or consumed by plants in areas of shallow ground water. Thus, providing that pumping is stratigically distributed to salvage all evapotranspiration and with no critical deterioration in water quality, the perennial yield of the valley-fill reservoir is approximately 6,700 acre-feet. This estimate is 1,700 acre-feet larger than that made by Sinclair (1962).

The maximum amount of natural discharge that eventually can be salvaged by pumping in the general area of development in 1967 in the north half of Hualapai Flat will be governed by the annual pumping rate at which pumping lifts become uneconomical to maintain or at which a significant influx of poor quality water from beneath the playa or adjacent Black Rock Desert might occur. The fault barriers in the alluvium north of the playa and in the hot spring area (pl. 1) are additional factors that could effect the amount of natural discharge that may be economically salvaged. These fault barriers may hinder the salvage of natural discharge, which consequently would reduce somewhat the annual pumping rate that could be indefinitely maintained in wells to the north. On the other hand, as water levels decline and storage depletion causes a gradient to be established toward the pumping areas, these faults should also inhibit somewhat the northward migration of poor quality water from beneath the playa.

As previously stated, at least 4,000 acre-feet per year of natural discharge that occurs near the southern end of the development (table 14) probably can be salvaged before water-level declines become excessive. Continued salvage of discharge would require additional declines in water levels until eventually pumping in localized areas may be economically feasible only for high-value crops.

The optimum quantity of natural discharge that can ultimately be salvaged by pumping from the general area of development as of 1967 is dependent upon both hydrologic and economic factors and cannot be precisely determined at this time. It probably will be at least 4,000 acre-feet but less than the perennial yield.

The estimated net pumpage in 1967 was 7,400 acre-feet (table 13), which exceeds the estimated perennial yield by about 10 percent. If all permits to pump ground water (approximately 26,500 acre-feet per year) were fully exercised, the resulting net pumpage of about 17,000 acre-feet per year would be more than twice the perennial yield. Sustained pumping at 1967 rates or higher would withdraw more water from the valley-fill reservoir than is annually replenished; consequently, no equilibrium would be possible (fig. 9, case III). Moreover, sustained pumping at the perennial yield rate (fig. 9, case II) may eventually cause excessive lifts and conditions of local overdraft in the well field before all discharge is salvaged. An eventual reduction of pumping at the north end of the valley, probably would allow a new equilibrium to be economically attained at a net rate of annual pumping less than the perennial yield (fig. 9, case I).

Storage Depletion

No ground-water source can be developed without causing some storage depletion. The magnitude of depletion varies with the amount of pumpage, the hydraulic characteristics of the system, and the distance of development from any recharge and discharge boundaries in the ground-water system. Few desert valleys have well-defined recharge boundaries, such as live streams or lakes; however, most have well-defined discharge boundaries, such as areas of evapotranspiration.

Transitional storage reserve has been defined by Worts (1967, p. 50) as the quantity of water in storage in a ground-water reservoir that can be extracted and beneficially used during the transition period between equilibrium conditions in a state of nature and the new equilibrium conditions under the perennial yield concept of ground-water development. Thus, the transitional storage reserve is a specific amount of the total ground water in storage; it is water in addition to and developed along with the long-term amount provided by the recharge.

Transitional storage reserve is generally computed assuming an idealized distribution of pumping. The storage depletion thus calculated includes the assumption that all natural discharge will be salvaged as efficiently as possible and that the resulting

water-level declines will be as small as possible. The transitional storage reserve, in this sense, is primarily a property of the ground-water reservoir. A more extensive discussion of transitional storage reserve in relation to ground-water development and perennial yield has been given by Worts (1967).

Ground-water development seldom occurs under hydrologically ideal conditions. Irrigation pumping in most developed valleys is distributed in accordance with the occurrence of good soils, accessibility, the location of previously patented acreage, or other reasons. Consequently, pumping tends to be distributed asymmetrically with respect to the flow pattern of the natural system and is commonly concentrated in localized areas. The hydrologic implications of such patterns of development are that natural discharge will be more difficult to salvage, greater volumes of material must be dewatered, and water-level declines will be greater than with an idealized pattern of development. The long-term result of such patterns of development will be one of two possibilities; either (1) it will be economically feasible to salvage all natural discharge and thus pump at a sustained rate equal to the perennial yield in spite of the fact that more water must be withdrawn from storage than was computed in the transitional storage reserve and that resulting water-level declines in the vicinity of pumping will be substantially greater than those that would occur with an ideal distribution of pumping; or (2) it will not be economically feasible to salvage all natural discharge and eventually pumpage will either decrease (due to economic attrition) or have to be limited to a rate less than the perennial yield to prevent pumping lifts throughout the development from becoming uneconomical to maintain. In either case, a quantity of water that typically is greater than the computed transitional storage reserve must be withdrawn from storage to salvage a quantity of water that is equal to or less than the perennial yield.

In this report, the storage depletion that will occur during the period of transition from a natural equilibrium to a new equilibrium with an annual net pumpage equal to the perennial yield is estimated as: (A) the transitional storage reserve (primarily a property of the ground-water reservoir) which assumes the highest possible efficiency in the salvage of natural discharge; and (B) a first approximation of the storage depletion required to salvage the perennial yield by pumping from the general area of development as of 1967.

The following assumptions are made to obtain estimates: (1) in case A, wells would be stratigically situated in, near, and around the areas of natural discharge so that evapotranspiration could be stopped and subsurface outflow reduced with a minimum of

water-level drawdown in pumped wells. In case B, pumping would remain situated in the same general area as in 1967; (2) a perennial water level 50 feet below land surface would curtail virtually all evapotranspiration from ground water; (3) in case A, over the long term, pumping would cause a moderately uniform depletion of storage throughout most of the valley fill, except in the playa deposits (mostly clay), which would drain at a slower rate. In case B, a hydraulic gradient from the south end of the valley toward the area of pumping would develop as equilibrium is approached (fig. 9, case II). Excessive gradients would not develop because water would migrate primarily through comparatively permeable deposits beneath and around the edges of the playa and the faults in the northern part of the discharge area (pl. 2) would not be effective barriers to ground-water movement. Water-level declines would range from about 45 feet at the south end of the valley to at least 150 feet in parts of the well field. The weighted areal decline would be roughly 80 feet; (4) the specific-yield values of the dewatered interval would be approximately the same as those shown in figure 3; (5) the water levels would remain in the range of economic pumping lift for the intended use; (6) pumping would have little effect on the adjacent Black Rock Desert area; and (7) the water would be of suitable quality for the desired use.

Table 18 summarizes estimates of the storage depletion required to salvage the perennial yield under both distributions of pumping. These first approximations indicate that salvage of the perennial yield by pumping from the general area of development as of 1967 would require about twice the storage depletion as would be required with the idealized distribution of pumping and that maximum water-level declines would be about three times as great. Moreover, if the low-transmissibility playa deposits and faulted alluvium prove effective barriers to the movement of water from the south end of the valley toward pumping, storage depletion and consequent water-level declines greater than those estimated in table 18 would occur.

Considerable time will be required to approach equilibrium conditions with the existing distribution of pumping. Assuming uniform rates of storage depletion and salvage of natural discharge, the annual pumpage (Q) and the time in years (t) during which depletion would take place can be approximated from the following equation:

$$Q = \frac{\text{Storage depletion}}{t} + \frac{\text{Perennial yield}}{2}$$

Table 18.--Summary of estimates of (A) transitional storage reserve and (B) storage depletion required to salvage the perennial yield by pumping from the general area of development as of 1967

Estimate	Area affected (acres)1/ (1)	Water-level decline (feet) Range N. half valley	Range S. half valley	Weighted average (2)	Average specific yield2/ (percent) (3)	First approximation (acre-feet, rounded) (1)x(2)x(3)
(A) Transitional storage reserve	45,000	45	45	45	12	a 240,000
						b -22,000
						c 220,000
(B) Storage depletion required to salvage the natural discharge by pumping from the general area of development as of 1967	45,000	45 to >150	15 to 45	80	13	a 470,000
						b -22,000
						c 450,000

1. Valley-fill reservoir storage unit shown in figure 3.
2. Determined from figure 3.
a. Includes about 20,000 acre-feet of moderately mineralized water in playa deposits.
b. Estimated storage depletion through spring 1967 (table 16).
c. Estimated storage remaining as of spring 1967.

Using (1) the equation and the estimated storage depletion of 450,000 acre-feet (table 18, estimate B), (2) the estimated perennial yield of 6,700 acre-feet, and (3) a pumping rate (Q) equal in quantity to the perennial yield, in accordance with the general intent of Nevada water law, the time (t) to deplete the storage is computed to be about 130 years.

The economic implications of the estimated storage depletion and consequent water-level decline required to salvage all natural discharge by pumping from existing developments are that water levels may be expected to decline for a considerable period of time. In the areas of maximum change, nonpumping water levels may ultimately decline 150 feet or more and stand at 250 feet or more below land surface.

In the event that pumping in the north half of Hualapai Flat is eventually reduced to a rate less than the perennial yield (fig. 9, case I) the quantity of storage depletion and magnitude of water-level decline necessary before a new equilibrium could be attained would be appreciably reduced from that estimated in table 18 (part B).

Future Development

The foregoing sections on yield indicate that sustained pumping from the general area of development in 1967 will result in comparatively large drawdowns before a quantity of natural discharge equal to the perennial yield is salvaged. Moreover, virtually all permits to pump ground water are for areas in the northern part of the valley. If pumping in this area could eventually be reduced to a rate less than the perennial yield, a limited amount of ground-water development at the south end of the valley would salvage most of the water currently wasting there as natural discharge. Factors that would tend to limit development at the south end of the valley are: (1) the predominately granitic sands probably would be less productive than the aquifers at the north end of the valley; and (2) deep wells in some areas may encounter highly mineralized hot water that is not suitable for agricultural use.

Geothermally heated water is also a potential resource of the area. Well 34/25-2dd was drilled in the hot spring area (pl. 1) in an attempt to locate geothermal sources for steam-electric power. The resulting discharge, about 1 cfs of boiling water, produced insufficient steam for power development. Another well, reportedly drilled south of the Granite Ranch in the 1930's, is said to have discharged considerable quantities of steam. Thus, future exploration may yet discover a sufficient steam reservoir for power development.

SUMMARY AND CONCLUSIONS

This second appraisal of the water resources of Hualapai Flat has led to the following conclusions regarding the adequacy of supply, effects of development, and types of data needed to refine the flow system and response characteristics of the valley-fill reservoir.

1. All development to date and all applications for future development are at the northern end of Hualapai Flat. As of November 1967, total permits to pump about 26,500 acre-feet per year have been issued by the State Engineer.

2. The estimated net pumpage in 1967 was 7,400 acre-feet, which is slightly in excess of the estimated perennial yield of 6,700 acre-feet. The net pumpage of record (1960-67) totals 28,000 acre-feet and has been supplied almost entirely from storage. However, a gradually increasing percentage of the annual pumpage will be supplied from salvaged (redirected) discharge in future years.

3. Because pumping is both localized and asymmetrically distributed with respect to natural discharge, a large quantity of stored water must be withdrawn before the natural discharge can be salvaged. A first approximation shows that 470,000 acre-feet of stored water (about twice the transitional storage reserve) would have to be removed to salvage the perennial yield by pumping from the approximate 1967 area of development. If pumpage were held to the perennial yield rate and assuming a linear decrease in natural discharge and stored water, about 130 years of pumping would be required to deplete the indicated storage and bring the system to a new equilibrium. Water levels at the northern end of the development would have declined 150 feet or more, depending on the effectiveness of hydrologic barriers formed by bedrock boundaries of the valley-fill reservoir and by faults in the alluvium within the reservoir. Pumping lifts would also be increased somewhat during the summer due to concentrated pumping and hydrologic barriers, and might locally exceed 300 feet. Thus, even though pumping is limited to the perennial yield rate, local overdraft could occur before the entire perennial yield of Hualapai Flat is developed.

4. If the rate of pumping from the current (1967) area of development is eventually reduced to less than the perennial yield, the resulting pre-equilibrium water-level declines would be less than previously indicated. The optimum long-term pumping rate would be determined by the quantity of natural discharge that could be salvaged economically by pumping and cannot be precisely evaluated at this time. It probably would be at least 4,000

acre-feet but less than the perennial yield. In the event that cash crops, such as seed or produce eventually become the dominant crops, or if technological advances increase profit margins for alfalfa hay, farmers would then be able to pay more for their water. Consequently, a greater part of the perennial yield could be economically salvaged by pumping than if conditions remained the same as in 1967.

5. About 60 percent of the total estimated runoff of 5,400 acre-feet per year occurs as streamflow in the major drainages where it is potentially available for use. However, because of the seasonal distribution of flow and because of infiltration and natural water losses between points of maximum flow and points of use, only about 10 percent of the average annual runoff arrives at points of use during the growing season. Seasonal distribution of flow could be improved by upstream storage facilities, if feasible, and by reduction of infiltration and natural water losses by lined ditches or pipelines. Increased use of surface water in the irrigated area could partly reduce the demand for heavy pumping and minimize localized areas of excessive water-level decline. However, because much of the ground-water recharge is derived from runoff, development of surface-water supplies would increase the total available supply only by the amount that use by native vegetation and evaporation of streamflow in canyons and on the alluvial fans is reduced.

6. The cause-and-effect relations (pumpage versus the distribution and amount of water-level decline and associated factors) for the 7-year period, spring 1960-spring 1967, are first approximations developed from an estimated gross pumpage of 31,000 acre-feet (estimated net pumpage 21,000 acre-feet). Future refinements of these relations will require reasonably accurate records of annual pumpage, periodic water-level measurements in most wells (preferably in the spring before pumping begins), periodic discharge measurements of the major streams, and monitoring the chemical quality of pumped water. Several precipitation gages in the mountains would provide valuable data for refining runoff and recharge estimates, and a weather station in the developed area would provide needed specific information concerning the growing season and crop water requirements.

7. A reappraisal of Hualapai Flat in about 10 years, or sooner if required, would be desirable to evaluate the effects of pumping on the flow system, the magnitude of storage depletion, and the extent of any overdraft that might then exist. A special study of the hydraulic barriers may be desirable at an earlier date, if water levels continue to decline excessively in localized areas. Those findings would provide the basis for timely decisions for the administration and management of the water resources of Hualapai Flat.

Numbering System for Wells and Springs

The numbering system for wells and springs in this report is based on the rectangular subdivisions of the public lands, referenced to the Mount Diablo base line and meridian. It consists of three units: the first is the township north of the base line; the second unit, separated from the first by a slant, is the range east of the meridian; and the third unit, separated from the second by a dash, lists the section number followed by two letters that designate the quarter section, and the quarter-quarter section, respectively. The northeast quarter of a subdivision is designated by the letter a, the northwest quarter by the letter b, the southwest quarter by the letter c, and the southeast quarter by the letter d. Following the letters, a number indicates the order in which the well or spring was recorded within the 40-acre subdivision. For example, well 35/23-23bd1 is the first well recorded in the SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 23, T. 35 N., R. 23 E., Mount Diablo base line and meridian.

Because of the limitation of space, wells and springs are identified in figure 1 only by that part of the number which designates the subdivision of the section and, if two or more wells are in one subdivision, the order in which the well or spring was recorded in that section.

Table 19.--Records of selected wells and testholes

Owner: USGS, U.S. Geological Survey, testhole
Use: D, domestic; I, irrigation; O, observation, S, stock; U, unused; Des, destroyed
Specific capacity: In gallons per minute (gpm) per foot of drawdown; R, reported
Altitude: Determined from topographic maps
Water-level measurements: Depth, in feet, below land-surface datum; +, water stands above land surface, well may flow; E, estimated; R, reported by driller
Remarks: Dis, discharge; SLN, State log number, from the files of the State Engineer

Location	Name or owner	Year drilled	Depth (feet)	Diameter (inches)	Use	Specific capacity	Pumping lift July 1967	Land surface altitude (feet)	Water-level measurement Date	Water-level measurement Depth	Remarks
34/23-1aa1	A. F. Jackson	--	--	4	S,I	--	--	4,038	11- 4-66	+	Dis 15 gpm
-1aa2	A. F. Jackson	--	--	--	D	--	--	4,036	1950	+ 8.0±	
									11- 4-66	+ 3-4±	Dis 20 gpm
-2da	John Casey	--	--	--	--	--	--	--	11- 4-66	+20±	Steam well
									4- 8-67		Dis<5 gpmE
-2dd	John Casey	--	840	--	--	--	--	--	4- 8-67	+	Steam well
											Dis 440 gpm
-14ac	John Casey	--	--	--	D	--	--	--	11- 4-66	+ .5	Dis 3-4gpmE
-25ca	--	1947	200	4 3/4	S	--	--	4,025	--	+	SLN 88
-25cb	--	1947	200	4 3/4	S	--	--	4,025	--	+	SLN 85
-35aa	Granite Ranch	--	78	3	S	--	--	4,030	8- 2-67	+1.5	Dis 4 gpm E
-35ab1	Granite Ranch	1947	180	--	Des	--	--	--	7-14-47	20 R	SLN 90
-35ab2	Granite Ranch	1947	400	--	Des	--	--	--	7- -47	15 R	SLN 91
34/24-3bb	USGS H-7	1967	42	1½	O	--	--	4,008	6-14-67	27.10	--
-5bb	USGS H-5	1967	22	1½	O	--	--	4,033	8- 3-67	+ 1.87	--
-5cb1	Finley	--	--	4	S	--	--	4,032	11- 4-66	+	Dis 10gpm E
-5cb2	Finley	--	--	4	S	--	--	4,032	11- 4-66	+	Dis 5 gpm E
-6bb1	Jackson	--	123	5	S	--	--	4,038	11- 4-66	+ 7	Dis 10gpm E
-6bb2	Jackson	--	104	4	S	--	--	4,038	11- 4-66	+	Dis 20gpm E
-6da	Finley	--	--	--	S	--	--	4,025	11- 4-66	+	Dis 20gpm E
-9c	Granite Ranch	1947	490	4	S	--	--	--	7-24-47	1.5 R	SLN 89
-17ac	USGS H-10	1967	4.5	1½	O	--	--	4,014	10-23-67	3.13	--

Table 19.--Continued

Location	Name or owner	Year drilled	Depth (feet)	Diameter (inches)	Use	Specific capacity	Pumping lift July 1967	Land surface altitude (feet)	Water-level measurement Date	Water-level measurement Depth	Remarks
34/24-17bd	USGS H-11	1967	13.5	1½	O	--	--	4,012	10-28-67	2.13	--
-19b	Granite Ranch	1947	200	4	S	--	--	--	--	--	SLN 87
35/23-1bb	Moore	1962	383	16	I	15 R	--	4,194	3- -62	113 R	SLN 6560
									4- 6-67	130.96	
-1bd	Moore	1963	445	16	I	--	--	4,173	3- -63	94 R	SLN 7233
									4- 6-67	108.81	
-1dc	Moore	1962	375	16	I	--	--	4,151	1- -63	73 R	SLN 7235
									4- 6-67	105.75	
-2cb	Tenacio	1963	330	16	I	31	165	4,163	1- -63	92 R	SLN 7045
									4- -67	103.19	
-11ab	Tenacio	1961	307	16	I	30	140	4,144	12- -61	70 R	SLN 6865
									4- -67	85.12	
-11da	Tenacio	1966	402	16	I	12	155	4,135	4- -67	75.39	SLN 9061
-12ba	Spoo	1964	354	16	I	58 R	103	4,130	4- -64	63 R	SLN 7987
									4- -67	72.74	
-12bb	Moore	1961	304	16	I	62	--	4,144	5- -61	70 R	SLN 6866
									4- -67	107.85	Nearby wells may be pumping
-12cb	Spoo	1960	200	16	I	--	--	4,130	5- -60	55 R	SLN 5263
									4- -67	71.67	
-13aa	Ferris	1963	360	16	I	100	71	4,110	4- -63	43 R	SLN 7236
									4- -67	51.32	
-13bc	Ferris	1964	125	12	D	--	--	4,132	5- -64	68 R	SLN 7986
									4- -67	72.05	
-13bd	Harold Ferris	1964	377	16	I	49	--	4,122	4- -64	59 R	SLN 7932
									4- -67	65.38	
-13db1	Tenacio	1960	200	--	D	--	--	4,118	3- -60	45 R	SLN 5221
									4- -67	58.25	
-13db2	Tenacio	--	--	--	I	45	89	4,118	4- -67	62.7	--
-23ad	Sand Springs Land Co.	1964	321	16	I	52	--	4,126	5- -64	67 R	SLN 7990
									4- -67	72.94	

Table 19.--Continued

Location	Name or owner	Year drilled	Depth (feet)	Diameter (inches)	Use	Specific capacity	Pumping lift July 1967	Land surface altitude (feet)	Water-level measurement Date	Water-level measurement Depth	Remarks
35/23-23bd1	Sand Spring Land Co.	--	--	--	I	--	--	4,158	4- -67	94.57	--
-23bd2	Sand Spring Land Co.	--	--	--	I	--	--	4,158	4- -67	94.08	--
-24ab	Dave Iverson	1951	206	16	I	--	--	4,107	4- -51	45 R	SLN 1600
									4- -67	53.71	
-24db1	John Fitz	1962	280	16	I,D	--	--	4,100	7- -62	40 R	SLN 6666
									4- -67	45.27	
-24db2	John Fitz	1960	207	16	I	44	95	4,095	4- -60	37 R	SLN 5167
									4- -67	44.15	
-25ac	Jackson	1960	158	16	I	49	58	4,092	4- -60	26 R	SLN 5166
									4- -67	33.63	
-25dd	--	--	29	6	U	--	--	4,067	4- -67	13.85	--
-26ab	Sand Spring Land Co.	1964	342	16	I	34	--	4,113	6- -64	45	SLN 7991
									4- -67	49.35	
-26db	Sand Spring Land Co.	1964	321	16	I	29 E	75	4,094	7- -64	33	SLN 7992
									4- -67	37.02	
-35ba	USGS H-9	1967	66	1½	O	--	--	4,092	6- -67	30.63	
-36da1	Jackson	--	308	6	--	--	--	4,052	1960±	+ 6 R	--
									4- -67	+ .5 E	
-36da2	Jackson	--	20	20	S	--	--	4,054	4- -67	1.15	Formerly flowed
-36da3	Jackson	--	180	6	S	--	--	4,054	1960±	+ 4 R	
									4- -67	0	
35/24-6ca	Richard Bailey	1964	310	16	I	27	--	4,129	3- -64	63 R	SLN 7979
									4- -67	71.22	
-7bb	Bailey	--	--	--	I	--	--	4,129	4- -67	66.36	--
-7cb	Moore	1963	350	16	I	--	--	4,113	2- -63	39 R	SLN 7234
									4- -67	53.96	
-8cb	Bailey	--	--	16	D	--	--	4,122	4- -67	57.11	--
-8cc1	Bailey	--	--	16	U	--	--	4,104	5- -65	36.85	
									4- -67	39.64	
-8cc2	Bailey	--	--	16	U	--	--	4,105	4- -67	40.95	

Table 19.--Continued

Location	Name or owner	Year drilled	Depth (feet)	Diameter (inches)	Use	Specific capacity	Pumping lift July 1967	Land surface altitude (feet)	Water-level measurement Date	Water-level measurement Depth	Remarks
35/24-17cc	USGS H-6	1967	62	1½	O	--	--	4,080	7- -67	52.98	
									12- -67	33.40	
-19bb	Dave Iverson	--	--	--	I	--	--	4,090	8- -67	43.24	
-19ca	John Fitz	1965	340	16	I	24	--	4,085	4- -67	26.86	SLN 8713
-29cd	USGS H-5	1967	22	1½	O	--	--	4,061	6- -67	10.84	
-30bb	John Fitz	1965	340	16	I	--	--	4,085	4- -67	28.34	SLN 8712
-30ca	--	--	24	6	U	--	--	4,071	1- -62	10.56	
									5- -67	17.18	
-30cb	Jim Finley	--	50	20	D	--	--	4,078	4- -67	23.08	
-31ab1	Jackson	1960	190	16	I	15	52	4,058	4- -60	+	SLN 5169
									4- -67	4.61	
-31ab2	Jackson	--	--	6	S	--	--	4,055	1960±	+	
									11- 4-66	3.19	
-32ac	USGS H-1	1967	15	1½	O	--	--	4,054	4- -67	11.68	
-32dd1	USGS H-2	1967	15	1½	O	--	--	4,031	6- -67	7.32	
-32dd2	USGS H-4	1967	66	1½	O	--	--	4,031	6- -67	+ 1.25	
-33ac	USGS H-8	1967	44	1½	O	--	--	4,034	6- -67	31.16	
36/23-36ab	--	1962	627	16	I	15	--	4,211	4- -62	108 R	SLN 6998
									4- -67	123.15	
-36db	Tenacio	--	--	--	I,D	--	--	4,190	7- -67	114.70	
-36dd	Tenacio	1961	285	16	I	33	156	4,172	11- -61	91 R	SLN 6326
									4- -67	113.82	

Table 20.--Selected drillers' logs of wells

Material	Thickness (feet)	Depth (feet)
34/23-35ab2		
Sand, granitic, with seams of orange mica	80	80
Sand, fine and coarse, and fine mica	10	90
Bentonite mixed with fine mica	70	160
Quicksand, fine orange mica	25	185
Sand, granitic, and cemented clay (brown)	100	285
Sand, coarse, and soft mica	15	300
Clay, white, and granitic sand	9	309
Clay, green, hard	2	311
Mica, orange and black, and black sand	13	324
Granite, hard, iron cemented	2	326
Clay, blue, sticky, and red mica	1	327
Clay, light yellow and white	23	350
Clay, light yellow and white in sand and small gravel	2	352
Sand, granitic, and light yellow mud	3	355
Clay, blue, and granitic sand	15	370
Mica, golden, and granitic sand	15	385
Clay, light brown, purple clay, soft mica	15	400
35/23-2cb		
Topsoil, brown, sandy	2	2
Clay, brown, sandy, gravel	6	8
Clay, yellow, sandy, gravel	29	37
Clay, brown, sandy, gravel	42	79
Clay, yellow, sandy, gravel	12	91
Clay, yellow, sandy, soft	29	120
Clay, yellow, sandy, soft, gravel streaks	61	181
Sand, silt, and gravel	11	192
Clay, yellow, sandy, soft, gravel	18	210
Sand and gravel with silt	35	245
Clay, yellow, sandy, with fine gravel	10	255
Sand and gravel	47	302
Sand, silt, and gravel with some yellow clay	20	322
Clay, yellow, sandy, gravel	8	330
35/23-11da		
Topsoil, sandy	4	4
Sand, yellow, fine, with silt	7	11
Sand, brown, fine, with silt	13	24
Sand, fine to coarse	1	25
Sand, brown, fine, with silt	5	30
Sand, fine to coarse, with gravel	4	34
Sand, fine to coarse, with gravel and yellow clay	5	39
Clay, yellow, soft	21	60
Sand, fine to coarse, with gravel	12	72
Sand, coarse, with silt and loose gravel	9	81
Sand, fine to coarse, with gravel	1	82
Sand, coarse, with gravel and dry yellow clay	10	92
Sand, fine to coarse, with gravel	2	94
Sand, coarse, with gravel	8	102
Gravel with dry yellow clay and coarse sand	6	108
Sand, coarse, and gravel	6	114
Clay, reddish brown, soft, sandy	6	120
Clay, brown, soft, sandy	8	128
Sand, coarse	3	131
Sand, coarse, with silt and fine gravel	6	137
Sand, coarse, with gravel and silt	4	141
Clay, yellow, soft, with fine to coarse sand and gravel	18	159
Clay, yellow, soft, sandy	12	171
Sand, fine to coarse, with gravel and silt	7	178
Clay, yellow, hard, sticky	3	181
Sand, fine to coarse, with gravel	11	192
Clay, yellow, soft, sandy	3	195
Sand, coarse, and gravel	5	200
Clay, yellow, soft, sandy	9	209
Sand, fine to coarse, with gravel, silt, and yellow clay	21	230
Clay, yellow, soft, sandy, and gravel	12	242

Table 20.--Continued

Material	Thickness (feet)	Depth (feet)
35/23-11da - continued		
Sand, fine to coarse, with gravel	9	251
Clay, yellow, soft, sandy	2	253
Sand, fine to coarse, with gravel, silt, and yellow clay	7	260
Sand, coarse, and fine gravel	3	263
Clay, yellow, sticky, very hard	13	276
Sand, coarse, with silt and gravel	13	289
Clay, yellow, soft, sandy	7	296
Sand, fine to coarse, with silt and gravel	15	311
Clay, yellow, soft, sandy	7	318
Sand, coarse, with silt and gravel	2	320
Sand, fine to coarse, with silt and gravel	9	329
Sand, coarse, and fine gravel with silt	17	346
Sand, fine to coarse, with silt and some gravel	17	363
Sand, fine to coarse, with silt and gravel	29	392
Sand, fine to coarse with silt and gravel, yellow clay	10	402
35/23-12ba		
Topsoil, brown	2	2
Silt, sandy	1	3
Clay, brown, sandy, soft	13	16
Clay, yellow, sandy, soft	9	25
Sand and gravel	4	29
Clay, yellow, sandy, soft	33	62
Sand and gravel	16	78
Clay, yellow, sandy, soft	14	92
Sand and gravel	8	100
Clay, yellow, sandy, soft, with gravel streaks	35	135
Sand and gravel	3	138
Clay, yellow, sandy, soft	11	149
Sand and gravel	3	152
Clay, yellow, sandy, soft	15	167
Sand, gravel, some silt	5	172
35/23-12ba - continued		
Clay, yellow, soft	3	175
Sand, silt, and gravel	6	181
Clay, yellow, sandy, soft	16	197
Sand, silt, and gravel	3	200
Sand, coarse, with silt and gravel	29	229
Clay, yellow, sticky	6	235
Sand and gravel	15	250
Clay, yellow, sticky, hard	22	272
Sand and gravel	4	276
Clay, brown, sticky, hard	14	290
Sand and gravel	3	293
Clay, yellow, sticky with streaks of gravel	34	327
Clay, yellow, sticky, very hard	27	354
35/23-13aa		
Topsoil, sandy	2	2
Hardpan	1	3
Clay, brown, soft, sandy	9	12
Sand, yellow, coarse	9	21
Clay, yellow, soft, sandy	61	82
Clay, yellow, with sand and gravel	12	94
Clay, yellow, soft, sandy	16	110
Clay, yellow, sandy, with gravel	10	120
Clay, yellow, soft, sandy	32	152
Sand and gravel	7	159
Clay, yellow, hard, sticky	13	172
Sand and gravel with silt	21	193
Sand, yellow, with silt	15	208
Sand, coarse, with gravel	5	213
Clay, yellow, soft, sandy	23	236
Sand and gravel	3	239
Sand, yellow, with silt	2	241
Clay, yellow, sandy	4	245
Clay, yellow, with sand and gravel	7	252
Clay, yellow, soft, sandy	22	274
Clay, yellow, with sand and gravel	25	299
Clay, yellow, soft, sandy	15	314
Sand, gravel, and silt	34	348
Clay, yellow, hard, sticky	12	360

Table 20.--Continued

Material	Thickness (feet)	Depth (feet)
35/23-23ad		
Topsoil, sandy	3	3
Clay, brown, sandy	3	6
Sand and silt, with gravel and some brown clay	14	20
Clay, brown, sandy	3	23
Clay, yellow, sandy, and gravel	8	31
Sand and gravel, yellow clay	5	36
Clay, yellow, sandy, and gravel	16	52
Clay, yellow, hard	6	58
Clay, yellow, sandy, soft	11	69
Sand, gravel, and some silt	2	71
Clay, yellow, sandy, soft	2	73
Sand, gravel, some yellow clay	39	112
Clay, yellow, sandy, soft	8	120
Sand, coarse, and fine gravel	4	124
Clay, yellow, sandy, soft	5	129
Sand, coarse, with gravel	5	134
Clay, yellow, sticky	12	146
Sand and gravel	6	152
Clay, yellow, sticky	6	158
Sand and gravel, with yellow clay streaks	30	188
Clay, yellow, sticky	8	196
Sand, silt, gravel, and some yellow clay	32	228
Clay, yellow, sticky	17	245
Sand, silt, gravel, and some sticky, yellow clay	17	262
Clay, yellow, very hard and sticky, some gravel	28	290
Clay, yellow, sticky, some softer sand	11	301
Rock, black, weathered	20	321
35/23-24ab		
Topsoil	2	2
Clay	43	45
Gravel and clay	15	60
Gravel and sand	13	73
Clay	5	78
Gravel and sand, water-bearing	4	82
Sand, fine, and clay	5	87
35/23-24ab - continued		
Clay, red	4	91
Clay and gravel, water-bearing	9	100
Gravel, large	20	120
Clay, gray	5	125
Gravel, water-bearing	15	140
Clay, brown	10	150
Clay and gravel	10	160
Clay	5	165
Gravel and water	15	180
Not reported	26	206
35/23-25ac		
Topsoil	15	15
Clay, brown, sandy	10	25
Clay, blue	13	38
Gravel	7	45
Clay, brown, sandy	10	55
Gravel, medium	13	68
Clay, sandy	10	78
Gravel, coarse to cobblestone	32	110
Clay, sandy	17	127
Gravel, large to cobblestone	20	147
Gravel, hard, cemented	11	158
35/23-26db		
Topsoil, sandy	2	2
Hardpan, yellow	2	4
Clay, yellow, sandy	7	11
Clay, brownish-gray, soft	2	13
Clay, gray, sandy, very soft	9	22
Clay, yellow, hard, with some sand and gravel	19	41
Clay, yellow, soft, with sand and gravel	40	81
Clay, yellow, sticky, some gravel	15	96
Clay, yellow, sandy, soft, with some gravel streaks	25	121
Clay, yellow, sticky	6	127
Clay, yellow, sandy, soft, with gravel	34	161
Clay, yellow, sticky	21	182
Clay, yellow, sandy, soft, with some sticky streaks	32	214
Sand and gravel	4	218
Clay, yellow, sandy, soft	21	239

Table 20.--Continued

Material	Thickness (feet)	Depth (feet)
35/23-26db - continued		
Sand and gravel, with some yellow clay	5	244
Clay, yellow, very sticky	6	250
Sand, silt, and gravel	6	256
Clay, yellow, sticky, very hard, some gravel	53	309
Rock, black, weathered	10	319
Rock, black, hard	2	321
35/24-6cc		
Topsoil, brown, sandy	2	2
Hardpan, brown	1	3
Clay, brown, sandy	12	15
Clay, yellow, sandy, with gravel	7	22
Clay, brown, sandy, soft	5	27
Clay, yellow, sandy, with gravel	21	48
Clay, brown, sandy, soft	10	58
Sand and gravel	4	62
Clay, yellow, sandy, with gravel	10	72
Sand, coarse, and gravel	30	102
Sand, coarse, gravel, and some silt	10	112
Sand, coarse, gravel, and some yellow clay	35	147
Sand, coarse, and gravel	12	159
Clay, yellow, sandy, soft	2	161
Sand and gravel	2	163
Sand, yellow, fine, with gravel	18	181
Sand, yellow, fine, with silt, gravel, and yellow clay	31	212
Clay, yellow, sandy, firm	10	222
Clay, grayish-yellow, soft, with fine gray sand lenses	30	252
Clay, yellow, sandy, and gravel	43	295
Clay, yellow, hard, and very sticky	15	310
35/24-31ab		
Topsoil	15	15
Marshy, with odor	5	20
Gravel, fine to medium	23	43
Clay, brown	12	55
Sand, coarse, and medium gravel	12	67
Clay, brown and blue	29	96
Gravel, medium to coarse	6	102
Clay, brown	38	140
Gravel, medium to coarse	12	152
Clay, brown, sandy	5	157
Gravel, medium to coarse	20	177
Clay, brown, hard	5	182
Gravel, coarse	3	185
Clay, brown, hard	5	190

Table 21.--Generalized logs of U.S. Geological Survey test holes

[Logs based primarily on material brought to the surface by power auger and on relative rates of drilling. Consequently, they are interpretive and highly generalized, and thus represent only the gross character of the materials drilled.]

Material	Thickness (feet)	Depth (feet)
34/24-3bb (H-7)		
Silt and clay, light brown	7	7
Clay, silty, light brown	5	12
Clay, sandy	10	22
Gravel	1	23
Clay, gray brown	4	27
Silt, sandy, traces fine gravel	5	32
Sand, silty, traces fine gravel	5	37
Silt, sandy, some clay	5	42
34/24-5cc (H-3)		
Silt, light brown	7	7
Silt and clay, gray, traces sand	15	22
34/24-17ac (H-10)		
Clay, silt and evaporites, porous, fluffy	.5	.5
Clay, silty, light brown	4	4.5
34/24-17bd (H-11)		
Clay, silt and evaporites, porous, fluffy	.5	.5
Clay, silty, gray	3	3.5
Clay, dark gray or green, some interbedded silt and fine sand	10	13.5
35/23-35ba (H-9)		
Sand, medium, some fine gravel, 2 feet larger cemented	7	7
Gravel, some coarse sand	5	12
Sand, silty	5	17
Silt, clayey	5	22
Clay, silty	5	27
Silt, some interbedded gravel	5	32
Sand, silt, clay, and gravel	10	42
Sand, some clay and gravel, poor sample return	9	66
35/24-17cc (H-6)		
Sand and silt, light brown	7	7
Sand, silty	5	12
Sand, silty, brown	5	17
Sand and silt	5	22
Sand, silty, some coarse sand	5	27
Sand(?), poor sample recovery	10	37
Sand, silty	5	42
Sand, silt; some fine gravel, poor sample recovery	15	57
Sand and clay	5	62
35/24-29cd (H-5)		
Silt and clay, light brown	7	7
Clay, silty, gray	5	12
Clay, silty, dark gray	5	17
Clay, silty, gray	5	22
35/24-32ac (H-1)		
Silt, sandy, light brown	2	2
Silt and clay, gray brown	13	15
35/24-32dd1 (H-2)		
Silt and clay, brown and gray brown	5	5
Clay, dark gray, smells of SO_2, several thin layers tuffa(?)	10	15
35/24-32dd2 (H-4)		
Silt, clayey, light brown	7	7
Clay, black	5	12
Clay, dark gray	10	22
Clay, poor sample recovery	5	27
Clay	15	42
Clay, sandy	5	47
Sand, brown, some clay	19	66
35/24-33ac (H-8)		
Sand, light brown	12	12
Sand, medium and coarse gravel, some silt and clay beds	32	44

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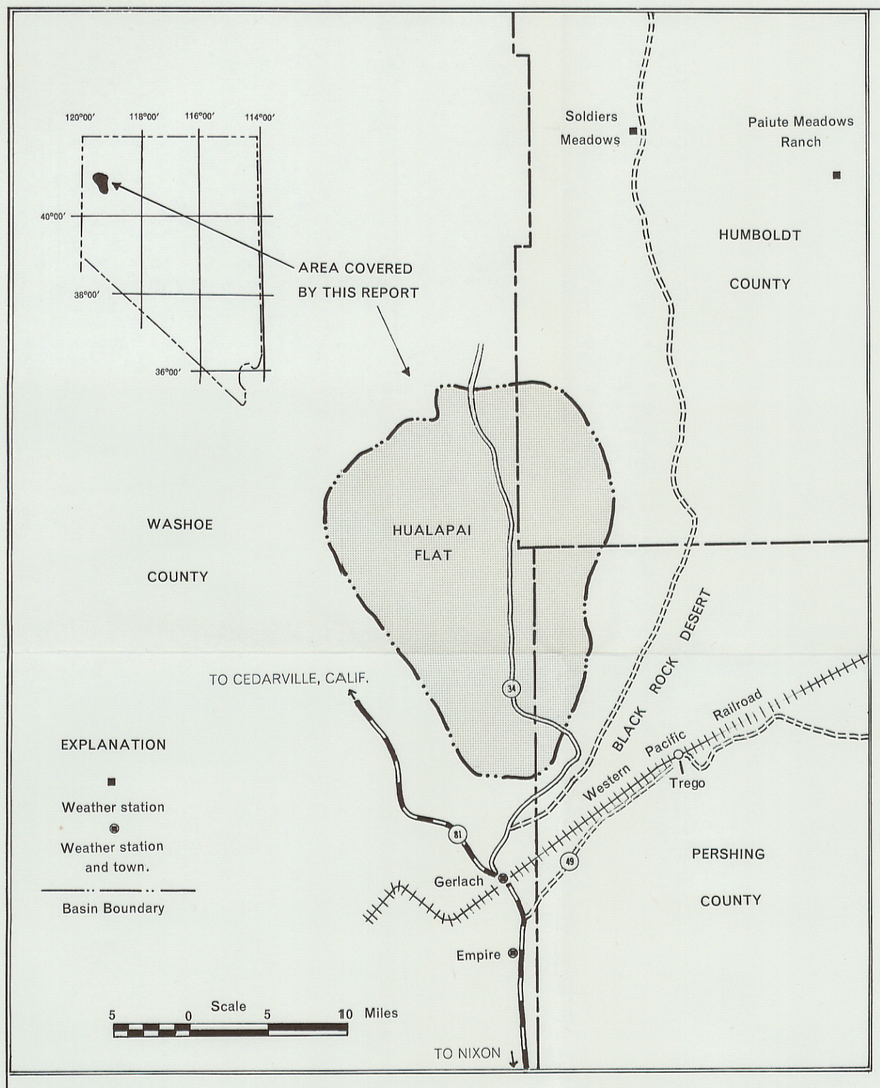

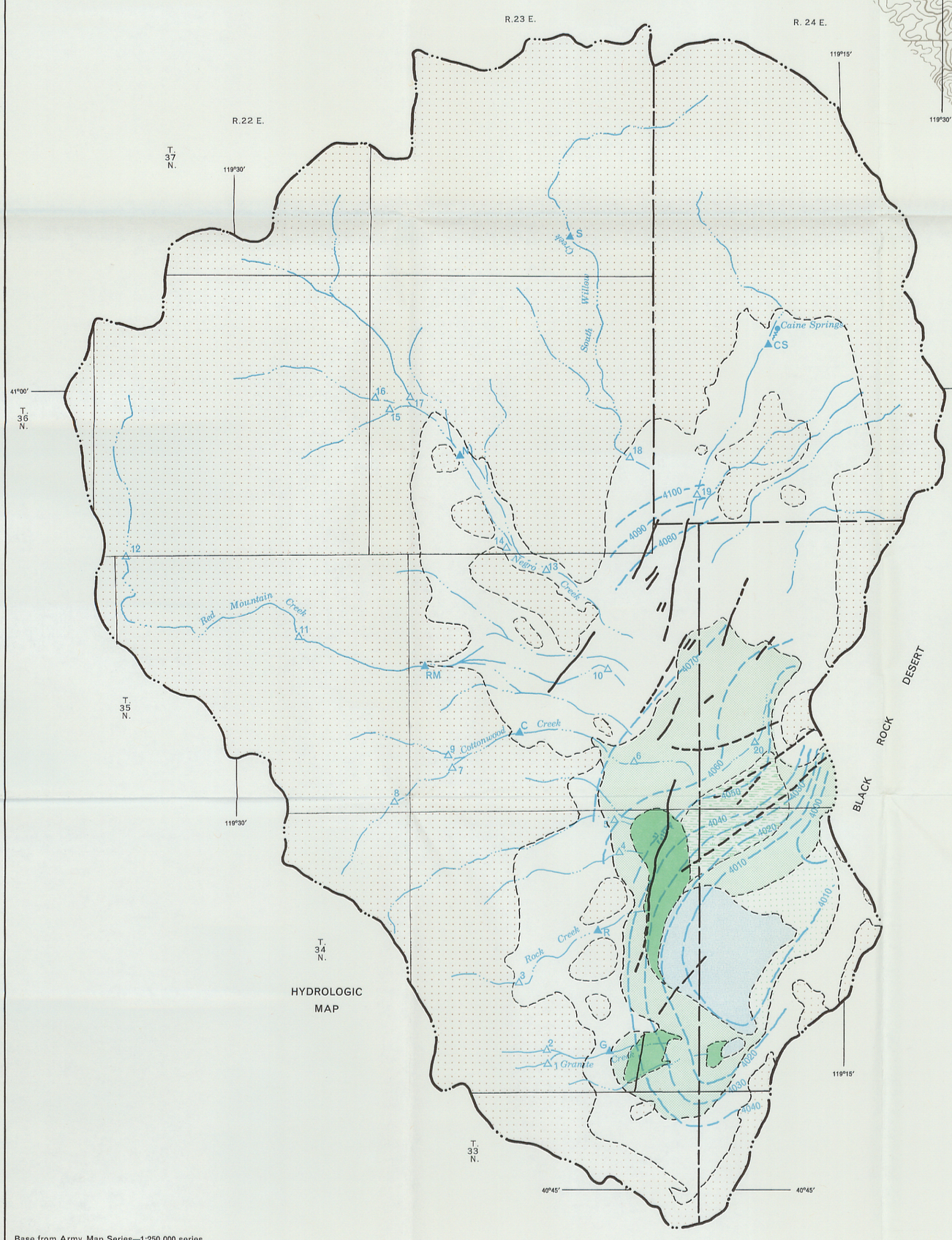

EXPLANATION

HYDROLOGY

- Valley-fill deposits — Principal ground-water reservoir
- Consolidated rocks — Commonly act as barriers to ground-water movement
- Phreatophyte areas
- Principally greasewood, rabbitbrush and saltgrass
- Principally meadowgrass and native hay; includes some saltgrass and rabbitbrush
- Principally saltgrass, rabbitbrush and greasewood; includes some buckbrush, wildrye and shadscale
- Bare soil, Sparse greasewood, and grease wood mounds
- Playa
- Spring
- 4020 — Water-level contour spring 1960 shows altitude of water level. Dashed where approximately located. Contour interval 10 feet. Datum is mean sea level
- CS — Miscellaneous site
- 7 — Supplemental site
- Streamflow measurement site and number or letter, (see table 22)

GEOLOGY

QUATERNARY

- PLEISTOCENE AND HOLOCENE — Playa deposits: Primarily silt, clay and evaporites
- PLEISTOCENE AND HOLOCENE — Younger alluvium: Unconsolidated gravel, sand, silt, and clay Yields water to wells where saturated
- PLEISTOCENE — Older alluvium: Semiconsolidated gravel, sand, silt, and clay Supplies most of the water to irrigation wells

TERTIARY

- Volcanic rocks: Primarily rhyolite, andesite, and basalt includes some diatomite and tuffaceous mudstone

CRETACEOUS

- Granitic rocks: Principally granodiorite

PERMIAN

- Metavolcanic and metasedimentary rocks Metamorphosed andesite and basalt flows, breccias and tuffs intercalated with some recrystallized limestone, pebble conglomerate, and other fine-grained sediments

U/D — Fault, dashed where approximately located or inferred
U; upthrown side
D; downthrown side

Topographic contour interval 200 feet
Datum is mean sea level

Basin Boundary
Contact

Scale
1 0 1 2 3 Miles

Base from Army Map Series—1:250,000 series Vya (1961), and Lovelock (1955).

Consolidated rock geology adapted from Bonham (1962) and Wilden (1964); unconsolidated deposits and hydrology by J.R. Harrill (1967).

PLATE I.—GENERALIZED GEOLOGIC AND HYDROLOGIC MAPS OF HUALAPAI FLAT WASHOE, PERSHING, AND HUMBOLDT COUNTIES, NEVADA