UNITED STATES
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GEOHYDROLOGIC RECONNAISSANCE OF LAKE MEAD NATIONAL RECREATION AREA—LAS VEGAS WASH TO OPAL MOUNTAIN, NEVADA

By R. L. Laney

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JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey
Box FB-44
Federal Building
301 West Congress Street
Tucson, Arizona 85701

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CONVERSION FACTORS

For readers who prefer to use the International System of Units (SI) rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain SI (metric) unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per year (gal/yr)	3.785	liter per year (L/yr)

GEOHYDROLOGIC RECONNAISSANCE OF LAKE MEAD NATIONAL RECREATION AREA—LAS VEGAS WASH TO OPAL MOUNTAIN, NEVADA

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ABSTRACT

The study is a geohydrologic reconnaissance of about 170 square miles in the Lake Mead National Recreation Area from Las Vegas Wash to Opal Mountain, Nevada. The study is one of a series that describes the geohydrology of the recreation area and that identifies areas where water supplies can be developed.

Precipitation in this arid area is about 5 inches per year. Streamflow is seasonal and extremely variable except for that in the Colorado River, which adjoins the area. Pan evaporation is more than 20 times greater than precipitation; therefore, regional ground-water supplies are meager except near the Colorado River, Lake Mead, and Lake Mohave. Large ground-water supplies can be developed near the river and lakes, and much smaller supplies may be obtained in a few favorable locations farther from the river and lakes. Ground water in most of the area probably contains more than 1,000 milligrams per liter of dissolved solids, but water that contains less than 1,000 milligrams per liter of dissolved solids can be obtained within about 1 mile of the lakes.

Crystalline rocks of metamorphic, intrusive, and volcanic origin crop out in the area. These rocks are overlain by conglomerate and mudstone of the Muddy Creek Formation, gravel and conglomerate of the older alluvium, and sand and gravel of the Chemehuevi Formation and younger alluvium. The crystalline rocks, where sufficiently fractured, yield water to springs and would yield small amounts of water to favorably located wells. The poorly cemented and more permeable beds of the older alluvium, Chemehuevi Formation, and younger alluvium are the better potential aquifers, particularly along the Colorado River and Lakes Mead and Mohave.

Thermal springs in the gorge of the Colorado River south of Hoover Dam discharge at least 2,580 acre-feet per year of water from the volcanic rocks and metamorphic and plutonic rocks. The discharge is much greater than could be infiltrated in the drainage basin above the springs. Transbasin movement of ground water probably occurs, and perhaps the larger part of the spring discharge is underflow from Eldorado Valley.

The more favorable sites for ground-water development are along the shores of Lakes Mead and Mohave and are the Fire Mountain,

Opal Mountain to Aztec Wash, and Hemenway Wash sites. Wells yielding several hundred gallons per minute of water of acceptable chemical quality can be developed at these sites.

INTRODUCTION

A series of geohydrologic reconnaissance studies of the Lake Mead National Recreation Area is being made by the U.S. Geological Survey in cooperation with the National Park Service. The area of this report includes about 170 mi^2 from Las Vegas Wash to Opal Mountain (fig. 1). The investigation was undertaken to appraise the water resources in the area and to locate potential sources of potable water other than the Colorado River. The investigation included: (1) reconnaissance geologic mapping at a scale of 1:62,500; (2) collection and analysis of well and spring data; (3) determination of the geologic and hydrologic controls on the occurrence, movement, and chemical quality of ground water; and (4) recommendation of sites that are favorable for future ground-water development.

The report area is bounded on the east by Lake Mead (maximum lake level 1,221 ft above the National Geodetic Vertical Datum of 1929—NGVD of 1929), the Colorado River, and Lake Mohave (maximum lake level 647 ft above the NGVD of 1929); on the west by the River Mountains and the Eldorado Mountains; on the north by Las Vegas Wash; and on the south by Opal Mountain (fig. 1). The altitude is about 635 ft above the NGVD of 1929 near Lake Mohave, about 3,700 ft in the River Mountains, and about 5,000 ft in the Eldorado Mountains just west of the boundary of the recreation area. Most of the area ranges in altitude from 635 to 2,500 ft. The climate is arid and is characterized by hot summers and mild winters. The average annual precipitation is about 5 in., and the average annual temperature is about 68°F at nearby Boulder City (fig. 1), which is at an altitude of 2,525 ft.

ROCK UNITS AND THEIR WATER-BEARING CHARACTERISTICS

The area is underlain by crystalline and sedimentary rocks (fig. 2). Metamorphic and plutonic rocks crop out in the central and southern parts of the Eldorado Mountains, in the rugged canyon of the Colorado River near Willow Beach, between Boulder City and Hoover Dam, and on Saddle Island. Volcanic rocks are on and near Opal Mountain, in the central and northern parts of the Eldorado Mountains, in places in the canyon of the Colorado River, north and west of Hoover Dam, and in the River Mountains. The Fortification Basalt Member of the Muddy Creek Formation is exposed locally in the northern part of the Eldorado Mountains and northeast and southeast of Boulder City.

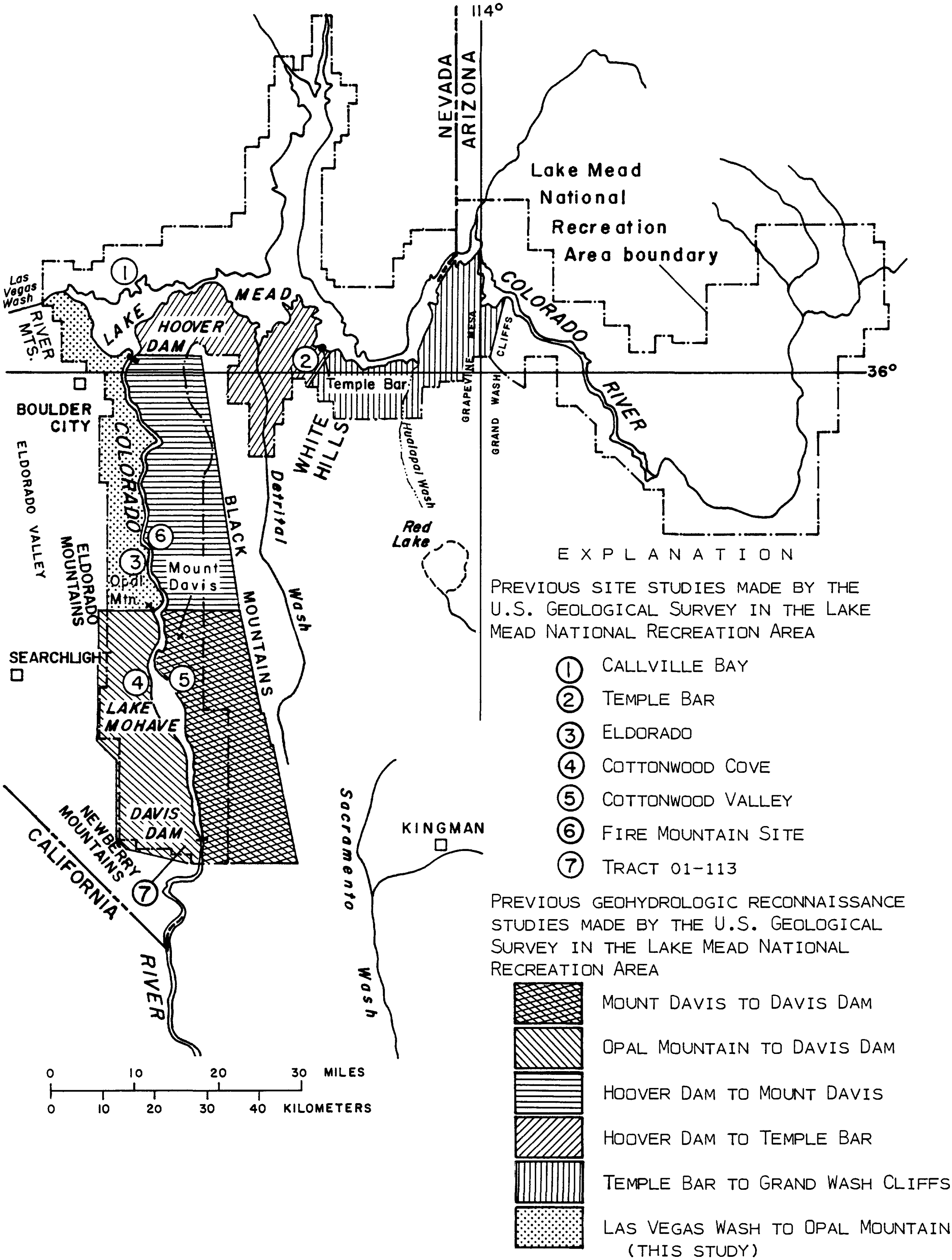


Figure 1.--Index map of Lake Mead National Recreation Area showing areas of this and previous studies made by the U.S. Geological Survey.

(page 4, large plate)

Exposed sedimentary rocks are the Muddy Creek Formation of late Tertiary age, older alluvium, Chemehuevi Formation of Pleistocene age, and younger alluvium. The Muddy Creek Formation, exclusive of the Fortification Basalt Member, consists of a conglomerate facies and a mudstone facies. The formation crops out north and south of Eldorado Canyon, in the northern part of the Eldorado Mountains, near Boulder City, between Saddle Island and Las Vegas Wash, and in places near Opal Mountain. The Muddy Creek Formation unconformably overlies older crystalline rocks. The older alluvium occurs mainly near Opal Mountain, in places along Lake Mohave, and along Las Vegas Wash and unconformably overlies the Muddy Creek and older rocks. The Chemehuevi Formation is exposed mainly between Saddle Island and Las Vegas Wash and locally near Lake Mohave south of Lonesome Wash and near Opal Mountain. The younger alluvium is along the courses of modern streams and on slopes near some of the mountains.

Terrace-gravel deposits, although common, are thin and are ignored as a mappable unit. The gravel is light grayish brown, brown, and light reddish brown. It is weakly cemented and consists of subangular sand, gravel, cobbles, and boulders of local origin; the upper few feet may be cemented by caliche. The unit generally is less than 15 ft thick.

Metamorphic and Plutonic Rocks

The metamorphic and plutonic rocks are gneiss, schist, and granitic pegmatite of Precambrian age and mostly finely crystalline intrusive granitic rocks and smaller amounts of rhyolitic to basaltic dikes of Tertiary age. The gneiss, schist, and pegmatite form highly complex to chaotic assemblages that are considerably altered, faulted, and sheared; the density of faults may be as great as 20 per square mile (Anderson, 1969, p. 37; 1977; 1978; Longwell and others, 1965, p. 11), but only a few of the faults are shown on figure 2. Gneiss, schist, and pegmatite dominate in the northern part of the Eldorado Mountains north of Lonesome Wash and Saddle Island. Elsewhere, the unit is mainly intrusive granitic rocks and lesser gneiss, schist, and volcanic rocks. The granitic rocks include the Boulder City pluton (Longwell, 1963; Anderson, 1969), which has been dated by the potassium-argon method at 13.8 m.y. (million years); other plutons in the western Lake Mead region have radiometric dates that range from 12.6 to 16.9 m.y. (Anderson and others, 1972, p. 280).

Ground water is contained in and moves along fractures in the metamorphic and plutonic rocks. South of Hoover Dam, springs discharge as much as 500 gal/min from exposed fractures and faults (fig. 2). In the southern part of the Eldorado Mountains sheared and faulted schist, gneiss, and granitic rocks may yield less than 5 gal/min to springs, wells, and mine shafts.

Volcanic Rocks

The volcanic rocks of Tertiary age include the Patsy Mine Volcanics, 15.2 to 22.8 m.y.; tuff of Bridge Spring, 15.3 to 15.5 m.y.; Mount Davis Volcanics, 10.9 to 14.6 m.y. (Anderson, 1971, p. 45); and clastic rocks (Longwell and others, 1965, p. 56-58). On the basis of many observations of structurally displaced blocks, the total thickness may be as great as 17,000 ft. The volcanic rocks are mainly basaltic to rhyolitic lava flows, monolithologic flow breccia, tuff, welded tuff, and interbedded clastic rocks. In many places, especially in the River Mountains and elsewhere near contacts with intrusive plutons, the volcanic rocks are chemically altered, sheared, fractured, and faulted.

Spring discharge ranged from 1 to 294 gal/min of water from faults and fractures in the volcanic rocks along the Colorado River south of Hoover Dam (fig. 2). Where saturated near Lakes Mead and Mohave, the unit may yield as much as 10 gal/min of water to wells.

Muddy Creek Formation

The Muddy Creek Formation of late Tertiary age is divided into the conglomerate facies, mudstone facies, and Fortification Basalt Member. The conglomerate facies is the most widespread. Near Boulder City, conglomerate grades laterally into mudstone within a few hundred feet, and near Las Vegas Wash, the gradation occurs within a few tens of feet. Erosional remnants of the conglomerate unconformably overlie mudstone in places near Las Vegas Wash. The conglomerate and mudstone facies are interbedded with or overlain by the Fortification Basalt Member east of Boulder City and in the northern part of the Eldorado Mountains.

Conglomerate Facies

The conglomerate facies is well exposed near Lake Mohave, south of Eldorado Canyon, in the northern part of the Eldorado Mountains, and between Saddle Island and Las Vegas Wash. The unit is poorly sorted silt to boulder subangular detritus, moderately to well cemented by calcite. The sand and coarser detritus were derived mostly from volcanic rocks and are set in a silty matrix that is light reddish brown, reddish brown, grayish reddish brown, brown, and tan. The conglomerate is coarser and contains more large fragments near the mountains, which were the source areas. Generally, only a few tens of feet of vertical section is exposed; in the northern part of the Eldorado Mountains, however, as much as 200 ft is exposed. The facies generally dips less than 20°. Some steeply dipping or nearly vertical faults offset the facies, but displacements generally are less than 5 ft.

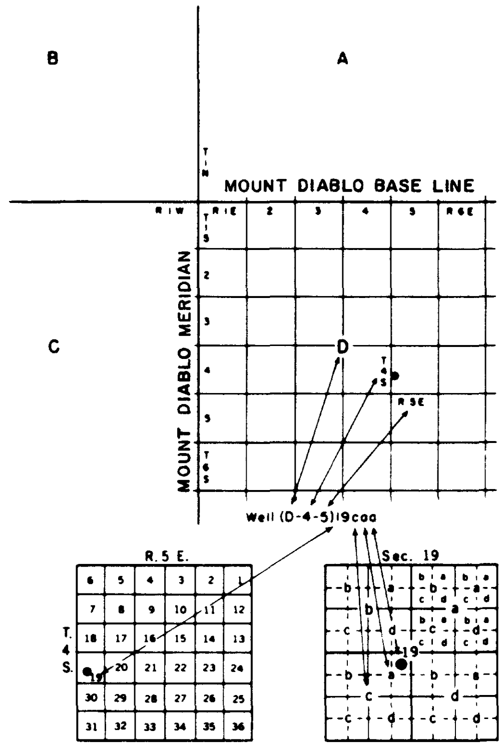
Although the conglomerate facies is mapped as one unit, it consists of an upper part and a lower part separated by an unconformity. East of Lake Mohave between Hoover Dam and Mount Davis, Bentley (1979c) divided the conglomerate of the Muddy Creek Formation into a grayish-brown upper part and a reddish-brown lower part. Northwest of Saddle Island, the unconformity is easily observed. Near Eldorado Canyon, however, it is much less evident, and westward from the mouth of the canyon, the upper part grades into reddish-brown conglomerate that is indistinguishable from the conglomerate of the lower part. In general, the lower part is dark reddish brown, forms rounded slopes, and contains more fine-grained material than the upper part. The upper part generally is grayish reddish brown, brown, or tan and at a distance has a grayish-brown appearance. The upper part tends to form cliffs, especially near Lake Mohave.

Only one well has been drilled in the conglomerate facies in the report area. Well (D-26-65)3cdc (figs. 2 and 3; table 1) supplied a now-abandoned marina at the mouth of Eldorado Wash; in August 1967 the well was discharging 13 gal/min. Wells could yield as much as 10 gal/min of water if drilled near Lake Mohave; north of Hoover Dam, however, the facies probably is drained of water.

Mudstone Facies

The mudstone facies is exposed east and southeast of Boulder City, between Saddle Island and Las Vegas Wash, and south of Las Vegas Wash. Near Boulder City, the facies consists of light-reddish-brown silty sandstone, sandy siltstone, mudstone, and fine-grained white to gray bedded tuff and gypsum; about 60 ft of dark-gray manganiferous silty gypsum beds are included between thin beds of tuff (McKelvey and others, 1949). Between Saddle Island and Las Vegas Wash, the facies is mainly light-reddish-brown gypsiferous siltstone that includes beds of white tuff as much as 2 ft thick. The mudstone facies grades westward into the conglomerate facies within 200 ft. South of Las Vegas Wash, the mudstone is deformed into a south-plunging syncline and is composed of reddish-brown mudstone and gypsiferous mudstone that contains as much as 40 ft of interbedded white to gray gypsum in the upper part. The more resistant gypsum forms a caprock over the mudstone. In places the grayish-brown upper part of the conglomerate unconformably overlies the gypsum. The mudstone facies generally dips no more than 10° and is nearly flat lying in much of the area. Although less than 100 ft of section generally is exposed, the unit may be as much as 1,000 ft thick in the Three Kids manganese district in the southeastern part of T. 21 S., R. 63 E. (Hunt and others, 1942, p. 301).

The mudstone facies is nearly impermeable in most of the area. Northwest of Saddle Island, the facies extends beneath Lake Mead, and wells near the lake may yield less than 1 gal/min of poor-quality water.



The well and spring numbers used in this report are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Nevada and northern California is based on the Mount Diablo meridian and base line, which divide the area into four quadrants. These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well or spring number indicates the township, the second the range, and the third the section in which the well or spring is situated. The lowercase letters a, b, c, and d after the section number indicate the well or spring location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well or spring number. In the example shown, well number (D-4-5)19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, T. 4 S., R. 5 E. Where there is more than one well or spring within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

Figure 3.--Well- and spring-numbering system used in this report.

Table 1.--Records of selected wells and springs in and near the Lake Mead National Recreation area—Las Vegas Wash to Opal Mountain

Location: See figure 3 for description of well- and spring-numbering system.
Depth of well: R, reported.
Land-surface altitude: NGVD of 1929, National Geodetic Vertical Datum of 1929.

Yield: E, estimated; R, reported.
Use: N, not used; FR, fish refugium; M, mining.
Remarks: C, chemical analysis of water shown in table 2.

Location	Aquifer	Depth of well (feet)	Diameter of casing (inches)	Depth of casing (feet)	Land-surface altitude (feet above NGVD of 1929)	Water level			Yield		Use	Remarks
						Altitude (feet above NGVD of 1929)	Depth below land surface (feet)	Date measured (month, year)	Amount (gallons per minute)	Date measured		
(D-22-64)14cdb	Younger alluvium, Chemehuevi Formation, and possibly the volcanic rocks in lower part	200	8	200	1,230	1,095	135R	6-55	--------	--------	N	Well near Boulder Beach campground. Surface casing, 0-55 ft, 12 in. diameter. Driller reported unable to lower water level by bailing; altitude of water table about the same as altitude of surface of Lake Mead. Driller's log: 0 to 300 ft, lime and sandstone, gravel.
(D-22-65)29dbb	Volcanic rocks	--------	--------	------	800	-------	------	------	172	5-17-77	FR	C; spring, in gorge of Colorado River south of Hoover Dam; part of water used for pupfish refugium.
(D-22-65)32acc	Metamorphic and plutonic rocks	--------	--------	------	650	---------	--------	--------	20E	5-17-77	N	C; spring, in gorge of Colorado River south of Hoover Dam.
(D-22-65)32bcb	do.	--------	--------	------	960	---------	--------	--------	556	5-17-77	N	C; spring, largest measured discharge of springs in gorge of Colorado River south of Hoover Dam; water issues from fractures in deep steep-walled canyon near intersection of canyon and major fault mapped by Anderson (1969).
(D-22-65)32bda	do.	--------	--------	------	680	---------	--------	--------	25E	5-17-77	N	C; spring, in gorge of Colorado River south of Hoover Dam; discharge estimated at cement V-notch weir at mouth of mine tunnel.
(D-23-65)5cbd1	do.	--------	--------	------	840	---------	--------	--------	248	5-17-77	N	C; springs, in gorge of Colorado River south of Hoover Dam; measuring point downstream from (D-23-65)5cbd1 and (D-23-65)5cbd2; unsurveyed.
(D-23-65)5cbd2	do.	--------	--------	------	860	---------	--------	--------				
(D-23-65)8cdd	Volcanic rocks	--------	--------	------	880	---------	--------	--------	294	5-17-77	N	C; spring, in gorge of Colorado River south of Hoover Dam; measuring point about a quarter of a mile downstream from spring. Spring near steep west-dipping fault that separates the Mount Davis Volcanics and Patsy Mine Volcanics (Anderson, 1977); unsurveyed.
(D-23-65)21bca	do.	--------	--------	------	670	---------	--------	--------	1E	1-15-76	N	C; spring, in gorge of Colorado River south of Hoover Dam; water issues from intersection of canyon and fault rubble zone; unsurveyed.
(D-26-65)3cdc	Conglomerate facies of the Muddy Creek Formation	350	10.75	350	820	655 650	165 170	8-67 2-76	13	8-17-67	N	C; abandoned well; furnished the public supply at Nelsons Landing. Driller's log: 0 to 5 ft, sand and gravel; 5 to 44 ft, gravel and boulders; 44 to 105 ft, cemented gravel; 105 to 150 ft, red-cemented gravel; 150 to 350 ft, cemented gravel.
(D-26-65)20cab	Metamorphic and plutonic rocks	700R	--------	------	1,680	1,380	300R	--------	3R	--------	M	C; well, water supply for Capital Mines at Capital Camp.
(D-26-65)30bbb	do.	--------	--------	------	2,080	---------	--------	--------	0	12-10-76	N	Spring in canyon of Aztec Wash in the Eldorado Mountains. Reported discharge about 11 gal/min in 1906 and dry in 1973; diversion dam constructed at spring site; was used as water source for Capital Mines.
(D-27-64)12abc	do.	--------	--------	------	2,030	---------	--------	--------	0	2-12-76	N	Spring in Eldorado Mountains; salt crusts and damp ground; saltcedar, mesquite, and other vegetation in area of spring in bottom of canyon.
(D-27-64)12cbd	do.	--------	--------	------	2,190	---------	--------	--------	0.1E	2-12-76	N	C; spring in Eldorado Mountains; water issues from alluvium where two rock ribs cross canyon bottom.

Fortification Basalt Member

The Fortification Basalt Member of the Muddy Creek Formation consists of a series of basalt flows. The flows are intercalated with the conglomerate facies in the northern part of the Eldorado Mountains and overlie the mudstone facies and metamorphic and plutonic rocks east of Boulder City. The flows are dark-gray to black dense to vesicular olivine basalt and are visually indistinguishable from basalt flows in the upper part of the Mount Davis Volcanics (Anderson, 1977). The flows are exposed in cliffs and on the tops of mesas and plateaus and are drained of water. In the western Lake Mead region the flows have radiometric dates that range from about 4 to 11 m.y. (Anderson and others, 1972, table 1).

Older Alluvium

The older alluvium is late Tertiary and early Quaternary in age and is exposed in a large area between Aztec Wash and Opal Mountain. Scattered remnants are present between Aztec Wash and Lonesome Wash and near Las Vegas Wash. The older alluvium consists mainly of weakly to moderately cemented sand, gravel, cobbles, and boulders deposited in alluvial fans that spread downward from the mountains. In places the unit includes weakly consolidated silt and clay and moderately to well-cemented conglomerate.

The sand, gravel, cobbles, and boulders are light grayish brown to brown and are mainly subangular granitic and volcanic rocks. The particle size decreases with increasing distance from source areas, and sorting is poor to fair. In places near Eldorado Canyon the older alluvium is in channels that are cut into the conglomerate facies of the Muddy Creek Formation. The older alluvium is most common and thickest near well-developed drainages that now extend deeply into the southern part of the Eldorado Mountains. Remnants too small to map are perched along canyon walls in the mountains. Stratification is from faint to well defined, and the bedding is thin to medium in thickness; faint crossbeds are present in places.

Near Lake Mohave and Las Vegas Wash, the older alluvium is as much as 30 percent rounded clasts. The contrast between the rounded clasts and the locally derived subangular clasts is great. The better rounded clasts are exotic to the area and may be, in part, equivalent to the old river deposits described by Longwell and others (1965, p. 49). The exotic clasts near the Colorado River are quartzite, granite, limestone, and small amounts of chert and jasper that have been brought into the area by the river.

Locally, weakly consolidated light-reddish-brown, brown, and tan silt and clay crop out near Lake Mohave. Some is well laminated and contains or is capped by beds of rounded gravel. A few thin layers of white gypsum are present in places.

Well-cemented grayish-brown conglomerate is in the lower part of the older alluvium along Las Vegas Wash and in places near Eldorado Canyon and the mouth of Aztec Wash. Some brown gypsiferous silt is interbedded near the mouth of Las Vegas Wash. Clast size and composition are similar to those in the overlying more common and less-cemented conglomerate, but rounded clasts are not as abundant in the lower part. The subrounded clasts are exotic and are limestone, granite, and quartzite. Other clasts are locally derived basalt, andesite, and welded tuff. Along Las Vegas Wash, the conglomerate is in a well-defined channel that is cut into rocks of the Muddy Creek Formation; the unit weathers to huge isolated blocks where it overlies the mudstone facies of the Muddy Creek Formation.

In the central and eastern Lake Mead region outcrops of older alluvium that contain the subrounded to rounded exotic clasts are called Colorado River deposits, and outcrops that contain entirely locally derived subangular clasts are called the local gravel unit (Laney, 1979a; 1979b). Deposits of subrounded to rounded material occur in every major regional drainage system tributary to the Colorado River (Longwell, 1936, pl. 4) and may be correlative with the Colorado River deposits.

The older alluvium unconformably overlies all older rocks. Most of the unit shows little deformation and dips generally are less than 10°. Near Eldorado Canyon and Aztec Wash, however, the well-cemented conglomerate is in fault contact with the conglomerate facies of the Muddy Creek Formation, and dips exceed 20° in places.

Generally only a few tens of feet of the older alluvium is exposed, and the total thickness probably is less than 150 ft. The well-cemented conglomerate is 25 to 30 ft thick along Las Vegas Wash, but only a few feet of the rock is exposed elsewhere.

The older alluvium generally is drained of water; however, where the coarse material is saturated near Lakes Mead and Mohave, the unit may yield 500 gal/min of water to wells; the silt and clay probably will yield less than 10 gal/min. The possibilities of developing a ground-water supply near Lake Mohave are discussed in the section entitled "Proposed Areas for Ground-Water Exploration."

Chemehuevi Formation

The Chemehuevi Formation of Pleistocene age is exposed mainly between Saddle Island and Las Vegas Wash and is as much as 30 ft thick. The unit is undeformed and dips less than 2°; it unconformably overlies the older alluvium, Muddy Creek Formation, and volcanic rocks. Small scattered remnants of the unit crop out near Lake Mohave south of Lonesome Wash.

Light-colored fluvial deposits near and along the Colorado River are equivalent to the Chemehuevi Formation as described by Bentley (1979a; 1979b; 1979c), Longwell (1936; 1963), and Longwell and others (1965). In the eastern Lake Mead region Laney (1979b) divided the Chemehuevi Formation into the fan-gravel facies and Colorado River facies. Deposits that represent the fan-gravel facies are exposed between Saddle Island and Las Vegas Wash. Because the areal extent of the exposed Colorado River facies is small, the facies was not mapped separately for this study. The Chemehuevi Formation—equivalent to the Colorado River facies of Laney (1979b)—was mapped by Longwell (1936) near Saddle Island and in places along Gypsum Wash in the northwestern part of what is now Las Vegas Bay; these areas are now under water. Longwell did not include alluvial-fan detritus as part of the Chemehuevi Formation; however, locally derived alluvial-fan detritus near Saddle Island is similar to the river deposits identified as Chemehuevi by Longwell. Near the mouth of Boulder Canyon about 7 mi northeast of Saddle Island, fan-gravel deposits are interbedded with river deposits that were identified as Chemehuevi Formation by Longwell (1936, p. 1446-1447 and pl. 15). In the eastern Lake Mead region the river deposits grade laterally into locally derived fan gravel (Lucchitta, 1966, p. 182 and fig. 39). Thus, the river and fan-gravel deposits are interpreted to be, at least in part, equivalent.

Between Saddle Island and Las Vegas Wash, the Chemehuevi Formation consists of light-brown, tan, and reddish-brown silty sand, gravel, cobbles, and boulders; the deposits are poorly sorted and weakly cemented. Most clasts are composed of intermediate to mafic volcanic rocks from the nearby mountains. Calcium carbonate accumulations are present in the upper part of the unit, but no dense caliche was observed. Bedding generally is indistinct, particularly in the fine-grained parts, but thin sand and gravel beds, cut-and-fill structures, and faint crossbeds are present in places. The deposits are remnants of alluvial fans that probably once covered much of the area.

Exposures near Saddle Island generally are brown to reddish-brown sand, gravel, cobbles, and boulders. Northwestward toward Las Vegas Wash, the deposits are lighter colored and contain more silt. Near the wash, as much as 10 ft of the upper part of the formation is gypsiferous, and in places recrystallized gypsum crystals form a binder around the coarser detritus. The lighter color and gypsum probably are the result of erosion and redeposition of white to light-gray gypsiferous mudstone and gypsum of the Muddy Creek Formation near Las Vegas Wash.

On the north and south sides of Hemenway Wash, scattered remnants of alluvial fans consist of reddish-brown sand- to boulder-size material. Near the channel, small outcrops of moderately cemented reddish-brown sand and gravel are mapped with the younger alluvium. The Chemehuevi Formation may be present at shallow depths beneath much of Hemenway Wash.

Erosional remnants of coarse-grained deposits too small to be shown on the geologic map are present at the mouths of some of the canyons in the southern part of the River Mountains. About 30 ft (vertical) of brown to reddish-brown weakly consolidated moderately well-sorted sand and gravel crops out in a canyon about 0.3 mi from the mouth in the SE¼SE¼NW¼ sec. 22, T. 22 S., R. 64 E. The deposit is well bedded and contains lenticular beds, crossbeds, and only a small amount of detritus in the cobble- and boulder-size range. These scattered remnants may be part of the Chemehuevi Formation.

Near Lake Mohave south of Lonesome Wash, the Chemehuevi Formation consists of scattered deposits of tan to light-gray weakly cemented silt, clay, sand, gravel, and cobbles. The unit includes clasts of locally derived subangular volcanic rocks and exotic rounded clasts of quartzite, granite, limestone, chert, and small but noticeable amounts of jasper. Bedding is poorly defined, particularly in the coarse-grained parts. The remnants are less than 50 ft thick.

The Chemehuevi Formation may yield as much as 200 gal/min of water to shallow wells northwest of Saddle Island, where the formation is saturated by water from Lake Mead. South of Lonesome Wash, the unconsolidated river deposits could yield as much as 1,000 gal/min of water to wells if the deposits are saturated by water from Lake Mohave; however, the small areal extent and location of these permeable deposits at or only slightly below lake level make development speculative. Elsewhere, the Chemehuevi Formation is drained of water.

Younger Alluvium

The younger alluvium of Quaternary age is exposed in modern stream channels and flood plains and includes fan and sheet deposits near bedrock slopes. The deposits consist of pale-brown to grayish-brown unconsolidated and undeformed sand and gravel of local origin. The younger alluvium probably is less than 20 ft thick and is drained of water in most of the area; however, the unit may yield as much as 500 gal/min of water to shallow wells near Lake Mohave and Opal Mountain. The supply would not be dependable because normal fluctuations in the level of the lake would cause the deposits to be drained of water.

HYDROLOGY

In the Las Vegas Wash to Opal Mountain area the average annual precipitation is so small that most is evaporated or transpired; therefore, streamflow is erratic, the amount is small, and annual infiltration of precipitation or streamflow to the ground-water reservoir is almost insignificant. The only reliable sources of significant amounts of water of acceptable chemical quality are the Colorado River and Lakes Mead and Mohave. Water from these sources infiltrates adjacent rocks, and wells can be drilled to develop the infiltrated water. Lesser amounts of water can be developed by wells drilled in favorable locations at greater distances from the Colorado River, but the production probably would be less than 10 gal/min.

Surface Water

Streams are seasonal except for the Colorado River and Las Vegas Wash. Because the average annual precipitation is only about 5 in. and the potential evaporation rate is more than 20 times greater, most of the precipitation evaporates soon after it reaches the ground or is transpired by vegetation. Streamflow is meager, extremely variable, and occurs only about once a year in any one drainage basin (Bentley, 1979c, p. 18); only a small amount of flow recharges the ground-water reservoir. Las Vegas Wash is perennial, however, and flow for October 1, 1975, to September 30, 1976, was 58,660 acre-ft, a large part of which was treated sewage effluent and wastewater from industrial plants (U.S. Geological Survey, 1977).

Ground Water

Ground water is derived from two principal sources: (1) infiltrated water from Lakes Mead and Mohave and (2) regional ground-water underflow in the basins that drain to the lakes. The saturated thickness of permeable rocks is greater near the lakes than it is away from the lakes. Water levels in the saturated deposits vary in response to changes in the level of the lakes. When the lake levels rise above the water levels in adjacent aquifers, water from the lakes infiltrates into the adjacent permeable deposits; when the lake levels decline to positions below water levels in adjacent aquifers, water stored in the permeable deposits is discharged to the lakes. Most of the ground water in the permeable deposits adjacent to Lakes Mead and Mohave infiltrated from the lakes. The greatest potential for ground-water development is probably within 1 mi of the shorelines. The older alluvium, younger alluvium, and Chemehuevi Formation are potentially the more productive aquifers near the lakes (see section entitled "Proposed Areas for Ground-Water Exploration"). The regional ground-water system in the basins that drain to Lakes Mead and Mohave is controlled, in part, by the levels of the lakes. The general direction of ground-water movement in the regional system is eastward toward the lakes. Few well data are available to define the hydraulic gradient or other hydraulic properties of the water-bearing materials.

A large supply of ground water is in the upstream reaches of Las Vegas Wash in Las Vegas Valley, which is more than 5 mi west of the report area (Malmberg, 1965, p. 58-59). Granite and other rocks of low permeability, which underlie the wash in the eastern part of Las Vegas Valley, prevent significant ground-water underflow out of the valley.

West of Lake Mohave near Eldorado Canyon, the conglomerate facies of the Muddy Creek Formation contains ground water. The older alluvium probably is drained of water. Small amounts of water can be obtained from fractures in metamorphic and plutonic rocks.

North of Hoover Dam all the rock units—except those near Lake Mead—contain little or no ground water. No permanent springs are known to exist in the volcanic rocks, which form a large part of the River Mountains. No ground water was found during excavation of the 3.8-mile-long River Mountains tunnel, which runs from the center of sec. 5, T. 22 S., R. 64 E., to the northeast corner of sec. 3, T. 22 S., R. 63 E. (U.S. Bureau of Reclamation, 1973, p. 36).

Thermal springs issue from granitic and volcanic rocks along a 5-mile reach of the Colorado River south of Hoover Dam. Discharges ranged from less than 1 to 556 gal/min at temperatures that ranged from 26° to 63°C.

Springs

All identified springs issue from metamorphic and plutonic rocks or volcanic rocks (table 1). Two types of springs are present: (1) springs having small discharges and cool temperatures and (2) springs having small to large discharges and warm to hot temperatures.

Three cool-temperature springs issue from granitic rocks in the Eldorado Mountains. Spring (D-26-65)30bbb in Aztec Wash was not flowing at the land surface when visited in December 1976, but adequate water was available near the land surface to support saltcedar, mesquite, grass, and weeds. A diversion dam had been built across a narrow part of the wash, and alluvial deposits filled the channel behind the dam. A 4-inch pipe extended down the wash from the dam. Numerous steeply dipping fractures and shears in the outcropping granitic rocks are the probable source of the ground water. Grass and weeds were growing in some fractures a few feet above the bottom of the wash. Ground water probably flows through the fractures and collects in the thin alluvial deposits. The diversion dam was constructed about 1906, and the water was piped northeast to a mill at Capital Mines at Capital Camp. Discharge was reported to be about 10 gal/min when the dam was constructed, but the spring went dry in 1973 (E. W. Estrella, mine owner, oral commun., 1976).

Springs (D-27-64)12abc and (D-27-64)12cbd are just west of the recreation area boundary. Although no water was flowing at the land surface from spring (D-27-64)12abc in February 1976, salt crust, damp ground, saltcedar, and mesquite were present in the canyon bottom near the spring. The rocks near the spring consist of light-colored granitic rocks and dark andesitic to dioritic intrusive rocks. Prominent north-trending steeply eastward-dipping faults, shear planes, and joints cross the canyon at the spring. Water probably seeps from the faults, shear planes, and joints into the thin alluvial deposits in the canyon bottom. Spring (D-27-64)12cbd had an estimated discharge of 0.1 gal/min when visited in February 1976. Most of the water issues from thin alluvial deposits behind two resistant bedrock ribs that extend across the canyon bottom. Prominent steeply dipping fractures trend north and east in light-colored granitic rocks, which are intruded locally by black basaltic dikes.

All springs that yield warm to hot water are in granitic and volcanic rocks in the gorge of the Colorado River south of Hoover Dam. Geologic structure rather than rock type controls the location of these springs. Many springs are at the intersections of canyons and northwest-trending faults and joints. The springs are numerous seeps too small to measure individually—at or below normal river level—or are well-defined orifices as much as 300 ft above river level.

The greatest discharge measured—556 gal/min in May 1977—was from spring (D-22-65)32bcb, which issues from fractures in the sides of a steep-walled canyon. Temperature at the measuring point was 34°C but was as high as 60°C in water from small nearby seeps. The highest temperature of 63°C was measured at spring (D-22-65)32acc, which discharges about 20 gal/min.

Discharge of the major springs on both sides of the Colorado River is about 1,600 gal/min or 2,580 acre-ft/yr (table 1; Bentley, 1979c, table 2); this is a minimum value because discharge from the many seeps was not measured or estimated. A catchment area of about 47 mi^2 drains to the reach of the Colorado River that contains the springs. Assuming an annual precipitation of 5 in., the amount of water that falls on the catchment area is about 4.1×10^9 gal/yr or about 7,800 gal/min; therefore, a minimum of 21 percent of the precipitation on the catchment area would have to be recharged to account for the observed spring discharge. West of the study area in Eldorado Valley, estimated recharge is 0.5 percent of the annual precipitation (Rush and Huxel, 1966, p. 14). Using the 0.5-percent figure as a basis for calculation, more than 1,800 mi^2 of catchment area would be required to account for the 1,600 gal/min of spring discharge. Thus, the springs discharge much more water than can be recharged within the 47-square-mile area, and an external water source is postulated. Two likely sources of the water are Lake Mead and Eldorado Valley. The faults and fractures that control the location of springs could provide conduits for transbasin transfer of water.

Most of the faults near the springs extend northward into Lake Mead, which is as much as 500 ft higher than the springs (fig. 2). This head differential potentially could force large amounts of water from Lake Mead through the faults and fractures; however, thermal springs discharging about 2,200 gal/min were present at the time of excavation for the foundation of Hoover Dam on the Nevada side of the river (U.S. Bureau of Reclamation, 1950, p. 177-179). Therefore, the springs probably were present before the construction of Hoover Dam, and Lake Mead may not be the source of the water. The temperature of the spring water tends to preclude Lake Mead as the source.

The faults in the Eldorado Mountains and in the canyon near the Colorado River extend under the eastern part of Eldorado Valley (Anderson, 1977). Ground water may flow from Eldorado Valley through this system of faults and fractures to discharge as springs near the Colorado River. Eldorado Valley is a topographically closed basin; natural ground-water recharge is estimated to be 1,100 acre-ft/yr, and ground-water use in the basin is negligible (Rush and Huxel, 1966, p. 17 and 21). Evapotranspiration is negligible because the depth to water beneath the playa in the center of the basin is at least 270 ft and the altitude of the water table is about 1,450 ft above the NGVD of 1929; therefore, a subsurface outlet must be present or ground water would discharge to the playa. All the estimated 1,100 acre-ft/yr of recharge to Eldorado Valley must leave by ground-water flow, but this amount is only about 43 percent of the discharge of the major springs. If all the water to the thermal springs originates in Eldorado Valley, the estimated recharge to the valley would have to be increased at least 2.3 times. On the basis of the highest observed ground-water temperature of 63°C, a mean annual air temperature of 21°C (70°F), and an assumed average geothermal gradient of 0.8°C per 100 ft, the spring water would have to circulate to a depth of at least 5,200 ft.

A reported spring in a canyon about 1 mi west of Roaring Rapids, which is about 3 mi southwest of Willow Beach, was not visited by the author. The estimated discharge is less than 1 gal/min from fractured volcanic rocks, and the water collects in two shallow pools cut in the canyon bottom (Bill Burke, National Park Service, and Gayle Kobetich, U.S. Fish and Wildlife Service, oral commun., 1978). The spring is perennial and has been stocked with fish since 1971. The water temperature varies with the ambient air temperature and ranged from 11° to 26°C in 1976-77. The following water-quality characteristics were analyzed in the field in 1977 (Gayle Kobetich, U.S. Fish and Wildlife Service, oral commun., 1978):

Total alkalinity	205 mg/L
Hardness as $CaCO_3$	120 mg/L
Carbon dioxide (CO_2)	0 mg/L
Oxygen (O_2)	6-18 mg/L

Wells

Information is available for only three wells in the report area. Well (D-26-65)20cab was drilled in granitic and metamorphic rocks at Capital Camp and reportedly yields 3 gal/min. The well bottoms in mineralized schist and gneiss. Small amounts of water seep into two mine shafts near the well; however, most of the mine shafts that were examined in the Eldorado Mountains were dry. Well (D-26-65)3cdc in Eldorado Canyon penetrates the conglomerate facies of the Muddy Creek

Formation. A discharge of 13 gal/min was measured at this well in August 1967. Water from the well furnished the public supply for the marina at Nelsons Landing; the well was capped after the closing of Nelsons Landing.

Well (D-22-64)14cdb was drilled near the mouth of Hemenway Wash where the younger alluvium is at the surface. The well is 200 ft deep and may extend through the fan deposits of the Chemehuevi Formation and bottom in volcanic rocks. The well is unused, and yield data are not available. The driller reported that he was unable to lower the water level by bailing, which is not surprising because the well is only a few tens of feet from the shoreline of Lake Mead.

Quality of Water

Nine water samples were collected for chemical analysis from springs in the volcanic rocks and metamorphic and plutonic rocks; one chemical analysis of water from a well that taps the conglomerate facies of the Muddy Creek Formation was available from an earlier study (table 2). Dissolved-solids concentrations range from 643 to 2,790 mg/L. The maximum concentration for dissolved solids in public water supplies is 500 mg/L, as proposed in the secondary drinking-water regulations of the U.S. Environmental Protection Agency (1977b, p. 17146). The U.S. Environmental Protection Agency (1977a, 1977b) has established national regulations and guidelines for the quality of water provided by public water systems. The regulations are either primary or secondary. Primary drinking-water regulations govern constituents in drinking water that have been shown to affect human health. Secondary drinking-water regulations apply to constituents that affect esthetic quality. The primary regulations are enforceable either by the Environmental Protection Agency or by the States; in contrast, the secondary regulations are not Federally enforceable. The secondary regulations are intended as guidelines for the States. The regulations express limits as "maximum contaminant levels," where contaminant means any physical, chemical, biological, or radiological substance or matter in water. Generally, the highest concentrations of dissolved solids are in water from the thermal springs. Most of the water has a sodium sulfate composition, although concentrations of chloride equaled or exceeded those of sulfate in water from three thermal springs. Calcium was the second most abundant cation. Only in the water from spring (D-23-65)21bca were concentrations of chloride, fluoride, and sulfate less than the recommended maximum concentrations for public water supplies established by the U.S. Environmental Protection Agency (National Academy of Sciences and National Academy of Engineering, 1973; p. 61, 66, 89). Nearly all the water that was sampled was of poorer quality than that from Lake Mohave. The recommended maximum concentration for sulfate and for chloride is 250 mg/L. The recommended maximum concentration for fluoride differs according to the annual average maximum daily air temperature. The amount of water consumed by humans, and therefore the amount of fluoride ingested,

Table 2.--Chemical analysis of water from selected sources and quality criteria, Lake Mead National Recreation Area—Las Vegas Wash to Opal Mountain

[Analyses by U.S. Geological Survey. Results in milligrams per liter, except as indicated. Dissolved solids calculated by adding the carbonate equivalent of bicarbonate plus other determined constituents]

Location (unsurveyed)	Source	Depth of well (feet)	Date of collection	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrite and nitrate (N)	Orthophosphate (P)	Soluble phosphorus (P)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Non carbonate	Specific conductance (micromhos at 25°C)	pH (units)	Aquifer and remarks
(D-22-65) 29dbb	Spring	------	2-11-76	30.0	28	0.010	0.010	70	3.1	190	4.5	112	0	360	130	3.6	1.0	0.0	0.0	849	94	96	1,300	8.5	Volcanic rocks.
(D-22-65) 32acc	Spring	------	2-11-76	63.0	45	.010	.720	200	4.5	480	12	84	0	780	480	4.1	.12	.0	.0	2,050	70	450	3,500	8.2	Metamorphic and plutonic rocks.
(D-22-65) 32bcb	Spring	------	1-15-76 5-17-77	33.0 34.0	44	.000	.000	160	5.8	410	11	90	0	720	380	4.0	.14	.00	.00	1,780	70	350	2,760	8.2	Metamorphic and plutonic rocks. Temperatures as high as 60°C in water from small seeps.
(D-22-65) 32bda	Spring	------	2-11-76	47.0	54	.010	.020	140	10.0	290	10	136	0	610	180	4.1	.15	.03	.01	1,370	110	280	2,150	8.2	Metamorphic and plutonic rocks.
(D-23-65) 5cbd1 (D-23-65) 5cbd2	Spring Spring	------ ------	1-15-76	30.0	40	.010	.000	290	4.8	680	17	41	0	730	1,000	3.9	.15	.00	.00	2,790	30	710	4,780	7.9	Metamorphic and plutonic rocks. Analysis is representative of discharge of the combined discharge of both springs.
(D-23-65) 8cdd	Spring	------	1-15-76	27.0	34	.010	.000	290	10.0	650	15	48	0	660	1,100	3.0	.16	.00	.00	2,790	40	730	4,560	7.8	Volcanic rocks.
(D-23-65) 21bca	Spring	------	1-15-76	26.0	25	.010	.000	37	6.9	160	3.1	79	0	180	180	1.4	2.1	.21	.07	643	64	56	1,040	7.6	Volcanic rocks.
(D-26-65) 3cdc	Park Service unused well	350	8-17-67	24.2	22	.01	------	68	22.0	142		66	0	404	66	1.0	------	------	------	769	54	208	1,210	7.2	Conglomerate facies of the Muddy Creek Formation.
(D-26-65) 20cab	Capital Mine well (reported)	700	3-30-76	------	20	.000	.160	180	110.0	130	6.9	173	0	900	44	2.5	.01	.00	.00	1,480	140	760	1,960	6.9	Metamorphic and plutonic rocks.
(D-27-64) 12cbd	Spring	------	2-12-76	13.5	16	.030	.010	240	36	170	14.0	136	0	780	78	1.8	24.0	.12	.04	1,510	110	640	2,050	7.5	Metamorphic and plutonic rocks.
Colorado River below Hoover Dam[1]		------	5-11-76	12.5	8.0	.010	------	85	29	100	4.9	165	0	290	84	.4	.42	------	.01	685	330	200	1,090	8.1	Representative of the quality of the water entering Lake Mohave for the period October 1975 to September 1976.
Maximum recommended concentrations for for public water supplies[2]		------	-------	------	-----	.3	.05	-----	-----	-----	-----	-----	---	250	250	1.4	------	------	------	------	------	------	-------	-----	--------------

[1]Data from U.S. Geological Survey (1977).
[2]U.S. Environmental Protection Agency (National Academy of Sciences and National Academy of Engineering, 1973, p. 48-104).

depends partly on air temperature. The maximum concentration for fluoride in this area is 1.4 mg/L.

The one sample of water from a well that taps the conglomerate facies of the Muddy Creek Formation is not sufficient to predict the water quality everywhere in the facies. The mudstone facies is likely to contain poor-quality water because of the gypsum in the unit. No water samples are available from the older alluvium, Chemehuevi Formation, or younger alluvium; however, where these units are coarse grained and saturated by water from Lakes Mead or Mohave, the quality of the ground water probably will be similar to that of lake water.

PROPOSED AREAS FOR GROUND-WATER EXPLORATION

The more productive wells will be in the unconsolidated to semiconsolidated rocks adjacent to Lakes Mead and Mohave. Considerable water also is available from the volcanic and granitic rocks in the gorge of the Colorado River south of Hoover Dam; however, the rugged terrain and poor quality of the water will limit development and use of this source. Smaller amounts of water can be obtained from fractured crystalline rocks elsewhere near the lakes, and small quantities may be obtained from the units farther from the lakes. Small quantities of water probably can be obtained from the conglomerate facies of the Muddy Creek Formation south of Lonesome Wash. One site that is under consideration by the Park Service for development and two additional sites have the potential for development of large quantities of ground water.

Site 1—Fire Mountain

Large quantities of water can be obtained from the older alluvium at the Fire Mountain site—a proposed marina—on the shore of Lake Mohave about 1 mi southeast of the mouth of Eldorado Canyon. The older alluvium, the conglomerate facies of the Muddy Creek Formation, and the volcanic rocks are exposed at the site. The older alluvium at this site consists of weakly cemented sand, gravel, cobbles, and boulders in a well-defined relict river channel (fig. 2) and may yield as much as 500 gal/min of water to wells. The conglomerate facies and volcanic rocks probably will yield no more than about 10 gal/min of water to wells.

The older alluvium has the greatest ground-water potential at the site because the deposits are permeable and extend below the level of Lake Mohave. The thickness, the water-bearing properties of the unit below lake level, and the deepest part of the relict river channel can be verified, if necessary, by test drilling along a northeast-trending line at a right angle to the trend of the channel in the NW¼ sec. 13, T. 26 S., R. 65 E. (fig. 2). Water in the older alluvium probably will be similar in chemical quality to lake water, which contains about 700 mg/L of dissolved solids (table 2).

Site 2—Opal Mountain to Aztec Wash

Wells may produce from 10 to 500 gal/min of water from the older alluvium near Lake Mohave between Opal Mountain and Aztec Wash. The site is not as favorable as site 1 and a detailed hydrogeologic site evaluation should be made at any potential well location in this area. Coarse channel deposits of gravel and cobbles may be penetrated. The older alluvium, however, contains silt and clay that would restrict the flow of infiltrating water from Lake Mohave. Gypsum is present locally in the silt and clay. The conglomerate facies of the Muddy Creek Formation is exposed in places between Lake Mohave and the exposures of the older alluvium and could be penetrated at shallow depths throughout this area.

Shallow test drilling would be required to evaluate the development potential. A well in this area could produce water that has a composition similar to that of Lake Mohave if coarse channel deposits are penetrated. If the well penetrates fine-grained silt and clay that contains gypsum, poor-quality water could be produced.

Site 3—Hemenway Wash

Wells that produce large quantities of water can be developed near the mouth of Hemenway Wash, which is underlain by younger alluvium. The Chemehuevi Formation and possibly volcanic rocks could be penetrated at shallow depths. Water levels would correspond closely to the level of Lake Mead. In a now-abandoned well at Boulder Beach (table 1), the driller reported that he was unable to lower the water level by bailing. Wells probably could be developed to yield as much as 500 gal/min of water; however, the yield would depend on the level of Lake Mead.

SELECTED REFERENCES

Anderson, R. E., 1969, Notes on the geology and paleohydrology of the Boulder City pluton, southern Nevada, _in_ Geological Survey Research 1969: U.S. Geological Survey Professional Paper 650-B, p. B35-B40.

__________1971, Thin skin distension in Tertiary rocks of southeastern Nevada: Geological Society of America Bulletin, v. 82, no. 1, p. 43-58.

__________1977, Geologic map of the Boulder City 15-minute quadrangle, Clark County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-1395.

___________1978, Geologic map of the Black Canyon 15-minute quadrangle, Mohave County, Arizona, and Clark County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-1394.

Anderson, R. E., Longwell, C. R., Armstrong, R. L., and Marvin, R. F., 1972, Significance of K-Ar ages of Tertiary rocks from the Lake Mead region, Nevada-Arizona: Geological Society of America Bulletin, v. 83, no. 2, p. 273-287.

Bentley, C. B., 1979a, Geohydrologic reconnaissance of Lake Mead National Recreation Area—Mount Davis to Davis Dam, Arizona: U.S. Geological Survey Open-File Report 79-691, 34 p.

___________1979b, Geohydrologic reconnaissance of Lake Mead National Recreation Area—Opal Mountain to Davis Dam, Nevada: U.S. Geological Survey Open-File Report 79-692, 36 p.

___________1979c, Geohydrologic reconnaissance of Lake Mead National Recreation Area—Hoover Dam to Mount Davis, Arizona: U.S. Geological Survey Open-File Report 79-690, 37 p.

Hunt, C. B., McKelvey, V. E., and Wiese, J. H., 1942, The Three Kids manganese district, Clark County, Nevada: U.S. Geological Survey Bulletin 936-L, p. 297-319.

Laney, R. L., 1979a, Geohydrologic reconnaissance of Lake Mead National Recreation Area—Hoover Dam to Temple Bar, Arizona: U.S. Geological Survey Open-File Report 79-689, 42 p.

___________1979b, Geohydrologic reconnaissance of Lake Mead National Recreation Area—Temple Bar to Grand Wash Cliffs, Arizona: U.S. Geological Survey Open-File Report 79-688, 72 p.

Longwell, C. R., 1936, Geology of the Boulder Reservoir floor, Arizona-Nevada: Geological Society of America Bulletin, v. 47, no. 9, p. 1393-1476.

___________1963, Reconnaissance geology between Lake Mead and Davis Dam, Arizona-Nevada: U.S. Geological Survey Professional Paper 374-E, 51 p.

Longwell, C. R., Pampeyan, E. H., Bowyer, Ben, and Roberts, R. J., 1965, Geology and mineral deposits of Clark County, Nevada: Nevada Bureau of Mines Bulletin 62, 218 p.

Lucchitta, Ivo, 1966, Cenozoic geology of the upper Lake Mead area adjacent to the Grand Wash Cliffs, Arizona: University Park, Pennsylvania State University, unpublished doctoral dissertation, 218 p.

Malmberg, G. T., 1965, Available water supply of the Las Vegas ground-water basin, Nevada: U.S. Geological Survey Water-Supply Paper 1780, 116 p.

McKelvey, V. E., Wiese, J. H., and Johnson, V. H., 1949, Preliminary report on the bedded manganese of the Lake Mead region, Nevada and Arizona: U.S. Geological Survey Bulletin 948-D, p. 83-101.

National Academy of Sciences and National Academy of Engineering, 1973 [1974], Water quality criteria, 1972: U.S. Environmental Protection Agency Report, EPA-R3-73-033, 594 p.

Rush, F. E., and Huxel, C. J., Jr., 1966, Ground-water appraisal of the Eldorado-Piute Valley area, Nevada and California: Nevada Department of Conservation and Natural Resources, Water Resources-Reconnaissance Series Report 36, 30 p.

U.S. Bureau of Reclamation, 1950, Geological investigations—U.S. Bureau of Reclamation, Boulder Canyon Project final reports: U.S. Bureau of Reclamation Bulletin 1, pt. 3, 231 p.

__________ 1973, Final construction geology report, River Mountains tunnel and outlet portal structure: U.S. Bureau of Reclamation duplicated report, 88 p.

U.S. Environmental Protection Agency, 1976 [1978], Quality criteria for water: U.S. Environmental Protection Agency publication, 256 p.

__________ 1977a, National interim primary drinking water regulations: U.S. Environmental Protection Agency Report, EPA-570/9-76-003, 159 p.

__________ 1977b, National secondary drinking water regulations: Federal Register, v. 42, no. 62, March 31, 1977, p. 17143-17147.

U.S. Geological Survey, 1977, Water resources data for Arizona, water year 1976: U.S. Geological Survey Water-Data Report AZ-76-1, 674 p.