UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GEOHYDROLOGIC RECONNAISSANCE OF LAKE MEAD NATIONAL RECREATION AREA—HOOVER DAM TO MOUNT DAVIS, ARIZONA

Open-File Report 79-690

Prepared in cooperation with the National Park Service

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CONTENTS

ILLUSTRATIONS

TABLES

GEOHYDROLOGIC RECONNAISSANCE OF LAKE MEAD NATIONAL RECREATION AREA—HOOVER DAM TO MOUNT DAVIS, ARIZONA

By

C. B. Bentley

INTRODUCTION

A series of geohydrologic reconnaissance investigations is being made in the Lake Mead National Recreation Area by the U. S. Geological Survey at the request of the National Park Service. Individual well-site studies have been made at Callville Bay, Temple Bar, Eldorado, Cottonwood Cove, and Cottonwood Valley; geohydrologic reconnaissance studies have been made in the areas from Mount Davis to Davis Dam (Bentley, 1969) and Opal Mountain to Davis Dam (Bentley, 1970). The area of this report is on the east side of the Lake Mead National Recreation Area and extends from Hoover Dam to Mount Davis (fig. 1).

This investigation was undertaken to appraise the water resources in the area and to locate additional water supplies. The investigation included: (1) collection and analysis of well-production data; (2) determination of streamflow and ground-water interrelations;

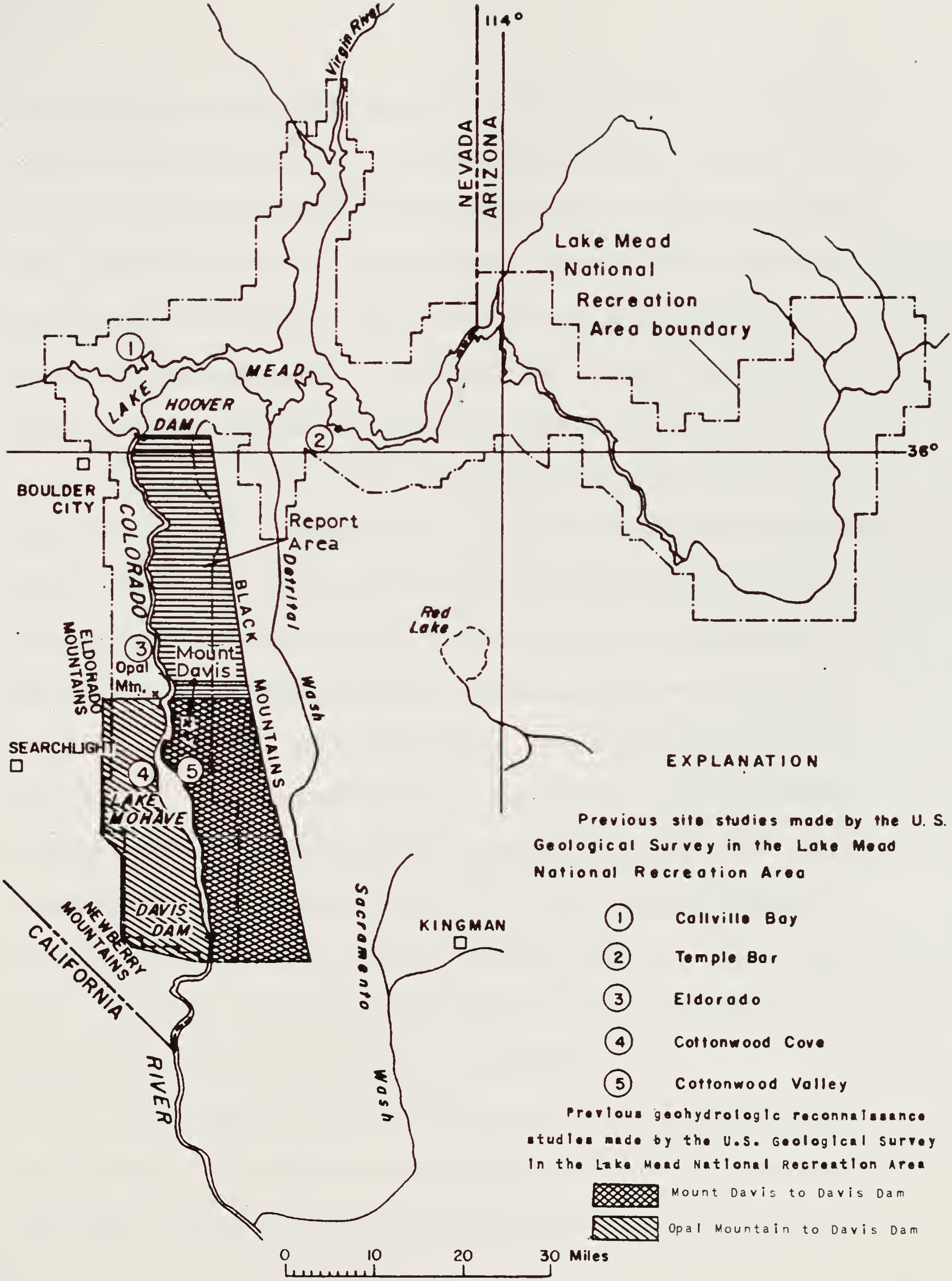


Figure 1. --Area of report.

(3) collection and analysis of spring data; (4) determination of the chemical quality of water; (5) reconnaissance geologic mapping at a scale of 1:62,500; (6) determination of the storage and yield characteristics of the rocks; and (7) determination of the geologic controls on the hydrologic boundaries. The investigation was made under the immediate supervision of H. M. Babcock, district chief of the Water Resources Division of the U. S. Geological Survey in Arizona.

The report area is characterized by rugged topographic relief and is bounded by the Colorado River on the west and the Black Mountains on the east (fig. 1). The area is about 5 to 10 miles wide and is about 30 miles long. The northern one-third of the area has steep slopes and vertical-walled bedrock canyons, and the southern two-thirds has deeply incised alluvial and bedrock slopes. The altitude ranges from about 635 feet above mean sea level at Lake Mohave to about 5,200 feet at Wilson Ridge in the northern part of the Black Mountains. The summit of Mount Wilson, which is half a mile east of the Lake Mead National Recreation Area boundary, is at an altitude of 5,445 feet. Most of the area is between 1,000 and 3,000 feet above mean sea level, and the only level areas are those along the large washes.

The climate is arid and is characterized by hot summers and mild winters. The average annual precipitation is about 5 inches in the Lake Mead National Recreation Area and ranges from about 3 inches in

the lower altitudes to about 10 inches in the mountains. The average annual precipitation is 3. 5 inches at Davis Dam, which is 25 miles south of the report area at an altitude of 650 feet above mean sea level, and is 5. 2 inches at Boulder City, Nevada, which is 5 miles west of the report area at an altitude of 2, 525 feet above mean sea level (U. S. National Climatic Center, data issued annually). In most of the area the vegetation is cactus, creosote-bush, and mesquite; along the shoreline of Lake Mohave, however, saltcedar is the dominant vegetation.

ROCK UNITS AND THEIR WATER-BEARING CHARACTERISTICS

The report area is underlain principally by crystalline rocks, although sedimentary rocks crop out extensively on the dissected slopes from the Black Mountains to Lake Mohave (fig. 2). The crystalline rocks include granitic and metamorphic rocks, which are mainly Pre-cambrian in age; volcanic rocks of Tertiary age; and the Fortification Basalt Member of the Muddy Creek Formation of Tertiary age. The granitic and metamorphic rocks form the basement complex and are the ultimate barrier to the movement of ground water.

The sedimentary rocks are in the north-trending valleys that subsided in reference to the uplifted Black Mountains block. The offset between the valleys and the mountain block is along north-trending faults and probably occurred in the interval of 12 to 6 million years before the present or prior to and concurrent with the deposition of the Muddy Creek Formation; the relative vertical displacement along the faults may be about 6,000 feet (R. E. Anderson and others, written commun., 1970). The sedimentary rocks were grouped into five units for purposes of mapping—a lower and an upper unit of the Muddy Creek Formation, older alluvium, Chemehuevi Formation, and younger alluvium. The thin terrace and piedmont gravels that crop out in the area are not differentiated from the underlying units.

The Muddy Creek Formation is the oldest differentiated sedimentary rock unit in the map area and unconformably overlies the volcanic rocks of Tertiary age and older units. The Muddy Creek Formation is divided into a lower unit, an upper unit, and the Fortification Basalt Member. Flows of the Fortification Basalt Member overlie the basal, intermediate, and uppermost beds of the Muddy Creek. The older alluvium is present mainly as erosional remnants on slopes in the southern part of the area; it unconformably overlies the Muddy Creek Formation, the volcanic rocks of Tertiary age, and the Precambrian rocks. The Chemehuevi Formation occurs as small discrete outcrops near the shores of Lake Mohave; it unconformably overlies the Muddy Creek Formation, the volcanic rocks, and to the south, the older alluvium. The younger alluvium is exposed in the flood plains and stream channels and is the most recent deposit in the area.

Granitic and Metamorphic Rocks

The oldest rocks exposed in the area are granite, granitic gneiss, and schist of Precambrian age. An interbedded quartzite and garnet-mica schist exposure in sec. 1, T. 29 N., R. 23 W. (unsurveyed), a similar exposure in secs. 12 and 13 that was mapped as Cambrian

sedimentary rocks by Longwell (1963, pl. 1), and a large granitic pluton of Miocene age (R. E. Anderson and others, written commun., 1970) that has intruded the Precambrian complex at Mount Wilson in the northern part of the Black Mountains are mapped with the granitic and metamorphic rocks in this report (fig. 2). Abundant dikes, which range in composition from basalt to rhyolite, intrude the Precambrian and younger rocks.

The granitic and metamorphic rocks generally do not yield water except along fractures and weathered zones. Only two wells have been drilled in the unit in the report area, and the wells have been abandoned. One of the wells had a reported yield of 10 gpm (gallons per minute).

Volcanic Rocks

The volcanic rocks crop out extensively near Lake Mohave and overlie the granitic and metamorphic rocks in parts of the Black Mountains. Reconnaissance studies of the rocks have been made by Schrader (1909), Wilson (1962), and Longwell (1963), and more detailed studies have been made by Anderson (1971) and by Anderson and others (written commun., 1970).

The volcanic rocks are about 16,000 feet thick, are Tertiary (Miocene) in age, and are composed of andesitic, rhyolitic, and

basaltic flows, flow breccias, and associated tuff and agglomerate (R. E. Anderson and others, written commun., 1970). Thin deposits of arkosic detritus that locally underlie the volcanic rocks (Longwell, 1963; R. E. Anderson and others, written commun., 1970) are included in this unit (fig. 2). In most of the area many faults cut the volcanic rocks, and the rocks dip 15°-50° E. In the southern part of the area, the rocks dip 5°-60° W.

The volcanic rocks transmit some water through fractures and interbedded tuff and agglomerate beds; in general, however, the unit is too impermeable to yield water readily to wells. The unit yields moderate quantities of water to at least six hot springs along a 5-mile stretch of the Colorado River below Hoover Dam (fig. 2).

Muddy Creek Formation

In the area of this report the Muddy Creek Formation is dominantly a coarse clastic sedimentary deposit that comprises three units—a lower unit, an upper unit, and the Fortification Basalt Member. Thin basalt flows assigned to the Fortification Basalt Member of the Muddy Creek cap the slopes and mesas. Near Hoover Dam, the Muddy Creek Formation rests on a volcanic flow dated by the potassium-argon method at 12.0 ± 0.2 million years, and on Callville Mesa about 10 miles north of Hoover Dam, a mesa-capping flow dated at 11.1 million years

overlies sedimentary beds of the Muddy Creek. A nearby flow that overlies the volcanic rocks of Miocene age has been assigned by Anderson and others (written commun., 1970) to the Fortification Basalt Member and is dated at 11.3 ± 0.3 million years. Sedimentary beds near the top of the formation are capped by a flow of the Fortification Basalt Member that is dated at 4.9 ± 0.4 million years and are intruded by a mafic dike that is dated at about 4 to 5 million years. The base of the Muddy Creek is about 11.3 million years old, and the top is about 4.5 million years old; therefore, the Muddy Creek Formation is Pliocene in age (R. E. Anderson and others, written commun., 1970).

In previous reports by Bentley (1969; 1970) on the Lake Mead National Recreation Area, the Muddy Creek Formation was mapped and described as pre-Bouse alluvium and Bouse Formation undifferentiated and as pre-Bouse alluvium; these units are now known to be the Muddy Creek Formation. Beds of the Bouse Formation interfinger with gravel beds of the Muddy Creek, and a potassium-argon date of 8.1 ± 0.5 million years for a vitric tuff in the basal limestone of the Bouse Formation (Damon, 1970, p. 40, 42) indicates that the Bouse and Muddy Creek Formations probably are time equivalents and that the Bouse, as described by Metzger (1968) and Smith (1970), is a brackish-water to marine facies of the Muddy Creek Formation.

Lower unit. --The lower unit of the Muddy Creek Formation is several hundreds of feet thick and consists of conglomerate, sandstone, and silt. The deritus is mainly subangular fragments of granite, granitic gneiss, and andesite, which are moderately to firmly cemented with calcium carbonate. In general the grain size ranges from silt to fine gravel, but pebble and cobble beds are common. Lateral gradation from coarse- to fine-grained material is common. The unit has a distinctive pink to reddish-brown color. Individual beds generally are less than 3 inches thick and are distinct in the silt and sandstone; bedding generally is indistinct in the conglomerate, except where cross-beds are present. The unit contains a large landslide lens, which crops out in a continuous exposure 4 to 8 miles southeast of Hoover Dam (Longwell, 1951). The landslide is a breccia of angular blocks of granitic and metamorphic debris that was derived from the Black Mountains; the blocks are several feet in diameter. A mudflow is present at the base of the breccia.

The lower unit unconformably overlies the volcanic and the granitic and metamorphic rocks. The unit appears to have been deposited on a surface of rugged relief in basins that contained lakes during much of the period of deposition (Longwell, 1963, p. 9). The gravel is offset by high-angle faults that generally have less than 100 feet of displacement, and the beds dip as much as 20° E.; however, in places

the gravel is in fault contact with the volcanic rocks, and displacements of as much as 3,000 feet are indicated (Longwell, 1963, p. 35-37).

The lower unit of the Muddy Creek is not known to yield water to wells or springs in the area. Although the unit is poorly to moderately permeable, in most places it is above the water table and is drained. Where the gravel is underlain by impermeable rocks, however, it may be partly saturated and may yield small to moderate quantities of water to wells.

Upper unit.--The upper unit of the Muddy Creek Formation crops out in the northern two-thirds of the map area east and north of Jumbo Wash near Willow Beach Campground and in the southern part of the report area near the shores of Lake Mohave (fig. 2). The unit is as much as 1,000 feet thick and consists of gravel and coarse-grained sandstone. About 12 miles south of the report area, gravel beds of the upper unit interfinger with silt, clay, marl, and limestone typical of the Bouse Formation as described by Metzger (1968; written commun., 1971).

The gravel in the upper unit of the Muddy Creek Formation consists of angular to subangular fragments of granitic and volcanic rocks that were deposited as fans from local canyons and sparse, moderately rounded pebbles of diorite and quartzite that are exotic to

the area. The grain size ranges from silt to cobbles, and the clasts are moderately to firmly cememted with calcium carbonate. The gravel is light to medium gray, and bedding is irregular and generally indistinct. The coarse-grained sandstone crops out along both banks of an unnamed wash, which is accessible by jeep trail, in the north-central part of T. 26 N., R. 22 W. (unsurveyed). The sandstone is from 30 to 40 feet thick, and the grain size increases toward the east and west edges of the exposure, where volcanic cobbles and boulders are common. A 3-foot-thick tuff bed crops out along the west edge of the exposure. The sandstone is moderately cememted with silica, is light brownish gray, and generally is in parallel beds 1 to 3 inches thick; however, bedding is indistinct toward the east and west edges of the outcrop.

The upper unit overlies the lower unit and appears to be disconformable with it. The alluvial deposits of the upper unit are interbedded with clay, silt, sand, marl, and limestone of probable marine to brackish-water origin 10 to 12 miles south of Mount Davis along Lost Cabin Wash (Bentley, 1969, p. 7-9). The sandstone beds in T. 26 N., R. 22 W. probably are still-water deposits and an upstream estuarine facies of the marine to brackish-water beds in the Bouse Formation of Metzger (1968). The central axis of the depression at the

time of deposition of the still-water beds was about 4 miles east of the present course of the Colorado River.

Although the upper unit of the Muddy Creek Formation is not known to yield water to wells or springs in the area, small to moderate yields may be expected from wells drilled in the unit. Well yields probably will be less with increased distance from Lake Mohave because of the decrease in saturated thickness of the unit and the greater distance from the source of recharge.

Fortification Basalt Member.--The Fortification Basalt Member of the Muddy Creek Formation is a series of black, dark-gray, and brown olivine basalt flows that cap mesas and slopes in the northern half of the area (Longwell, 1963, p. 29-33; R. E. Anderson and others, written commun., 1970). The basalt flows are dated at 11.3 $\pm$ 0.3 to about 4.5 million years (Damon, 1965; Armstrong, 1970; R. E. Anderson and others, written commun., 1970). The oldest flow overlies the volcanic rocks of Miocene age, and the youngest flow overlies gravel of the upper unit of the Muddy Creek Formation. The basalt flows have a combined thickness of about 300 feet, generally are tilted less than 5°, and in places are offset as much as 100 feet by faults. The flows cap mesas and slopes and are not known to yield water to wells or springs in the report area.

Older Alluvium

The older alluvium of probable late Tertiary and early Quaternary age is present in scattered exposures throughout the report area. The older alluvium is composed of exotic material transported into the area by the southward-flowing Colorado River and of locally derived fan gravel deposited by westward-flowing streams. The exotic material consists of gray and brown clay, gray and yellowish-gray sand, and well-rounded pebbles of granite, schist, quartzite, limestone, and chert. The sand and pebbles are well sorted. The fan gravel consists of nearly unsorted silt to cobble-size angular fragments of granitic and volcanic rocks and is olive, brownish, yellowish, or pinkish gray. The older alluvium shows abundant channel scouring and filling. Bedding is irregular and generally is indistinct in the fan deposits; crossbedding is common in the river deposits, except in the clay and silt deposits where evenly laminated beds from a fraction of an inch to 3 inches thick are well developed. The older alluvium is weakly to moderately cemented by calcium carbonate. The thickness of the unit is unknown; however, in the report area the exposures are not more than 100 feet thick.

The older alluvium is unconformable with the underlying units and generally overlies the upper unit of the Muddy Creek Formation. The unit is nearly horizontal, and little structural deformation was

observed. Some well-cemented steeply dipping gravel beds crop out near Lake Mohave opposite the Eldorado Campground; the beds were mapped as older alluvium by Longwell (1963, p. 11-13). The beds contain rock fragments of local origin only, are lithologically similar to the upper unit of the Muddy Creek Formation, and are included in that unit in this report.

The weakly cemented zones in the older alluvium, especially the better sorted deposits reworked by the Colorado River near Lake Mohave, appear to be moderately to highly permeable, and, where the unit is saturated, it may yield moderate to large amounts of water to wells. The largest yields will be obtained near Lake Mohave, where the saturated thickness of the unit is greatest, and yields can be expected to decrease with increased distance from the lake.

Chemehuevi Formation

The Chemehuevi Formation of Pleistocene age is exposed only in isolated outcrops on the terraces that border Lake Mohave in the southern third of the report area. The formation is composed of alternating beds of weakly cemented silt, clay, sand, and rounded pebble gravel overlain by unconsolidated gravel capped by sand. The gravel consists of particles of granite, schist, quartzite, limestone, and chert.

The clay and silt are planar bedded and locally are ripple bedded, and the beds generally are less than 2 inches thick; bedding in the coarser materials is not well defined. No structural deformation was observed. Generally, the Chemehuevi Formation unconformably overlies the upper unit of the Muddy Creek Formation in the report area.

The formation, although not widespread, is an excellent aquifer. No wells have been drilled in the unit in the report area, but, where saturated, it will transmit water readily to wells.

Younger Alluvium

The younger alluvium of Holocene age is exposed in the stream channels and flood plains in the mountains and on the alluvial slopes. The unit is composed of crudely stratified unconsolidated sand and gravel. The younger alluvium is mainly of local origin, although a few deposits transported into the area by the Colorado River are present along the river between Hoover Dam and Willow Beach; the deposits are small and are not mapped separately in this report. In most places the thickness of the unit is probably less than 50 feet. The younger alluvium is not structurally deformed.

The younger alluvium generally is drained of water away from Lake Mohave; however, where it is saturated adjacent to the lake it may yield moderate to large quantities of water to wells, and, where it is

underlain by impermeable rock in mountain canyons, it may yield small to moderate quantities of water to wells. Well No. 2 at the Willow Beach Campground obtains moderate quantities of water from the younger alluvium, and well No. 1 at the campground also probably obtains moderate quantities of water from this unit, although reliable yield figures are not available.

STREAMFLOW

All the streams in the report area are ephemeral, except the Colorado River. Ringbolt Wash near Hoover Dam is the only ephemeral stream in the area for which streamflow data are available; however, the U. S. Geological Survey has maintained four additional crest-stage gaging stations in the surrounding area for several years (table 1). The data from these stations indicate that streamflow from the small drainage basins near Lake Mohave is meager and extremely variable; flow occurs only about once a year from any one drainage basin. The annual flow of the streams ranges from zero to several times the volume of the mean annual flow. The estimated mean annual discharge per unit area for the five stations is about 5 acre-feet per square mile. Because of the extremely skewed distribution of data, however, the mean probably is misleading; the skewness may be due to the occurrence of

one or more large runoff events, and the chance of occurrence of such events is fairly high. Therefore, the median value of the data is a better measure of the central tendency. The median unit discharge is 3.0 acre-feet per year, which is considered to be the most reliable estimate of the average annual runoff for the area.

Most of the streams have drainage basins of only a few square miles. Jumbo Wash, which discharges into Lake Mohave at Willow Beach Campground, has the largest drainage basin—about 35 square miles. Applying the estimated unit discharge of 3.0 acre-feet per square mile to the stream, a mean annual flow of about 100 acre-feet is obtained.

Because of the small quantity and variable flow characteristics of the surface water in the area, no additional studies of runoff or runoff utilization were made. No runoff was observed during fieldwork; therefore, no surface-water samples were collected from the ephemeral streams for chemical analysis.

GROUND WATER

Movement and Occurrence

Lake Mohave is the principal source of recharge to the water-bearing formations in the report area. The ultimate barrier restricting

ground-water movement is the granitic and metamorphic rocks that underlie the area. Prior to the existence of Lake Mohave, ground water in the sedimentary rocks flowed westward from the recharge areas near the mountains and discharged into the Colorado River. After the completion of Davis Dam and the filling of Lake Mohave, water from the lake moved downward and outward into the adjacent permeable rock units. Consequently, since the filling of the lake—the approximate mean lake surface is 635 feet above mean sea level—the permeable rock units that adjoin the lake have become saturated with ground water to the lake surface and drain and fill in response to lake-level changes. During high stage, water from Lake Mohave is backed upstream to the face of Hoover Dam. During low stage, however, 10 to 12 miles of free-flowing water moves between Hoover Dam and the upper end of the lake. Where the permeable rocks adjoin the lake along the shoreline in the central and southern parts of the report area, the movement of the water in the rocks is entirely under the influence of the altitude of the lake surface.

The regional ground-water level is higher than it was prior to the filling of the lake, but the regional ground-water movement is still westward from the mountains toward the lake; the gradient is about 150 feet per mile. In a few areas, ground water may accumulate above

the regional water level in a thin saturated layer in the unconsolidated rocks that overlie impermeable units. The alluvial units near Lake Mohave probably are hydraulically connected, although sufficient data to substantiate this assumption are lacking. In general, the ground water is unconfined, but local artesian conditions exist because of variations in the vertical permeability of the alluvial aquifer.

The distance that the saturated permeable sedimentary rocks extend from Lake Mohave is dependent on the altitude of the contact between these rocks and the underlying impermeable rocks in relation to the mean altitude of the lake surface—635 feet above mean sea level. The thickness of the unconsolidated sedimentary rocks between the lake and the mountains is not known; therefore, the distance from the lake that ground water can be obtained in substantial amounts cannot be estimated accurately. The meager subsurface data for the area south of Mount Davis indicate that the chances of completing a well capable of producing more than about 300 gpm are favorable in the unconsolidated sedimentary rocks within about a mile of the lake and that the chances become less favorable as the saturated thickness decreases with increased distance from the lake. If the aquifer is the older alluvium, the degree of sorting and dependent permeability will decrease with increased distance from the lake, and well yields probably will be smaller.

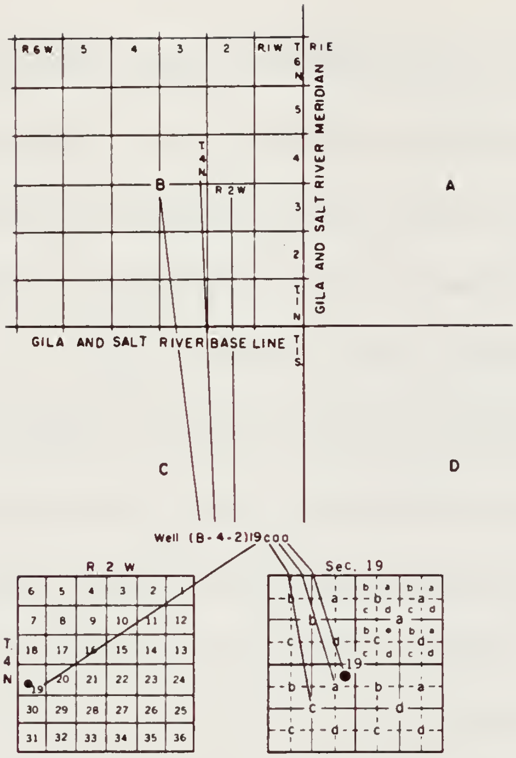
Data for the few wells and springs in the area are given in table 2 and are summarized in the following paragraphs. The well and spring locations are shown on figure 2; all well locations are described in accordance with the well-numbering system used in Arizona, which is explained and illustrated in figure 3.

Wells.--Four wells, all at Willow Beach, have been completed in the area; two have been abandoned, and two are used for public supply at the Willow Beach Campground (table 2). The mines in the area are not known to contain water.

Springs.--During this investigation, an attempt was made to locate the springs in the area and to obtain the pertinent hydrologic data regarding them (table 2). The only known springs are the hot springs—temperatures 45.0°-61.5°C—along the Colorado River half a mile to 5 miles south of Hoover Dam. Six hot springs were located during this investigation, and others undoubtedly exist in the small unexplored tributary canyons and gorges. In addition, numerous seeps issue from the sheer canyon walls half a mile to 2 miles south of Hoover Dam.

Recharge and Discharge

Infiltration of lake water into the water-bearing formations bounding Lake Mohave is sufficient to maintain the ground-water surface



The well and spring numbers used by the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the State 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 (0.65-km^2) tract, the second the 40-acre (0.16-km^2) tract, and the third the 10-acre (0.04-km^2) tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within the 10-acre (0.04-km^2) tract, three lowercase letters are shown in the well or spring number. In the example shown, well number (B-4-2)19caa designates the well as being in the $NE\frac{1}{4}NE\frac{1}{4}SW\frac{1}{4}$ sec. 19, T. 4 N., R. 2 W. Where more than one well or spring is within a 10-acre (0.04-km^2) tract, consecutive numbers beginning with 1 are added as suffixes.

Figure 3.--Well- and spring-numbering system in Arizona.

at about the same altitude as the mean lake level. Recharge to the formations from the lake occurs when the lake stage is rising, and discharge to the lake occurs when the lake stage is falling.

Recharge from the infiltration of streamflow is small because the area receives only a small amount of precipitation, most of which returns to the atmosphere through evaporation and through transpiration by plants. Only a small part of the precipitation collects in the stream channels; some of the water in the channels flows into Lake Mohave and some of it infiltrates to the ground-water reservoir. The source of the saline water that issues from the hot springs along the Colorado River is unknown, but the springs existed prior to the construction of Hoover Dam.

The amount of ground-water discharge is small in the report area; some water is discharged by evapotranspiration and from wells and springs. As mentioned previously, when the lake level declines, ground water discharges to the lake. Evapotranspiration losses from ground water probably are less than 50 acre-feet per year in the report area; most of the losses are by saltcedar and other phreatophytes near Lake Mohave. The two functioning wells discharge about 10 acre-feet of water per year; well (B-29-22)29dcc1 is on standby and is seldom used. An estimated 500 acre-feet per year of saline water is discharged by the six hot springs. This estimate should be doubled to

include the discharge from the numerous seeps and from uninventoried springs in the small canyons and gorges. The amount of water that is discharged directly into the Colorado River from springs that issue below river level is not known.

Aquifer and Well-Production Characteristics

The Chemehuevi Formation, although not widespread, is the best potential water-yielding unit in the report area. A step-drawdown test was made by personnel of the U. S. Geological Survey in September 1967 on the National Park Service well in the Cottonwood Valley (Bentley, 1969, p. 22). The well was drilled to a depth of 200 feet in the Chemehuevi Formation and the test data indicate that the formation will yield water to wells at a rate of 1, 000 gpm. The transmissivity was computed to be about 18, 000 ft^3 (cubic feet) per day per foot of aquifer, which is equivalent to a transmissibility of about 130, 000 gpd (gallons per day) per foot (Bentley, 1969, p. 22-23).

The younger alluvium and the rounded gravel deposits in the older alluvium are highly permeable and will yield water readily to wells. A pumping test was attempted by personnel of the U. S. Geological Survey in October 1970 on well (B-29-22)29dcc2 in the Willow Beach Campground; well (B-29-22)29dcc1 was used as an observation well. Most of the water-bearing zone penetrated was in the

younger alluvium. The wells were drilled 80 feet apart near the mouth of Jumbo Wash about 300 feet from the mean shoreline of Lake Mohave. The test was unsuccessful because it was physically impossible to measure the water level in the well while it was being pumped; however, the test was completed to determine the effect of the pumping well on the observation well. The well was pumped at a rate of 425 gpm for a period of 8 hours. The drawdown in the observation well was less than 0. 3 foot, which indicates a high rate of recharge from the lake. The rounded gravel deposits in the older alluvium are capable of yielding as much as 1, 000 gpm of water to wells, as indicated by a pumping test on a well that penetrated the unit in the Cottonwood Cove Campground (Bentley, 1970, p. 24-25). The transmissivity was estimated to be as much as 3, 000 ft^3 per day per foot, which is equivalent to a transmissibility of about 20, 000 gpd per foot.

QUALITY OF WATER

Water samples were collected for chemical analysis from one well and two springs during this investigation (table 3). In addition, water samples were collected from two wells and from Lake Mohave prior to this investigation, and the analyses are included in table 3.

Well (B-29-22)29dcc2 obtains water from the unconsolidated sedimentary rocks adjacent to Lake Mohave. Although somewhat more mineralized, the water is similar in chemical characteristics to the water from the lake, which indicates that the rocks are recharged by water from Lake Mohave. The mineral content of the water in the unconsolidated sedimentary rocks probably will increase with increased distance from the lake as a result of the longer time of contact of the water with the alluvial material. Wells (B-29-22)29bad1 and (B-29-22)29bad2, which have been destroyed, obtained water from the granitic and metamorphic rocks near Lake Mohave. Springs (B-30-23)10cac and (B-30-23)26bcc issue from fractures in the volcanic rocks. The chemical quality of the water from these sources is poor; however, the highly mineralized water that issues from the hot springs probably is not representative of the chemical quality of the water in the volcanic rocks.

The dissolved-solids concentrations in the ground water from all sources range from 1, 050 mg/l (milligrams per liter) in well (B-29-22)29dcc2 to 3, 420 mg/l in well (B-29-22)29bad1 (table 3). The U. S. Public Health Service (1962) has recommended that water for drinking purposes should contain no more than 500 mg/l of dissolved solids; however, water containing a higher dissolved-solids content is used if better water is not available. All the water sampled in the

study area, including that from Lake Mohave, contains dissolved solids in excess of the recommended limit, and some of the water contains more than six times the recommended limit.

The latest recommendations of the U. S. Public Health Service (1962) give lower, optimum, and upper limits for fluoride based on the annual average of maximum daily air temperature. For the report area, the limits are 0. 6 mg/l (lower), 0. 7 mg/l (optimum), and 0. 8 mg/l (upper). Concentrations of more than twice the optimum value constitute grounds for rejection of the supply. Fluoride concentrations in the ground water sampled in the report area range from 0. 9 to 4. 2 mg/l; water from Lake Mohave contains only 0. 6 mg/l fluoride. The fluoride content in the ground water only from well (B-29-22)29dcc2 meets the U. S. Public Health Service standards. Iron concentrations in the water from well (B-29-22)29bad2, sulfate concentrations in the water from all sources, and chloride concentrations in the water from well (B-29-22)29bad1 and from the two springs exceed the recommended limits established by the U. S. Public Health Service (1962).

The temperature of the saline water from the hot springs is about 60°C, with the exception of that from spring (B-30-23)26bcc, which is 45°C. The fracture openings from which spring (B-30-23)26bcc discharges are much smaller than those of the other springs, which may account for the cooler temperature of the water.

PROPOSALS FOR EXPLORATION

The most productive wells will be in the unconsolidated sedimentary rocks where they occur adjacent to Lake Mohave. The two most favorable areas for future ground-water development are in the older alluvium in the northwest part of T. 25 N., R. 22 W.(unsurveyed), in the southwestern part of the map area and in the Chemehuevi Formation near the lake opposite Eldorado in sec. 24, T. 27 N., R. 23 W. (unsurveyed). In addition, the alluvial deposits at the mouths of the large washes near the lake in the southern three-quarters of the map area may be of sufficient thickness to be saturated. Small to moderate yields may be obtained from wells drilled in the upper unit of the Muddy Creek Formation near the lake, along the west side of T. 26 N., R. 22 W. (unsurveyed), in the upper unit near the large exposure of older alluvium in the center of T. 26 N., R. 22 W. (unsurveyed), and in the valley of Jumbo Wash.

The volcanic rocks may transmit small quantities of water to wells, particularly near Lake Mohave where the rocks receive recharge from the lake. Although wells drilled in these rocks probably will yield less than 20 gpm, the chemical quality of the water may be sufficiently better than that of the water in the alluvial units to justify exploratory drilling in areas where a large water supply is not required. Because

of the rugged nature and general inaccessibility of volcanic rock areas near the lake, drill sites should be selected primarily on the basis of accessibility.

Test wells in the sedimentary units should be drilled to consolidated rock or to a depth where a sufficient water supply is obtained—probably 50 to 75 feet below the static water level in the Chemehuevi Formation and in the younger alluvium, 100 to 200 feet in the older alluvium, and 200 to 300 feet in beds of the Muddy Creek Formation. Drill cuttings should be collected at 10-foot intervals and sieve analyses made of the cuttings from the saturated zone to determine the necessary length and size of well screen. Water of the best chemical quality probably will be obtained from the more permeable beds because the contact surface is smaller, there are fewer exchangeable ions than in the finer units, and, during withdrawal, the water will be in contact with the alluvial material for a shorter time; therefore, it is suggested that the thick silt and clay units be sealed off. If a cable-tool rig is used, water samples should be collected during drilling for chemical analysis to note changes in water quality with depth.

SUMMARY

The principal water-bearing units in the report area are the saturated sedimentary rocks adjacent to Lake Mohave; the lake is the

main source of recharge. The Chemehuevi Formation and the older and younger alluvium generally will yield 1,000 gpm of water to properly constructed and developed wells in places where the saturated zones are 50 feet thick or greater. The upper unit and perhaps the lower unit of the Muddy Creek Formation may yield small to moderate quantities of water to wells. The water level in the sedimentary rocks adjacent to the lake is about 635 feet above mean sea level—about the same altitude as the mean lake surface. The most favorable areas for future ground-water development are in the older alluvium in the northwest part of T. 25 N., R. 22 W. (unsurveyed) and in the Chemehuevi Formation near the lake in sec. 24, T. 27 N., R. 23 W. (unsurveyed). In addition, the alluvial deposits at the mouths of the large washes near the lake in the southern three-quarters of the map area may be of sufficient thickness to be saturated.

The mineral content of the ground water from the unconsolidated deposits adjacent to the lake exceeds the recommended limits set by the U. S. Public Health Service; however, the water may be used for a public supply because water of better quality is not available. The mineral content of the water increases with increased distance from the lake as a result of longer contact of the water with the alluvial material. For the same reason, water in the more permeable units probably will be of better chemical quality than the water in less permeable material.

The potential for surface-water development is almost nonexistent in the report area, except for the Colorado River. Flow in the ephemeral streams is meager—an average of about 100 acre-feet per year from the largest drainage basin—and is extremely variable from year to year.

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Table 1. --Mean annual flow at selected gaging stations on ephemeral streams in northwestern Arizona, southern Nevada, and southeastern California

Stream	Location	Period of record	Altitude (feet)	Drainage area (square miles)	Mean annual flow 1/ (acre-feet)	Range of annual flows (acre-feet)	Mean annual flow per unit area (acre-feet per square mile)	Average number of runoff events per year
Sacramento Wash tributary near Topock, Ariz.	SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 14, T. 16 N., R. 20 W., Gila and Salt River meridian and base line, Arizona	1964-70	969	11.3	19.3	0-110	1.7	1.3
Little Meadow Creek near Oatman, Ariz.	NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 16, T. 19 N., R. 19 W., Gila and Salt River meridian and base line, Arizona	1965-70	2,900	8.5	33.8	0-200	4.0	1.0
Ringbolt Wash near Hoover Dam, Ariz.	SW$\frac{1}{4}$ sec. 19, T. 30 N., R. 22 W., Gila and Salt River meridian and base line, Arizona	1965-70	1,800	1.2	.18	0- 0.8	.15	1.0
Eldorado Valley tributary near Nelson, Nev.	SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 36, T. 24 S., R. 63 E., Mount Diablo meridian and base line, Nevada	1964-70	2,470	1.4	21.7	0-100	15.5	1.0
Chemehuevi Wash tributary near Needles, Calif.	SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 19, T. 5 N., R. 23 E., (unsurveyed), Santa Barbara meridian and base line, California	1960-70	1,580	2.0	6.1	0- 18	3.0	.5

1/ Mean annual flow estimated from peak-flow record (B. N. Aldridge, written commun., 1970), except that of Chemehuevi Wash tributary near Needles, Calif., for 1963-68 period, when the station was equipped with a flood-hydrograph recorder.

Table 2. --Occurrence of water in wells and springs in the Lake Mead National Recreation Area — Hoover Dam to Mount Davis

Location: See figure 3 for description of well-numbering system.
Land-surface altitude: Determined from U.S. Geological Survey topographic maps.
Water level: R, reported.

Yield: E, estimated; R, reported.
Use: N, not used; PS, public supply.
Remarks: C, chemical analysis of water shown in table 3.

Location	Name or type of occurrence	Aquifer	Depth of well (feet)	Diameter of casing (inches)	Depth of casing (feet)	Land-surface altitude (feet above mean sea level)	Water level		Yield (gpm)	Use	Remarks
							Depth below land surface (feet)	Date measured (month, year)			
(B-29-22)29bad1	Willow Beach Fish Hatchery well No. 1	Granitic and metamorphic rocks	90	--------	------	660	-----------	-----------	-------	N	C; well abandoned and destroyed; unsurveyed.
29bad2	Willow Beach Fish Hatchery well No. 2	do.	80	--------	------	680	41 R	5/67	10 R	N	C; well abandoned and destroyed; unsurveyed.
29dcc1	Willow Beach Campground well No. 1	Younger alluvium	68	8	68	660	24.9	10/70	-------	PS	Unsurveyed.
29dcc2	Willow Beach Campground well No. 2	do.	-------	11	------	660	26.0	10/70	425	PS	C; unsurveyed; 16 foot water level at high lake level reported.
(B-30-23)10bcd	Hot spring	Volcanic rocks	-------	--------	------	650	-----------	-----------	30 E	N	
10cac	do.	do.	-------	--------	------	650	-----------	-----------	20 E	N	C; temperature 61.0°C.
10cba	do.	do.	-------	--------	------	660	-----------	-----------	100 E	N	Temperature 61.5°C.
10cdb	do.	do.	-------	--------	------	680	-----------	-----------	100 E	N	
15cbd	do.	do.	-------	--------	------	750	-----------	-----------	5 E	N	
26bcc	do.	do.	-------	--------	------	760	-----------	-----------	50 E	N	C; temperature 45.0°C.

Table 3.--Chemical analyses of water from selected sources and drinking-water standards, Lake Mead National Recreation Area—Hoover Dam to Mount Davis

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

Location	Source	Date of collection	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Aquifer
															Calcium, magnesium	Noncarbonate			
3-29-22)29bad1[1/]	Willow Beach Fish Hatchery Well No. 1	1962	-----	32	Trace	401	92	498	178	0	1,800	311	-------	3,420	1,380	1,234	--------	8.1	Granitic and metamorphic rocks.
29bad2[2/]	Willow Beach Fish Hatchery Well No. 2	1967	-----	-----	.4	252	50	300	-------	------	1,050	156	2.7	2,219	840	------	2,780	----	Do.
29dcc2	Willow Beach campground Well No. 2	9/28/70	30.0	27	----	118	33	196	209	0	440	128	.9	1,050	430	259	1,680	8.1	Younger alluvium.
3-30-23)10cac	Hot spring	10/23/70	61.0	38	----	270	9.8	731	66	0	845	910	4.2	2,840	715	661	4,400	8.0	Volcanic rocks.
26bcc	do.	10/23/70	45.0	37	----	230	13	600	35	0	560	890	2.8	2,350	630	602	3,830	7.7	Do.
	Lake Mohave	1/ 9/69	-----	9.5	0	88	31	109	163	0	300	97	.6	715	348	215	1,150	8.2	
aximum recommended concentrations for drinking water[3/]		---------	-----	-----	.3	--------	-------	---------	-------	------	250	250	[4/] .8	500	--------	------	--------	----	

1/ Analysis reported by Willow Beach Fish Hatchery, Bureau of Sport Fisheries and Wildlife.

2/ Analysis reported by Arizona State Health Laboratory.

3/ Data from U.S. Public Health Service (1962).

4/ Mandatory maximum content: 1.4 mg/l.