Geohydrologic Reconnaissance of Lake Mead National Recreation Area—Las Vegas Wash to Virgin River, Nevada

By R.L. LANEY and J.T. BALES

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CONTENTS

PLATE

[Plate is in pocket]

FIGURES

CONTENTS

TABLES

CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
gallon per minute (gal/min)	0.06309	liter per second
cubic foot per second (ft^3/sec)	0.02832	cubic meter per second
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
degree Fahrenheit (°F)	°C = (°F-32)/1.8	degree Celsius

In this report, water temperatures are given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8(°C) + 32$$

Sea level: In this report *sea level* refers to the National Geodetic Vertical Datum of 1929—A geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called *Sea Level Datum of 1929*.

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By R.L. Laney *and* J.T. Bales[1]

Abstract

This study is the last of a series of eight geohydrologic reconnaissance studies that were done in the Lake Mead National Recreation Area. The studies were done to evaluate the water resources in the recreation area and to identify areas having potential for the development of water supplies that would be adequate for marinas and campgrounds. The study area includes about 250 square miles north of Lake Mead from Las Vegas Wash to the Virgin River (Overton Arm), Nevada. Volcanic rocks, consolidated sedimentary rocks, and unconsolidated to semiconsolidated sedimentary rocks underlie the area. Surface-water sources include the Colorado River, Virgin River, Muddy River, and Las Vegas Wash. Elsewhere in the area, streamflow is meager and extremely variable. Ground water originates from four sources: (1) subsurface flow in local basins, (2) infiltration of water from Lake Mead into permeable rocks near the lake, (3) subsurface flow in valleys of perennial streams, and (4) subsurface flow in consolidated rocks of the Muddy Mountains. The quantity of water from Lake Mead that has saturated rocks adjacent to the lake probably is greater than the quantity of ground water from all the other sources. Rocks saturated by water from the lake probably extend less than 0.5 mile inland from the lake shore. The quality of virtually all the ground water in the area is not acceptable for drinking purposes.

The most favorable areas for obtaining ground water are those underlain by the coarse-grained deposits of the older alluvium and the younger alluvium adjacent to Lake Mead. The least favorable areas are those underlain by the mudstone facies of the Muddy Creek Formation and fine-grained rocks of the Horse Spring Formation. Four areas identified as having potential for ground-water development are (1) near Overton Beach, (2) west of Callville Bay, (3) near Middle Point, and (4) in the lower Moapa Valley. Usable quantities of water probably can be obtained at these sites, but the quality of the water may not be acceptable for drinking purposes. Test drilling for potable water supplies should be considered only as exploration.

INTRODUCTION

The Lake Mead National Recreation Area (LMNRA) includes Lake Mead and Lake Mohave. Lake Mead extends from Hoover Dam to about 105 mi up the former course of the Colorado River, and Lake Mohave extends 67 mi from Davis Dam to the base of Hoover Dam (fig. 1). The two lakes have about 700 mi of shoreline, which consists of wide gravel beaches, shadowed coves, and steep canyon walls. These physical settings provide opportunities for boating, fishing, swimming, scuba diving, water skiing, and beach camping. In addition, the surrounding desert canyons and mountains provide opportunities for hiking,

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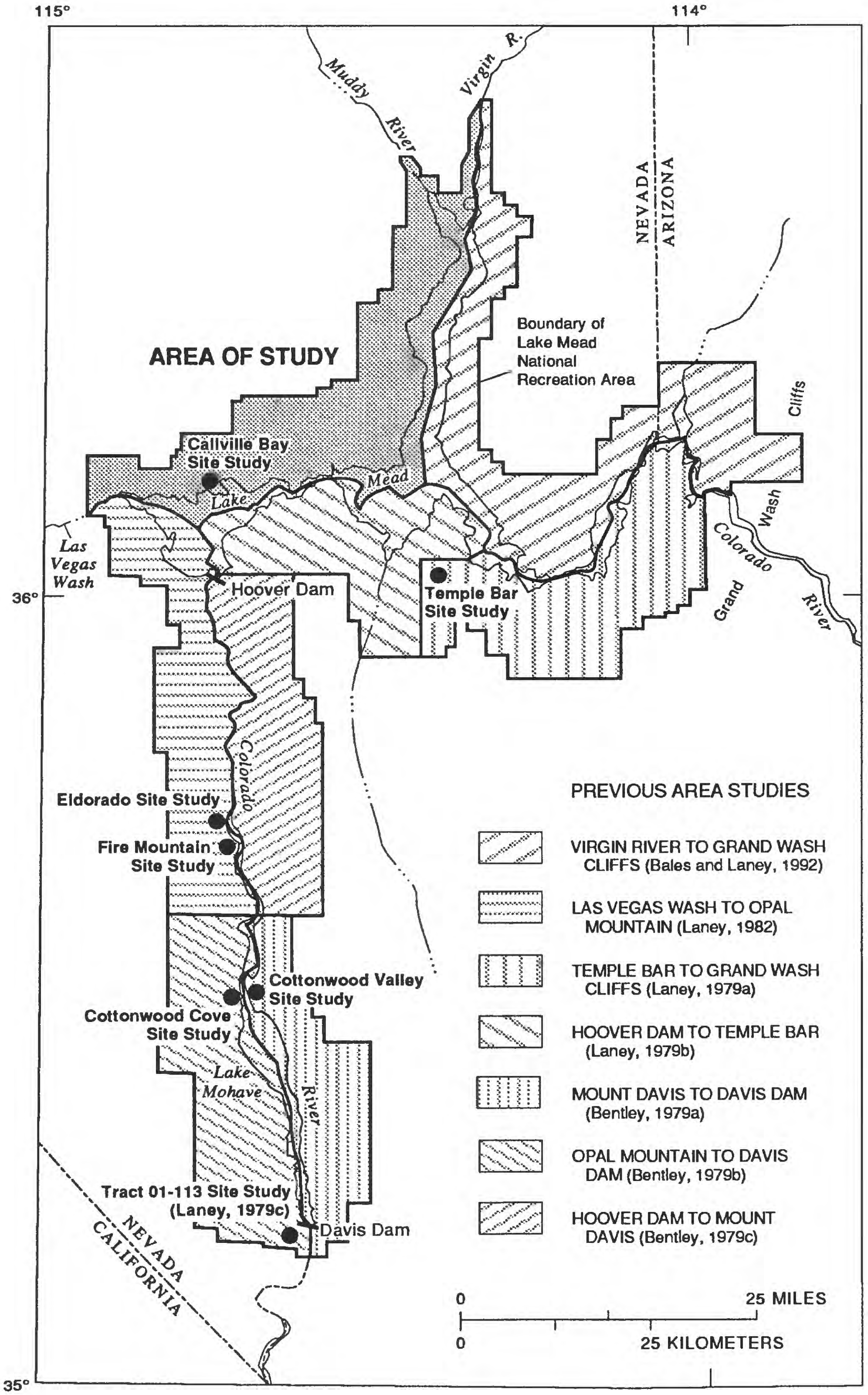


Figure 1. Area of study and areas of previous geohydrologic reconnaissance studies and site studies in the Lake Mead National Recreation Area west of Grand Wash Cliffs, Arizona and Nevada.

climbing, and photography. Use of the area has increased steadily over the years, and in 1993 more than 9.3 million people visited the recreation area. As the number of visitors increases, so does the demand for potable water.

This report concludes a series of eight geohydrologic reconnaissance studies of the Lake Mead National Recreation Area by the U.S. Geological Survey in cooperation with the National Park Service (fig. 1). The original intent of the project was to conduct studies of the entire LMNRA. After the studies were begun, the area east of the Grand Wash Cliffs was eliminated from the project.

The studies were done to evaluate the water resources in the recreation area and identify areas having potential for development of water supplies that would be adequate for marinas and campgrounds. Each study included (1) reconnaissance geologic mapping at a scale of 1:62,500, (2) an inventory of wells and springs, (3) determination of the chemical quality of ground water, and (4) determination of the geologic controls on the occurrence and movement of ground water. This report describes the last in a series of eight study areas. Figure 1 shows the locations of the study areas and the title, author, and the publication date of each report.

The area of this report includes about 250 mi^2 north of Lake Mead from Las Vegas Wash to the Virgin River (Overton Arm), Nevada (pl. 1). Altitudes range from about 1,200 ft above sea level at the lake level to more than 3,000 ft in the Black Mountains and Muddy Mountains. In the central part of the study area, most of the terrain is underlain by volcanic rocks and consolidated sedimentary rocks and slopes steeply toward Lake Mead. In the western part, between Las Vegas Wash and Callville Bay and in the northern part north of Echo Bay, most of the land surface is underlain by alluvial material that slopes more gently toward the lake. The climate is arid; summer temperatures range from about 80 to 115°F, and winter temperatures range from about 35 to 55°F (Arizona State University, 1975). The average annual precipitation ranges from 4 to 8 in. (Hardman, 1965). At Lake Mead, the annual lake evaporation is about 20 times the annual precipitation (Houghton and others, 1975).

Acknowledgments

The authors wish to express their appreciation to the personnel of the National Park Service, Lake Mead National Recreation Area, for the support that was provided to the members of the U.S. Geological Survey as this series of investigations was done. This support included providing information on wells and springs, logistics and transportation to remote areas, and general concern for our personal safety during the field phases of the investigations. Also, we wish to thank the Stauffer Chemical Company for providing logs for four of their test wells near Overton Beach.

ROCK UNITS AND THEIR WATER-BEARING CHARACTERISTICS

The study area is underlain by volcanic rocks, consolidated sedimentary rocks, and unconsolidated to semiconsolidated sedimentary rocks. A summary of the rock units and their hydrogeologic characteristics is listed in table 1. The mapped rock units are described below.

Most of the volcanic rocks underlie a large part of the mountainous area between Callville Bay and Echo Bay (pl. 1). The volcanic rocks include intermediate to mafic lava flows and flow breccia, felsic tuff and mafic to felsic intrusive rocks of varying composition and texture. Basalt flows of less widespread extent make up the Fortification Basalt Member of the Muddy Creek Formation. The Fortification Basalt Member is present northwest of Callville Bay, north of Echo Bay, and at Middle Point.

Sedimentary rocks include, from oldest to youngest: Paleozoic and Mesozoic sedimentary rocks, undifferentiated; Horse Spring Formation and Muddy Creek Formation of Tertiary age; older alluvium of Tertiary and Quaternary age; and colluvium and alluvium and younger alluvium of Quaternary age.

Table 1. Summary of rock units and their hydrogeologic characteristics

Rock unit	Rock type	Estimated potential yield to wells where saturated	Remarks
Younger alluvium	Silty sand, gravel, and boulders	A few tens to a few hundred gallons per minute	Present along bottoms of present-day washes. Saturated only near Lake Mead, in Moapa Valley and locally where large springs discharge in washes.
Colluvium and alluvium	Silty sand, gravel, and boulders	Generally unsaturated	Caps terraces along and underlies younger alluvium in present-day washes; is present on alluvial slopes and fans, and may be on older rock units as a veneer too thin to map. Upper few feet may be cemented with caliche.
Older alluvium	Silty sand, gravel, and boulders; silty, sandy gravel/cobble conglomerate and silty sandstone; locally contains gypsiferous silt	A few tens to a few hundred gallons per minute	Present between Las Vegas Wash and Callville Bay and Echo Bay and Virgin River; generally unsaturated between Las Vegas Wash and Callville Bay, but saturated near Overton Beach.
Muddy Creek Formation			
Mudstone facies	Mudstone, siltstone, gypsiferous mudstone and siltstone, sandstone, bedded gypsum and massive halite	Generally less than 1 gallon per minute to springs; unknown quantities of water are lost to evapotranspiration by diffuse upward seepage over a wide area east of the Muddy Mountains	Most widespread sedimentary rock unit in the area. Bedded gypsum and massive halite are present in the area bounded by Echo Bay, Overton Beach, and the Muddy Mountains.
Fortification Basalt Member	Basalt flows	Near Lake Mead, less than ten to a few tens of gallons per minute depending on the degree of fracturing	Caps prominent mesa near Callville Bay and present near Middle Point and locally north of Echo Bay.
Conglomerate facies	Silty gravel to well-cemented silty conglomerate	Virtually no potential as a source of water	A minor unit in report area; present near Las Vegas Wash and north of Callville Bay.
Muddy Creek Formation, undifferentiated	Basal fanglomerate, light-colored clastic and evaporite beds, some dark manganiferous sandstone and intercalated lava flows of Fortification Basalt	Near Lake Mead less than 1 gallon per minute to a few tens of gallons per minute depending on rock type	Present near Middle Point, formation not mapped in sufficient detail to show extent of individual facies.
Volcanic rocks	Intermediate to mafic flows and flow breccia, felsic tuff, and mafic to felsic intrusive rocks of varying composition and texture	Near Lake Mead, a few tens of gallons per minute depending on degree of fracturing	Underlies much of mountainous area between Callville Bay and Echo Bay and at scattered locations west of Callville Bay.

Table 1. Summary of rock units and their hydrogeologic characteristics—Continued

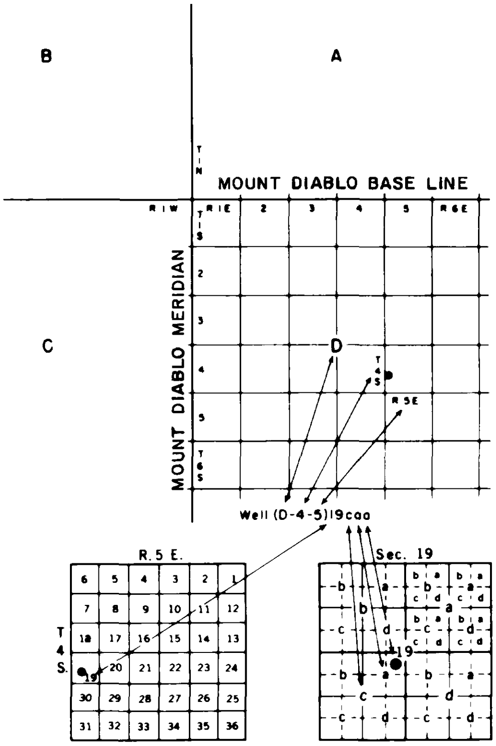
Rock unit	Rock type	Estimated potential yield to wells where saturated	Remarks
Horse Spring Formation	Tuff, limestone, gypsiferous mudstone, sandstone, conglomerate, and gypsum	Less than 1 gallon per minute	Present from near Blue Point Spring southwestward to Las Vegas Wash along the boundary of the area and locally near Echo Bay; Bitter Spring discharges more than 10 gallons per minute of water from the unit to the younger alluvium in Echo Wash; source of water may be the Paleozoic and Mesozoic sedimentary rocks, undifferentiated, via fault zone that extends to the Rogers Spring Fault.
Paleozoic and Mesozoic sedimentary rocks, undifferentiated	Limestone, dolomite, sandstone, quartzite, and shale	Discharges several hundreds of gallons per minute to springs along the Rogers Spring Fault on the east side of the Muddy Mountains. Elsewhere less than 1 gallon per minute	Present in the Muddy Mountains and in and around Pinto Valley.

Paleozoic and Mesozoic Sedimentary Rocks, Undifferentiated

Consolidated sedimentary rocks that range in age from Paleozoic to Mesozoic are exposed along the east side of the Muddy Mountains, northward along the LMNRA boundary, and in Pinto Valley and Pinto Ridge, and nearby areas in the Black Mountains (pl. 1). The rocks consist of limestone, dolomite, sandstone, quartzite, and shale; and include the Sultan Limestone, Monte Cristo Limestone, Bird Spring Formation, red beds of lower Permian age, Kaibab Formation, Toroweap Formation, Moenkopi Formation, Chinle Formation, Moenave Formation, Kayenta Formation, Aztec Sandstone, Willow Tank Formation, and Baseline Sandstone (Bohannon, 1983). The rocks were folded and faulted during a number of periods of deformation from Late Mesozoic to as recently as 10 million years ago (m.y.; Bohannon, 1983, table 1). The deformation developed potential pathways for the movement of ground water. Along the east side of the Muddy Mountains, two large springs—Rogers Spring (D-18-67)12dda and Blue Point Spring (D-18-68)6dcc (fig. 2)—and a number of smaller springs discharge more than 1,000 gal/min from the Sultan and Monte Cristo Limestones along the Rogers Spring Fault (pl. 1). The springs are in a discharge area of the carbonate-rock aquifer system of eastern Nevada and western Utah (Prudic and others, 1993, p. 65). Elsewhere within the study area, only a few springs are present in the Paleozoic and Mesozoic rocks and none of these springs discharge large volumes of water like those along the east side of the Muddy Mountains.

Horse Spring Formation

The Horse Spring Formation of Tertiary age is exposed from Blue Point Spring southwestward through Bitter Spring Valley and discontinuously to Las Vegas Wash; in addition, the unit is exposed from Echo Bay northward (pl. 1). Major rock types include white and green tuff, white limestone; reddish-brown gypsiferous mudstone and very fine grained sandstone; grayish-brown to reddish-brown conglomerate; and tan, white, and pink gypsum. Locally, in the western part of the area, intermediate to mafic lava flows are interbedded with the formation. Bohannon (1983) divided the Horse Spring Formation into four members—Lovell Wash Member, Bitter Ridge Limestone Member, Thumb Member, and Rainbow Gardens Member. The principal member present in the LMNRA is the Thumb Member, which consists of a sandstone, tuff, and gypsum facies; a conglomerate facies; and a breccia



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 baseline, 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 NE1/4NE1/4SW1/4 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 2. Well- and spring-numbering system used in this report.

facies. The sandstone, tuff, and gypsum facies is most widespread in the LMNRA. The unit was involved in major faulting and folding that also has affected older rocks in the area (pl. 1). In some places, beds of the unit are steeply dipping to vertical.

The Horse Spring Formation is a confining unit that potentially yields less than 1 gal/min of highly mineralized water to wells. Bitter Spring in Echo Wash about 1 mi west of the LMNRA boundary (pl. 1), however, yields about 10 gal/min of moderately mineralized water. Water discharges from the younger alluvium in the bottom of the wash, which is cut into the Horse Spring Formation. The spring is near the intersection of the Rogers Spring Fault, the Borax Fault, and other unnamed faults, which probably provide a pathway for the movement of water from the carbonate rocks in the Muddy Mountains (see section entitled "Subsurface Flow in Consolidated Rocks of the Mountains").

Volcanic Rocks

Volcanic rocks of Tertiary age are exposed in much of the mountainous area between Callville Bay and Echo Bay and, locally, northeast of Las Vegas Wash (pl. 1). The unit consists of intermediate to mafic lava flows and flow breccia, felsic tuff, and mafic to felsic intrusive rocks of varying composition and texture. Volcanic rocks between Callville Bay and Echo Bay make up a complex andesitic stratovolcano of late Miocene age (Anderson, 1973). The volcanic complex was disrupted by left-lateral movement on a series of northeastward-trending strike-slip and oblique-slip faults. The cumulative lateral displacement on the entire fault zone was estimated to be 35 to 40 mi (Anderson, 1973, p. 12). Only selected faults from the many that were mapped by Anderson are shown on plate 1. Basalt flows of much less areal extent make up the Fortification Basalt Member of the Muddy Creek Formation. These flows are discussed under the section on the Muddy Creek Formation.

Volcanic rocks in this area of the LMNRA are not known to yield water to springs; however, the structural forces that have faulted and fractured the rocks have provided numerous potential pathways for the movement of water. Volcanic rocks near Lake Mead could yield to wells a few tens of gallons per minute of water that infiltrates from the lake depending on the degree of fracturing.

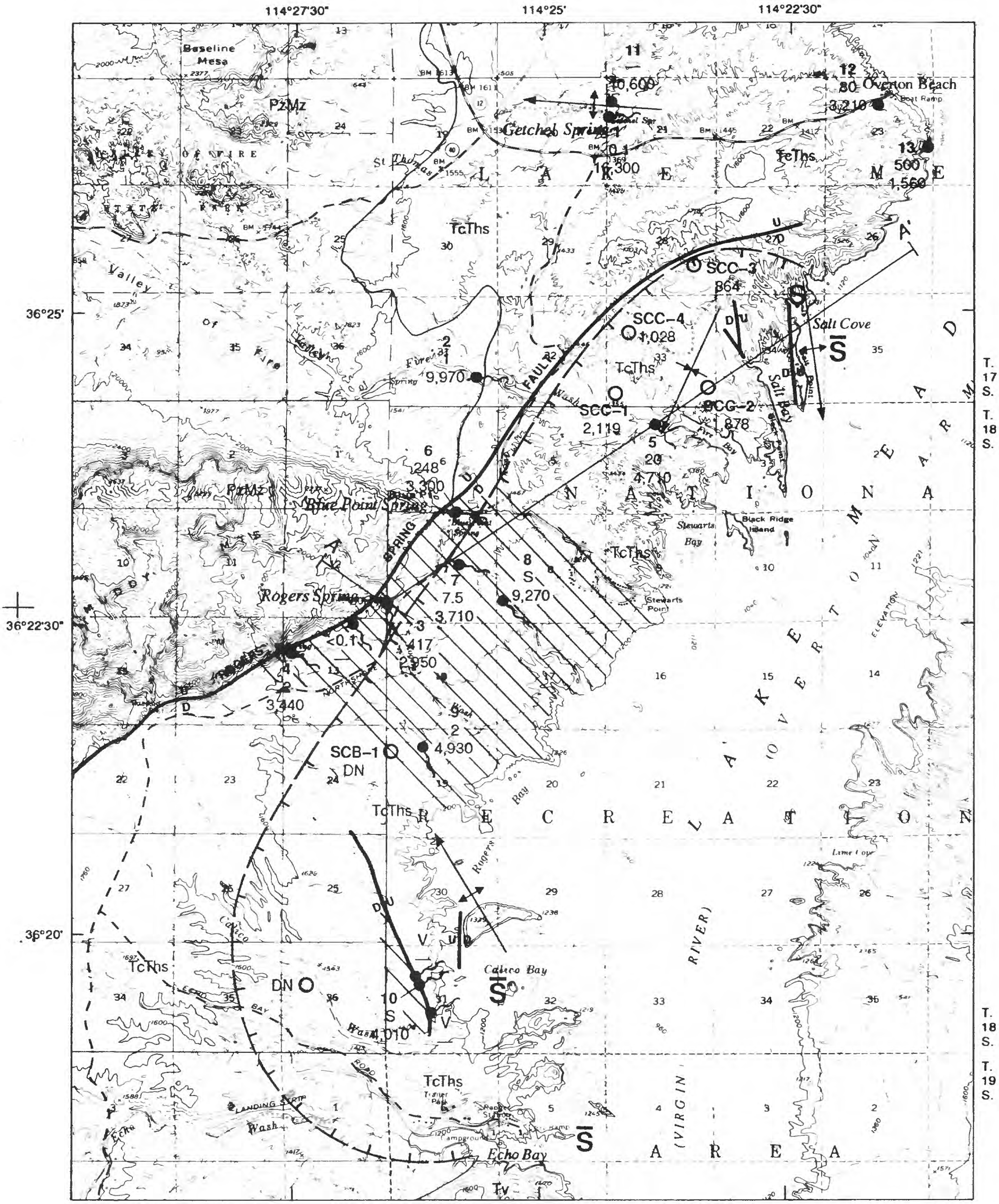
Muddy Creek Formation

In the Lake Mead region, the Muddy Creek Formation makes up a widespread sedimentary unit that was deposited in closed basins during the development of the Basin and Range province (Bohannon, 1984, p. 58). Between Las Vegas Wash and the Virgin River, the most common rocks in the unit are mudstone, siltstone, and fine-grained sandstone. Gypsum is present as bedded deposits or as disseminated accumulations in the mudstone, siltstone, and sandstone. Sediments that contain halite crop out in the Overton Arm area (Longwell, 1928, 1936; Longwell and others, 1965), and on the basis of drill-hole data, halite is in the subsurface west of Overton Arm (Mannion, 1963). Conglomerate may be present at the basin margins. For purposes of this report, the Muddy Creek Formation is divided into a mudstone facies, a conglomerate facies, and the Fortification Basalt Member in most of the study area. Near Middle Point in the southeastern part of the study area, the formation was mapped as an undifferentiated unit.

Mudstone Facies

The mudstone facies is exposed near Las Vegas Wash and between Echo Bay and the Virgin River, where it is the most widespread unit (pl. 1). The mudstone facies consists of weakly to moderately cemented light reddish-brown to brown mudstone, gypsiferous mudstone, siltstone, and very fine grained sandstone. Dirty-gray bedded gypsum and colorless to gray massive halite are present between Echo Bay and Overton Beach (pl. 1). Gypsum may be disseminated throughout or interbedded with the other rocks of the Muddy Creek Formation. Near Valley of Fire Wash and North Shore Road, sec. 32, T. 17 S., R. 68 E., the facies virtually is all bedded gypsum.

Halite crops out in the cores of truncated anticlines at four locations between Echo Bay to about 2 mi southwest of Overton Beach (fig. 3).



Base from U.S. Geological Survey
Overton Beach 1:62,500, 1953

R. 67 E. R. 68 E.

0 1 2 MILES

0 1 2 KILOMETERS

Geologic mapping and well and spring inventory by R.L. Laney and J.T. Bales, 1977–92. Geology modified from Bohannon (1983). Locations of test holes and extent of halite from Mannion (1963) and J.A. Rhodes, (Stauffer Chemical Company, written commun., 1986).

Figure 3. Generalized geology, extent of halite in the Muddy Creek Formation, and location of selected springs and exploratory test holes on the west side of Overton Arm, Lake Mead National Recreation Area.

EXPLANATION

TcThs	MOSTLY FINE-GRAINED SEDIMENTARY ROCKS, EVAPORITE DEPOSITS, AND LOCALLY BASALT FLOWS OF THE MUDDY CREEK FORMATION—Locally, fine-grained sedimentary rocks and evaporite deposits of the Horse Spring Formation; overlying younger coarse-grained sedimentary deposits present in part of the area are not shown
Tv	INTERMEDIATE AND MAFIC LAVA FLOWS AND FLOW BRECCIA, FELSIC TUFF, AND MAFIC TO FELSIC INTRUSIVE ROCKS
PzMz	LIMESTONE AND DOLOMITE
	APPROXIMATE AREA WHERE SURFICIAL MATERIALS CONSIST LARGELY OF IMPURE GYPSUM AND OTHER PRECIPITATED SALTS—Surface may be composed of powdery clayey fluff lacking structure to coarsely crystalline gypsum, which, in places, may conform to the local surface topography, suggesting deposition at the land surface by springs and seeps; associated with ground-water discharge along the Rogers Spring Fault
	GEOLOGIC CONTACT
U D	FAULT—High-angle fault; U, upthrown side; D, downthrown side
	APPROXIMATE SUBSURFACE EXTENT OF HALITE IN THE MUDDY CREEK FORMATION—Teeth point toward the halite
A A'	TRACE OF GENERALIZED GEOLOGIC SECTION—In figure 4
	ANTICLINE—Showing approximate trace of crest plane and direction of plunge
	SYNCLINE—Showing approximate trace of trough plane and direction of plunge
S	HALITE OUTCROP
$\bar{S}$	HALITE OUTCROP NOW COVERED BY LAKE MEAD
SCC–1 2,119	TEST HOLE—Upper letter–number is identifier used by Stauffer Chemical Company; lower number is depth, in feet below land surface to the top of the halite in the Muddy Creek Formation; DN, indicates data not available
12 80 3,210	WELL—Upper number is a site identifier used in figure 5; middle number is reported yield, in gallons per minute; lower number is dissolved-solids concentration, in milligrams per liter
4 2 3,440	SPRING—Upper number is a site identifier used in figure 5; middle number is discharge, in gallons per minute; lower number is dissolved-solids concentration, in milligrams per liter; S, indicates a spring where discharge was too diffuse to make a discharge measurement or estimate; V, indicates presence of phreatophytes, but no visible discharge

Figure 3. Continued.

Three of the halite outcrops have been covered by Lake Mead. Data were available from four of six test holes that were drilled between Echo Bay and Overton Beach in the early 1960's by the Stauffer Chemical Company (J.A. Rhodes, geologist, Stauffer Chemical Company, written commun., 1986). The top of the halite in four of the test holes ranges from 864 to 2,119 ft below the land surface (fig. 3 and table 2). The following tabulation summarizes the occurrences of halite in the test holes:

Well number[1] and test-well number[2]	Depth of hole, in feet	Top of halite, in feet below the land surface	Thickness of halite penetrated by well, in feet	Material at bottom of hole
(D-17-68)28dac, SSC-3	2,230	864	780	Halite-bearing shale
(D-17-68)33bca, SSC-4	1,338	1,028	310	Halite
(D-17-68)33ccc, SSC-1	3,058	2,119	939	Halite
(D-17-68)33dda, SSC-2	3,634	1,878	1,756	Halite

[1]See figure 2 for the spring- and well-numbering system used in this report.

[2]The numbers SSC-1 through 4 were used by Stauffer Chemical Company to identify their test wells.

Halite crops out in local dome-like bulges on the crests of anticlines. Faults and folds near the halite outcrops probably have resulted from a combination of regional-tectonic forces and the tendency of halite, which is less dense than the surrounding sediments, to flow upward. Upward movement of the salt is indicated in an exposure of halite near the crest of an anticline at Salt Cove (pl. 1 and fig. 3). Gypsum caps and drapes over the halite parallel to the contact, which steepens to about 70° on the flanks of the halite mass (Mannion, 1963, p. 171). Mannion reported a steeply dipping normal fault with about 1,100 ft of stratigraphic displacement on the west side of the anticline; in addition, he reported that the nearly vertical flanks of other anticlines in the area are in part faulted. Some halite in cores from drill holes showed faults, slickensides, and sheared textures, indicating probable movement within the halite mass (Mannion, 1963, p. 172). The faulted-halite domes are in sharp contrast to the gently dipping fine-grained sediments of the surrounding mudstone facies.

The halite is in the lower part of the Muddy Creek Formation and is of nonmarine origin (Mannion, 1963). Probable contemporaneous deposits of halite are about 20 mi to the south across Lake Mead in Detrital Valley (Laney, 1979b, p. 13). The Overton Arm-Detrital Valley area of the Lake Mead region is filled almost entirely with fine-grained clastic rocks and evaporites of the mudstone facies of the Muddy Creek Formation (Anderson and Laney, 1975). These deposits impede the flow of ground water in the Overton Arm area.

Where the mudstone facies is saturated, it potentially yields less than a gallon per minute of highly mineralized water to wells. East of the Rogers Spring Fault, water diffuses upward to the surface of the mudstone facies over an area of at least 5 mi^2. The source of the water is the carbonate rocks in the Muddy Mountains west of the fault. As much as 7 gal/min of water discharges at a few well-defined spring orifices in the mudstone facies, but a much larger unknown quantity of water is discharged by evapotranspiration. The hydrologic assessment of the mudstone facies is discussed in more detail in the section entitled "Hydrology."

Conglomerate Facies

The conglomerate facies is a minor unit in this area of the LMNRA and is exposed near Las Vegas Wash and north of Callville Bay (pl. 1). The conglomerate facies consists of light reddish-brown, bright reddish-brown, brown to tan, weakly to moderately consolidated silty gravel to well-cemented silty conglomerate. Clasts generally are subangular and are made up of intermediate to mafic volcanic rocks and granitic rocks near Las Vegas Wash and mostly limestone and dolomite near Callville Bay.

In the report area, no springs are known to exist in the conglomerate facies. Virtually no potential exists for developing water supplies in this facies.

Fortification Basalt Member

The Fortification Basalt Member of the Muddy Creek Formation caps Callville Mesa northwest of Callville Bay and is interbedded with the mudstone facies between Echo Bay and Overton Beach (pl. 1). Near Middle Point, the basalt was included with undifferentiated rocks of the Muddy Creek Formation and, therefore, is not shown separately on plate 1 in that area. The Fortification Basalt Member is a series of dark-gray, olivine, and olivine-augite basalt flows (Bohannon, 1984, p. 57). The unit is as much as 300 ft thick at Callville Mesa and generally less than 100 ft thick in the Overton Arm area and near Middle Point.

The Fortification Basalt Member was dated with the potassium-argon method at 5.88±0.18 m.y. on samples from the type section at Fortification Hill near Hoover Dam (Damon and others, 1978). Flows on Callville Mesa were dated at 11.3±0.3 m.y. (Anderson and others, 1972, table 1), flows about $1\frac{1}{2}$ mi west of Salt Bay on Overton Arm were dated at 8 m.y. (Eberly and Stanley, 1978, table 1, sample 124). Bohannon (1983) did not consider these flows as part of the Fortification Basalt Member because of the younger date at the type section. Anderson and others (1972, p. 277 and table 1), however, group flows dated between 3.7 and 11.3 m.y. as part of the Fortification Basalt Member. Anderson and others (1972) consider the date of the Callville Mesa flows as postdating most of the large-scale fault displacements that affected older volcanic rocks in the Black Mountain area. In addition, similar basalt flows dated within the age range of 3.7 to 11.3 m.y. (Anderson and others, 1972) are associated with the Muddy Creek Formation throughout the LMNRA and have been so described in this series of reports. Regardless of whether or not all the flows are part of the Fortification Basalt Member, the dates provide an estimate of the age of the Muddy Creek Formation. For continuity with the other seven reports of this series, the flows of Callville Mesa and Overton Arm are considered to be part of the Fortification Basalt Member of the Muddy Creek Formation.

The Fortification Basalt Member is not a potential source of water in the report area because it generally is unsaturated. Flows near Lake Mead between Echo Bay and Overton Arm, however, might produce as much as a few tens of gallons of water per minute depending on the amount of fracturing.

Muddy Creek Formation, Undifferentiated

Rocks of the Muddy Creek Formation are exposed near Middle Point and include a basal volcanic-clast fanglomerate, light-colored lacustrine clastic and evaporite beds, which include some dark manganiferous sandstone, and intercalated lava flows of the Fortification Basalt Member (Anderson, 1973, p. 7). The Muddy Creek Formation was not mapped in sufficient detail in the Middle Point area to differentiate the extent of the individual facies. Overall, the water-bearing characteristics of the unit is poor, and if it is saturated near Lake Mead, the water-bearing characteristics would be similar to the Muddy Creek Formation elsewhere in the area.

Older Alluvium

Older alluvium of late Tertiary and early Quaternary age marks the transition from closed-basin deposition to the development of through-flowing integrated drainages of the Colorado and Virgin River systems. The unit is exposed from Las Vegas Wash to Callville Bay and from Echo Bay to the Virgin River (pl. 1). The older alluvium consists of light brown, brown, light grayish-brown, and locally bright reddish-brown, weakly to moderately cemented silty sand, gravel and boulders, light grayish-brown silty, sandy gravel and cobble conglomerate, and silty sandstone.

The unit contains subangular clasts of intermediate to mafic volcanic rocks, limestone, and dolomite deposited on alluvial fans from nearby mountains. Toward the Colorado and Virgin Rivers (now covered by Lake Mead), the locally derived deposits are intermixed with subrounded to rounded clasts of quartzite, granite,

Table 2. Drillers' logs and modified lithologic logs, Lake Mead National Recreation Area, Las Vegas Wash to Virgin River

Stratigraphic unit	Rock description	Thickness (feet)	Depth (feet)
(D-17-68)23abc			
Older alluvium	Sand and gravel	72	72
	Gravel	7	79
	Cemented gravel	29	108
	Loose gravel (water)	5	113
	Red sand	6	119
	Red clay	4	123
	Brown sand	9	132
	Sand and gravel (water)	11	143
	Coarse sand	7	150
	Red sand	25	175
TOTAL DEPTH			175
(D-17-68)23dad			
Older alluvium	Sand and gravel	40	40
	Sand and little gravel	8	48
	Sand and gravel	17	65
	Sand and little gravel	5	70
	Sand	10	80
	Sand and gravel	6	86
	Cemented gravel	1	87
	Gravel and sand	3	90
	Sand	7	97
	Gravel and sand	8	105
	Clay, sand, and gravel (water)	5	110
	Cemented gravel	1	111
	Sandy clay and gravel	3	114
	Sand (water)	4	118
	Sand and gravel	25	143
	Sandstone	13	156
	Quicksand (water)	6	162
	Gravel and sand cemented	8	170
Muddy Creek Formation, mudstone facies	Clay and sand	11	181
	Sticky clay	1	182
	Sandstone	10	192
	Sticky clay	1	193
	Sandstone	13	206
	Sandstone	5	211
TOTAL DEPTH			211
(D-17-68)28dac			
[From Stauffer Chemical Company's lithologic log of test hole SSC-3. Modified and condensed by R.L. Laney in 100- to 2,237-foot interval. All depths measured from kelly bushing, 9.8 feet above ground level. Logs based on cuttings 0 to 660 feet, core 660 to 1,263 feet, and cuttings and core 1,263 to 2,230 feet]			
Older alluvium	Clay and gravel	100	100

Table 2. Drillers' logs and modified lithologic logs, Lake Mead National Recreation Area, Las Vegas Wash to Virgin River—Continued

Stratigraphic unit	Rock description	Thickness (feet)	Depth (feet)
(D-17-68)28dac—Continued			
Muddy Creek Formation, mudstone facies	Clay and shale, reddish brown to greenish brown, trace to 20-percent gypsum	560	660
	Shale, soft to hard, brown to green, anhydrite as thin finely crystalline stringers in shale to massive bedded coarsely crystalline, minor glauberite in upper part of interval, anhydrite and glauberite increase in lower part of interval, bedding dips as much as 38° to vertical axis of core	204	864
	Halite 10 to 90 percent, transparent, coarsely crystalline, anhydrite and glauberite in upper part of interval, minor grayish-green shale, bedding dips as much as 30° to vertical axis of core	780	1,644
	Shale, grayish-green, brown, light gray, light reddish-brown, interbedded anhydrite, halite and glauberite	586	2,230
TOTAL DEPTH----------			2,230
(D-17-68)33bca			
[From Stauffer Chemical Company's lithologic log of test hole SSC-4. Modified and condensed by R.L. Laney for entire log. Logs based on cuttings 0 to 1,022 feet and core 1,022 to 1,338 feet]			
Muddy Creek Formation,	Clay, shale, clayey siltstone, light brown to mudstone facies gray brown	185	185
	Clay, shale, light brown, brownish gray, gypsiferous	635	820
	Clay, shale, grayish brown, brown, as much as 20-percent glauberite and gypsum	202	1,022
	Glauberite, glassy, fine to very coarse, generally massive with some bedding, minor gray silt or clay	6	1,028
	Halite, colorless to gray, fine to coarsely crystalline, sparse to as much as 20-percent glauberite, disseminated brown silt, in places, halite is strongly shattered, and bedding dips as much as 45° to vertical axis of core	310	1,338
TOTAL DEPTH----------			1,338
(D-17-68)33ccc			
[From Stauffer Chemical Company's lithologic log of test hole SSC-1. Modified and condensed by R.L. Laney in 65- to 3,058-foot interval]			
Older alluvium	Gravels with local caliche beds as much as 8 feet thick	65	65

Table 2. Drillers' logs and modified lithologic logs, Lake Mead National Recreation Area, Las Vegas Wash to Virgin River—Continued

Stratigraphic unit	Rock description	Thickness (feet)	Depth (feet)
(D-17-68)33ccc—Continued			
Muddy Creek Formation, mudstone facies	Clay, some silt, light brown, locally greenish or grayish brown	585	650
Muddy Creek Formation, Fortification Basalt Member	Basalt, very dark gray to black, fine grained	29	679
Muddy Creek Formation, mudstone facies	Clay, similar to 65- to 650-foot interval, but with traces of gypsum below 1,170 feet	881	1,560
	Anhydrite, gray to white, impure, fine to coarsely crystalline, minor green shale	4	1,564
	Shale, siltstone and clay, brown to light brown, trace to 20-percent glauberite, traces of gypsum	555	2,119
	Halite, light gray, white, brownish gray, pure to impure, finely to coarsely crystalline to irregular masses, minor brown silty sandstone, some glauberite, minor tuff	939	3,058
TOTAL DEPTH			3,058
(D-17-68)33dda			
[From Stauffer Chemical Company's lithologic log of test hole SSC-2. Modified and condensed by R.L. Laney for entire log. All depths measured from kelly bushing, 9.8 foot above ground level. Logs based on cuttings 0 to 1,830 feet, mostly core 1,830 to 2,940 feet, and cuttings 2,940 to 3,634 feet]			
Colluvium and alluvium	Clay, sand and gravel, buff to light reddish brown	40	40
Muddy Creek Formation, mudstone facies	Clay and soft shale, reddish brown, buff and bright reddish brown, trace of gypsum	440	48
Muddy Creek Formation, Fortification Basalt Member	Basalt, black, very fine grained amygdules filled with zeolite, some interbedded red to brown shale	80	560
Muddy Creek Formation, mudstone facies	Shale, reddish brown, buff, bright red, becoming grayer and greener with depth in interval, as much as 30-percent gypsum	1,270	1,830
	Glauberite, white, coarsely to very coarsely crystalline, interbedded shale reddish brown to brown and grayish green	48	1,878
	Halite, transparent, coarsely crystalline to very coarsely crystalline; thin interbeds of light-gray and light-brown siltstone, sandstone and shale; as much as 30-percent glauberite in upper part of interval	1,756	3,634
TOTAL DEPTH			3,634

Table 2. Drillers' logs and modified lithologic logs, Lake Mead National Recreation Area, Las Vegas Wash to Virgin River—Continued

Stratigraphic unit	Rock description	Thickness (feet)	Depth (feet)
(D-19-68)5cac			
Older alluvium	Sand	12	12
	Sand and gravel	20	32
	Gravel	9	41
	Sand	12	53
	Gravel	15	68
	Sand	9	77
	Gravel	16	93
	White sand and gravel (water)	23	116
	Red sand and gravel	15	131
Horse Spring Formation	Gray clay	8	139
	White sand and gravel	3	142
	White clay	3	145
	Red sandy clay	40	185
	Blue and red clay	30	215
	Red sandy clay	40	255
	Salt (water)	10	265
	Red sandy clay and salt	35	300
TOTAL DEPTH			300
(D-19-68)5cbd			
Older alluvium	Gravel	136	136
Muddy Creek Formation, mudstone facies or Horse Spring Formation	Red sandy clay	39	175
TOTAL DEPTH			175
(D-21-65)9dbb			
Older alluvium	Gravel and boulders	22	22
	Cemented gravel	131	153
	Red clay and gravel	16	169
	Cemented gravel	9	178
Horse Spring Formation	Red sandy clay	22	200
TOTAL DEPTH			200

limestone, dolomite, volcanic rocks and, in places, minor but distinctive red jasper and black chert of more distant origin. The rounded material was transported into the area by the ancestral through-flowing drainages of the Colorado and Virgin River systems and forms thick channel-type deposits. These deposits contain abundant crossbedding and cut-and-fill structures. Locally derived deposits generally are poorly sorted, but where the unit consists of beds of sand interbedded with rounded river gravel, the unit may be moderately sorted. Individual beds of silt may be interbedded with the rounded gravel and, in places, the silt is gypsiferous. Bedding ranges from indistinct to distinct and cross beds commonly are associated with the better sorted and rounded river-deposited material. Wind-blown sand and silt are present locally.

The thickness of the older alluvium ranges from a few inches in veneers of lag gravels that were too thin to map to exposures as much as 300 ft thick. Representative thicknesses are 50 ft near Las Vegas Wash, 150 ft near Callville Bay, 250 ft near Echo Bay, 100 ft near Overton Beach, 30 ft at the south end of Mormon Mesa, and 150 to 200 ft at the junction of the Muddy and Virgin Rivers southeast of Mormon Mesa (pl. 1).

In most of the area where it is exposed, the older alluvium is virtually flat lying or dips only a few degrees. Locally, the unit is faulted and folded and beds dip as much as 50°. Faults generally are high angle and of small displacement. Remnants of relic river deposits are present where the folding and faulting may have determined the location of the river channel. The most striking example of this structural control on the deposition in the report area is at Middle Point (pl. 1). The older alluvium consists of silt, sand, and rounded river gravel deposited in a syncline formed in rocks of the Muddy Creek Formation. Near the east and west limbs of the syncline, older parts of the older alluvium were involved in the folding, and beds dip 40 to 50°. Folding continued during the deposition of the older alluvium at this location because younger parts of the unit unconformably overlie the older parts. Folding, and possible faulting, formed a downwarped area through which the developing ancestral Colorado and Virgin Rivers flowed. A similar, but much less extensive, syncline is well exposed in a wash about 2.5 mi west of Swallow Bay in the NW1/4 SW1/4 sec. 13, T. 21 S., R. 64 E. (unsurveyed; pl. 1). Sand and gravel of the older alluvium is folded into a westward-trending syncline that contains well-sorted, cross-bedded sand along the axis of the structure. Structural control on the location of ancestral river channels and deposition of the older alluvium also has been described south of Lake Mead in the LMNRA (Laney, 1979a, p. 35).

Prominent erosion surfaces are developed on the older alluvium as a result of at least four major cycles of denudation (Longwell, 1928). Some of the surfaces are quite prominent in the Overton Arm area. The highest, oldest, and most prominent erosion-surface remnant is on Mormon Mesa, which is about 650 ft above the levels of the Muddy River and Virgin River (pl. 1). The upper levels of the dissected surface that extends westward from Echo Bay to the Muddy Mountains may be correlative with the surface on Mormon Mesa on the basis of similar development of caliche in the upper few feet of the unit. As much as 8 ft of caliche underlies the surface of both areas. The upper 4 ft of the most indurated material on Mormon Mesa is termed "calcrete" by Gardner (1972, p. 144) for "caliche concrete." Similar material underlies the surface of the older alluvium west of Echo Bay. In a detailed study of the origin of the caliche on Mormon Mesa, Gardner (1972, p. 143) concluded that the caliche formed largely from pedogenic processes, probably under slowly aggrading, aeolian conditions. The thickness of the caliche is less on lower-level, younger erosion surfaces that are underlain by the older alluvium. Near Overton Beach, the caliche is 2 to 4 ft thick where remnants of the surface remain.

The older alluvium consists of an upper and lower part that are most evident near the shores of Lake Mead between Las Vegas Wash and Callville Bay and from Echo Bay to the Virgin River (pl. 1). The two parts could not be traced with certainty throughout the area, thus, they were not mapped separately. The upper part consists of weakly to moderately cemented silty sand and gravel, which unconformably overlies the lower part that consists of sandstone and conglomerate. Both parts contain an overall similar mix of subangular rock clasts from nearby mountains and rounded clasts of more distant origin. The lower part is strongly cemented with calcium carbonate, is not greatly fractured, and tends to form large vertically faced slabby blocks where undercut by streams. The distinction between the two parts has importance when considering the movement of water from Lake Mead to wells drilled in the older alluvium near the lake. Between Las Vegas Wash and Callville Bay, only the lower part is in contact with the water of Lake Mead and the upper part is unsaturated. Between Echo Bay and the Virgin River, the lower part is in contact with Lake Mead north of Overton Beach. At Overton Beach and at the junction of the Muddy and Virgin Rivers, only the upper part is exposed and extends beneath the lake.

The upper part of the older alluvium near Lake Mead potentially could yield several hundred gallons of water per minute to properly located and constructed wells. The yield of water to wells from the lower part is dependent on the amount of fracturing, and yields to wells probably would be only a few tens of gallons of water per minute. The hydrologic aspects of the unit are discussed in more detail in the section entitled "Favorable Areas for Ground-Water Development."

Colluvium and Alluvium

Colluvium and alluvium consist of tan to grayish-brown, light-orange brown, subangular to angular silty sand, gravel, and boulders. The alluvium caps terraces and underlies the younger alluvium along the present-day washes. The colluvium is present on alluvial slopes, and fans and may be on older rock units as a veneer too thin to map. Along washes, the unit may include deposits of younger alluvium. The upper few inches to a few feet of the deposits on terrace surfaces may be cemented with caliche. Along washes the unit probably is less than 50 ft thick. The colluvium and alluvium generally are unsaturated but could yield a few hundred gallons of water per minute to wells near Lake Mead. The yields would vary with lake levels, and the unit might not be a dependable source of water.

Younger Alluvium

The younger alluvium consists of tan to grayish-brown, subangular to angular silty sand, gravel, and boulders of local origin. The unit underlies the bottoms of present-day washes and is saturated only near Lake Mead, in Moapa Valley and locally where springs discharge in washes. The unit probably is less than 25 ft thick, but when combined with the colluvium and alluvium, the total may be as much as 50 ft thick and as much as 150 ft thick in Moapa Valley. The combined thickness of the two units could yield a few tens to a few hundred gallons of water per minute to wells near Lake Mead at the mouths of large washes; however, the amount of available saturated thickness would vary with lake levels.

HYDROLOGY

The average annual precipitation in the study area ranges from 4 to 8 in. (Hardman, 1965). The average annual evaporation is about 15 times greater than the precipitation on the basis of the comparison of average annual precipitation to evaporation maps of Kohler and others (1959). As a result, most precipitation evaporates soon after it reaches the ground or is transpired by vegetation. Surface-water sources include the Colorado River, Virgin River, Muddy River, and Las Vegas Wash, which have perennial flow in the area. Elsewhere in the area, streamflow is meager and extremely variable, but occasional floodflows may result from local intense thunderstorms. Rush (1968) estimated that less than 1 percent of the precipitation is recharged to the ground-water system in the study area. Major sources of ground water include infiltration of water into permeable rocks near Lake Mead and subsurface flow from the consolidated rocks of the Muddy Mountains. Springs along the Rogers Spring Fault on the east side of the Muddy Mountains discharge more than 1,000 gal/min of water at defined orifices. Probably several hundreds of gallons of water per minute more is discharged by diffuse upward leakage through fine-grained sedimentary rocks and by evapotranspiration east of Rogers Spring Fault.

Surface Water

Perennial streams in the LMNRA include the Colorado River, Virgin River, Muddy River, and Las Vegas Wash. All these streams except the Colorado River discharge to Lake Mead within the study area. Mean annual discharge of the three streams is shown in table 3. The mean annual discharge of 172 ft^3/s of Las Vegas Wash above Three Kids Wash below Henderson, Nevada, is based on only 4 years of record—water years 1989, 1990, 1991, and 1992. Discharge and water-quality records have been collected from 1957 to 1983 and 1985 to 1988 at a gaging station near Henderson, Nevada, about 2 mi upstream (Hess and others, 1993). However, the average discharge for the 3 years at the gaging station above Three Kids Wash is more representative of

Table 3. Discharge at continuous-record gaging stations in and near Lake Mead National Recreation Area, Las Vegas Wash to Virgin River

[Data from Hess and others, 1993]

Station name and location	Mean annual discharge		Period of record
	Cubic feet per second	Acre-feet per year	
Virgin River at Litttlefield, Arizona, about 36 miles upstream from Lake Mead	235	171,000	October 1929 to September 1992
Muddy River above Lake Mead near Overton, Nevada (pl. 1)	8.91	6,450	October 1978 to September 1983; October 1984 to September 1992
Las Vegas Wash above Three Kids Wash, below Henderson, Nevada, about 4 miles upstream from Lake Mead	172	125,000	May 1988 to September 1992; average discharge based on complete year's records in water year 1989–92; discharge includes treated sewage effluent and some wastewater from municipal and industrial sources

current discharge of surface water to Lake Mead than is the long-term average discharge of Las Vegas Wash. Discharge of Las Vegas Wash has increased about eight times since the late 1950's. A considerable part of the discharge consists of treated sewage effluent and wastewater from municipal and industrial sources that have increased over the years as the population and water use in the Las Vegas metropolitan area have increased.

The average annual discharge of 8.91 ft^3/s in the Muddy River above Lake Mead near Overton, Nevada (table 3), is representative of the surface-water flow reaching Lake Mead from this stream. Continuous stream-discharge records at a gaging station near Glendale, Nevada, about 16 mi upstream from Lake Mead show an average annual discharge of 43.8 ft^3/s (Hess and others, 1993, p. 75). The difference in the flow at the two stations represents diversions from the river for irrigation in Moapa Valley and a wildlife-management area. Part of the water diverted for irrigation is consumed and part is recharged to the ground-water flow system beneath Moapa Valley and then discharged to Lake Mead as subsurface flow.

Few measurements of surface-water flow have been made in the larger washes of LMNRA where streamflow occurs on the average of about once a year (Bentley, 1979a). Peak flood discharge was determined at a crest-stage partial-record station on Valley of Fire Wash in the northeastern part of the area (pl. 1, table 4). The table shows the annual maximum discharge for water years 1987–92.

Table 4. Annual maximum discharge at crest-stage partial-record gaging station at Valley of Fire Wash near Overton, Nevada (see pl. 1 for location)

[Sources of data: 1984, 1987, Pupacko and others (1989a, b); 1989, Pupacko and others (1990); 1990, Bostic and others (1991); 1991, Garcia and others (1992); 1992, Hess and others (1993). Dashes indicate no data]

Measurement date	Gage height, in feet	Discharge, in cubic feet per second
7–22–84	-------	[1]220
7–16–87	-------	[1]649
10–24–87	45.16	120
8–17–89	43.29	[1]30
8–16–90	55.65	4,940
3–15–91	40.95	[1]100
3–15–92	41.62	[1]230

[1]Estimated.

Ground Water

Information on ground water was obtained from an inventory of 13 springs and 6 wells in and near the study area (tables 2, 5, and 6). Additional data from three wells in Moapa Valley were obtained from Rush (1968, table 19). Stauffer Chemical Company provided well logs for four of their test holes between Echo Bay and Overton Beach (pl. 1, table 2). These logs provided information on the geologic units in the subsurface from which inferences on the movement of ground water were made.

The sources of ground water in the study area include:

1. Subsurface flow in local basins that drain to Lake Mead,
2. Infiltration of water from Lake Mead into adjacent permeable rocks,
3. Subsurface flow in valleys of perennial streams, and
4. Subsurface flow from the consolidated rocks of the Muddy Mountains.

The sources of ground water are discussed in a qualitative or semiquantitative manner only to provide perspective for the relative potential of the sources in the study area. A water budget was not developed for the ground-water flow system.

Subsurface Flow in Local Basins that Drain to Lake Mead

Low rates of average annual precipitation and high rates of evaporation in the study area limit the recharge from precipitation to less than 1 percent of the total precipitation (Rush, 1968, p. 23). The average annual precipitation ranges from 4 to 8 in. One percent of an average of 6 in. of precipitation per year is equivalent to about 3 acre-ft of recharge per square mile or about 800 acre-ft over the study area. This is a relatively small quantity of water compared with other sources of ground water in the area.

Infiltration of Water from Lake Mead into Adjacent Permeable Rocks

In terms of the entire Lake Mead area, the water that infiltrates the permeable rocks adjacent to the lake is the largest source of ground water. Langbein (1960, p. 100–102) estimated that at any given level of Lake Mead a volume of water equivalent to about 12 percent of the lake capacity is in bank storage. Lake Mead at full capacity (at an altitude of 1,221 ft) contains 29,680,000 acre-ft of water, and about 3,600,000 acre-ft of water would be in bank storage. As the lake level rises, water moves into the permeable rocks and the water table rises. Conversely, when the lake level declines, water stored in the permeable rocks is discharged into the lake and the water table declines. Rocks saturated by lake water probably extend less than 0.5 mi from the lake.

Subsurface Flow in Valleys of Perennial Streams

The subsurface flow to Lake Mead in the lower Virgin River Valley was estimated on the basis of a basinwide water budget at about 40,000 acre-ft/yr (Glancy and Van Denburgh, 1969, p. 51 and table 16). The flow probably is through both the alluvium and the underlying consolidated rocks. The authors acknowledged that this estimate may be unreasonably large and in considerable error. The subsurface flow in the lower Moapa Valley was estimated to be at about 1,100 acre-ft/yr (Rush, 1968, table 7). Rush also estimated that the subsurface flow in the alluvium in Las Vegas Wash was less than 400 acre-ft/yr. Significant subsurface flow beneath Las Vegas Wash in the study area is not likely because the stream has cut a channel into the mudstone facies of the Muddy Creek Formation (pl. 1). The mudstone facies has low permeability and does not transmit large quantities of ground water.

Subsurface Flow in Consolidated Rocks of the Muddy Mountains

Subsurface flow in the consolidated rocks of the mountains is a significant source of ground water only along the east side of the Muddy Mountains. Near the Rogers Spring Fault, several springs discharge a total of about 1,000 gal/min of water (fig. 3). Most of the discharge is from two

Table 5. Records of selected springs in and near the Lake Mead National Recreation area, Las Vegas Wash to Virgin River

[Discharge: E, estimated; M, measured. Use: N, not used; R, recreation. Remarks: C, chemical analysis of water shown in table 7. <, less than]

Spring number	Water-bearing unit	Altitude of the land surface (feet)	Discharge: Amount (gallons per minute)	Discharge: Date measured or estimated	Use	Remarks
(D-17-68)21bcb2	Muddy Creek Formation, mudstone facies	1,370	0.1E	5–17–78	N	C; Getchel Spring; spring is near crest of a faulted west-plunging anticline; water discharges from a reverse fault in the mudstone facies of the Muddy Creek Formation in a 10- to 12-foot-deep gulley.
(D-17-68)31dbd	Paleozoic and Mesozoic rocks, undifferentiated	1,435	1E	5–5–77	N	C; unnamed spring in Valley of Fire Wash near power-transmission lines; water discharges from Aztec Sandstone at contact with Chinle Formation.
(D-18-67)12dda	Paleozoic and Mesozoic rocks, undifferentiated	1,595	[1]875M [1]780M 417M 720	10–25–63 2–5–68 5–18–77 (See remarks)	R	C; Rogers Spring; located along the Rogers Spring Fault on the east side of the Muddy Mountains; most of the water discharges into the bottom of a shallow pool from a nearly vertical fracture in brecciated limestone; about 720 gallons per minute average discharge based on continuous records since 1985 (Hess and others, 1993, p. 78).
(D-18-67)13aba	Mesozoic and Paleozoic rocks, undifferentiated	1,580	<.1E	5–5–77	N	Unnamed spring along Rogers Spring Fault; fault well exposed in sides of canyon; mesquite and other vegetation is immediately down the canyon from fault and covers an area of approximately 2 acres; water discharges from alluvium about 150 feet down the canyon from fault; considerably more water is lost to evapotranspiration than indicated by estimated discharge of the seep.
(D-18-67)13bcb	Mesozoic and Paleozoic rocks, undifferentiated	1,595	2E	5–4–77	N	C; unnamed spring along the Rogers Spring Fault; water discharges at contact of zone of brecciated limestone and cemented rubble about 200 feet down the canyon from the bedded limestone of the mountain front.

See footnote at end of table.

Table 5. Records of selected springs in and near the Lake Mead National Recreation area, Las Vegas Wash to Virgin River—Continued

Spring number	Water-bearing unit	Altitude of the land surface (feet)	Discharge		Use	Remarks
			Amount (gallons per minute)	Date measured or estimated		
(D-18-68)4bac	Older alluvium	1,235	20E 20E	5–19–78 2–25–92	N	C; unnamed spring near mouth of Valley of Fire Wash; water discharges from vegetated area that extends as much as 0.75 mile upstream from Lake Mead; estimated discharge is minimum because of probable seepage beneath the wash to the lake and evapotranspiration; most measurable flow issues from the older alluvium at several places on the left bank downstream from exposure of the mudstone facies of the Muddy Creek Formation.
(D-18-68)6dcc	Mesozoic and Paleozoic rocks, undifferentiated	1,580	[1]150E 248M	11–27–45 5–18–77	R	C: Blue Point Spring; located along the Rogers Spring Fault on the east side of the Muddy Mountains at Blue Point; at head of spring, water discharges at a rate of about 5 gallons per minute from fractured and shattered limestone in a depression in salt-encrusted soil and alluvium; discharge increases downslope to a picnic area where measurement was made; most of major washes between Blue Point Spring and spring (D-18-67)13bcb southwest of Rogers Spring contain thick growths of vegetation in the mudstone facies near the mountain front indicating seepage along and downslope of the fault.
(D-18-68)7acc	Muddy Creek Formation, mudstone facies	1,510	7.5M	5–19–78	N	C; unnamed spring downslope of culvert at North Shore Drive about 0.5 mile south of Blue Point Spring; flow accumulates in a small pond; discharge measured about 400 feet downsteam where water flows over a gypsum ledge; rock is reddish-brown mudstone interbedded with white gypsum; dip of beds undulates but is easterly near spring; at measuring point strike is N. 55 W., dip is 35 NE.

See footnote at end of table.

Table 5. Records of selected springs in and near the Lake Mead National Recreation area, Las Vegas Wash to Virgin River—Continued

Spring number	Water-bearing unit	Altitude of the land surface (feet)	Discharge: Amount (gallons per minute)	Discharge: Date measured or estimated	Use	Remarks
(D-18-68)8ccb	Muddy Creek Formation, mudstone facies	1,360	See remarks	5–19–78	N	C; unnamed spring about 0.5 mile down the canyon from spring (D-18-68)7acc; no measurable running water; water ponded in places in zone of thick vegetation about 150 feet wide and 0.25 mile long in canyon that is about 30 feet deep; may be partly water from spring (D-18-68)7acc.
(D-18-68)19bac	Older alluvium	1,320	2E	5–19–77	N	C; unnamed spring about 0.25 mile downstream from power-line road; water supports thick growth of vegetation about 150 feet wide and 0.33 mile long in wash about 30 feet deep; water discharges in wash bottom from weakly to moderately cemented silty and sandy gravel and cobbles that are overlain by fine-grained sand and silt; about 4 feet of gypsum caps the sequence; the sand and silt matrix of the gravel and cobbles are stained red; some gravel and cobbles are encased in soft black manganese oxide; the gravel and cobbles are the water-bearing sequence; the wash slope is greater than the dip of the beds and the spring is at the intersection of the two.
(D-18-68)31bdc	Muddy Creek Formation, mudstone facies	1,260	See remarks	5–18–78	N	C; unnamed spring on the west side of Calico Bay about 1.5 mile north of Echo Bay; a seep in an area of thick vegetation about 50 by 200 feet in wash about 50 feet deep; vegetation extends up the wash from the discharge point at the contact with mudstone and tuff of the Horse Spring Formation; two somewhat smaller areas of thick vegetation indicate seeps but no visible discharge about 0.15 mile to the northwest and 0.2 mile to the south; all three seeps are aligned near a northwestward-trending scarp that marks a fault separating the Muddy Creek Formation from

See footnote at end of table.

Table 5. Records of selected springs in and near the Lake Mead National Recreation area, Las Vegas Wash to Virgin River—Continued

Spring number	Water-bearing unit	Altitude of the land surface (feet)	Discharge: Amount (gallons per minute)	Discharge: Date measured or estimated	Use	Remarks
(D-18-68)31bdc—Continued						the Horse Spring Formation; the Muddy Creek mudstone facies at the seeps dips as much as 50° to the west; 0.25 mile to the west the dip is less than 10°; the mudstone of the Muddy Creek Formation is capped near the seeps by gravel and silt of the older alluvium; many of the clasts are well rounded and from a distant source; as much as 5 feet of gypsum caps the land surface and conforms to slope of the surface; the gypsum caps may represent older spring deposits.
(D-19-67)16bbc	Mesozoic and Paleozoic rocks, undifferentiated	1,665	[1]10E 10E	11–13–67 5–3–77	N	C; Bitter Spring in Echo Wash; water discharges from alluvium in wash cut into siltstone of Horse Spring Formation; thick vegetation covers an area about 100 feet wide by 1,000 feet downstream from head of spring; scattered phreatophytes extend for as much as a mile downstream from spring; losses to evapotranspiration and underflow through the alluvium probably greatly exceed the estimated discharge; spring is near the intersection of the Rogers Spring Fault and the Borax Fault (Bohannon, 1983), which may provide the conduit for water movement from the Paleozoic and Mesozoic sedimentary rocks, undifferentiated.
(D-20-66$\frac{1}{2}$)18bdc (unsurveyed)	Mesozoic and Paleozoic rocks, undifferentiated	1,920	<.1E	5–3–77	N	C; Sandstone Spring; water seeps from the Aztec Sandstone at the contact with the Moenkopi Formation; rocks strike N. 55° E. and dip 43° S.; a number of joints are in the exposure but one prominent joint that strikes N. 15° E. and dips about 85° NW contributes most of the water to the spring; water collects in box about 1.5 by 2 feet; overflow is piped about 100 feet downslope to a water trough.

[1]From Rush (1968) table 13).

Table 6. Records of selected wells, Lake Mead National Recreation Area, Las Vegas Wash to Virgin River

[Use: N, not used; I, industrial; D, domestic; T, exploration test hole. Water level and yield: M, measured as part of this study; R, reported. Remarks: C, water analysis in table 7; L, drillers' log in table 2; LMNRA, Lake Mead National Recreation Area. Dashes indicate no data]

						Water level		Yield			
Well number	Water-bearing unit	Altitude of the land surface (feet)	Depth of well (feet)	Diameter of casing (inches)	Depth of casing (feet)	Depth below land surface (feet)	Date	Amount (gallons per minute)	Date	Use	Remarks
(D-16-67)24ad(?)	Colluvium and alluvium	1,250	140	16 8	-----------	6R	1966	1,100	---------	I	From Rush (1968, table 14); well in lower Moapa Valley outside LMNRA; most water from 95- to 140-foot interval; location given by Rush (1968) was (D-16-67)24bd, but mudstone facies of the Muddy Creek Formation is exposed at (D-16-67)24bd; if the altitude is correct, location is more likely (D-16-67)24ad.
(D-16-68)7cb	Younger alluvium, colluvium and alluvium	-------	80	6	-----------	13.92M	11–10–67	---------	---------	D	C; from Rush (1968, table 19); well in lower Moapa Valley outside LMNRA; drilled to 500 feet; measurement by Rush.
(D-16-68)30ad	Younger alluvium, colluvium and alluvium	1,230	75	12	-----------	23R	1948	----------	---------	I	C; from Rush (1968, table 19); well in lower Moapa Valley outside LMNRA; most water from 52- to 73-foot interval.
(D-17-68)21bcb1	Muddy Creek Formation, mudstone facies	1,365	8	60	8	6.6M	5–18–77	----------	---------	N	C; dug well near Getchel Spring; lined with cement and stones; salt crust on walls; rock on land surface is gypsum covered with salt crusts.

Table 6. Records of selected wells, Lake Mead National Recreation Area, Las Vegas Wash to Virgin River—Continued

Well number	Water-bearing unit	Altitude of the land surface (feet)	Depth of well (feet)	Diameter of casing (inches)	Depth of casing (feet)	Water level: Depth below land surface (feet)	Water level: Date	Yield: Amount (gallons per minute)	Yield: Date	Use	Remarks
(D-17-68)23abc	Older alluvium	1,225	143	12 8	0 to 53 53 to 175	97.5R	11–19–64	80R	11–19–64	N	C; L; well at Overton Beach; was intended to be public supply well, but water is of poor quality; depth of hole was 175 feet, was plugged back to 143 feet; casing perforated from 133 to 143 feet; during 32-hour pumping test, drawdown stabilized at 120 feet below land surface (22.5 feet of drawdown) after about 6 hours of pumping; water level recovered to original level in about 1 hour at the end of pumping period; specific capacity is 3.6 gallons per minute per foot of drawdown; transmissivity estimated from specific capacity is about 700 feet squared per day from method of Theis and others (1963).
(D-17-68)23dad	Older alluvium and Muddy Creek Formation, mudstone facies	1,150	211	12	211	102.6R	11–21–61	500R	11–21–61	N	C; L; Stauffer Chemical Company supply well (?); driller's report to Nevada State Engineer locate well only in SE1/4 of sec. 23, T. 17 S., R. 68 E.; well located more precisely by Everett Robertson, (National Park Service, written commun., 1992), who visited the site in 1968 when well head was above the lake level; chemical analysis record from the Nevada Division of Health has a handwritten note stating "Stauffer

Table 6. Records of selected wells, Lake Mead National Recreation Area, Las Vegas Wash to Virgin River—Continued

Well number	Water-bearing unit	Altitude of the land surface (feet)	Depth of well (feet)	Diameter of casing (inches)	Depth of casing (feet)	Water level: Depth below land surface (feet)	Water level: Date	Yield: Amount (gallons per minute)	Yield: Date	Use	Remarks
(D-17-68)23dad—Continued											well, Overton Beach;" Stauffer Chemical Company drilled a number of test holes for halite exploration to the southwest (see records for the four wells that follow in this table); this well may have been a supply well intended for mining of evaporite minerals; well's location near Lake Mead probably accounts for the high reported discharge of 500 gallons per minute and water quality that is better than the quality of water from any other well in the area.
(D-17-68)28dac	Muddy Creek Formation, mudstone facies	1,408	2,230	----	------------	No water reported	---------	-----------	---------	T	L; Stauffer Chemical Company test hole SSC-3.
(D-17-68)33bca	Muddy Creek Formation, mudstone facies	1,379	1,338	----	------------	No water reported	---------	-----------	---------	T	L; Stauffer Chemical Company test hole SSC-4.
(D-17-68)33ccc	Muddy Creek Formation, mudstone facies	1,340	3,058	16	17	No water reported	---------	-----------	---------	T	L; Stauffer Chemical Company test hole SSC-1.
(D-17-68)33dda	Muddy Creek Formation, mudstone facies	1,318	3,634	----	------------	No water reported	---------	-----------	---------	T	L; Stauffer Chemical Company test hole SSC-2.

Table 6. Records of selected wells, Lake Mead National Recreation Area, Las Vegas Wash to Virgin River—Continued

						Water level		Yield			
Well number	Water-bearing unit	Altitude of the land surface (feet)	Depth of well (feet)	Diameter of casing (inches)	Depth of casing (feet)	Depth below land surface (feet)	Date	Amount (gallons per minute)	Date	Use	Remarks
(D-18-68)19bbc	Muddy Creek Formation, mudstone facies	1,371	-------	15 (outer) 4 (inner)	------------	----------	---------	-----------	---------	T	Stauffer Chemical Company test hole SCB-1; no log available; located in field 5-19-77.
(D-19-68)5cac	Older alluvium and Horse Spring Formation	1,220	120	10	120	83	6–26–56	-----------	---------	N	L; well at Echo Bay marina in patio area of motel (location by Everett Robertson, National Park Service, oral commun., 1992); hole drilled to 300 feet and backfilled and plugged from 120 to 300 feet; casing perforated from 94 to 116 feet; driller reported first water at 93 feet, "not fit for human use" and at 255 feet "salt water."
(D-19-68)5cbd	Older alluvium and Muddy Creek Formation, mudstone facies or Horse Spring Formation	1,230	175	10	175	125R	7–18–56	-----------	----------	N	L; well at Echo Bay marina; near National Park Service residential area (location by Everett Robertson, National Park Service, oral commun., 1992); casing perforated from 118 to 168 feet.
(D-21-65)9dbb	Older alluvium	1,225	200	24	------------	105R	10–12–67	30	10–12–67	N	C; L; exploratory well for water supply at Callville Bay; discharge of 30 gallons per minute was maximum sustained yield; water quality was not suitable for public supply.

springs—Rogers Spring, (D-18-67)12dda, and Blue Point Spring, (D-18-68)6dcc (table 5). Rogers Spring has a mean annual discharge of 1.58 ft^3/s, or about 720 gal/min, on the basis of continuous records since 1985 (table 5, this report; Hess and others, 1993, p. 78). A discharge of 0.55 ft^3/s, or about 248 gal/min, was measured in 1977 at Blue Point Spring (table 5). The other springs in this area discharge less than 10 gal/min of water, and at some sites, little measurable discharge was present. At all spring sites, substantial quantities of water are lost by direct evaporation and plant transpiration.

The source of the water to the springs along and near the Rogers Spring Fault is the ground-water flow system in the Carbonate-Rock Province of the Great Basin (Prudic and others, 1993). The flow in this system consists of shallow flow through basin-fill deposits and nearby mountains superimposed over a deep-flow system in carbonate rocks. The carbonate rocks are of Paleozoic age and cover about 100,000 mi^2 in the eastern part of Nevada, the western part of Utah, and small areas of adjacent States. The carbonate rocks have been greatly affected by compression, extension, faulting, volcanic episodes, and erosion (Prudic and others, 1993). Normal faulting of the carbonate rocks and other consolidated rocks during the Tertiary Period formed the present-day northeastward-trending mountain ranges and basins in the Great Basin. Although the flow system is regional in nature, discharge at any given natural outlet may be a mix of water from local and distant recharge areas.

The carbonate-rock flow system was divided into five regions and each region was divided into subregions. About one-third of the study area is in the Virgin River subregion and the remainder is in the Las Vegas subregion of the Colorado River region (Prudic and others, 1993, fig. 30). The springs that discharge along the Rogers Spring Fault are near the boundary of the Las Vegas and the Virgin River subregions.

The springs along and near the Rogers Spring Fault constitute the southernmost major discharge area of the carbonate-rock flow system (Prudic and others, 1993, fig. 30). This water may be a mix of subsurface flow from the Muddy Mountains to the west and subsurface flow from the north. Recharge in the adjacent Muddy Mountains is insufficient to supply all the water that discharges from the springs (Prudic and others, 1993, p. 69 and fig. 31). As the ground water flows to the Rogers Spring Fault, it encounters fine-grained sedimentary rocks and evaporite deposits of the Muddy Creek Formation and Horse Spring Formation that are east of the fault (figs. 3 and 4). The transmissive properties of these rocks are low, forcing water to emerge at the surface in the springs along the fault trace. Most of the surface flow is at Rogers Spring and Blue Point Spring, but unknown quantities of seepage diffuse upward through the fine-grained sedimentary rocks east of the fault and are discharged by seeps and small springs (figs. 3 and 4) and by evapotranspiration. Preferential movement of the ground water may be along faults and fractures. Spring (D-18-68)31bdc is an example of a spring along a northwestward-trending fault that separates fine-grained deposits of the Muddy Creek Formation from those of the Horse Spring Formation (fig. 3, pl. 1, and table 5). The northwestward-trending fault may be a conduit for water from the carbonate rocks along the Rogers Spring Fault.

About 5 mi^2 of land surface east of Rogers Spring and Blue Point Spring is underlain by surficial materials that consist largely of impure gypsum and other precipitated salts (fig. 3). The surface is composed of clayey powdery fluff lacking structure to coarsely crystalline gypsum. In a number of places, the coarsely crystalline gypsum may conform to the local surface topography suggesting deposition at the land surface by springs and seeps over a long period. These surficial deposits may have resulted from the diffuse upward leakage east of the Rogers Spring Fault (fig. 4). Preferential pathways through faults and fractures may have facilitated surface discharge at various locations. Accumulations of evaporite deposits may have clogged the spring or seep causing the discharge to shift to another location. Thus, discharge points may have shifted over time resulting in a build up of spring deposits over a wide area. The fine-grained deposits east of the Rogers Spring Fault prevent the subsurface movement of ground water directly to Overton Arm.

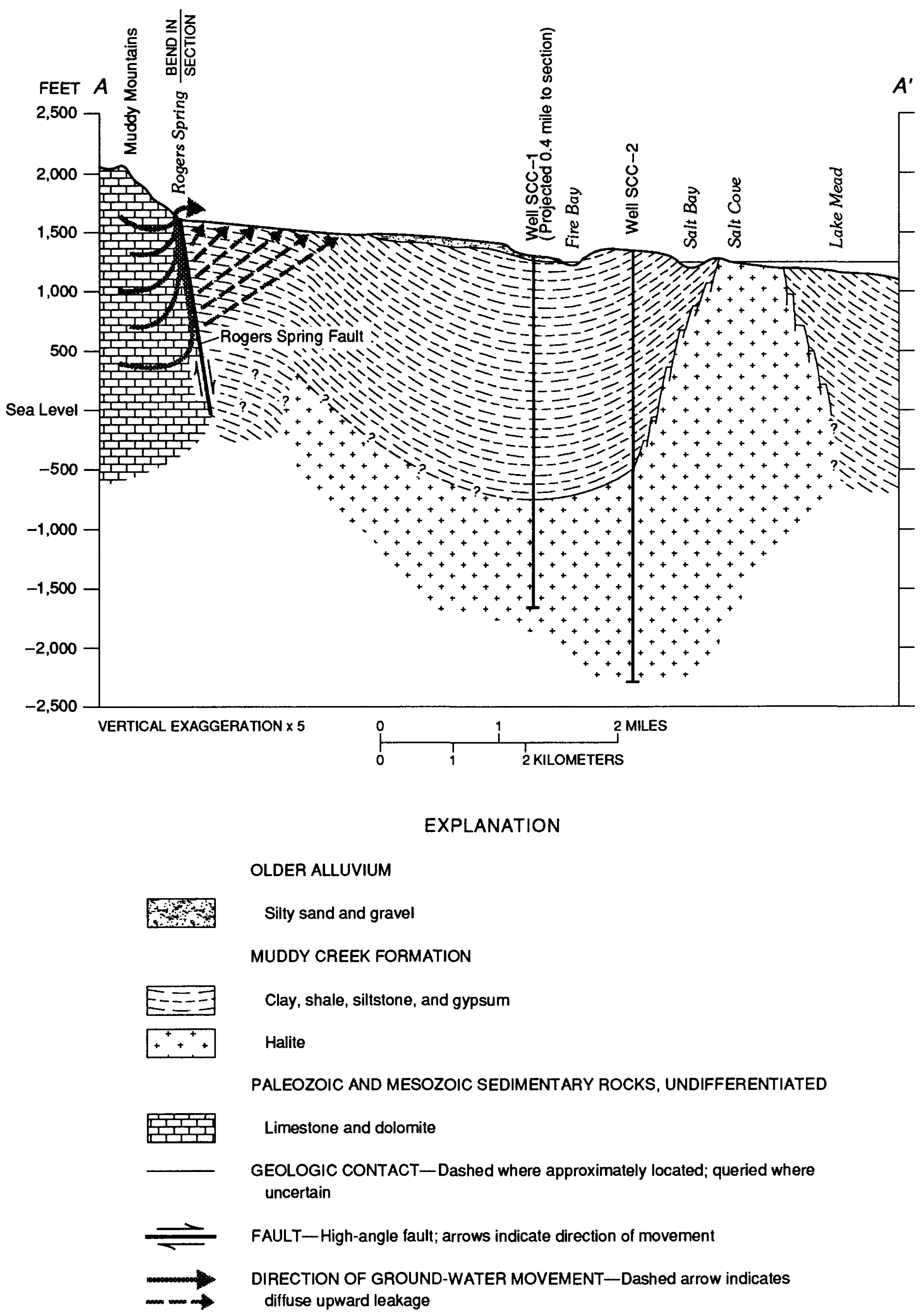


Figure 4. Generalized geologic section between the Muddy Mountains and Lake Mead, Lake Mead National Recreation Area. Trace of section shown in figure 3 and on plate 1.

QUALITY OF WATER

Water samples were collected for chemical analyses from 12 springs and 2 wells as part of this investigation. Three of the springs and one of the wells were sampled for chemical analyses in previous studies and the analyses are used in this report. Chemical analyses of water were available for four additional wells from other sources. Ten of the springs and five of the wells were north of the latitude of Echo Bay (pl. 1). None of the springs and wells sampled as part of this study or sampled as part of earlier studies had water of acceptable quality for drinking water on the basis of the constituents analyzed (U.S. Environmental Protection Agency, 1986a, b). Concentrations of sulfate from all springs and wells exceeded the U.S. Environmental Protection Agency (USEPA) Secondary Maximum Contaminant Level (SMCL) of 250 mg/L (table 7). Chloride exceeded the SMCL of 250 mg/L in samples from all but two springs—Bitter Spring (D-19-67)16bbc and Sandstone Spring (D-20-66$\frac{1}{2}$)18bdc (unsurveyed)—and one well (D-17-68)23dad.

Dissolved-solids concentrations of the water samples ranged from 1,150 to 16,300 mg/L (table 7). The lowest concentration, 1,150 mg/L, was from Sandstone Spring, (D-20-66$\frac{1}{2}$)18bdc (unsurveyed), which discharges from the Aztec Sandstone (Paleozoic and Mesozoic rocks, undifferentiated). The highest concentrations of dissolved solids were in water samples from the mudstone facies of the Muddy Creek Formation; water from spring (D-17-68)21bcb2, Getchel Spring, contained 16,300 mg/L, and water from a nearby well (D-17-68)21bcb1 contained 10,600 mg/L (table 7 and pl. 1).

Overall, the younger alluvium and older alluvium contained ground water with the lowest concentrations, and the mudstone facies of the Muddy Creek Formation contained ground water with the highest concentrations of dissolved solids. Although the lowest concentration of dissolved solids was obtained from Sandstone Spring in the Paleozoic and Mesozoic rocks, undifferentiated, all other samples of water from this unit contained dissolved-solids concentrations of more than 2,900 mg/L (table 7). The range in dissolved-solids concentrations from the four rock units is shown in the following table:

Unit	Number of analyses	Dissolved-solid concentrations, in milligrams per liter
Younger alluvium (and colluvium and alluvium?)	2	2,560 and 3,000
Older alluvium	4	1,560 to 4,710
Muddy Creek Formation	6	3,710 to 16,300
Paleozoic and Mesozoic rocks, undifferentiated	6	1,150 to 9,970

The trilinear diagram and tabulation in figure 5 show the chemical composition of a number of analyses of water from rock units west of Overton Arm. An evaluation of the data in the figure provides generalized information on:

1. The change in composition of ground water as the dissolved solids increase;
2. The quality of water in relation to rock type;
3. The change in composition of ground water along inferred flow paths from near Rogers Spring Fault to Lake Mead; and
4. Effects of dilution of ground water by water from Lake Mead.

The composition of the ground water ranges from a calcium magnesium sodium sulfate type at lower concentrations of dissolved solids to a sodium sulfate type at higher concentrations of dissolved solids (fig. 5). Bicarbonate generally makes up less than 10 percent of the anions in the water at any concentration of dissolved solids. The relative proportions of sulfate, chloride, and bicarbonate do not change greatly as the dissolved-solids concentrations increase. The most significant change in relative composition as the dissolved solids increase is an increase in sodium in relation to calcium and magnesium. This

Table 7. Chemical analyses of water from selected wells, springs, and Lake Mead and water-quality criteria, Lake Mead National Recreation Area, Las Vegas Wash to Virgin River

[Analyses by U.S. Geological Survey, except as indicated. Results in milligrams per liter, except as indicated; all analyses from unfiltered samples. °C; degrees Celsius; μS/cm, microsiemens per centimeter at 25°C. Dashes indicate no data]

Spring or well number	Source	Water-bearing unit	Date of collection	Temperature (°C)	Silica (as SiO_2)	Iron (as Fe)	Manganese (as Mn)	Calcium (as Ca)
(D-16-68)7cb	Well	Younger alluvium (colluvium and alluvium?)	[1]11–10–67	20	---	--------	-------	187
(D-16-68)30ad	Well	Younger alluvium (colluvium and alluvium?)	[1]11–10–67	20	---	--------	-------	422
(D-17-68)21bcb1	Well	Muddy Creek Formation, mudstone facies	5–16–77	16	15	0.020	0.020	470
(D-17-68)21bcb2	Getchel Spring	Muddy Creek Formation, mudstone facies	5–17–78	11	54	.020	.030	470
(D-17-68)23abc	Well	Older alluvium	5–19–78	---	43	.000	.180	300
			[2]2–9–72	---	--	.04	-------	384
			[1]1–31–66	---	43	.29	-------	405
(D-17-68)23dad	Well	Older alluvium	[2]4–4–73	---	---	.05	-------	171
(D-17-68)31dbd	Unnamed spring	Paleozoic and Mesozoic rocks, undifferentiated	5–5–77	22	16	.010	.020	590
(D-18-67)12dda	Rogers Spring	Paleozoic and Mesozoic rocks, undifferentiated	5–4–77	30	17	.030	.010	450
			[1]1–31–66	---	17	.02	-------	443
(D-18-67)13bcb	Unnamed spring	Paleozoic and Mesozoic rocks, undifferentiated	5–4–77	27	16	.010	.010	510
(D-18-68)4bac	Unnamed spring	Paleozoic and Mesozoic rocks, undifferentiated	5–19–78	24	21	.000	.030	510
(D-18-68)6dcc	Blue Point Spring	Paleozoic and Mesozoic rocks, undifferentiated	5–4–77	29	16	.010	.010	500
			[1]11–27–45	---	---	--------	-------	472
U.S. Environmental Protection Agency drinking water Maximum Contaminant Level (MCL) and Secondary Maximum Contaminant Level (SMCL) as noted (U.S.Environmental Protection Agency, 1986b, 1989)				---	---	.3 (SMCL)	.05 (SMCL)	-----

See footnotes at end of table.

Table 7. Chemical analyses of water from selected wells, springs, and Lake Mead and water-quality criteria, Lake Mead National Recreation Area, Las Vegas Wash to Virgin River—Continued

Spring or well number	Magnesium (as Mg)	Sodium (as Na)	Potassium (as K)	Lithium (as Li)	Bicarbonate (as HCO_3)	Carbonate (as CO_3)	Sulfate (as SO_4)	Chloride (as Cl)	Fluoride (as F)	Boron (as B)[3]
(D-16-68)7cb[1]	132	--------[4]478--------		-------	496	0	1,150	316	---	-------
(D-16-68)30ad[1]	133	--------[4]336--------		-------	281	0	1,670	256	---	-------
(D-17-68)21bcb1	340	2,400	140	1.400	150	0	6,300	820	1.9	8.80
(D-17-68)21bcb2	610	3,800	300	-------	270	0	8,800	2,100	2.6	17.0
(D-17-68)23abc	180	470	35	-------	280	0	1,600	440	3.0	1.90
	193	--------[4]526--------		-------	290	0	1,890	475	3.1	------
	216	551	35	-------	296	0	2,060	516	2.2	2.3
(D-17-68)23dad	108	--------[4]196--------		-------	261	0	743	215	2.4	------
(D-17-68)31dbd	510	1,900	130	1.10	240	0	4,800	1,900	2.0	7.30
(D-18-67)12dda	140	300	20	.600	160	0	1,600	340	1.4	1.10
	140	296	22	-------	166	0	1,680	334	1.5	1.2
(D-18-67)13bcb	160	340	23	.700	180	0	1,900	400	1.6	1.30
(D-18-68)4bac	260	600	45	-------	140	0	2,600	600	1.6	2.20
(D-18-68)6dcc	160	340	24	.660	160	0	1,800	380	1.5	1.30
	167	--------[4]317--------		-------	122	0	1,910	355	---	------
U.S. Environmental Protection Agency drinking water Maximum Contaminant Level (MCL) and Secondary Maximum Contaminant Level (SMCL) as noted (U.S.Environmental Protection Agency, 1986b, 1989)	----	-------	--------	-------	----	--	250 (SMCL)	250 (SMCL)	4.0 (MCL)	------

See footnotes at end of table.

Table 7. Chemical analyses of water from selected wells, springs, and Lake Mead and water-quality criteria, Lake Mead National Recreation Area, Las Vegas Wash to Virgin River—Continued

Spring or well number	Nitrogen NO_2+NO_3 (as N)	Phosphate, ortho (as PO_4)	Phosphate, ortho (as P)	Dissolved solids (calculated)	Hardness: Noncarbonate (as $CaCO_3$)	Hardness: Total	Specific conductance (µS/cm at 25°C): Laboratory	Specific conductance (µS/cm at 25°C): Field	pH (laboratory)
(D-16-68)7cb[1]	------	------	------	[5]2,560	602	1,010	3,400	--------	7.7
(D-16-68)30ad[1]	------	------	------	[5]3,000	1,370	1,600	3,700	--------	7.6
(D-17-68)21bcb1	0.01	0.21	0.07	10,600	2,400	2,600	--------	13,000	----
(D-17-68)21bcb2	-----	-----	-----	16,300	3,500	3,700	17,500	17,000	8.1
(D-17-68)23abc	-----	-----	-----	3,210	1,300	1,500	4,182	--------	7.6
	7.3	-----	-----	[5]3,620	1,520	1,760	--------	--------	7.4
	10	-----	-----	4,020	1,660	1,900	5,020	--------	7.1
(D-17-68)23dad	1.5	-----	-----	[5]1,560	656	870	--------	--------	7.6
(D-17-68)31dbd	.05	.21	.07	9,970	3,370	3,570	--------	13,000	7.9
(D-18-67)12dda	.33	.03	.01	2,950	1,570	1,700	--------	3,800	7.9
	.18	-----	-----	3,020	1,540	1,680	3,750	--------	7.3
(D-18-67)13bcb	.10	.03	.01	3,440	1,780	1,930	--------	3,900	----
(D-18-68)4bac	-----	-----	-----	4,710	2,200	2,300	5,620	5,300	7.9
(D-18-68)6dcc	.25	.06	.02	3,300	1,770	1,910	--------	4,250	8.1
	-----	-----	-----	[5]3,300	1,800	1,910	--------	--------	----
U.S. Environmental Protection Agency drinking water Maximum Contaminant Level (MCL) and Secondary Maximum Contaminant Level (SMCL) as noted (U.S.Environmental Protection Agency, 1986b, 1989)	10 (MCL)	-----	-----	500 (SMCL)	-------	------	--------	--------	6.6–8.5 (Acceptable range, SMCL)

See footnotes at end of table.

Table 7. Chemical analyses of water from selected wells, springs, and Lake Mead and water-quality criteria, Lake Mead National Recreation Area, Las Vegas Wash to Virgin River

Spring or well number	Source	Water-bearing unit	Date of collection	Temperature (°C)	Silica (as SiO_2)	Iron (as Fe)	Manganese (as Mn)	Calcium (as Ca)
(D-18-68)7acc	Unnamed spring	Muddy Creek Formation, mudstone facies	5–19–78	20	21	0.010	0.010	560
(D-18-68)8ccb	Unnamed spring	Muddy Creek Formation, mudstone facies	5–19–78	23	89	.020	.040	300
(D-18-68)19bac	Unnamed spring	Muddy Creek Formation, conglomerate facies	5–19–77	20	33	.030	.020	580
(D-18-68)31bdc	Unnamed spring	Muddy Creek Formation, mudstone facies	5–18–78	----	19	.000	.030	310
(D-19-67)16bbc	Bitter Spring	Younger alluvium/Horse Spring Formation	5–3–77	22	33	.010	.010	580
			[1]11–13–67	18	-----	-------	-------	601
(D-20-66½)18bdc (unsurveyed)	Sandstone Spring	Aztec Sandstone (Mesozoic and Paleozoic rocks, undifferentiated)	5–3–77	22	12	.060	.000	210
(D-21-65)9dbb	Well	Older alluvium	10–12–67	29	38	.000	-------	298
Lake Mead at Overton Beach[1]			1–31–66	----	11	-------	-------	88
Lake Mead at Boulder Beach,[6] about 4 miles northwest of Hoover Dam[1]			2–21–66	----	8.5	-------	-------	94
Lake Mead at South Cove,[7] near Sandy Point (Arizona)[8]			1–23–75	13.0	9.1	.01	.03	70
U.S. Environmental Protection Agency drinking water Maximum Contaminant Level (MCL) and Secondary Maximum Contaminant Level (SMCL) as noted (U.S. Environmental Protection Agency, 1986b, 1989)			----------	----	-----	.3 (SMCL)	.05 (SMCL)	----

See footnotes at end of table.

Table 7. Chemical analyses of water from selected wells, springs, and Lake Mead and water-quality criteria, Lake Mead National Recreation Area, Las Vegas Wash to Virgin River—Continued

Spring or well number	Magnesium (as Mg)	Sodium (as Na)	Potassium (as K)	Lithium (as Li)	Bicarbonate (as HCO_3)	Carbonate (as CO_3)	Sulfate (as SO_4)	Chloride (as Cl)	Fluoride (as F)	Boron (as B)[3]
(D-18-68)7acc	180	340	27	-------	220	0	2,100	370	1.5	1.40
(D-18-68)8ccb	720	1,700	130	-------	650	0	4,300	1,700	4.5	6.20
(D-18-68)19bac	250	580	18	0.960	170	0	2,700	680	2.0	1.80
(D-18-68)31bdc	150	760	28	-------	220	0	2,200	430	1.9	3.90
(D-19-67)16bbc	190	270	22	.830	140	0	2,400	160	2.8	1.50
	189	--------[4]251--------		-------	141		2,360	178	----	-------
(D-20-66½)18bdc (unsurveyed)	80	22	4.4	.070	130	0	740	18	1.4	.260
(D-21-65)9dbb	113	--------[4]828--------		-------	98	0	1,200	1,190	1.5	-------
Lake Mead at Overton Beach[1]	26	98	4.9	-------	153	0	282	88	.4	.28
Lake Mead at Boulder Beach,[6] about 4 miles northwest of Hoover Dam[1]	31	114	5.5	-------	151	0	326	104	.4	.21
Lake Mead at South Cove,[7] near Sandy Point (Arizona)[8]	28	86	4.4	-------	164	0	260	110	.4	-------
U.S. Environmental Protection Agency drinking water Maximum Contaminant Level (MCL) and Secondary Maximum Contaminant Level (SMCL) as noted (U.S. Environmental Protection Agency, 1986b, 1989)	----	-------	--------	-------	----	--	250 (SMCL)	250 (SMCL)	4.0 (MCL)	--------

See footnotes at end of table.

Table 7. Chemical analyses of water from selected wells, springs, and Lake Mead and water-quality criteria, Lake Mead National Recreation Area, Las Vegas Wash to Virgin River—Continued

Spring or well number	Nitrogen NO_2+NO_3 (as N)	Phosphate, ortho (as PO_4)	Phosphate, ortho (as P)	Dissolved solids (calculated)	Hardness		Specific conductance (µS/cm at 25°C)		pH (laboratory)
					Noncarbonate (as $CaCO_3$)	Total	Laboratory	Field	
(D-18-68)7acc	-----	-----	-----	3,710	2,000	2,100	4,410	4,190	7.5
(D-18-68)8ccb	-----	-----	-----	9,270	3,200	3,700	11,000	--------	7.7
(D-18-68)19bac	0.00	0.09	0.03	4,930	2,340	2,480	--------	5,600	----
(D-18-68)31bdc	-----	-----	-----	4,010	1,200	1,400	5,193	4,600	8.0
(D-19-67)16bbc	.02	.12	.04	3,730	2,110	2,230	--------	4,200	8.1
	-----	-----	-----	[5]3,670	2,160	2,280	4,100	--------	7.6
(D-20-66½)18bdc (unsurveyed)	.61	.03	.01	1,150	746	853	--------	1,470	8.3
(D-21-65)9dbb	-----	-----	-----	3,720	1,130	1,210	5,700	--------	7.0
Lake Mead at Overton Beach[1]	.5	-----	-----	676	202	328	1,060	--------	8.0
Lake Mead at Boulder Beach,[6] about 4 miles northwest of Hoover Dam[1]	.6	-----	-----	760	236	360	1,180	--------	8.2
Lake Mead at South Cove,[7] near Sandy Point (Arizona)[8]	4.1	.74	-----	654	160	290	995	--------	7.8
U.S. Environmental Protection Agency drinking water Maximum Contaminant Level (MCL) and Secondary Maximum Contaminant Level (SMCL) as noted (U.S. Environmental Protection Agency, 1986b, 1989)	10 (MCL)	-----	-----	500 (SMCL)	-------	-------	--------	--------	6.6–8.5 (Acceptable range, SMCL)

[1]From Rush (1968, table 16).
[2]Analysis by Nevada State Health Division.
[3]U.S. Environmental Protection Agency has no Secondary Maximum Contaminant Level for boron in drinking water. The criterion for water that is used for long-term use on sensitive crops is 0.75 milligrams per liter (U.S. Environmental Protection Agency, 1986a).
[4]Number is sodium plus potassium.
[5]Dissolved-solids calculation does not include silica.
[6]Boulder Beach is outside the study area (see Laney, 1982, fig. 2, for the location).
[7]South Cove is outside the study area (see Laney, 1979a, fig. 2, for the location).
[8]From Laney (1979a, table 3).

change in composition is indicated by the arrow on the trilinear diagram in figure 5.

For convenience, most of the analyses are discussed in groups that represent water quality from distinct sources and rock types. The groups are numbered I, II, III, and IV.

Water types in group I—site 3 [Rogers Spring (D-18-67)12dda], site 4 [spring (D-18-67)13bcb], site 6 [Blue Point Spring (D-18-68)6dcc], site 7 [spring (D-18-68)7acc], and site 15 [Bitter Spring (D-19-67)16bbc]—are representative of water from the regional carbonate-rock aquifer (fig. 5). Average dissolved-solids concentration of these five samples is about 3,400 mg/L. Water at sites 3, 4, and 6 discharges from carbonate rocks along the Rogers Spring Fault on the east side of the Muddy Mountains (fig. 3). Water at site 7, about 0.75 mi downslope from the Rogers Spring Fault, discharges from the mudstone facies of the Muddy Creek Formation. Water at site 15 (Bitter Spring, pl. 1), about 1.5 mi downslope from the fault, discharges from thin deposits of younger alluvium overlying fine-grained rocks of the Horse Spring Formation. Water from sites 7 and 15 is similar in composition to water from the carbonate rocks. Flow along faults and fractures in the Muddy Creek and Horse Spring Formations may provide conduits along which ground water can move from the carbonate rocks and discharge at sites 7 and 15 without significantly reacting with fine-grained deposits of these two formations.

Apparently, some of the ground water from the carbonate-rock aquifer passes through the Rogers Spring Fault and diffuses outward and upward through the older alluvium and the fine-grained mudstone facies of the Muddy Creek Formation (fig. 4, see section entitled "Subsurface Flow in Consolidated Rocks of the Muddy Mountains"). As the water flows through these units, it dissolves gypsum and halite from evaporate deposits and (or) from the sedimentary deposits that contain these minerals. Part of the water emerges from the mudstone facies and the older alluvium at defined springs and seeps (figs. 3 and 5); however, the measurable discharges of the springs and seeps are small compared with that of Rogers Spring and Blue Point Spring. Some of the water moves from the carbonate rocks to the older alluvium either directly or by way of the Muddy Creek Formation.

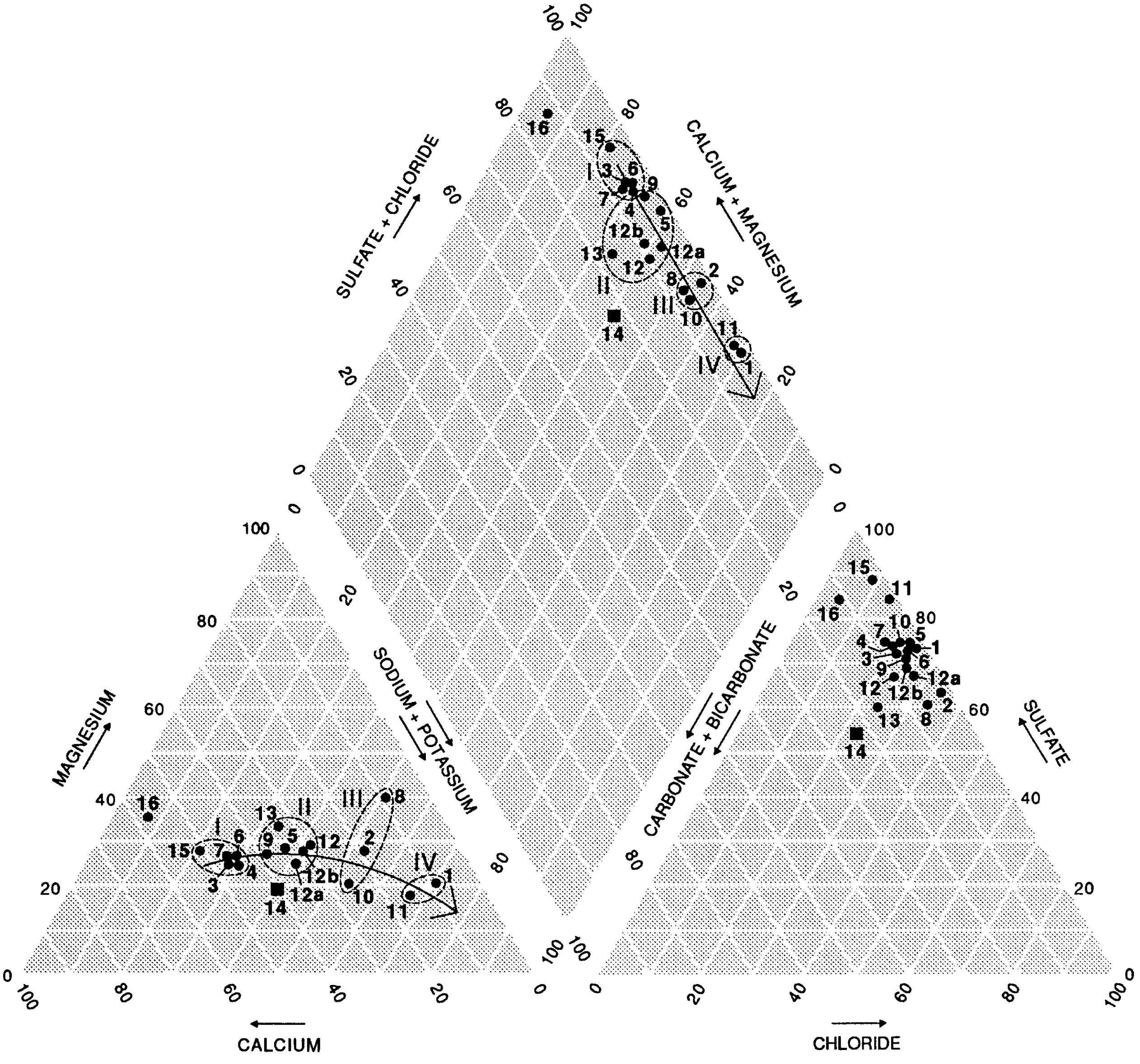
Water types in group II—site 5 [spring (D-18-68)4bac], site 9 [spring (D-18-68)19bac], site 12 [well (D-17-68)23abc], and site 13 [well (D-17-68)23dad]—are representative of water in the older alluvium. Sites 5 and 9 are less than 1.5 mi downslope from the Rogers Spring Fault (fig. 3). The dissolved-solids concentrations in water from site 5 and 9 are 4,710 and 4,930 mg/L, respectively. The dissolved-solids concentrations are greater than in water that discharges along the Rogers Spring Fault. The major change in chemical composition of water in the older alluvium at these two sites as compared with water from the carbonate-rock aquifer is a decrease in calcium and an increase in sodium (fig. 5). The composition of the water at sites 5 and 9 may have resulted from water in the carbonate-rock aquifer moving through the older alluvium and dissolving additional material.

Sites 12 and 13 are wells in the older alluvium at and near Overton Beach at Lake Mead (fig. 3). The dissolved-solids concentrations of water from sites 12 and 13 are 3,210 and 1,560 mg/L, respectively (fig. 5, table 7). The chemical composition of the water from these two wells probably is a mixture of water from the older alluvium and fresh water from Lake Mead.

The effect of infiltration of water from Lake Mead is shown by the composition of the water from the wells at sites 12 and 13 (fig. 5). Well 12, located a few hundred feet from Lake Mead at Overton Beach until it was destroyed in the 1980's, had a reported pumping yield of 80 gal/min and a perforated interval of 10 ft. Transmissivity of the older alluvium at this well is about 700 ft^2/d (table 6). The well was not used as a supply because of poor water quality; the dissolved-solids concentration was 3,210 mg/L in a sample collected in 1978 (fig. 3, table 7).

The well at site 13 is about 0.5 mi southeast of the well at site 12 (fig. 3). Currently (1992), the well head at site 13 is below the water surface of Lake Mead (table 6). The well had a reported pumping yield of 500 gal/min in 1961. The dissolved-solids concentration was 1,560 mg/L in a sample collected in 1973 (fig. 5, table 7).

The results of an aquifer test on well 12 showed that water-level drawdown stabilized after pumping 6 hours (table 6), indicating that hydrologic connection to Lake Mead was



EXPLANATION

→ CHANGE IN COMPOSITION AS DISSOLVED-SOLIDS CONCENTRATIONS INCREASE

COMPOSITION OF WATER—Number is site identifier. (See table on following page)

■ 14 LAKE MEAD

• 10 SPRING OR WELL

IV ◌ COMPOSITIONS OF WATER FROM SPRINGS AND WELLS GROUPED BY WATER-BEARING UNIT OR SOURCE—Roman numeral identifies chemical composition of water from specific watering-bearing unit or source (See below and table on following page)

WATER-BEARING UNITS AND SOURCES

- I PzMz(c), Paleozoic and Mesozoic sedimentary rocks, undifferentiated, and carbonate rocks
- II Qtal, older alluvium
- III PzMz(AS), Paleozoic and Mesozoic sedimentary rocks, undifferentiated, and Aztec Sandstone; Tcm, Muddy Creek Formation, mudstone facies
- IV Tcm, Muddy Creek Formation, mudstone facies

Figure 5. Relative composition of ground water and water from Lake Mead on the west side of Overton Arm, Lake Mead National Recreation Area.

[Water-bearing unit: Tcm = Muddy Creek Formation, mudstone facies; PzMz(AS) = Paleozoic and Mesozoic sedimentary rocks, undifferentiated, and Aztec Sandstone; PzMz(c) = Paleozoic and Mesozoic sedimentary rocks, undifferentiated, and carbonate rocks; Qtal = Older alluvium; Dashes indicate no data. <, less than]

Site identifier	Site location (see fig. 3 or pl. 1)	Site name and description	Water-bearing unit	Dissolved-solids concentration, in milligrams per liter	Discharge, in gallons per minute
1	(D-17-68)21bcb2	Getchel Spring	Tcm	16,300	0.1
2	(D-17-68)31dbd	Unnamed spring, upper Valley of Fire Wash	PzMz(AS)	9,970	1
3	(D-18-67)12dda	Rogers Spring	PzMz(c)	2,950	417
4	(D-18-67)13bcb	Unnamed spring on Rogers Spring Fault	PzMz(c)	3,440	2
5	(D-18-68)4bac	Unnamed spring, lower Valley of Fire Wash	Qtal	4,710	20
6	(D-18-68)6dcc	Blue Point Spring	PzMz(c)	3,300	248
7	(D-18-68)7acc	Unnamed spring, 0.5 mile south of Blue Point Spring	Tcm	3,710	7.5
8	(D-18-68)8ccb	Unnamed spring, 0.5 mile southeast of spring 7	Tcm	9,270	([1])
9	(D-18-68)19bac	Unnamed spring, northwest of Rogers Bay	Qtal	4,930	2
10	(D-18-68)31bdc	Unnamed spring west of Calico Bay	Tcm	4,010	([1])
11	(D-17-68)21bcb1	Dug well near Getchel Spring	Tcm	10,600	----
12	(D-17-68)23abc	Well at Overton Beach (Collected 5–19–78)	Qtal	3,210	80
12a	Do	Do (Collected 2–9–72)	Do	3,620	----
12b	Do	Do (Collected 1–31–66)	Do	4,020	----
13	(D-17-68)23dad	Stauffer Chemical Company well, south of Overton Beach	Qtal	1,560	500
14	Overton Beach	Lake Mead	----------	676	----
15	(D-19-67)16bbc	Bitter Spring (pl. 1 only)	PzMz(c)	3,730	10
16	(D-20-66$\frac{1}{2}$)18bdc, unsurveyed	Sandstone Spring (pl. 1 only)	PzMz(AS)	1,150	<.1

[1]Spring discharge too diffuse to measure.

Figure 5.—Continued

established. The reported discharge of 500 gal/min from well 13 and its location suggest a similar connection to the water of the lake. The relative compositions of water from the wells and Lake Mead are shown on the trilinear diagram (fig. 5). The composition of the water from both wells is shifted toward the composition of the lake as compared with other analyses of ground water in the area.

The composition of the water at the well sites before the impoundment of Lake Mead is unknown. The absence of these data prevents developing definite mixing relations between original native water at the sites and water from Lake Mead on the trilinear diagram in figure 5; however, inferences can be made about the effects of dilution by water from the lake at the sites by comparing the composition of the water in the older alluvium at sites 12 and 13 to that in the unit from sites 5 and 9 and Lake Mead. Site 14 on the trilinear diagram (fig. 5) represents the composition of water from Lake Mead at Overton Beach. If the chemical composition of the ground water in the older alluvium at sites 12 and 13 before impoundment of Lake Mead was similar to that in the older alluvium at sites 5 and 9, the positions of sites 12 and 13 on the cation/anion diamond (fig. 5) about midway between sites 5 and 9 and site 14 may represent an approximate mixing relation between native water in the older alluvium and water from Lake Mead.

Additional support for this mixing relation is suggested from a comparison of two other chemical analyses of water collected at site 12 in 1966 and 1972. The sample at site 12 discussed above was collected in 1978. The three analyses show a decrease of all chemical constituents with time, except fluoride (table 7). Dissolved-solids concentrations by year for the three samples are: 1966, 4,020 mg/L; 1972, 3,620 mg/L; and 1978, 3,210 mg/L. These two additional analyses plot close to the sample collected in 1978 on the cation and anion triangles and about halfway between analyses from site 14 and 5 on the cation/anion diamond. These limited data suggest that continuous pumping of a properly located well in the older alluvium near Overton Beach might purge the aquifer of the soluble minerals and result in pumped water similar in chemical composition to that of Lake Mead. The length of time required to achieve this result cannot be determined from the available data.

Group III contains the plots of water types from site 2 [spring (D-17-68)31dbd], site 8 [spring (D-18-68)8ccb], and site 10 [spring (D-18-68)31bdc] (fig. 3). The relative chemical composition of water from the three sites plot on the general trend of changing composition as the dissolved solids increase (fig. 5). The spring at site 2 discharges from the Aztec Sandstone west of Rogers Spring Fault at the contact with the Chinle Formation (fig. 3, table 5). The water sample from site 2 contained 9,970 mg/L of dissolved solids.

Springs at sites 8 and 10 discharge from the mudstone facies of the Muddy Creek Formation, but have considerable differences in dissolved-solids concentrations—9,270 mg/L at site 8 compared with 4,010 mg/L at site 10. Site 8 is unusual because it is as close to the carbonate rocks along the Rogers Spring Fault as are sites 5 and 9 but has a dissolved-solids concentration that is about two times larger (fig. 5). In addition, the relative proportions of cations in the water from site 8 are different than those from any other sample and do not plot on the cation trend line in the trilinear diagram. Water movement was not detected at the site when the sample was collected (table 5). The sample was collected from ponded water that may have been concentrated by evaporation.

Site 10 is about 3.5 mi downslope from the Rogers Spring Fault, yet has smaller dissolved-solids concentrations than springs closer to the fault—site 5 and 9 (fig. 5). In addition, the relative chemical composition plots farther down the dissolved-solids trend line than other samples that have similar dissolved-solids concentrations. Site 10 is along a northwestward-trending fault that may provide a more direct connection to flow from the carbonate-rock aquifer than sites closer to the Rogers Spring Fault. The chemical composition of the water from site 10, as compared with other water samples, may have resulted from a more direct flow path, shorter residence time, or the site being a greater distance from the influence of halite and gypsum deposits in the subsurface.

Group IV contains site 1 [Getchel Spring (D-17-68)21bcb2] and site 11 [well (D-17-68) 21bcb1]. Water from these two sites had the highest concentrations of dissolved solids of any water sample from the study area—16,300 mg/L from site 1 and 10,600 mg/L from site 11. Both sites are in the mudstone facies of the Muddy Creek Formation north of the Rogers Spring Fault, but water at the sites may have originated in the carbonate rocks, which are about 1.5 mi to the west. The sites are near the crest of a westward-plunging anticline. Data are not available to indicate the likelihood of halite and gypsum at shallow depth that could have affected the composition of the water from the sites.

Chemical composition of water from site 16 [Sandstone Spring (D-20-66$\frac{1}{2}$)18bdc] does not plot on the dissolved-solids trend line as do the compositions of water from the other sites. Sandstone Spring is in Pinto Valley about 11 mi southwest of Echo Bay (pl. 1). Water discharges from the Aztec Sandstone but has markedly different chemical composition from that of water from the Aztec Sandstone at site 2. Site 16 probably is the discharge point of a local flow system in the Black Mountains (pl. 1); whereas, water at site 2 probably originates in the carbonate-rock aquifer.

FAVORABLE AREAS FOR GROUND-WATER DEVELOPMENT

The potential for developing potable water supplies from wells in the area between Las Vegas Wash and the Virgin River is poor. Rocks of low permeability underlie much of the area, and the water is of poor quality for drinking. The most likely areas for developing potable water supplies from wells are in the younger alluvium and older alluvium near Lake Mead and most of these areas are not highly favorable. The intent of developing wells in these areas would be to induce infiltration of water from Lake Mead. The quality of water in Lake Mead is better than that of any spring or well that was sampled in the study area (table 7).

The areas considered for possible ground-water development are:

Area 1—Near Overton Beach;

Area 2—West of Callville Bay;

Area 3—Near Middle Point; and

Area 4—Lower Moapa Valley.

The areas are listed in order of decreasing favorability of obtaining potable water supplies from wells; however, the difference between the first three areas is negligible. Usable quantities of water probably can be obtained from wells in these areas, but the quality of water will be no better than that of Lake Mead and probably will be of poorer quality. Drilling for potable water in these areas should be considered only as exploration. Because this study is a reconnaissance evaluation, a detailed examination of these areas is needed before test-well drilling.

Area 1—Near Overton Beach

Well (D-17-68)23abc was drilled to a depth of 175 ft in the older alluvium at Overton Beach (tables 2 and 5). Well (D-17-68)23dad was drilled to a depth of 211 ft in the older alluvium about 0.75 mi southeast of Overton Beach (pl. 1, tables 2 and 5); the well encountered the mudstone facies of the Muddy Creek Formation at a depth of 170 ft. Water from both wells exceeded the USEPA SMCL (1989) for sulfate. Water from well (D-17-68)23abc exceeded the SMCL for chloride; dissolved-solids concentrations in three samples ranged from 3,210 to 4,020 mg/L (table 7). In water from well (D-17-68)23dad, the dissolved-solids concentration was 1,560 mg/L. This was the best quality water of any sample from the older alluvium in the study area.

A 32-hour aquifer test was conducted on well (D-17-68)23abc at Overton Beach in 1964 (table 6). The results of the test showed that the water-level drawdown in the pumping well stabilized at 120 ft below the land surface after about 6 hours of pumping at a reported rate of 80 gal/min, which suggests that the drawdown cone reached a steady recharge boundary. The only nearby source of water is Lake Mead, which at the time of the aquifer test was about 500 ft from the well site.

In 1961, well (D-17-68)23dad was reported to have been pumped at a rate of 500 gal/min during a pumping test. No details are available on length of pumping period and drawdown in the pumping well. This well was drilled from a land-surface altitude of about 1,150 ft, which is beneath the present (1993) level of Lake Mead.

The results of pumping and chemical analyses indicate that usable quantities of water can be obtained from the older alluvium in this area but the quality of water may not be acceptable for drinking. Although water pumped from the wells is mostly from Lake Mead, the quality of water was not acceptable because of solution of gypsum and other evaporite minerals that are in the fine-grained part of the older alluvium. Part of the dissolved solids from well (D-17-68)23dad may have come from the Muddy Creek Formation encountered in the lower part of the well.

Water of better quality might be obtained in this area by careful site analysis and drilling. Exploratory test wells would need to drilled into the sand and gravel deposits of the older alluvium at convenient locations along the shore of Lake Mead from Overton Beach southward to well (D-17-68)23dad. Likely locations are immediately southeast of the marina at Overton Beach. The well should be drilled by the cable-tool method and as close as possible to the maximum expected level of Lake Mead (1,221 ft). As the well is drilled, solid casing needs to be installed closely behind the drill bit. This technique would enable the sampling of water from very small zones at the bottom of the casing during the drilling, which is necessary to assess the quality of the water with depth. Other well-drilling methods could be used, but it is critical that uncontaminated point samples be collected as the well bore is deepened. The well should be drilled to a depth of 150 to 200 ft or until mudstone of the Muddy Creek Formation is encountered. If the mudstone is encountered, the drilling should be stopped and the mudstone cemented off from the well. Information from this method of drilling and sampling may delineate zones of water of poor quality and help to determine the section of the well to be screened or perforated. An aquifer test of 1- to 2-days duration should be conducted on the finished well. Specific conductance of the water should be monitored during the test to determine changes in dissolved-solids concentrations as pumping is continued. Pumping should be continued long enough to determine if the water quality improves within a reasonable amount of pumping time. Reduction of specific conductance with pumping time may give some indication of the flushing of soluble minerals from the aquifer. Water samples should be collected for chemical analysis.

Area 2—West of Callville Bay

An exploratory well for water supply, (D-21-65)9dbb, was drilled at the marina at Callville Bay in 1967 (pl. 1 and table 6). Water from the well contained 3,700 mg/L of dissolved solids (table 7). Sulfate and chloride concentrations were 1,200 and 1,190 mg/L, respectively. The well penetrated 178 ft of older alluvium and 22 ft of fine-grained deposits of the Horse Spring Formation.

A site for an exploration well in this area is west of Callville Bay at the south end of the peninsula near the west boundary of sec. 16, T. 21 S., R. 65 E. (pl. 1). The peninsula is underlain by the older alluvium, some of which is very coarse grained and would have considerable permeability. About 160 ft of the unit is exposed above the water of Lake Mead, but it is not known how much of the unit is beneath and saturated by the lake. An exploration well should be drilled at the southern end of the peninsula as close to the lake as possible. The older alluvium may be underlain by volcanic rocks or gypsiferous fine-grained deposits of the Horse Spring Formation. If either of these rock units is encountered, the drilling should be stopped. Similar drilling techniques that were recommended for the well near Overton Beach need to be used at this site.

Area 3—Near Middle Point

Deposits of the older alluvium that fill a relic river channel have potential for developing a water supply in a remote roadless area near Middle Point (pl. 1). The relic river channel occupies a syncline that was formed in rocks of the Muddy Creek Formation (undifferentiated). Beds in the older alluvium along the margins of the syncline dip similarly to those in the surrounding Muddy Creek Formation—as much as 50° (pl. 1). Younger parts of the older alluvium may unconformably overlie the older parts near the center of the syncline suggesting that deposition and folding of the rocks are in part contemporaneous.

The older alluvium in this area consists of sand, gravel, silt, and conglomerate. A large part of the deposit should have considerable permeability. Hydraulic connection of the deposits and Lake Mead probably occurs near the center of the syncline at either end of the relic channel. As is the case in the other areas for exploration, the water obtained at this location is from water that has infiltrated into the older alluvium from Lake Mead. The most favorable site for an exploratory test well would be near the center of the syncline at the southwest end of the channel as close to the maximum level of Lake Mead as possible. Drilling and sampling techniques similar to those used for the well near Overton Beach need to be used in this area.

Area 4—Lower Moapa Valley

Wells that may yield large quantities of water could be drilled in the younger alluvium near the mouth of the Muddy River in Moapa Valley (pl. 1). The younger alluvium and the underlying alluvium and colluvium, if present, may be as much as 100 ft thick. Wells that produce as much as 1,000 gal/min have been drilled into the younger alluvium in the Moapa Valley, for example well (D-16-27)24ad(?) (table 5) and other wells in Rush (1968, table 14). But, the quality of water from wells in Moapa Valley was poor for drinking purposes and the chemical analyses showed that sulfate and chloride exceeded the SMCL of 250 mg/L (U.S. Environmental Protection Agency, 1986a). If wells were drilled near Lake Mead in the lower part of Moapa Valley, the downvalley subsurface flow probably is great enough that only part of the discharge of the well would come from infiltration from Lake Mead. Thus, the quality might not be much better than that of the ground water moving down the valley toward the lake.

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