HYDROLOGY AND WATER QUALITY OF THE BEAVER DAM WASH AREA, WASHINGTON COUNTY, UTAH, LINCOLN COUNTY, NEVADA, AND MOHAVE COUNTY, ARIZONA

By Walter F. Holmes, George E. Pyper, Joseph S. Gates, Donald H. Schaefer, and Kidd M. Waddell

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
acre-foot (acre-ft)	0.001233	cubic hectometer
	1,233	cubic meter
acre-foot per year (acre-ft/yr)	0.00003907	cubic meter per second
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per mile ($ft^3/s/mi$)	0.0176	cubic meter per second per kilometer
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
foot per second (ft/sec)	0.3048	meter per second
foot squared per day (ft^2/d)	0.0929	meter squared per day
gallon per day (gal/day)	3.7854	liter per day
gallon per minute (gal/min)	0.06308	liter per second
inch (in.)	2.54	centimeter
inch per year (in/yr)	2.54	centimeter per year
mile (mi)	1.609	kilometer
square mile (mi^2)	2.59	square kilometer

Water temperature is reported 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.

Chemical concentration and water temperature are reported only in metric units. Chemical concentration is reported in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is reported in microsiemens per centimeter at 25 degrees Celsius (µS/cm).

Hydrology and Water Quality of the Beaver Dam Wash area, Washington County, Utah, Lincoln County, Nevada, and Mohave County, Arizona

By Walter F. Holmes, George E. Pyper, Joseph S. Gates, Donald H. Schaefer, and Kidd M. Waddell

ABSTRACT

Streamflow characteristics at sites on Beaver Dam Wash were determined from field measurements, gaging-station records, and correlation of records. Recharge to the alluvial channel-fill deposits on Beaver Dam Wash was calculated using long-term estimates of streamflow (1970-95) sites and flood-flow frequencies at sites on Beaver Dam Wash were calculated on the basis of regional relations. The 1970-95 estimated average discharge of Beaver Dam Wash at Enterprise, Utah, was 11 cubic feet per second; at Motoqua, Utah, 28 cubic feet per second; at Beaver Dam gage, 8 cubic feet per second; and Beaver Dam Wash at mouth, 12.5 cubic feet per second.

Ground water in the Beaver Dam Wash area is present in consolidated rocks and semiconsolidated and unconsolidated basin-fill and alluvial channel-fill deposits. Ground water in consolidated rocks in the higher-altitude mountainous areas provides the base flow of perennial reaches of streams and discharge to springs. Few wells produce water from consolidated rocks in the Beaver Dam Wash area.

Ground water in the semiconsolidated and unconsolidated basin-fill deposits is present in the Muddy Creek Formation, the post-Muddy Creek Tertiary gravels, the Quaternary alluvial-fan and tufa deposits, and in the Quaternary alluvial channel-fill deposits. Alluvial channel-fill deposits of Quaternary age are coarse grained and well sorted, yield large amounts of water to wells and springs, and are the most important water-producing formation in the Beaver Dam Wash area. Recharge to the alluvial channel-fill deposits is from stream infiltration and subsurface inflow from the Muddy Creek Formation. Long-term average (1970-95) recharge was estimated to be about 18,000 acre-feet per year. About 4,300 acre-feet is discharged by springs, 3,000 acre-feet is discharged by wells, about 8,450 acre-feet is discharged as subsurface outflow to the Virgin River alluvium or to the Muddy Creek Formation, and about 750 acre-feet is discharged by evapotranspiration.

Ground water near the mouth of Beaver Dam Wash is a mixture of a calcium-magnesium-sulfate type water in the Muddy Creek Formation or the overlying Tertiary-age gravels and a calcium-bicarbonate type water in the channel-fill deposits of Beaver Dam Wash. On the basis of the estimated range of dissolved-solids concentration of water discharging at the mouth of Beaver Dam Wash, the concentration of the inflow from Beaver Dam Wash is estimated to be about 1,300 mg/L lower than that of the Virgin River. This inflow provides some dilution to the concentration of dissolved solids in the Virgin River. Because the discharge of Beaver Dam Wash is quite small relative to that of the Virgin River, the amount of dilution is small during most years.

INTRODUCTION

The Beaver Dam Wash study area includes the southwestern corner of Utah, the southeastern edge of Nevada, and the northwestern corner of Arizona (fig. 1). The study area coincides with the Beaver Dam Wash drainage in the northern part. The southern part of the study area incorporates much of the topographically low area between the Beaver Dam and Virgin Mountains and Sand Hollow Wash, including the valley area south of the Virgin River. The total drainage area is about 820 mi^2 of which 51 percent is in Utah, 33 percent is in Nevada, and 16 percent is in Arizona. The Beaver Dam Wash area is experiencing rapid population and economic growth. The population of St. George, Utah, which is about 20 mi east of Beaver Dam Wash, increased from 11,350 in 1980 to 28,502 in 1990; and the population of Mesquite, Nevada, which is about 10 mi southwest of Beaver Dam Wash, increased from 500 in 1980 to 1,871 in 1990. Water is

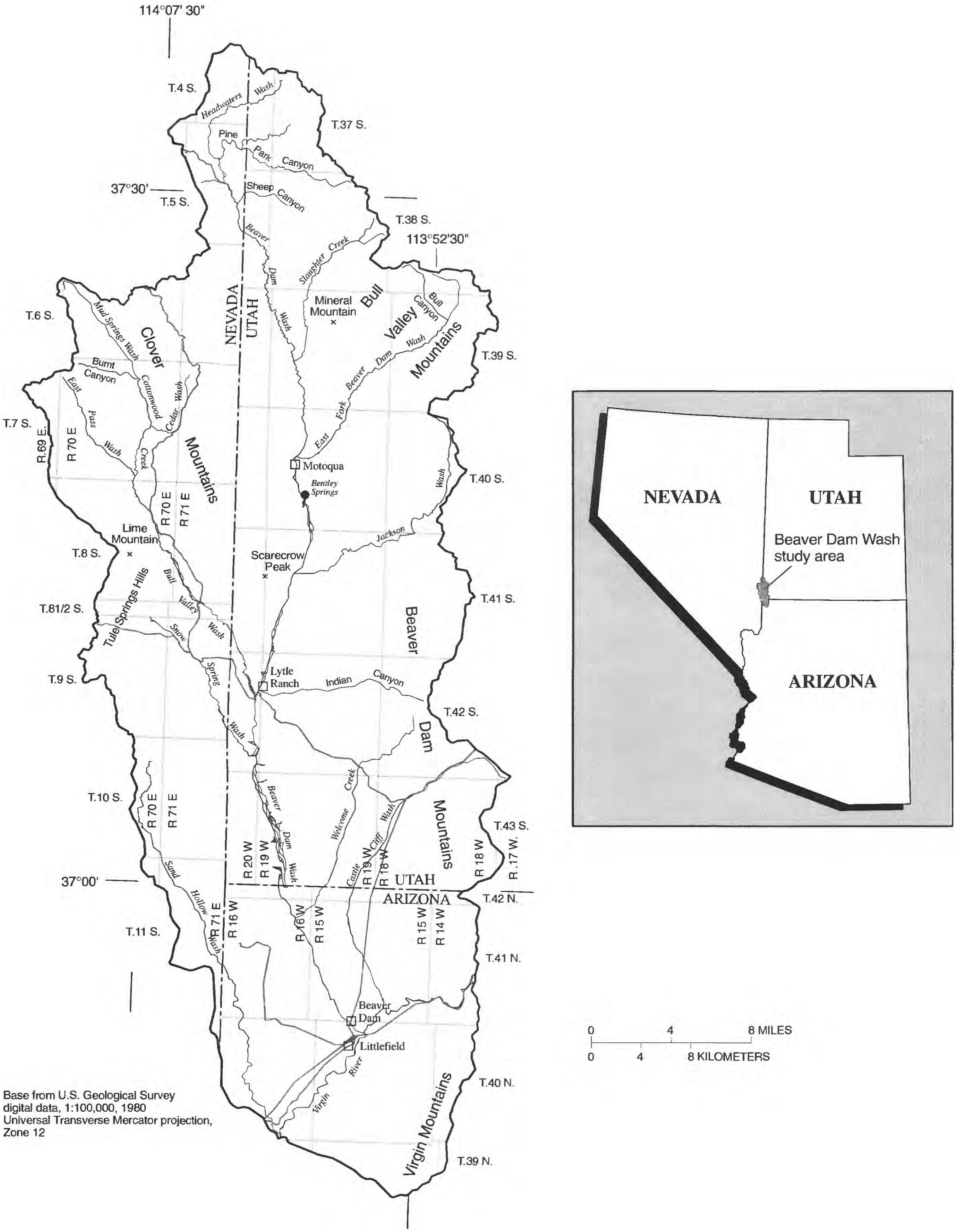


Figure 1. Location of Beaver Dam Wash study area, Utah, Nevada, and Arizona.

needed to supply increasing municipal, industrial, agricultural, and domestic use in this area. Although annual precipitation is as much as 23 in. in the mountains in the northern part of the study area, it is less than 7 in. in the southern part, where most of the population lives.

The upper drainage of Beaver Dam Wash, the largest drainage in the study area, is in the Beaver Dam and Bull Valley Mountains of Utah and the Clover Mountains of Nevada. Beaver Dam Wash generally extends southward to its confluence with the Virgin River. The U.S. Geological Survey, in cooperation with the Utah Department of Natural Resources, Division of Water Resources; Nevada Department of Conservation and Natural Resources; Arizona Department of Water Resources; and Bureau of Land Management, completed this study to improve the knowledge of the surface- and ground-water resources of the Beaver Dam Wash area. Numbering systems used for data-collection sites in Utah, Arizona, and Nevada are shown in figure 2.

Purpose and Scope

This report defines the ground- and surface-water resources of the Beaver Dam Wash study area and their chemical quality. The scope of this report was limited by time and funding constraints. Because of the small amount of surface water in the area and because the potential for ground-water development was unknown, the emphasis of this study was on the ground-water resources.

Because of a lack of data, the occurrence of ground water in Beaver Dam Wash was poorly known in most of its drainage and aquifers were not well defined. Although about 200 wells had been drilled in the lower part of the wash in Arizona, especially in and near the alluvial channel-fill deposits of Quaternary age, only about 20 wells had been drilled in the channel-fill deposits in the Utah and Nevada parts of the wash, and less than 10 wells had been drilled into the basin-fill deposits older than channel fill. As a result, little was known about most of the unconsolidated basin-fill deposits of the Beaver Dam Wash area, their hydrologic characteristics, the extent and characteristics of any aquifers within these deposits, and variations in quality of ground water. In particular, it was not known whether coarse-grained, well-sorted, permeable basin fill has been deposited along the flanks of the Beaver Dam Mountains, and if so, whether a significant part of this material is saturated and contains fresh water. The primary focus of this study was to obtain more information on ground water in the channel-fill deposits and in the basin-fill deposits older than channel fill.

Methods of Investigation

A phased approach was used to obtain information on occurrence of ground water and aquifers in the Beaver Dam Wash area. First, all available information was compiled on existing wells, including six test wells drilled by the Bureau of Land Management in the lower part of the wash in Arizona in the late summer and fall of 1992. Next, about 100 wells were inventoried in the field, water levels were measured, and water samples were collected from selected wells for chemical analysis. Geophysical surveys then were done in selected areas accessible to vehicles. Direct-current resistivity surveys were done along five roughly northeast-southwest sections and were joined by seven soundings to form a sixth north-south section (fig. 3) to obtain information on the thickness, saturated thickness, and general lithology of the basin-fill and channel-fill deposits and general quality of ground water. Seismic-refraction surveys were done along seven shorter lines located along resistivity sections (fig. 3) where resistivity data indicated the potential for aquifers with good-quality water in the basin-fill deposits or where specific information was needed to help locate a test well. The seismic data were used to help estimate thickness and saturated thickness of the basin-fill deposits and, at one location, the thickness of the channel-fill deposits and also the general basin-fill lithology.

Four locations were then selected for test wells using geophysical, geohydrologic, and other data. Three of these test wells were drilled to obtain specific information on the lithology of the basin-fill deposits and, at one of the three locations, the alluvial channel-fill deposits of Quaternary age. The fourth test well was drilled into the Navajo Sandstone in the northeastern part of the drainage to obtain information on ground water in that unit. In addition, water levels were measured in all the test wells to obtain accurate depths to water, and water samples were collected during air-rotary drilling and analyzed to obtain the approximate quality of water. Additional data from these as well as other wells in the area are published in a hydrologic-data report by Enright (1996). Finally, a slug test was done on an existing well completed in the Muddy Creek Formation to obtain an estimate of hydraulic conductiv-

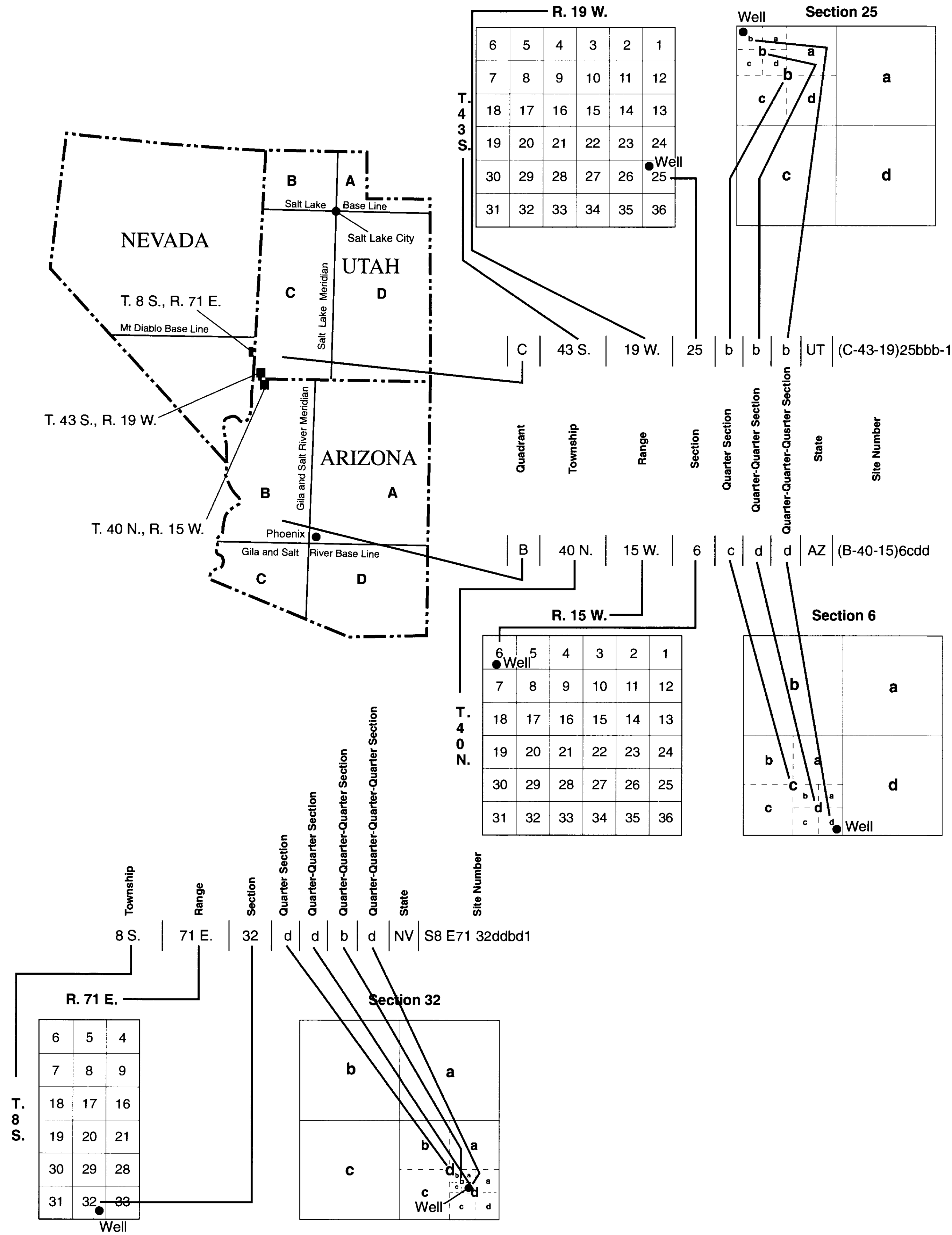


Figure 2. Numbering system for data-collection sites in Utah, Nevada, and Arizona.

EXPLANATION

Separate numbering systems are used in this report for data-collection sites in Utah, Nevada, Arizona, and in the Arizona part of the Navajo Indian Reservation. The numbering systems for the three States are based on the system of the Bureau of Land Management for land subdivision, which uses survey, quadrant, township, range, section, and position within the section to locate data-collection sites.

Each survey is divided into four quadrants by the intersection of a principal meridian and base line: the uppercase letter A denotes the northeast quadrant; B, the northwest quadrant; C, the southwest quadrant; and D, the southeast quadrant. Nevada does not use this part of the system. Townships are numbered starting at the base line and increase northward and southward. Ranges are numbered starting at the principal meridian and the numbers increase eastward and westward. A township defined by township and range numbers is subdivided into 36 sections and numbered as shown. Each section is subdivided into quarter sections, quarter-quarter sections, and quarter-quarter-quarter sections, which specify the location to within a 10-acre tract. For each subdivision of the section, the lowercase letter a denotes the northeast quarter; b, the northwest quarter; c, the southwest quarter; and d, the southeast quarter.

Utah

In Utah, the Bureau of Land Management system of land subdivision is used with two surveys. The Salt Lake Meridian and Salt Lake Base Line are used for all of Utah except for a small area in the northeast part of the State where the Uintah Meridian and Uintah Base Line are used.

The Utah number has the same format as the Arizona number. If there is no letter before the parentheses, the Salt Lake Meridian and Salt Lake Base Line apply. A well site has a number and three letters added as a suffix after the parentheses if a quarter-quarter-quarter section is given. A spring site has a capital letter "S" after the suffix. All other site numbers do not have a suffix.

Nevada

In Nevada, the number used from left to right specifies the township north or south of the Mt. Diablo Base Line, the range east of the Mt. Diablo Meridian, the section, and the subdivision of the section. The subdivision of the section is the same as in Utah and Arizona except that Nevada sections are subdivided four times to specify the location to within a 2.5-acre tract. The suffix is used in the same manner as in Arizona. For example, a well located within the SW1/4NW1/4SW1/4SW1/4 section 32, Township 8 South, Range 71 East, would have the number S8 E71 32ddbd1.

Arizona

The numbering system used in Arizona, except on the Navajo Indian Reservation, is based on the Bureau of Land Management system of land subdivision and the Gila and Salt River Meridian and Gila and Salt River Base Line. Within the parentheses, the capital letter denotes the quadrant and is followed by the township and range numbers. The section number is next, followed by three lowercase letters denoting the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section. If there is more than one data-collection site in the 10-acre tract, consecutive numbers beginning with 1 are added as suffixes, and a spring site has a capital letter "S" after the suffix.

Figure 2. Numbering system for data-collection sites in Utah, Nevada, and Arizona—Continued.

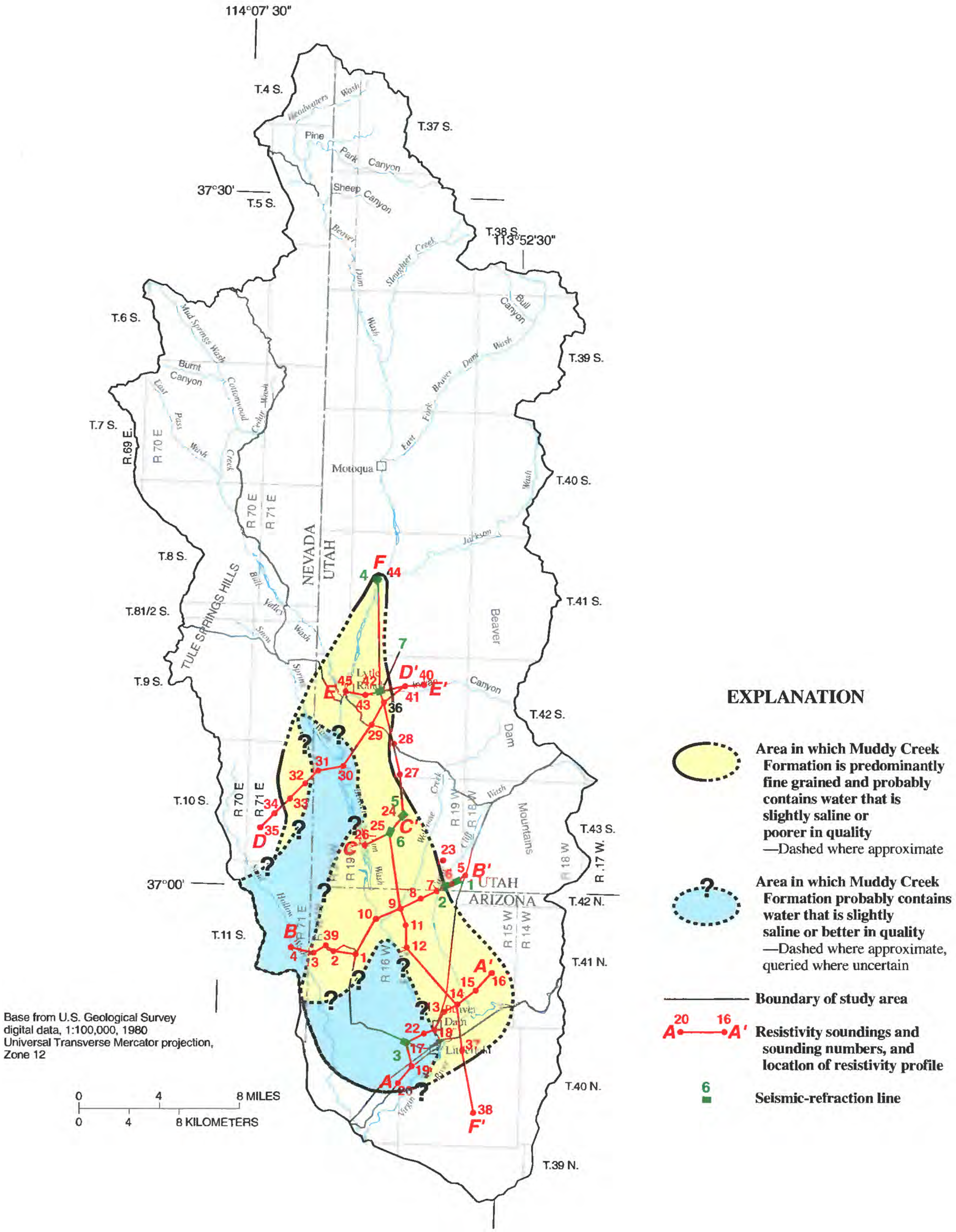


Figure 3. Location of resistivity soundings, seismic-refraction lines, the area in which the Muddy Creek Formation is predominantly fine grained and probably contains water that is slightly saline or poorer in quality, and areas in which the Muddy Creek Formation probably contains water that is slightly saline or better in quality, Beaver Dam Wash area.

ity. Aquifer tests were done on two wells to obtain values of transmissivity for the channel-fill deposits.

To obtain information on the flow regime of Beaver Dam Wash, streamflow was monitored at a gaging station and seepage studies were done along the wash during the spring and fall. Long-term average flows at selected sites were estimated by correlating short-term records from sites in the Beaver Dam Wash area with long-term records from sites in adjacent basins, and by use of regional equations developed for the area including Beaver Dam Wash drainage.

Responsibilities and Acknowledgments

U.S. Geological Survey personnel responsible for completion of this study are listed below. Walter F. Holmes provided overall supervision, directed the test drilling and aquifer testing, and interpreted most of the ground-water data. George E. Pyper was the project chief and the liaison with the Bureau of Land Management and the U.S. Fish and Wildlife Service, obtained all necessary permits, and collected most of the surface-water data. Joseph S. Gates planned and generally coordinated the geophysical surveys and interpreted much of the geologic and geohydrologic data. Donald H. Schaefer directed the collection of all seismic data and interpreted these data. Kidd M. Waddell interpreted the surface-water and water-quality data. In addition, Michael Enright collected most of the ground-water and some of the surface-water data, including water-quality data, and prepared a hydrologic-data report (Enright, 1996), and Adel A.R. Zohdy directed the collection of all direct-current resistivity data and interpreted these data (Zohdy and others, 1994).

A special thanks to the residents of the Beaver Dam Wash area, who provided access to wells, streams, and springs and also provided considerable support to the field investigations, and to Joseph Gates and George Pyper, who assisted with the completion of this report as volunteers after retirement.

GEOLOGY AND GEOHYDROLOGIC UNITS

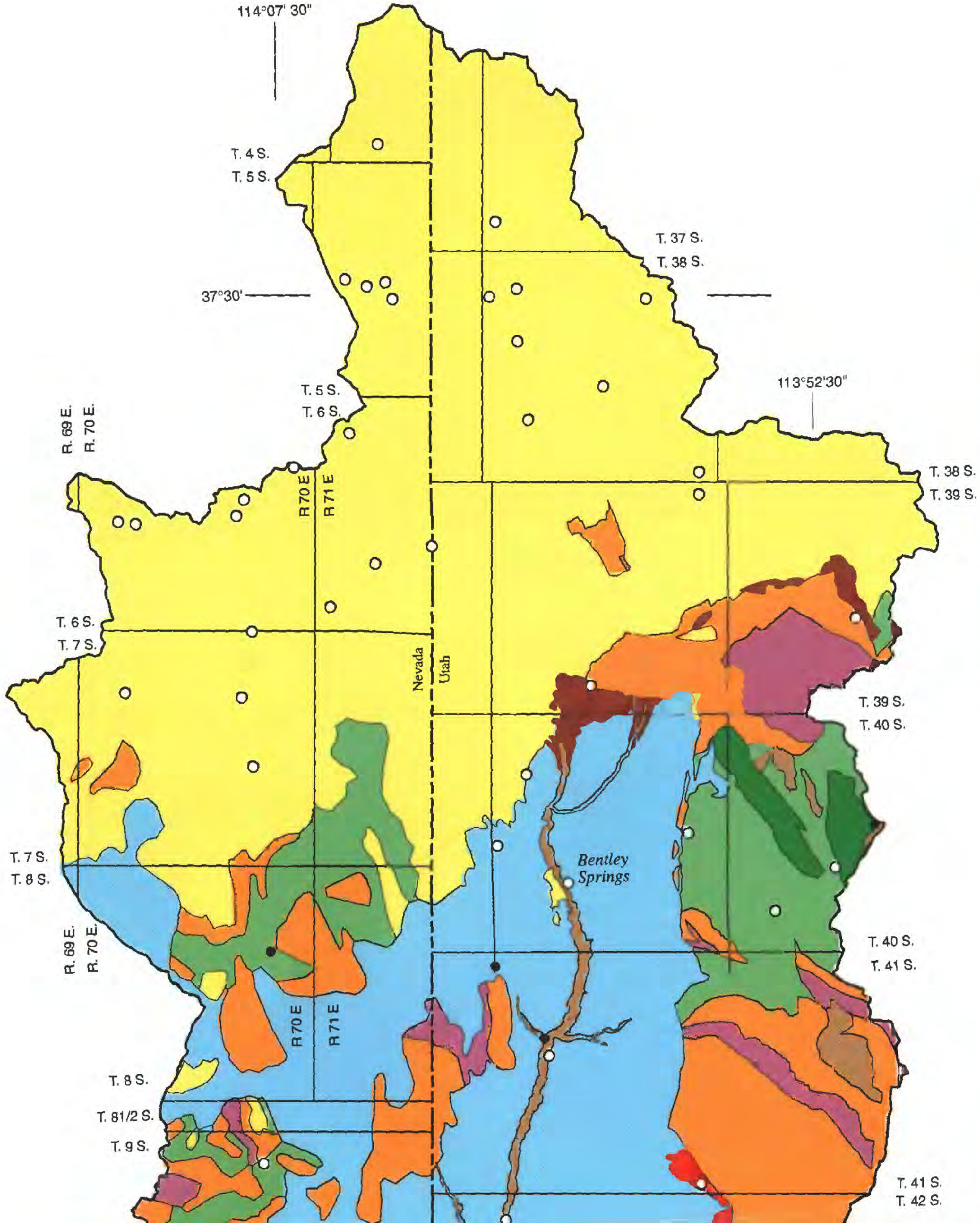
Rocks that range from Precambrian to Holocene age and that represent all geologic eras are exposed in the Beaver Dam Wash area. A generalized geohydrologic map of the study area (fig. 4) shows nine units compiled from maps prepared by Hintze (1986a, pl. 2), Moore (1972, pl. 1),Wilson and Moore (1959), Blank and Kucks (1989, pl. 3), Hintze (1980), Stewart and Carlson (1978), Glancy and VanDenburgh (1969, pl. 1), Hintze and others, 1994 (Motoqua and Gunlock topographic quadrangles), and Anderson and Hintze, 1993.

Regional Geology and Structure

The Beaver Dam Wash area is at the easternmost edge of the Basin and Range Province at the boundary with the Colorado Plateaus Province to the east (Fenneman, 1931). The area is considered part of the transition zone between the more tectonically stable Colorado Plateau and the extended and more faulted terrane of the Basin and Range. Structural highs in the area include the Beaver Dam Mountains on the east and the Virgin Mountains on the southeast, both of which expose rocks of Paleozoic and Precambrian age.

The Mesquite basin is a deep tectonic depression just west of the intersection of the southernmost Beaver Dam and the northernmost Virgin Mountains. This structural basin is defined by a pronounced gravity low and is mostly filled with sediments of Tertiary age (Blank and Kucks, 1989, pl. 2; Bohannon and others, 1993, fig. 2 and p. 511; and Baer, 1986, fig. 2). The Mesquite basin underlies much of the southern end of the Beaver Dam Wash area, including the part in Arizona, the adjacent part of Utah up to about 5 mi north of the Arizona/Utah border, and the adjacent parts of Nevada to about 3 to 8 mi west of the Arizona/Nevada and Utah/Nevada borders. The Mesquite basin is an east-tilted half graben bounded on the east and southeast by normal faults at the west front of the Beaver Dam Mountains (Bohannon and others, 1993, p. 511), that correspond to the Piedmont Fault mapped by Moore (1972, pl. 1).

Just northwest of the northern part of the Beaver Dam Wash area is a large volcanic-tectonic structure, the Caliente caldera complex. This structure was the source of ash-flow tuffs of Tertiary age that cover the northern end of the Beaver Dam Wash study area in the Clover and Bull Valley Mountains (Blank and Kucks, 1989, p. 4 and pl. 1). The Bull Valley Mountains bound the area on the northeast and are made up of rocks of Paleozoic and Mesozoic age capped with rocks of Tertiary age, mostly volcanic. Intrusive igneous rocks of Tertiary age crop out near Mineral Mountain in the northern end of the study area. This intrusion is the western end of a belt of intrusions in the Bull Valley Mountains and other areas to the east and northeast (Blank and Kucks, 1989, p. 1 and fig. 2).



EXPLANATION

Unconsolidated and semiconsolidated Quaternary–Tertiary basin-fill deposits

Quaternary alluvial channel-fill deposits

Quaternary-Tertiary basin-fill deposits

Muddy Creek and Claron Formation

Consolidated rocks

Tertiary volcanic rocks

Navajo Sandstone

Mesozoic rocks, other than the Navajo Sandstone

Paleozoic noncarbonate rocks

Paleozoic rocks, mostly carbonate

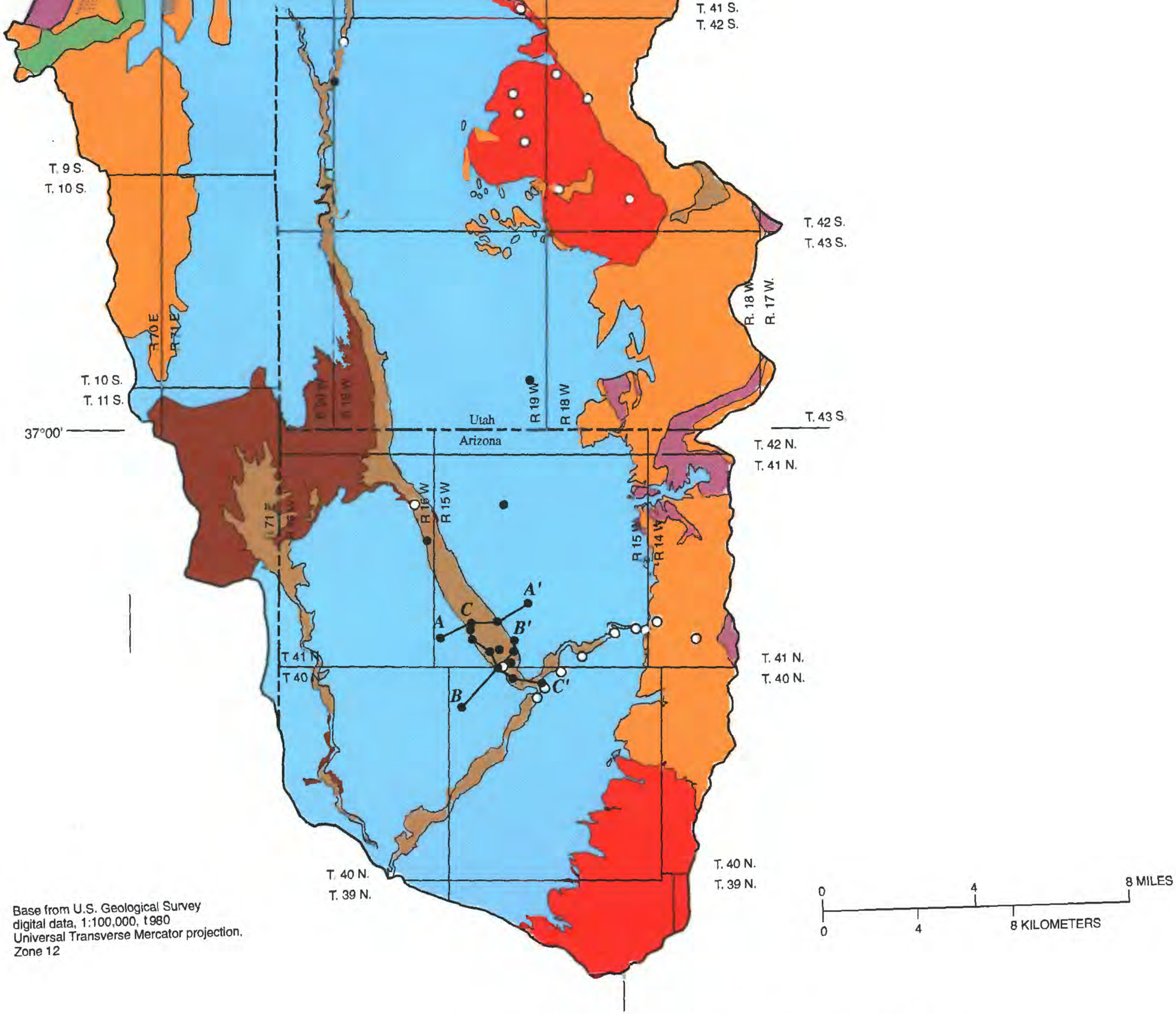
Precambrian rocks

Boundary of the study area

A —— *A'* **Location of geologic section (fig. 5)**

○ **Spring**

● **Well referred to in text**



Base from U.S. Geological Survey digital data, 1:100,000, 1980
Universal Transverse Mercator projection,
Zone 12

Figure 4. Generalized geology of the Beaver Dam Wash study area and location of springs, wells, and geologic sections.

Precambrian Rocks

Rocks of Precambrian age crop out at the southern end of the study area in the Virgin Mountains and on the east side of the study area in the Beaver Dam Mountains. The Precambrian rocks in the Virgin Mountains are granite and related crystalline intrusive igneous rocks and gneiss and schist (Wilson and Moore, 1959; Moore, 1972, pl. 1); the rocks in the Beaver Dam Mountains are gneiss, schist, and pegmatite (Hintze, 1986a, pl. 2). Because these rocks bear water only where fractured, they are a confining unit, and, where present, form a boundary of the ground-water system.

Paleozoic Rocks, Mostly Carbonate

Paleozoic rocks, most of which are carbonate, crop out along much of the eastern side of the study area in the northern end of the Virgin Mountains and in most of the Beaver Dam Mountains. These rocks also are exposed in the low mountains and hills on the western side of the study area, such as Scarecrow Peak, Lime Mountain, and the northeastern Tule Springs Hills (fig. 1). The Paleozoic carbonates include rocks of Cambrian, Devonian, Mississippian, Pennsylvanian, and Permian age (Hintze, 1986a, pl. 2; Hintze and others, 1994; Anderson and Hintze, 1993; Moore, 1972, pl. 1; and Stewart and Carlson, 1978).

The Paleozoic carbonate rocks may be water bearing and permeable where they are saturated and include solution-enlarged fractures, but little is known about where these conditions exist. The rocks probably are unsaturated where they are exposed in the uplands on the east and southeast of the study area, although solution openings and caves in the Beaver Dam Mountains indicate they were saturated and permeable at one time. Carbonate rocks likely are buried under thousands of feet of younger unconsolidated and semiconsolidated deposits and rocks in the low southern part of the area and may not be permeable, or if so, contain poor-quality water. In the western part of the area in Nevada, carbonate rocks may be saturated and permeable in the subsurface adjacent to exposed carbonates in the uplands. More detailed information may be required on the structure and stratigraphy of the Beaver Dam Wash study area to identify areas where Paleozoic carbonate rocks would yield good-quality water to wells.

Paleozoic Noncarbonate Rocks

Noncarbonate rocks of Paleozoic age crop out in the Beaver Dam Mountains, the southern foothills of the Bull Valley Mountains, and in the low mountains and hills on the western side of the study area in Nevada. These rocks include sandstone, shale, and siltstone, and the aggregate thickness and areal extent of outcrop are less than that of the Paleozoic carbonates. The noncarbonate rocks, especially the sandstones, may be locally water bearing and permeable where fractured or porous, but in general they probably are confining units.

Mesozoic Rocks, other than Navajo Sandstone

Rocks of Mesozoic age crop out at the northern end of the Beaver Dam Mountains and north into the southern slopes of the Bull Valley Mountains, in the Virgin Mountains, and in the uplands in Nevada, mostly northeast of Lime Mountain at the eastern end of the Clover Mountains. These rocks include sandstone, siltstone, shale, conglomerate, and limestone. Although several of the formations of the Mesozoic section, exclusive of the Navajo Sandstone, likely are aquifers at least locally, this stratigraphic interval probably functions mainly as a confining unit.

Navajo Sandstone

The Navajo Sandstone of Mesozoic age crops out in the area between the Beaver Dam and Bull Valley Mountains, where it dips to the northeast (Hintze and others, 1994). Although exposure is limited in the study area, it is shown as a separate unit because it is a known productive aquifer. Ten water wells have been drilled into the Navajo Sandstone by the city of St. George, Utah, along the Santa Clara River about 7 mi southeast of the outcrops of Navajo Sandstone on the eastern edge of the Beaver Dam Wash area (Freethey, 1993, fig. 4). These wells range in depth from 346 to 626 ft and yield water generally containing dissolved solids of less than 500 mg/L (Freethey, 1993, table 1). At least three of these wells yielded more than 1,500 gal/min (Cordova, 1978, table 6; drillers' logs in the files of the U.S. Geological Survey, Salt Lake City, Utah).

In the Beaver Dam Wash area, the Navajo Sandstone is a medium-grained, cross-bedded and jointed sandstone about 2,000 to 2,300 ft thick (Hintze and others, 1994). A test well drilled for this study, (C-40-

18)15dbd-1, penetrated 993 ft of fine-grained Navajo Sandstone. Outcrops 0.8 mi south of the test-well site were prominently jointed.

Tertiary Volcanic Rocks

The northern end of the study area in the eastern Clover Mountains (Anderson and Hintze, 1993) and western Bull Valley Mountains (Hintze and others, 1994) is covered with rocks of Tertiary age, almost all of which are volcanic. In the Cougar Canyon/Tunnel Spring Wilderness Study Area, which is in the northern tip of the Beaver Dam Wash study area east and southeast of Beaver Dam State Park, these rocks consist of dacitic to rhyolitic, welded and nonwelded ash-flow and air-fall tuffs, and some andesite and basalt derived from the Caliente caldera complex to the northwest (Conrad and others, 1990). These rocks are about 1,500 ft thick. Little work was done in this part of the Beaver Dam Wash area during the study so little is known of the hydrogeology of these rocks. They occur mostly at altitudes above 4,000 to 5,000 ft, where precipitation and the potential for recharge is greater than it is in the southern part of the area. Where they are fractured and relatively permeable, these rocks might yield water to wells locally. Springs discharge as much as 50 gal/min from volcanic rocks in the northern part of the area.

Unconsolidated and Semiconsolidated Quaternary-Tertiary Basin-Fill Deposits

Unconsolidated to semiconsolidated basin-fill deposits of Tertiary and Quaternary age are exposed at the surface of and underlie most of the low areas of the Beaver Dam Wash study area, especially in the southern two-thirds of the area. The Tertiary sediments probably include the Horse Spring Formation, the Muddy Creek Formation, and post-Muddy Creek Tertiary gravels; the Quaternary sediments include alluvial-fan and tufa deposits (combined with the post-Muddy Creek Tertiary gravels as a map unit) and alluvial channel-fill deposits (Schmidt, 1994, p. 8-20; Bohannon and others, 1993, p. 504-509 and figs. 4, 6, 7, 9, and 10). No geologic mapping was done during this study, so some of these parts of the Quaternary-Tertiary basin-fill deposits are not differentiated in figure 4. Sediments of Tertiary age make up most of this unit; deposits of Quaternary age form a relatively thin cover on the surface. The unit probably has a maximum thickness of more than 20,000 ft in the deepest part of the Mesquite basin at the southern end of the study area (Bohannon and others, 1993, figs. 8 and 10). The Quaternary alluvial-fan deposits are, at most, a few tens of feet thick, perhaps thicker in fan deposits at the margins of the low areas; the Quaternary tufa and alluvial channel-fill deposits can be more than 100 ft thick. Billingsley (1995) and Billingsley and Bohannon (1995) mapped the Littlefield and Elbow Canyon quadrangles at the southern end of the study area in Arizona. In these two quadrangles the deposits of Tertiary and Quaternary age have been differentiated, but this detailed information is not shown in figure 4.

Velocity profiles from the seismic-refraction survey provide information on the basin-fill deposits. These profiles are discussed in detail in the "Additional Information" section at the end of the report. Using velocity data, subdivisions of the basin-fill deposits, such as Quaternary alluvium, alluvial-fan deposits, and channel-fill deposits; post-Muddy Creek Tertiary gravels; and the Muddy Creek Formation can be differentiated. In addition, the velocity data can be used to identify the top of the consolidated rock beneath the basin-fill deposits. The velocity data indicate that the Quaternary deposits are less than 150 ft thick and that the post-Muddy Creek Tertiary gravels are as much as 600 ft thick.

Horse Spring Formation

The Horse Spring Formation is the oldest part of the basin-fill deposits. Schmidt (1994, p. 17-20) defined the Horse Spring Formation in the Farrier Quadrangle, about 40 mi west of the lower end of the Beaver Dam Wash study area, as material deposited during Miocene time when extensional deformation was creating the present basin-and-range structure. The Horse Spring Formation in the Farrier Quadrangle is a poorly sorted, thick-bedded, silty, sandy conglomerate and conglomeratic, silty sandstone deposited by fluvial and mass-wasting processes. Bohannon and others (1993, figs. 6, 7, 8, and 10) indicate, on the basis of seismic data, that the Horse Spring Formation makes up the lower part of the basin-fill deposits in the Mesquite basin. The "red sandstone unit" is included in this report with the Muddy Creek Formation as in Schmidt (1994, p. 16), although Bohannon and others (1993, fig. 4) place it between the Horse Spring Formation and Muddy Creek Formation. Because of the lack of detailed geologic mapping of the unconsolidated and semiconsolidated basin-fill deposits over the entire Beaver Dam Wash area, it is not known whether the

Horse Spring Formation crops out in the study area; Billingsley (1995) and Billingsley and Bohannon (1995) did not map any pre-Muddy Creek formations of Tertiary age in the Littlefield and Elbow Canyon quadrangles. In the lowermost end of the Beaver Dam Wash area in Arizona, the top of the Horse Spring Formation probably is at depths greater than about 2,000 ft (Bohannon and others, 1993, fig. 8), where it may not be permeable or contain water of good quality.

Muddy Creek Formation

The Muddy Creek Formation makes up most of the upper part of the basin-fill deposits in the Mesquite basin and in low areas to the north of the Mesquite basin but within the study area. On the basis of available geologic maps, areas were identified in figure 4 where the Muddy Creek Formation probably is exposed at the land surface. The formation is described by Schmidt (1994, p. 14-17) in the Farrier Quadrangle, 40 mi west of the study area, as fine-grained basin fill deposited during late Miocene time after cessation of extensional deformation. There it is a pale brownish-red, gypsiferous and calcareous, lacustrine, generally horizontally bedded, deposit that contains little or no fluvial alluvium and is mostly claystone and some fine-grained sandstone and siltstone, moderately well consolidated (Schmidt, 1994, p. 15-16). Billingsley (1995) and Billingsley and Bohannon (1995) described the formation in the Littlefield and Elbow Canyon quadrangles. As much as 200 ft of the upper part of the formation is exposed in these quadrangles; it is light reddish-brown gray and white, slope-forming, fine-grained, thin- to thick-bedded, calcareous, gypsiferous, siltstone, sandstone, and calcrete (Billingsley, 1995, p. 11). Billingsley (1995) and Billingsley and Bohannon (1995) do not follow Schmidt (1994) in mapping aggradational and regrade gravels of Tertiary age above the formation; they define conglomeratic gravels of ancestral Beaver Dam Wash and the Virgin River in the upper part of the formation, which may correspond to the post-Muddy Creek Formation gravels defined by Schmidt (1994).

Kowallis and Everett (1986, p. 70-75) studied gently northwest-dipping exposures of the Muddy Creek Formation just west of Mesquite, Nevada, about 7 mi southwest of the southern end of the Beaver Dam Wash study area. At this stratigraphic section, the formation is mostly poorly sorted, pinkish to pale orange, coarse- to fine-grained sand and sandstone with siltstone and mudstone. Some of the mudstone beds contain gypsum crystals. Overall, Kowallis and Everett (1986, p. 70-72 and 75) characterize it as fluvial and lacustrine sandstones, siltstones, and mudstones deposited as intrabasinal debris—coarse detritus, however, is almost completely absent. Kowallis and Everett (1986, p. 70-72 and 75) characterize the formation as mostly fluvial material, deposited during climatic conditions not much different from those of today, although parts of the formation probably were deposited during cooler and wetter climatic conditions than exist today.

Moore (1972, pl. 1, table 1, p. 22) mapped the formation in the Arizona part of the Beaver Dam Wash area. He described the formation as generally playa sediments deposited under intermittent lacustrine conditions—thin-to-medium-bedded clay, sand, and silt. Beds of gypsum are common locally. Hintze (1986b, p. 23-24) mapped the formation along Beaver Dam Wash just north of Motoqua, Utah, and in small exposures just southwest of the Beaver Dam Mountains, both in the study area. He described the formation as a clastic basin-fill deposit—pinkish mudstone, siltstone, and gravel dipping eastward.

A test well drilled during this study, (B-40-15)6cdd, 1.5 mi southwest of the town of Beaver Dam, penetrated the Muddy Creek Formation from about 140 ft to the total depth, 599 ft, according to the resistivity log of the well. At this location, the sample and resistivity logs indicated that the formation is predominantly silt and clay, with much sand and some gravel. Information from the test well indicated that the formation would not be a productive aquifer at the test site; however, wells drilled into and completed in the formation near Mesquite, Nevada, about 8 mi to the southwest, yield substantial amounts of water (Johnson, 1995).

Gravity data indicate that the deepest part of the Mesquite basin is in the southeastern corner of the study area, 2 to 3 mi west of the towns of Beaver Dam and Littlefield (Blank and Kucks, 1989, pl. 2; Bohannon and others, 1993, fig. 2A). Seismic data indicate that the thickest section of the formation is about 5 mi south of the center of the gravity low, or along and just south of the Virgin River, south-southwest of Beaver Dam and Littlefield (Bohannon and others, 1993, fig. 8A). This depositional and topographic low area may have persisted past the end of the time of deposition of the formation because two present-day drainages curve to the southeast as they approach the Virgin River from the north (D.L. Schmidt, U.S. Geological Survey, oral commun., 1994)—Beaver Dam Wash, perennial at its mouth, and the ephemeral Castle Cliff Wash to the east. Thus, at least during deposition of the formation, the finest material may have been deposited close to the Virgin Mountains, rather than farther to the west and northwest, as would be expected. Resistivity data also indicate thick, fine-grained unconsolidated deposits in the southeastern corner of the study area (see "Additional Information" section), and indicate fine-grained material was deposited close to the mountain front.

Post-Muddy Creek Tertiary Gravels and Quaternary Alluvial-Fan and Tufa Deposits

Above the Muddy Creek Formation are gravels of Tertiary age. Schmidt (1994, p. 8-12) described, in the Farrier quadrangle 40 mi west of the study area, a poorly sorted aggradational gravel deposited just after the closed basin in which the Muddy Creek was deposited was drained by integration of the area into the Colorado River drainage, and a well-sorted regrade gravel deposited later by a headward-eroding ancestral Virgin River and its tributaries. These gravels also are present in the Beaver Dam Wash area, although in the southern end of the study area they are probably less than 150 ft thick (figs. 5A and 5B). They make up about the upper 100 ft of material exposed in the bluffs on the west side of the incised Beaver Dam Wash where it is crossed by resistivity profile B-B' (see the "Additional Information" section) (D.L. Schmidt, U.S. Geological Survey, oral commun., 1994). The resistivity log of test well (B-40-15)6cdd, about 1.5 mi southwest of the town of Beaver Dam, shows a large decrease in resistivity at about 140 ft, which likely corresponds to the base of the post-Muddy Creek Tertiary gravels. Billingsley's (1995) map of the Littlefield quadrangle indicates that post-Muddy Creek gravels of Tertiary and Quaternary age are about 100 ft thick where exposed on the west wall of the valley incised by Beaver Dam Wash about 3 mi northwest of the town of Beaver Dam. These gravels are as much as about 500 ft thick farther to the north. At Lytle Ranch, where the wash is crossed by resistivity profile E-E' (see the "Additional Information" section), the post-Muddy Creek gravels of Tertiary age make up all the material, about 350 ft, exposed in the bluffs on the west side of the incised wash (Hintze, 1986b, fig. 6; D.L. Schmidt, U.S. Geological Survey, oral commun., 1994). These gravels, especially the well-sorted regrade gravel, would be permeable and would readily yield water to wells if saturated; however, in the Beaver Dam Wash area, they likely are unsaturated.

Test well (C-43-19)25bbb-1 (sounding 23, fig. 3), drilled during this study about 3.5 mi east of Beaver Dam Wash and about 1.5 mi north of the Utah/Arizona border, penetrated these post-Muddy Creek gravels from shallow depths down to either about 338 or 465 ft, although some of the shallow material probably was of Quaternary age. This material was unsaturated and composed of gravel, sand, silt, and clay, with more clay below 338 ft.

Sediments of Quaternary age probably were deposited on top of the post-Muddy Creek Tertiary gravels and are combined with them in figure 4 because no information is available to differentiate them for the entire study area. These Quaternary sediments probably are mostly alluvial-fan, ephemeral stream-channel, and mass-wasting deposits. They probably are thin or even absent in the lower parts of the study area and thickest, but probably still less than 100 ft thick, along the mountain fronts. These Quaternary deposits likely are all unsaturated.

Moore (1972, p. 22-24) mentioned that in the Virgin River valley near Littlefield, Arizona, the Muddy Creek Formation is overlain by a conglomerate capped by caliche. Moore informally referred to these rocks as the "Littlefield Formation," reporting its age as from late Tertiary to early Quaternary (see log of well (B-40-15)4acd on fig. 5C). Trudeau and others (1983, p. 326, 332) identified the "Littlefield Formation" around Littlefield Springs, across the Virgin River from Littlefield, Arizona, and stated that it is of Quaternary age. They state it is made up of an interbedded limestone and sandstone member overlying a conglomerate member, with a total thickness of about 200 ft. They describe the members of the "Littlefield Formation" as local aquifers and note that the Littlefield Springs, a series of springs that discharge near the top of the low bluffs on the south side of the Virgin River, are located near outcrops of the "Littlefield Limestone Member." The outcrops of the "Littlefield Formation" were visited during this study and appear to be mostly spring-deposited tufa and may be limited in areal extent. Billingsley (1995, map and p. 8) mapped this material as travertine of Holocene and Pleistocene(?) age and described it as gray, porous, thin-bedded calcium carbonate deposits derived from warm freshwater spring outlets along the east bank of the Virgin River near the Interstate 15 bridge crossing.

About 50 mi to the north-northeast of Beaver Dam Wash, in the internally drained Great Basin part of the Basin and Range Province of southwestern Utah, basin-fill deposits of Quaternary age in the Beryl-Enterprise area of the Escalante Desert are mostly saturated and are productive aquifers. In the Beaver Dam Wash area, however, the situation is much different. D.L.

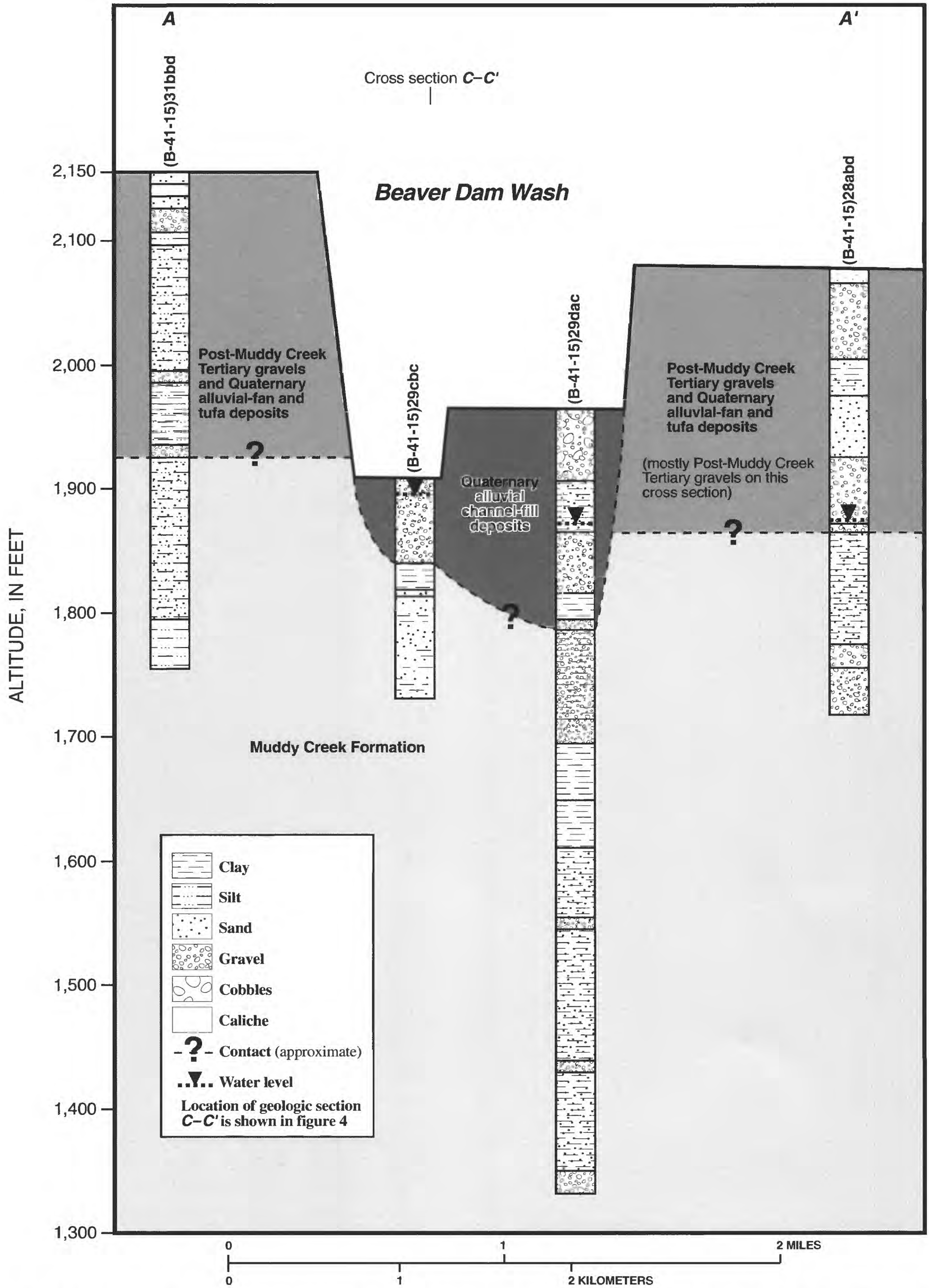


Figure 5A. Geologic section showing relation between the Muddy Creek Formation, post-Muddy Creek Tertiary gravels and Quaternary alluvial-fan and tufa deposits, and Quaternary alluvial channel-fill deposits near Beaver Dam, Arizona.

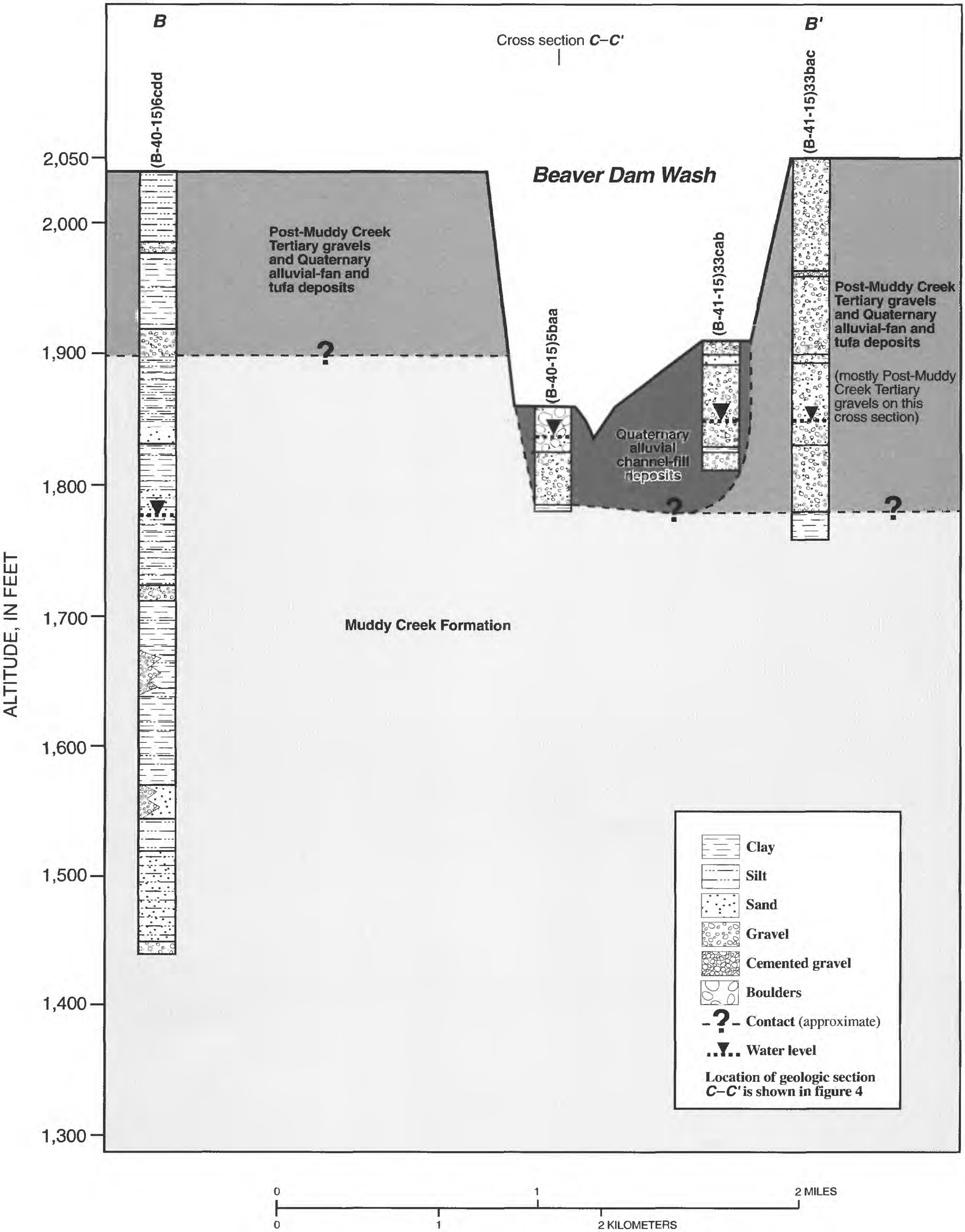


Figure 5B. Geologic section showing relation between the Muddy Creek Formation, post-Muddy Creek Tertiary gravels and Quaternary alluvial-fan and tufa deposits, and Quaternary alluvial channel-fill deposits near Beaver Dam, Arizona.

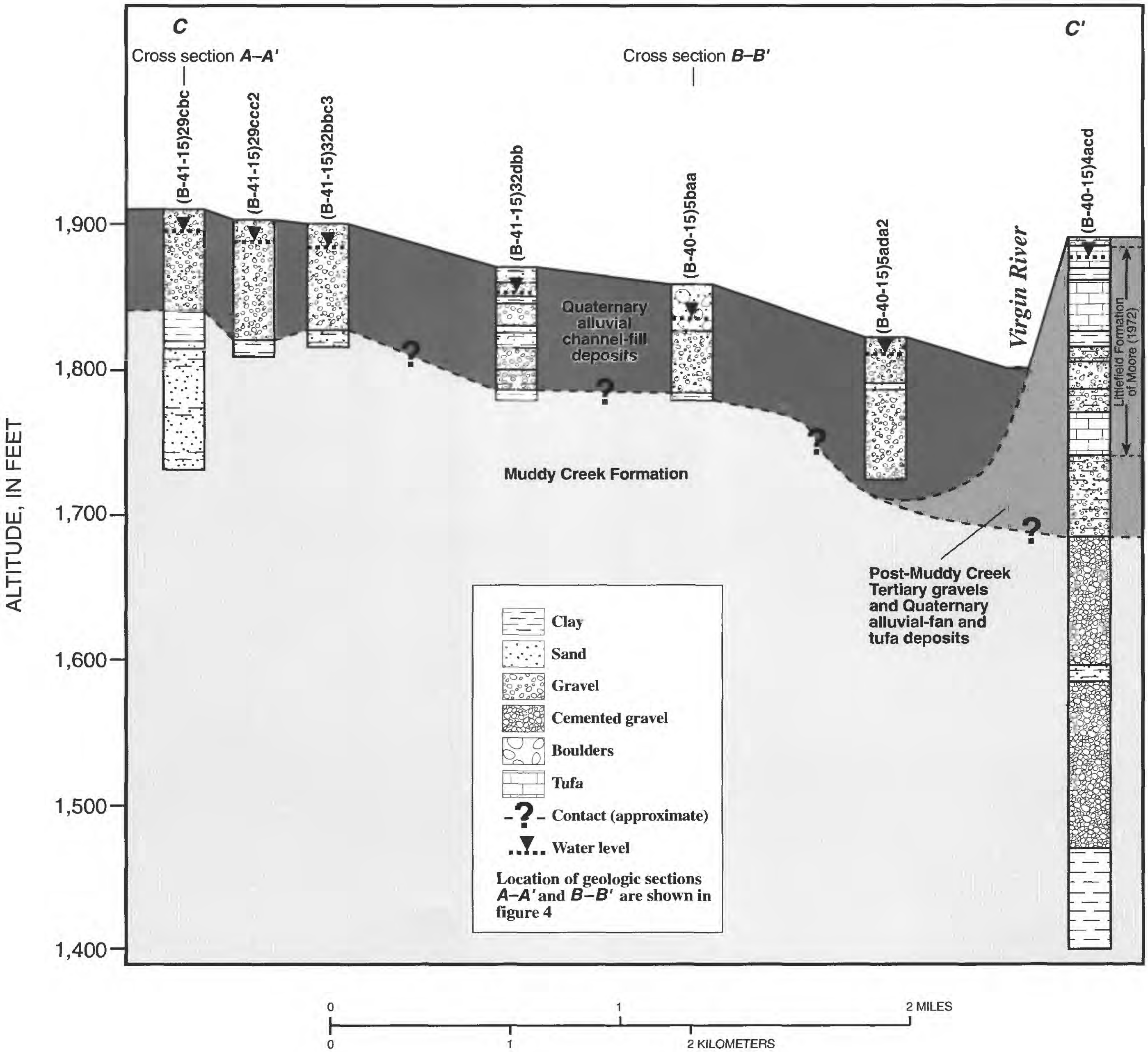


Figure 5C. Geologic section showing relation between the Muddy Creek Formation, post-Muddy Creek Tertiary gravels and Quaternary alluvial-fan and tufa deposits, and Quaternary alluvial channel-fill deposits near Beaver Dam, Arizona.

Schmidt (U.S. Geological Survey, written commun., 1996) believes that thick Quaternary basin-fill deposits do not exist in the Beaver Dam Wash area because the Virgin River was integrated during Pliocene time into the drainage of the then through-flowing Colorado River. Once integrated, the drainages of the Beaver Dam Wash area became entrenched and only areally restricted channel-fill and thin surficial deposits were deposited during the late Pliocene and through the entire Quaternary. One of these channel fillings of late Pliocene age in the incised Virgin River valley was thick and probably constitutes the Littlefield Formation of Moore (1972) (see log of well (B-40-15)4acd, fig. 5C). Later Quaternary channel-fill deposits tend to be thin. The Pliocene channel-fill deposits are more cemented, consolidated, and much less permeable than the Quaternary channel-fill deposits; however, the areally restricted distribution of any of these deposits greatly limits their value as regional aquifers.

Quaternary Alluvial Channel-Fill Deposits

The only deposits solely of Quaternary age that are differentiated in figure 4 are the alluvial channel-fill and terrace deposits along Beaver Dam Wash and its major tributaries, Sand Hollow Wash to the west, and the Virgin River. These deposits are also shown on the two geologic sections across Beaver Dam Wash and the one geologic section along the wash at Beaver Dam, Arizona (figs. 5A, 5B, and 5C). Schmidt (1994, p. 2-8) defined, in the Farrier quadrangle 40 mi west of Beaver Dam Wash, five distinguishable deposits of channel-fill deposits and terrace alluvium of Holocene and Pleistocene age; Billingsley (1995) defined six alluvial deposits in the Littlefield quadrangle; and Billingsley and Bohannon (1995) defined seven alluvial deposits in the Elbow Canyon quadrangle. These deposits have not been mapped in the rest of the Beaver Dam Wash area, but all or many of them are present as well. The channel alluvium along Beaver Dam Wash and its major tributaries, which is combined with the material of at least one older terrace about 60 to 80 ft higher on the east side of the wash just north of Beaver Dam, Arizona, is shown in figure 4. Quaternary alluvial channel-fill deposits also include channel alluvium along Sand Hollow Wash and along the Virgin River. These deposits are generally well-sorted, coarse-grained gravels, sands, and silt, and are mostly saturated (except for the alluvium along much of Sand Hollow Wash) and permeable. The alluvial channel-fill deposits are as much as about 100 to 175 ft thick (figs. 5A, 5B, and 5C) and yield water to wells along the wash, especially in and near the town of Beaver Dam.

Data from the direct-current resistivity surveys were used to estimate the thickness of channel-fill deposits at six locations, as discussed in the "Additional Information" section at the end of the report. Thicknesses estimated from resistivity data ranged from about 30 to 130 feet, about the same as the range estimated from well logs.

SURFACE-WATER HYDROLOGY

Precipitation

During 1961-90, the normal annual precipitation in the Beaver Dam Wash area averaged about 13 in. and ranged from less than about 7 in. at the lower altitudes near the mouth of Beaver Dam Wash to about 23 in. at the higher altitudes in the western and northwestern parts of the study area (fig. 6). To evaluate the precipitation during 1992-94, when most of the data for this study were collected, precipitation data at Lytle Ranch in the Beaver Dam Wash basin (site P1, fig. 6) and at Gunlock Powerhouse in the Santa Clara River basin (site P2, fig. 6) were compared to the 1961-90 normals for those sites.

During the 1992 water year, precipitation at sites P1 and P2 was about 40 percent greater than normal; during the 1993 water year, it was about 56 percent greater than normal; and during the 1994 water year, it was normal. Precipitation in February 1993 and March 1995 produced flooding throughout the study area (see section on "Flood Characteristics"). During 1994, when precipitation was near normal, very little, if any, surface runoff occurred at the mouth of Beaver Dam Wash (see section on "Estimates of Average Discharge for Selected Sites on Beaver Dam Wash").

Using the normal annual precipitation map for 1961-90 (fig. 6), the percentages of precipitation were computed for those parts of Beaver Dam Wash in Utah, Nevada, and Arizona. In the Beaver Dam Wash area, about 50 percent of the precipitation is in the Utah part, 35 percent is in the Nevada part, and 15 percent is in the Arizona part.

Streamflow

Variations in the discharge of Beaver Dam Wash can be related to precipitation and exchange of water between the stream and aquifer. Streamflow characteristics at selected sites on Beaver Dam Wash were deter-

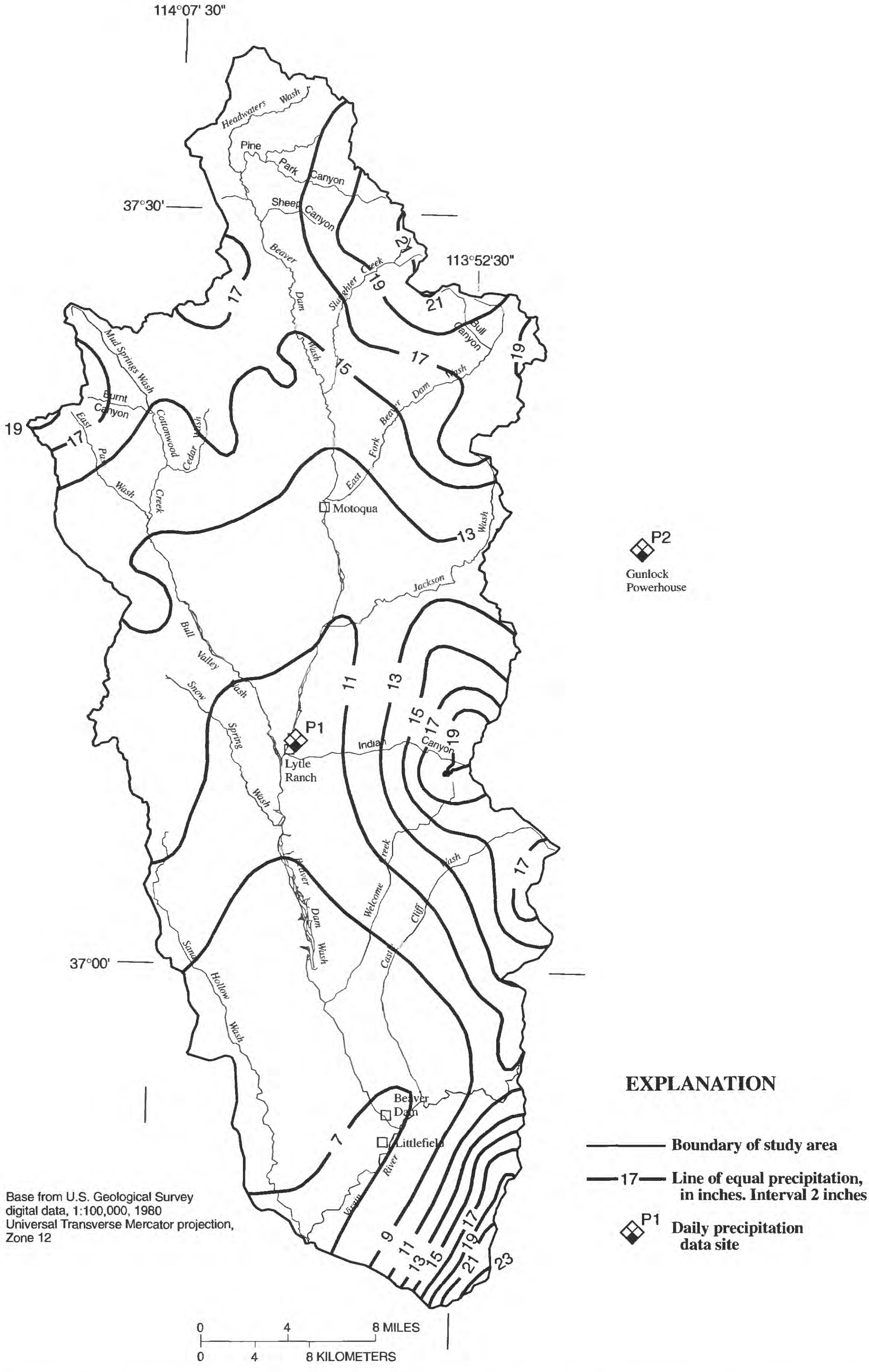


Figure 6. Normal annual precipitation for Beaver Dam Wash, 1961-90 (data from Utah Climate Center, Utah State University).

mined using field measurements and streamflow-gaging-station records, and by correlation of short-term records from stations in the Beaver Dam Wash area with long-term records from stations in nearby drainage basins. (The methods used to extend short-term records are described later in the report.) Long-term average annual discharges were estimated for sites S0, S11, S29, and S32 on Beaver Dam Wash (fig. 7) so that recharge to the alluvial channel-fill deposits could be determined. Flood-flow frequencies were calculated using data collected at the gaged sites, S0 and S29, and by regional procedures developed by Thomas, Hjalmarson, and Waltemeyer (1994).

Streamflow records are available for only two gaging stations in the Beaver Dam Wash drainage (fig. 8). The gaging station on Beaver Dam Wash near Enterprise, Utah (site S0), operated since October 1991, and Beaver Dam Wash at Beaver Dam, Arizona (site S29) operated only from February 1993 to September 1994. The records for nine other stations in nearby drainages with varying lengths of record are also included in figure 8.

Losing and Gaining Reaches of Beaver Dam Wash

Losing and gaining reaches were determined during spring runoff on April 14 and 16, 1993, and during low or base flows on October 20-21, 1993. The losing and gaining reaches provide an indication of the natural recharge and discharge areas along Beaver Dam Wash. The discharges on April 16 were slightly lower than on April 14, but the amounts of loss or gain and the reaches where the losses and gains occurred were very similar (fig. 9). To simplify the discussions that follow, only the discharges measured on April 14 are discussed.

On April 14, 1993, discharge was still high from seasonal runoff at the most upstream measuring site, S0, which is the location of a gaging station. The largest gain occurred between sites S0 and S11. Site S11 is just downstream from the confluence with the East Fork of Beaver Dam Wash. The discharge at site S0 was 26 ft^3/s and at site S11 was 95 ft^3/s. After subtracting the estimated inflow from East Fork (10 ft^3/s) the gain between sites S0 and S11 was about 5 ft^3/s/mi of reach. Between sites S11 and S14 there was a loss of 15 ft^3/s, but between sites S16 and S21 there was a loss of about 58 ft^3/s, which represents a loss of 6.2 ft^3/s/mi of reach. From site S21 to site S29 (gaging station), discharge decreased to 3.43 ft^3/s and then increased about 6.6 ft^3/s between site S29 and S32 at the mouth. Essentially all of the 95 ft^3/s of water measured at site S11 seeped into the channel fill between site S11 and the gaged site, S29.

During October 20-21, 1993 (fig. 10), gains were again measured between the uppermost site, S0 (gaging station), and site S11 just downstream from the confluence with the East Fork. Downstream from the East Fork the reaches of losses and gains alternate to the mouth of the stream. At sites S21 and S24, the bed of the wash was dry. Downstream from site S24 the discharge consistently increased to the mouth at site S32. The largest increase per river mile occurred in the 0.8-mile reach between sites S29 and S32 where the discharge increased by 5.9 ft^3/s, or 7.4 ft^3/s/mi of stream reach.

The drainage upstream from site S11 at Motoqua, Utah, is in a mountainous area that contains primarily consolidated rocks (mostly volcanic rocks of Tertiary age) and has relatively greater precipitation than areas at lower altitudes downstream from site S11. The drainage area downstream from site S11 contains primarily unconsolidated and semiconsolidated rocks that are more amenable to infiltration of recharge. These differences in geology and precipitation explain the gains in the upper basin upstream from the East Fork and the net losses from the stream in the lower basin (downstream of site S11, fig. 6).

The gaining and losing reaches downstream from site S11 are related to the amount of alluvial channel-fill deposits and capacity for storing water along the length of the stream. In gaining reaches the channel-fill deposits have relatively small storage capacity, and in losing reaches the opposite is true. For example, in the losing reach between sites S19 and S21, the water level in well (C-43-19)20bac-1 near the bed of the wash at site S21 at the downstream end of the reach (fig. 7) was reported to be 84 ft below land surface (Enright, 1996). Downstream from site S25, where the stream gains consistently to site S32 at its mouth, water levels in several wells along the bed of the wash are near or at the level of the bed of the wash.

Estimates of Average Discharge for Selected Sites on Beaver Dam Wash

The streamflow characteristics at the nine stations in basins near Beaver Dam Wash (fig. 8) were studied in an effort to extend the short-term records of gaged sites on Beaver Dam Wash to a longer base period and to estimate streamflow characteristics for ungaged sites on Beaver Dam Wash. Of the nine gaged sites in nearby basins (fig. 8), average annual dis-

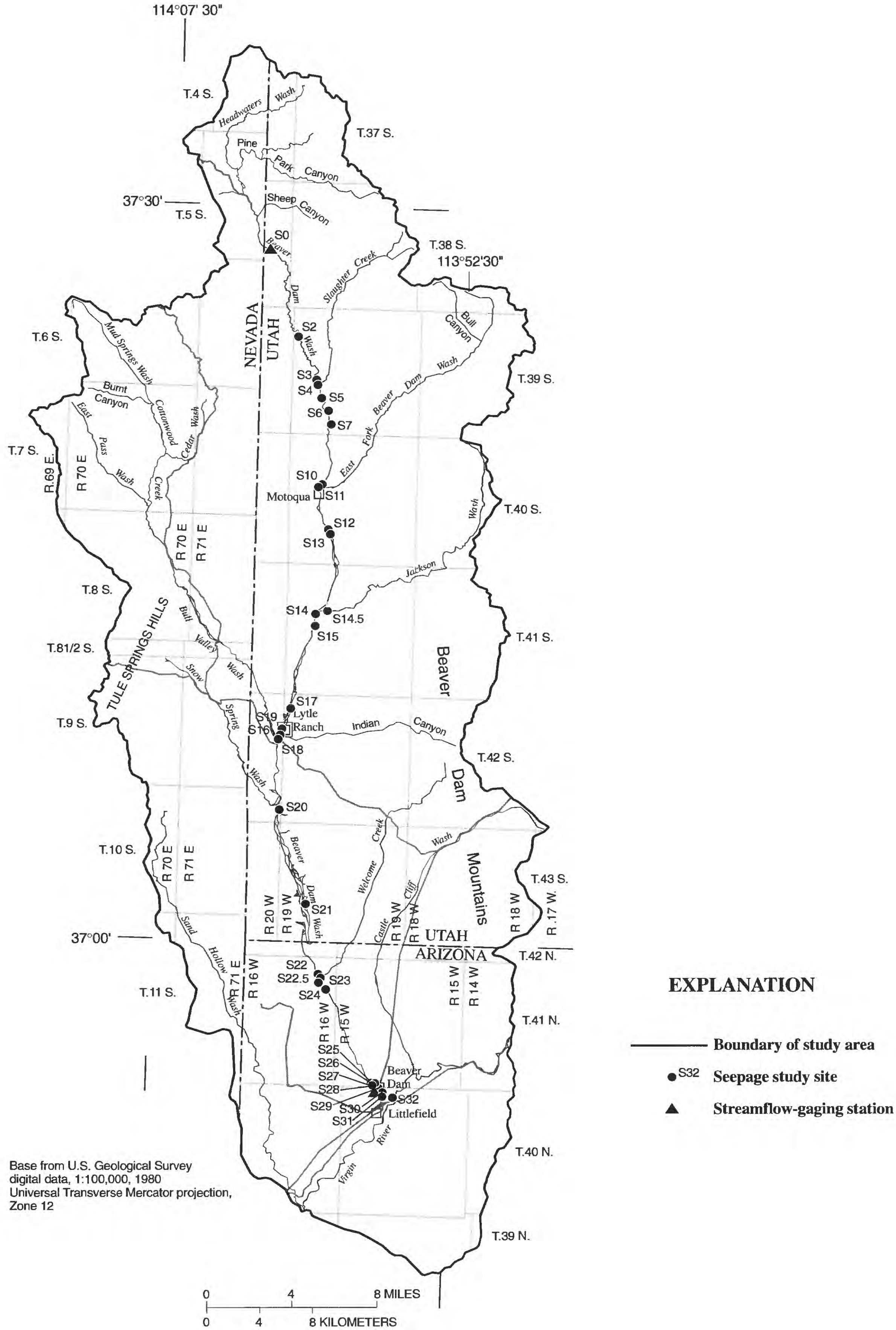


Figure 7. Location of streamflow-gaging stations and sites where streamflow measurements were taken in the Beaver Dam Wash area.

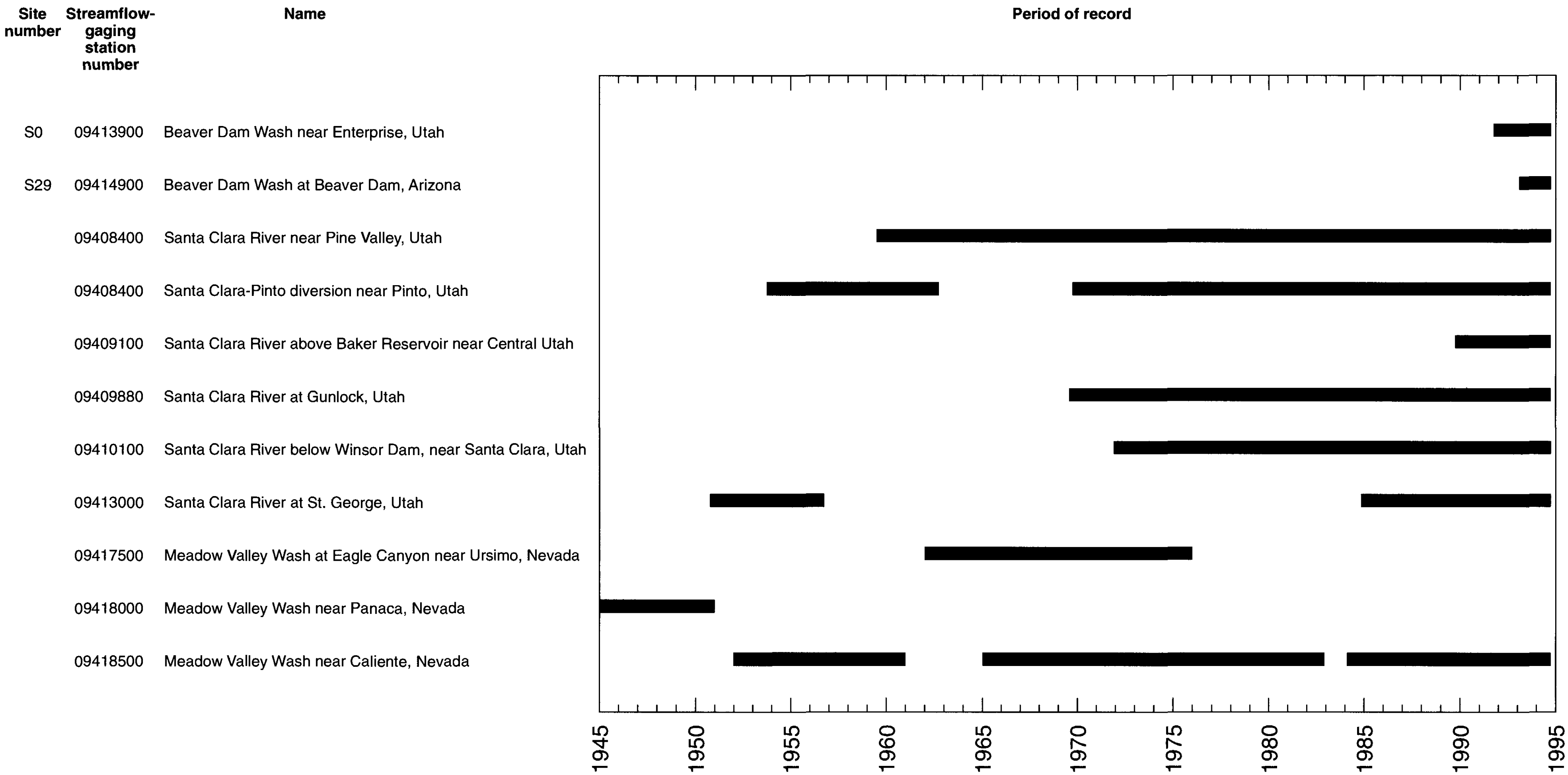


Figure 8. Streamflow-gaging records for Beaver Dam Wash drainage basin and other nearby basins. (See fig. 6 for location of stations and tables 1-3 for data.)

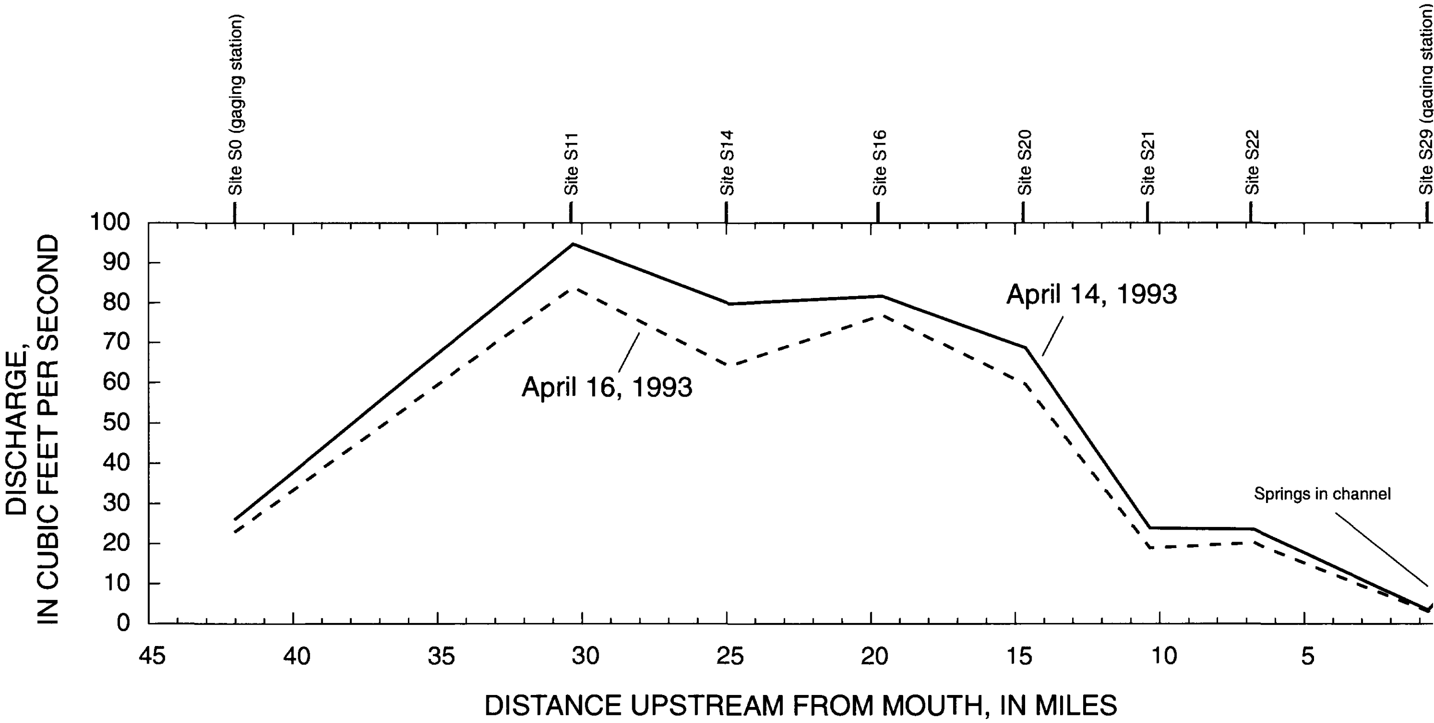


Figure 9. Streamflow for Beaver Dam Wash, April 14 and 16, 1993.

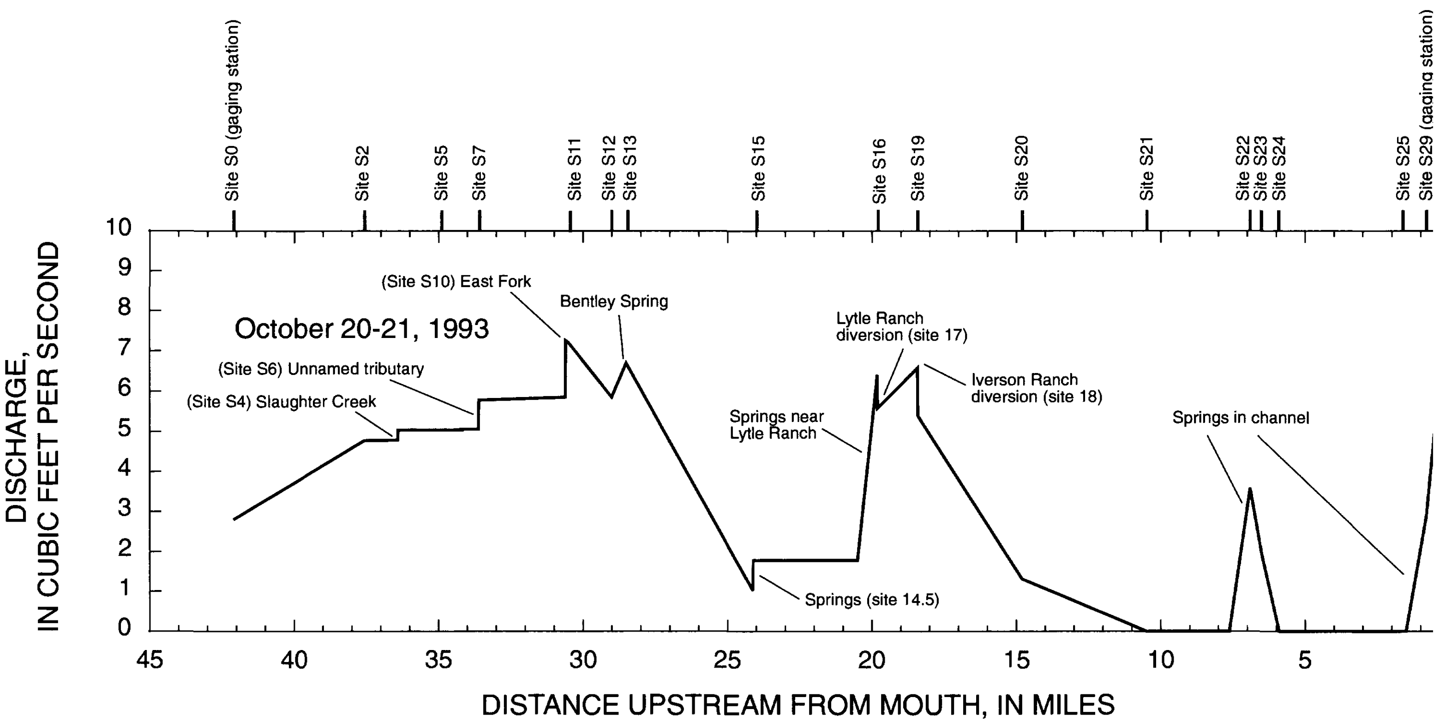


Figure 10. Streamflow for Beaver Dam Wash, October 20-21, 1993.

charges of the Santa Clara River at Gunlock, Utah, had the best correlation with those of Beaver Dam Wash at Enterprise, Utah (site S0). All of the sites, however, were found to be poorly correlated with the flows of Beaver Dam Wash at Beaver Dam, Arizona (site S29). This is partly because less than 2 years of record exist for site S29. The hydrographs of daily mean discharge for the Santa Clara River at Gunlock, Utah, and for sites S0 and S29 on Beaver Dam Wash are shown in figure 11.

Beaver Dam Wash at Enterprise, Utah (site S0)

The average annual discharges for Beaver Dam Wash at Enterprise, Utah, were regressed with the discharges for the Santa Clara at Gunlock, Utah, for the 1992-95 water years. The correlation coefficient for the regression was 0.98, and the standard error of estimate, expressed as a percentage of the average discharge, was about 20 percent. Using the regression and the 1970-95 average discharge for Santa Clara at Gunlock, Utah, the 1970-95 average discharge of Beaver Dam Wash at Enterprise, Utah, was estimated to be 11 $ft^3/s \pm 2\ ft^3/s$, and the1970-95 average annual discharge was estimated to range from 5.5 to 40 ft^3/s (fig. 12).

Beaver Dam Wash at Motoqua, Utah (site S11)

Most of the drainage to Beaver Dam Wash above Motoqua, Utah, is from volcanic rocks and provides most of the recharge to the unconsolidated and semiconsolidated basin-fill deposits downstream from Motoqua. Long-term average streamflow on Beaver Dam Wash near Motoqua was needed to estimate recharge to the alluvial channel-fill deposits downstream from Motoqua.

Long-term average discharge at Motoqua, Utah, was estimated using the estimated and measured record at Enterprise (site S0) for 1970-95 and a regional equation presented by Christensen, Johnson, and Plantz (1986, p. 4). The regional equation is used for estimating records at an ungaged site on the same stream with a gaged site. The regional equation is

$$Qu = Qg \bullet (Au/Ag)^{0.8} \quad (1)$$

where

Qu is the estimated 1970-95 average annual discharge at the ungaged downstream site at Motoqua (site S11), and

Qg is the 1970-95 average annual discharge (estimated for 1970-91 and gaged for 1992-95) at Enterprise (site S0).

Au and Ag represent the drainage areas above the ungaged and gaged sites, respectively.

The drainage area upstream from the gaged site (Ag) is 58 mi^2 and upstream from the ungaged site (Au) is 185 mi^2. Using equation 1 and the known drainage areas, the ratio of (Qu/Qg) = 2.5, which indicates that the flow at Motoqua (site S11) should be about 2.5 times greater than the flow at Enterprise (site S0). Three measurements were made in 1993 to determine the gain in the reach between sites S0 and S11. The average ratio of the discharge at Motoqua (site S11) to Enterprise (site S0) was 3.2, or slightly higher than the value of 2.5 determined using the regional regression equation.

Christensen, Johnson, and Plantz (1986, p. 5) indicate that the stream should be a gaining reach and that the ratio of drainage areas should be between 0.75 and 1.5 when using the regional regression equation. Seepage measurements made in 1993 indicated that the reach in Beaver Dam Wash from Beaver Dam Wash at Enterprise (site S0), to Motoqua (S11) is gaining, but the ratio of gaged to ungaged drainage area for sites S0 and S11 was 0.3, which is less than the lower limit of 0.75 recommended by Christensen, Johnson, and Plantz (1986, p. 5). Even though one of the criteria for using the regional regression equation was not met, the ratio of ungaged to gaged flow (Qu/Qg) of 2.5 was used to estimate the flow at Motoqua (site S11) instead of the ratio 3.2, which was based on only three measurements. Thus, the estimated 1970-95 average annual discharge for Beaver Dam Wash at Motoqua is $2.5 \bullet 11 \pm 2 = 28 \pm 5\ ft^3/s$. The error of $\pm 5\ ft^3/s$ reflects only the error for the estimate for site S0 at Enterprise. There is additional error for the estimate at site S11 (Motoqua) but it was not reported by Christiansen, Johnson, and Plantz (1986) for computations based on equation 1. The estimated record of average annual discharges for each year during 1970-95 at Motoqua (site 11) is shown in figure 12.

Beaver Dam Wash at Mouth, Arizona (site 32)

To estimate recharge to the unconsolidated and semiconsolidated basin-fill deposits, discharge at the mouth of Beaver Dam Wash (site 32) also was needed. The gage nearest the mouth of Beaver Dam Wash (site S29) has less than 2 years of record (February 1993 to September 1994) so the record had to be extended so

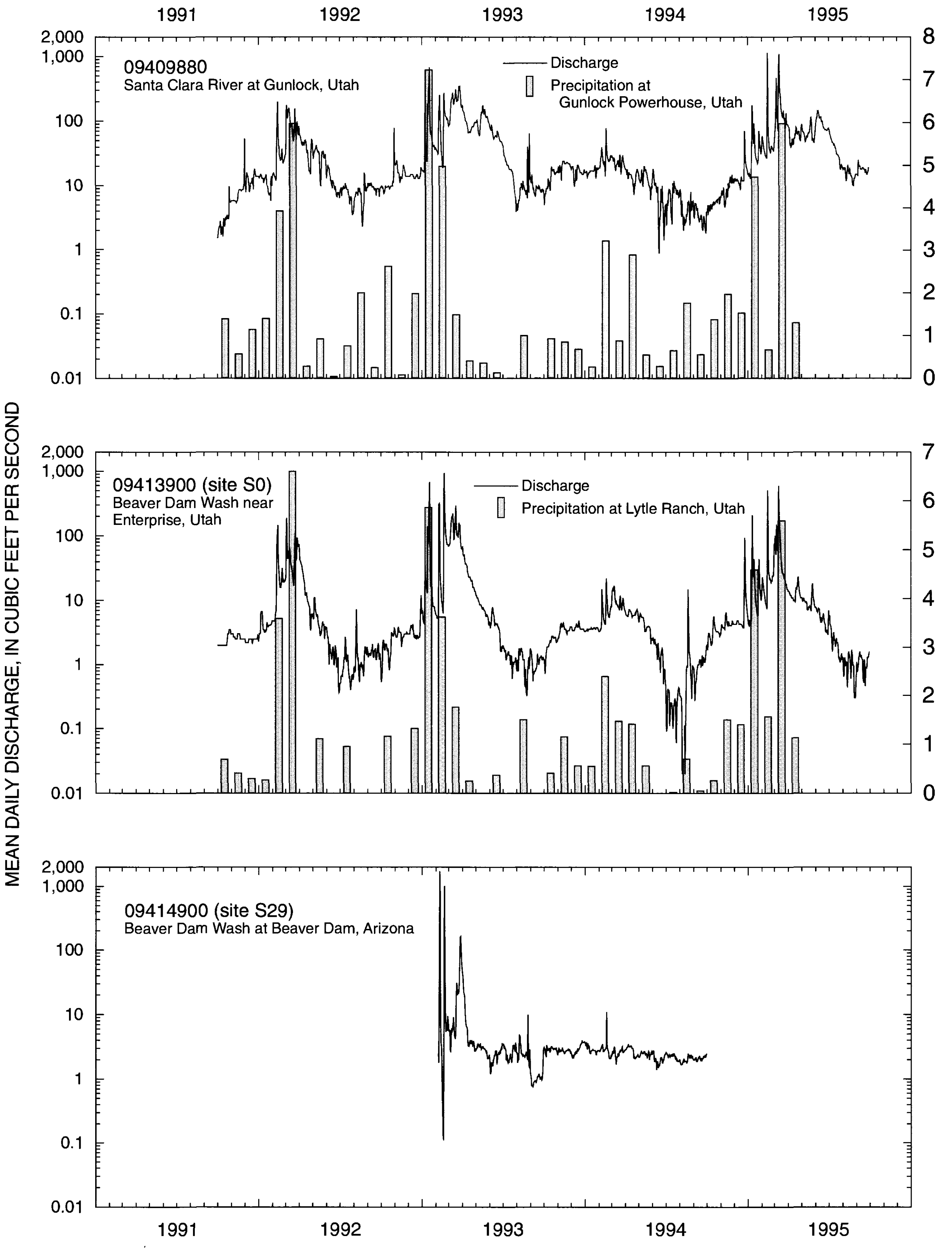


Figure 11. Mean daily discharge for streamflow-gaging stations on the Santa Clara River and Beaver Dam Wash, 1991-95, and precipitation at Gunlock Powerhouse and Lytle Ranch, Utah, 1991–95.

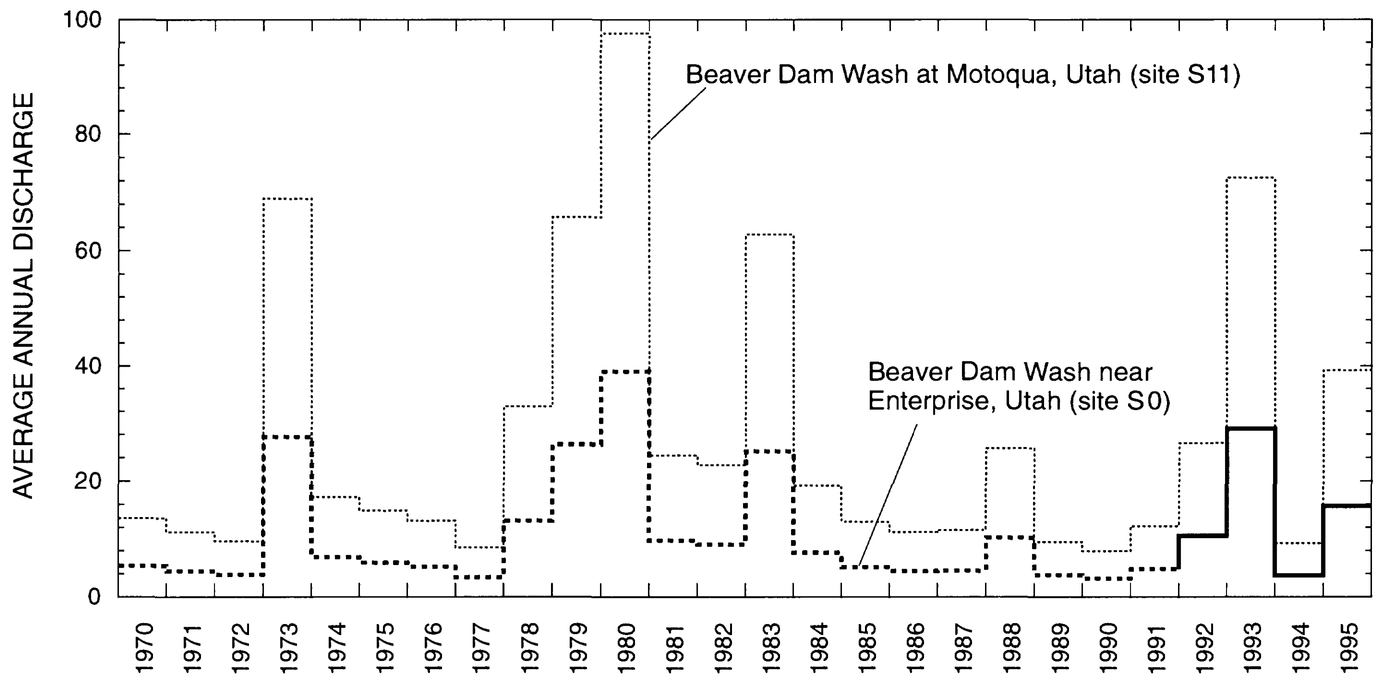


Figure 12. Measured (solid line) and estimated (dashed line) average annual discharge for Beaver Dam Wash at Enterprise, Utah, and Beaver Dam Wash at Motoqua, Utah, 1970-95.

that the long-term average discharge could be estimated for 1970-95. Because of the lack of an adequate site, the gage was installed about 0.8 mi above the mouth. There is considerable gain from seepage and springs in the reach between the gage (site S29) and the mouth (site S32). To obtain a long-term estimate at the mouth, the flow at site S29 was estimated for 1970-95 and then extended to the mouth using miscellaneous measurements taken concurrently at site S29 and site S32 during 1990-95.

Much of the reach between Motoqua (site S11) and the gage at Beaver Dam, Arizona (site S29), is a losing reach, and the ratio of drainage area upstream from site S11 to that upstream from site S29 is only 0.3. Thus, both criteria specified by Christensen, Johnson, and Plantz (1986) were not met, and the regional equation used for extending the record for site S11 was not used for site S29. Average discharge for 1970-95 at site S29 was estimated using the average ratio of the gaged flow at site S29 to that of site S0 during the 1993-94 water years and the 1970-95 estimated average flow at site S0 as shown below.

Q1970-95, sites 29 =[(Q1993-94, site S29)/(Q1993-94, site S0)]•(Q1970-95, site S0) (2)

where

Q1993-94, site S29 = 21 + 2.6 = 23.6 ft^3/s,

Q1993-94, site S0 = 29 + 3.7 = 32.7 ft^3/s, and

Q1970-95, site S0 = 11 ft^3/s.

By entering these values into equation 2, we can calculate that Q1970-95, site S29 = (23.6/32.7)•11 = 8 ft^3/s.

Spring discharge and seepage result in considerable gain between the gage (site S29) and the mouth of the stream (site S32). Little or no surface runoff enters the reach between the gage (site S29) and the mouth (site S32), so total discharge at the mouth (site S32) was estimated by adding the gains measured in the reach to that measured and estimated at the upstream gaged site (site S29).

The estimated average annual discharges for 1970-95 at the gaged site (S29) and at the mouth of Beaver Dam Wash (S32) are subject to large error. The long-term discharges can be improved by a longer period of data collection at the gaged site.

Net gain in base flow between sites S29 and S32

At approximately monthly intervals, 16 measurements of instantaneous flow were made during low-flow periods during 1993-94 at sites S29 and S32 so that the gain in discharge in the 0.8-mi reach could be estimated. Based on the measurements of the discharge at site S29 (gage) and site S32 (mouth), discharge was about 3.5 times greater at the mouth (site S32) than at the gage (site S29). During the 1990-94 water years, base flow measured and estimated at site S29 averaged about 2.5 ft^3/s (table 1), and base flow measured at site S32 averaged 7.8 ft^3/s. Except for the 1993 water year, about 1 ft^3/s also was estimated to have been diverted from the 0.8-mi reach for each year back to at least 1970. The diversion was temporarily destroyed during the 1993 water year because of a flood. Assuming that all of the diverted water was consumed during 1990-92 and 1994, the net gain during 1990-94 was estimated to be:

Net gain between sites S29 and S32 = 7.8 - 2.5 + 0.8 = 6.1 ft^3/s.

Historical trend in base flow at Beaver Dam Wash at mouth (site S32)

Although less than 2 years of gaged record exist for site S29 on Beaver Dam Wash, miscellaneous measurements were made at site S32 during 1946-94. Most, if not all, of the miscellaneous measurements were made during periods of low or base flow with no storm runoff. During 1946-82, 19 measurements were made at the mouth (site S32), and discharge ranged from 0.74 to 6.9 ft^3/s and averaged 4.7 ft^3/s (includes estimated 1 ft^3/s of diverted water). During 1990-94, 64 measurements were made at site S32, and discharge ranged from 5.5 to 12.8 ft^3/s and averaged 8.6 ft^3/s. Thus, the average base flow at the mouth (site S32) during 1990-94 was about 4 ft^3/s, or 1.9 times greater than that during 1946-82. The reason(s) for the increased base flow in the 0.8-mi reach during 1990-94 is not known.

Net Loss Between Beaver Dam Wash at Motoqua, Utah (site S11) and Beaver Dam Wash at mouth (site S32)

From the summary of discharges in table 2, the losses and gains for estimating net recharge to the channel-fill deposits between sites S11 and S32 can be

Table 1. Summary of low-flow measurements used for estimating net gain of discharge in 0.8-mile reach of Beaver Dam Wash between gage (site S29) and mouth (site S32)

[e, estimated using ratio of discharge at mouth (site S32) to discharge at gage (site S29) during 1993-94; m, based on average of measured discharge for indicated years]

Net gain between sites: Column 4 equals column 2 plus column 3 minus column 1.

Water year	Discharge, in cubic feet per second			
	Site S29 (at gage) (1)	Site S32 (at mouth) (2)	Diversion between sites S29 and S32 (3)	Net gain between sites S29 and S32 (4)
Average 1946-82	1.3 e	3.7 m	1.0	3.4
1990	2.3 e	7.1 m	1.0	5.8
1991	2.4 e	7.5 m	1.0	6.1
1992	2.4 e	7.3 m	1.0	5.9
1993	2.5 m	9.0 m	0	6.5
1994	2.6 m	8.1 m	1.0	6.5
Average 1990-94	2.5	7.8	.8	6.1
Average 1970-95	1.5	5.1	.9	4.5

made. During the 1993 water year, the net loss was 72 - 27.5 = 45 ft^3/s (rounded) and the average for 1970-95 was 28 -12.5 = 16 ft^3/s (rounded).

Flood Characteristics

Knowledge of the recurrence intervals and magnitudes of peak flows is useful for the design of dams, culverts, and other structures. Flood-frequency curves were developed for sites S0, S11, and S29 on Beaver Dam Wash (fig. 13). The flood-frequency curves were prepared from regional flood-frequency equations developed by Thomas, Hjalmarson, and Waltemeyer (1994) for a regional area that includes Beaver Dam Wash. The flood-frequency equations relate flood magnitude to mean basin altitude and drainage area. Selected basin, climate, and streamflow characteristics for Beaver Dam Wash are compiled in table 3.

A flood peak of 1,740 ft^3/s occurred at site S0 on March 11, 1993. According to the regional regressions, the recurrence interval of this flood peak is about 40 years. At site S29 a flood peak of 5,940 ft^3/s occurred on February 10, 1993, and a peak of 13,000 ft^3/s occurred on March 12, 1995. The recurrence intervals for the two flood peaks are about 20 years and 55 years, respectively.

GROUND-WATER HYDROLOGY

Ground water in the Beaver Dam Wash area is present in both consolidated rocks and semiconsolidated and unconsolidated basin-fill and alluvial channel-fill deposits. Ground water in consolidated rocks in the higher-altitude mountainous areas provides the base flow of perennial reaches of streams and discharge to springs. Ground water in the consolidated rocks probably provides recharge to the semiconsolidated and unconsolidated basin-fill deposits through subsurface inflow. Ground water in the basin-fill deposits also provides the base flow to perennial reaches of Beaver Dam Wash and discharge to springs in the lower-altitude areas. Most ground-water withdrawals from wells are from the unconsolidated basin-fill deposits.

Consolidated Rocks

Consolidated rocks crop out in about one-half of the study area. Ground water is present in volcanic rocks of Tertiary age, igneous and metamorphic rocks of Precambrian age, carbonate rocks of Paleozoic age, and sedimentary rocks of Mesozoic age including the Navajo Sandstone. Few wells produce water from consolidated rocks in the Beaver Dam Wash area. Well (C-40-18)15dbd-1 produces water from the Navajo Sandstone, and wells (C-41-19)6bbc-1, (C-41-19)8cdc-1, and 8/70-14a produce water from consolidated rocks, possibly partly from Paleozoic-age formations that are mostly carbonates (Glancy and VanDenburgh, 1969, table 22; and Enright, 1996, table 1).

Recharge

Recharge to the consolidated rocks in the Beaver Dam Wash area is from infiltration of precipitation and streamflow, and subsurface inflow. Data on the total

Table 2. Summary of measured and estimated average annual discharge at sites on Beaver Dam Wash and Santa Clara River at Gunlock, Utah

[m, measured discharge in cubic feet per second at gaging station; e, estimated discharge in cubic feet per second; Site on Beaver Dam Wash, see figure 2 for location]

Water year(s)	Discharge, in cubic feet per second: Site on Beaver Dam Wash				
	S0	S11	S29	S32	Santa Clara River at Gunlock
1992	10.6 m	26 e	—	—	23.1 m
1993	29 m	72 e	21 m	27.5 e	62.5 m
1994	3.7 m	9 e	2.6 m	9.1 e	13.9 m
1995	15.7 m	39 e	—	—	34.5 m
Average 1970-95	11 e	28 e	8 e	12.5 e	24.4 m

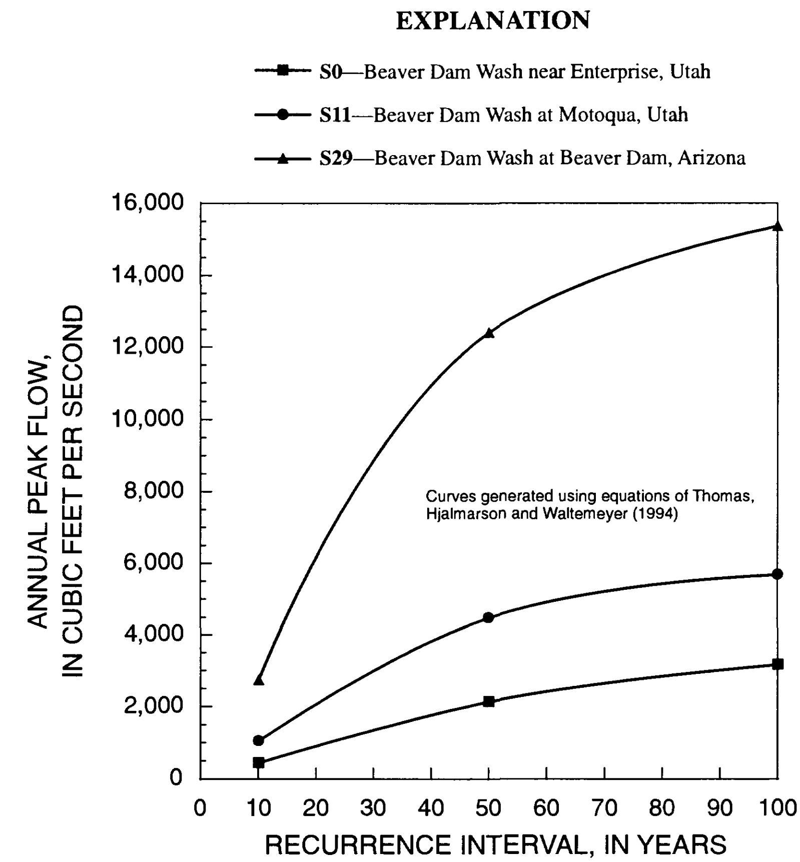


Figure 13. Flood-frequency curves for sites S0, S11, and S29 on Beaver Dam Wash.

Table 3. Selected basin, climate, and streamflow characteristics for gaged and ungaged sites on Beaver Dam Wash
Site number: See figure 6 for location.
Estimate of average annual discharge: In cubic feet per second.
Low-flow statistics: In cubic feet per second.
Peak discharge for indicated recurrence interval: In cubic feet per second.
Annual peak discharge of record: —, no data.

Site number	Contributing drainage area (square miles)	Mean basin altitude (feet)	Mean annual precipitation (inches)	Estimate of average annual discharge, 1970-95	Peak discharge for indicated recurrence interval: 10 year	50 year	100 year	Annual peak discharge of record	Date of measurement
S0	58	5,740	17	11	440	2,130	3,160	1,440	02/19/93
								1,740	03/11/95
S11	185	5,350	17	28	1,050	4,480	5,680	—	—
S29	575	4,520	13	8	2,730	12,400	15,900	5,940	02/10/93
								13,000	03/12/95

amount of recharge to consolidated rocks are not available. Infiltration of precipitation on consolidated rocks, which averages about 13 in/yr in the Beaver Dam Wash area, probably is the largest source of recharge. Recharge is greatest in the high-altitude areas above 5,000 ft and is at a maximum rate during the late winter and early spring when infiltration of the melting snowpack is greatest and evapotranspiration is small. Trudeau and others (1983) report recharge to be about 11 ft^3/s to consolidated rocks from infiltration of precipitation near the eastern boundary of the Beaver Dam Wash area.

Recharge from infiltration of streamflow probably occurs in major tributaries to Beaver Dam Wash. Recharge to consolidated rocks from the main Beaver Dam Wash channel is probably minimal. Beaver Dam Wash is underlain, at a shallow depth, by consolidated rocks (mostly volcanic rocks of Tertiary age) upstream from Motoqua, Utah. Data collected during seepage studies and reported by Enright (1996, table 5) do not show any streamflow losses to consolidated rocks upstream from Motoqua. Downstream from Motoqua, Beaver Dam Wash is underlain by semiconsolidated and unconsolidated basin-fill deposits. U.S. Geological Survey gaging station 09413900, Beaver Dam Wash near Enterprise (S0), has an estimated average discharge of 11 ft^3/s, and the measurement site downstream near Motoqua (S11) has an estimated discharge of 28 ft^3/s (table 2). This also indicates that Beaver Dam Wash is a gaining stream between the gage (S0) and Motoqua (S11).

Recharge from subsurface inflow occurs along the east side of the Beaver Dam Wash area. Trudeau and others (1983) report about 50 ft^3/s of subsurface recharge from the Virgin River east of the Beaver Dam area near Bloomington, Utah, where during low flow, the Virgin River loses its entire flow. Trudeau and others (1983) conclude that the water lost from streamflow in the Virgin River recharges carbonate rocks, moves to the west, and reappears as spring discharge near Littlefield, Arizona. Glancy and VanDenburgh (1969, fig. 2) also indicate that subsurface inflow is entering the Beaver Dam Wash area from the east but do not quantify it.

Movement

The direction of ground-water movement in consolidated rocks in the Beaver Dam Wash area is largely unknown. Because the consolidated rocks in the Beaver Dam Wash area have little primary permeability, the direction of movement probably is controlled by the location of the recharge areas; the density, interconnection, and orientation of fractures, and in the case of carbonate rocks, the size and interconnection of primary and secondary solution openings; and the location of discharge areas. Intergranular movement of ground water occurs in the Navajo Sandstone and possibly other sandstone units in the area, but movement of ground water through fractures in these units also is substantial.

In the mountainous, high-altitude, northern part of the Beaver Dam Wash area, the general direction of ground-water movement probably is toward areas of lower altitude at the bottom of Beaver Dam Wash and its major tributaries upstream from Motoqua. This is evidenced by measured gains in streamflow between U.S. Geological Survey gaging station 09413900, Beaver Dam Wash near Enterprise (S0), and a measurement site near Motoqua (S11), as mentioned in the "Recharge" section of this report. In general, springs in the northern part of the area probably are not large enough to cause significant deviations from the general direction of ground-water flow.

A possible exception to the general direction of ground-water flow in consolidated rocks in the northern part of the area is water in the Navajo Sandstone. On the northeastern border of the study area, the ground-water flow direction in the Navajo Sandstone could be toward the east where a number of production wells in the Navajo Sandstone supply water to the city of St. George, Utah. If there is a hydraulic connection, the water-level gradient in the Navajo Sandstone between well (C-40-18)15dbd-1 (Enright, 1996, table 1) at the eastern boundary of the study area and the water-supply wells for the city of St. George near Gunlock Reservoir, about 5 mi east, is about 36 ft/mi to the east.

On the southeastern side of the Beaver Dam Wash area in the Virgin River Gorge, springs discharge a total of about 20 ft^3/s from rocks of Paleozoic age (Trudeau and others, 1983). The direction of ground-water movement over a large area probably is toward these springs.

Wells drilled recently near the city of Mesquite, Nevada, produce large amounts of ground water from the Muddy Creek Formation that is similar in chemical composition to ground water in Beaver Dam Wash. Johnson (1995 and oral commun., 1994) suggests that a possible source for the water is underlying carbonate rocks, which transmit water through vertical faults to wells in the Muddy Creek Formation. Additional data are needed before this contention can be proven, but if the theory is correct, ground-water movement in carbonate rocks in some western and southwestern parts of the Beaver Dam Wash area may be toward the southwest.

Discharge

Discharge from consolidated rocks is to springs, seepage to streams, and possibly to subsurface outflow. Trudeau and others (1983) report that springs discharge about 20 ft^3/s from rocks of Paleozoic age in the Virgin River Gorge. In the northern part of the area, about 30 small springs discharge from consolidated rocks, primarily volcanic rocks of Tertiary age.

Ground water discharges from consolidated rocks into streams in the higher, northern part of the Beaver Dam Wash area. Beaver Dam Wash is a gaining stream between the gage near Enterprise, Utah, and Motoqua, Utah (see "Losing and Gaining Reaches of Beaver Dam Wash" section). Similar gains can be expected in other reaches of Beaver Dam Wash and its major tributaries in the higher, northern part of the area.

Discharge from consolidated rocks to subsurface outflow may occur along the western and southwestern boundary of the Beaver Dam Wash area. As reported in the "Movement" section of this report, water quality in wells near Mesquite, Nevada, is similar to the quality of water from wells and surface water in Beaver Dam Wash. The flow paths and mechanism for the movement of water from the Beaver Dam Wash area to Mesquite, Nevada, are unknown. On the basis of movement of ground water in consolidated rocks in the Beaver Dam Wash area, the most plausible flow path would be through Paleozoic carbonate formations, but in the southern part of the Beaver Dam Wash area carbonates may be thousands of feet deep. Along the northeastern boundary of the area, water in the Navajo Sandstone may move toward the east to discharge points along the Santa Clara River or to wells that supply water to the city of St. George, Utah.

Unconsolidated and Semiconsolidated Quaternary-Tertiary Basin-Fill Deposits

Ground water is present in the Muddy Creek Formation, the post-Muddy Creek Tertiary gravels and Quaternary alluvial-fan and tufa deposits, and the Quaternary alluvial channel-fill deposits, which collectively are termed the unconsolidated and semiconsolidated Quaternary-Tertiary basin-fill deposits (fig. 4). The Horse Spring Formation probably is in the subsurface in the Beaver Dam Wash area, but no outcrops of the formation have been mapped, and possible ground-water occurrence in the Horse Spring Formation will not be discussed in this report. The post-Muddy Creek Tertiary gravels and Quaternary alluvial-fan and tufa deposits have the largest surface exposure but are unsaturated in most of the Beaver Dam Wash area. The Muddy Creek Formation underlies these deposits and the alluvial channel-fill deposits, and in the southern part of the Beaver Dam Wash area extends to depths of several thousand feet. Despite the prominence of the Muddy Creek Formation in the subsurface, its poorly sorted, fine-grained nature restricts ground-water movement and well withdrawals.

Several large springs discharge water from the Quaternary tufa deposits of the Littlefield Formation of Moore (1972) and Trudeau and others (1983) on the south side of the Virgin River near its confluence with Beaver Dam Wash, but these deposits occupy only a small area. Near the mouth of the Virgin River Gorge, other springs discharge additional water from the Littlefield Formation to the Virgin River.

The Quaternary alluvial channel-fill deposits are the most important water-producing formation in the Beaver Dam Wash area. The channel-fill deposits are coarse grained and well sorted and yield large amounts of water to wells and springs. Although the Quaternary alluvial channel-fill deposits are of limited areal extent and volume, their relation to surface water and springs and the large number of wells that withdraw water from them make them the most important water-bearing unit in the Beaver Dam Wash area. The relation between the Muddy Creek Formation, undifferentiated post-Muddy Creek Tertiary gravels and Quaternary alluvial-fan and tufa deposits, and alluvial channel-fill deposits near Beaver Dam, Arizona, is shown in figures 5A, 5B, and 5C. The unconsolidated and semiconsolidated basin-fill units are discussed generally in the order of their importance to the known ground-water flow system in the area: alluvial channel-fill deposits, post-Muddy Creek Tertiary gravels and Quaternary alluvial-fan and tufa deposits, and Muddy Creek Formation.

Alluvial Channel-Fill Deposits

Ground water occurs in alluvial channel-fill deposits in Beaver Dam Wash and the Virgin River flood plain. The alluvial channel-fill deposits are in the southern two thirds of the Beaver Dam Wash drainage and along a short reach of the flood plain of the Virgin River in the southern part of the area. Some alluvial channel-fill deposits are in Big Bend and Sand Hollow

Washes west of Beaver Dam Wash, but this fill probably is unsaturated. The alluvial channel-fill deposits in Beaver Dam Wash and along the Virgin River generally are saturated.

Wells completed in the alluvial channel-fill deposits yield large amounts of water to irrigation wells in Beaver Dam Wash and the Virgin River flood plain and account for almost all of the ground-water withdrawals from basin-fill deposits in the Beaver Dam Wash area. Wells completed in the alluvial channel-fill deposits supply water for agricultural and culinary use and also for watering a golf course in Beaver Dam, Arizona.

Water in the alluvial channel-fill deposits is in hydraulic connection with surface water in the Beaver Dam Wash area, and several wetland areas are dependent upon ground water in the alluvial channel-fill deposits. The primary focus of this study was the alluvial channel-fill deposits of Beaver Dam Wash. The estimated ground-water budget for the alluvial channel-fill deposits is shown in table 4. The estimated average annual water budget for Beaver Dam Wash and the alluvial channel-fill deposits for 1970-95 is shown as a schematic diagram in figure 14. The elements of figure 14 are discussed in the following sections on recharge to and discharge from the alluvial channel-fill deposits.

Recharge

Recharge to the alluvial channel-fill deposits from stream infiltration and subsurface inflow from the Muddy Creek Formation was estimated to be about 41,000 acre-ft in 1993, an abnormally wet year, and the long-term average (1970-95) was estimated to be about 18,000 acre-ft/yr. Recharge from infiltration of precipitation on the alluvial channel-fill deposits is not significant because of the small surface area, low average annual precipitation, and high potential evapotranspiration in the area. Recharge from stream infiltration occurs along the flood channel of Beaver Dam Wash. Streamflow measurements (Enright, 1996, table 5) and records from gaging stations (Enright, 1996, tables 6 and 7) were used to help quantify the amount and location of recharge from stream infiltration.

Recharge from stream infiltration in 1993 was estimated by subtracting the annual discharge of Beaver Dam Wash upstream from the springs near the mouth from the estimated annual discharge of Beaver Dam Wash at Motoqua, Utah. The road crossing at Motoqua represents the farthest upstream point in Beaver Dam Wash where substantial channel-fill deposits are present. Tributary inflow to Beaver Dam Wash downstream from Motoqua is small on the basis of observations of no flow during seepage studies and other field activities; therefore, only streamflow in the

Table 4. Estimated ground-water budget for the alluvial channel-fill deposits in Beaver Dam Wash

Budget element	1993	1970-95
	Recharge, in acre-feet per year	
Stream infiltration	38,800	15,600
Subsurface inflow from Muddy Creek Formation	1,900	1,900
Total Recharge (rounded)	**41,000**	**18,000**
	Discharge, in acre-feet per year	
Springs	6,500	4,300
Subsurface outflow		
Virgin River alluvial fill	5,000	5,000
Muddy Creek Formation[1]	11,200	4,400
Evapotranspiration	1,000	800
Wells	3,000	3,000
Total Discharge (rounded)	**27,000**	**18,000**
Water going into storage	**14,000**	**0**

[1]Discharge as subsurface outflow to the Muddy Creek Formation is computed as the difference between total recharge (not rounded) and the total of all other discharge elements, minus the change in storage. This number also represents recharge to the Muddy Creek Formation from stream infiltration along Beaver Dam Wash.

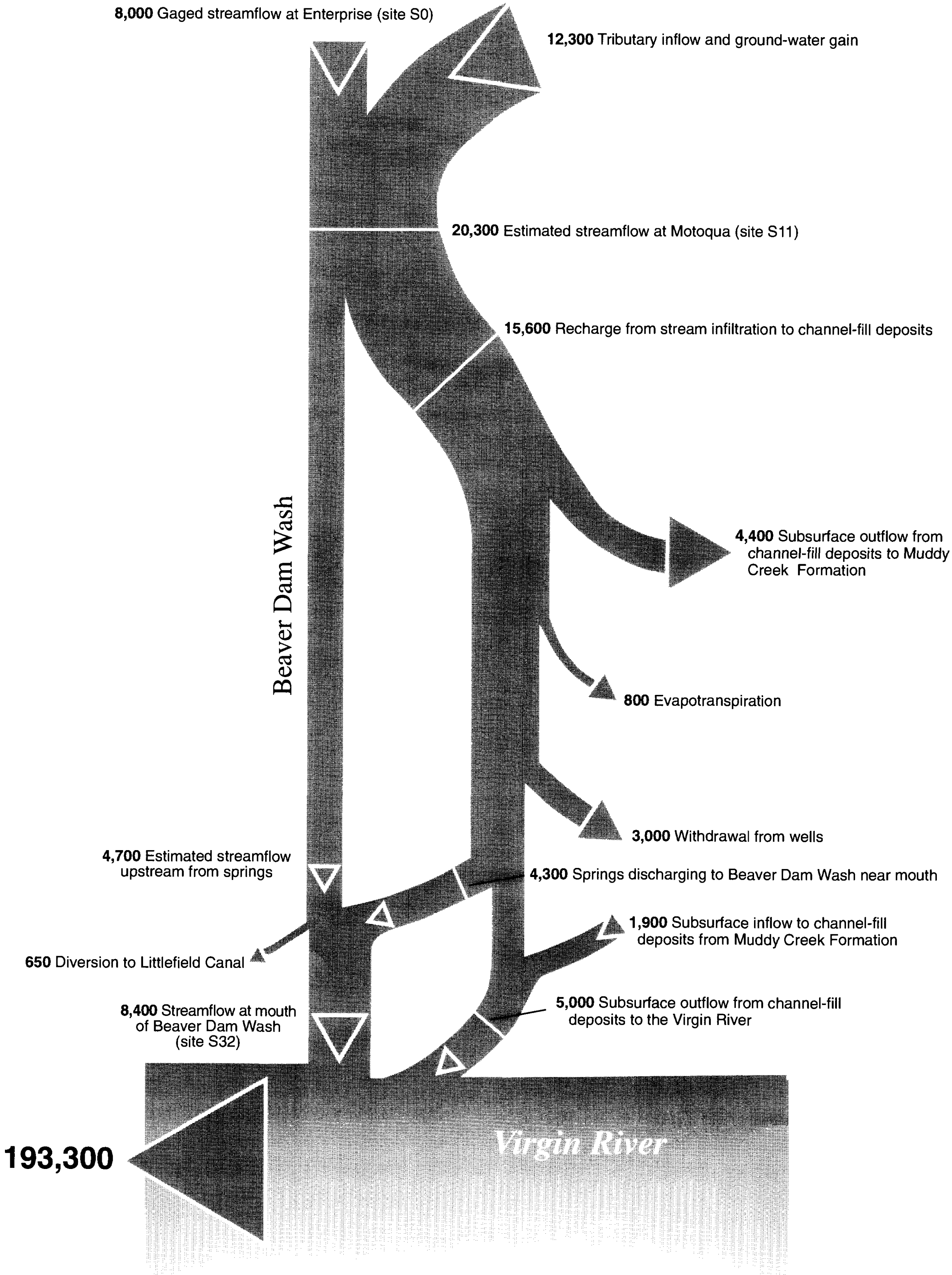


Figure 14. Flow chart showing the estimated average annual water budget (in acre-feet per year) for Beaver Dam Wash and its alluvial channel-fill deposits, 1970-95.

main channel of Beaver Dam Wash at Motoqua is used in calculating recharge from stream infiltration. The discharge of Beaver Dam Wash downstream from the confluence with the East Fork at the road crossing at Motoqua, Utah, during 1993 was estimated to be 72 ft^3/s or 52,200 acre-ft (site S11, table 2). The discharge of Beaver Dam Wash upstream from the springs near the mouth in 1993 was estimated by subtracting the low-flow measurement at site S29 (2.5 ft^3/s or 1,800 acre-ft, table 1), which represents springs discharging above the gage, from the 1993 estimate of average discharge at site S29 (21 ft^3/s or 15,200 acre-ft, table 2). The discharge of Beaver Dam Wash upstream from the springs near the mouth in 1993 was estimated to be 13,400 acre-ft. On the basis of these estimates of streamflow, the total amount of recharge from stream infiltration to the alluvial channel-fill deposits in 1993 was about 38,800 acre-ft (52,200 minus 13,400).

The estimated long-term average (1970-95) discharge at the road crossing at Motoqua, Utah (site S11), was 28 ft^3/s or 20,300 acre-ft/yr, and the long-term average of Beaver Dam Wash upstream from the springs near the mouth was 8 ft^3/s (5,800 acre-ft) minus 1.5 ft^3/s (1,100 acre-ft) or 4,700 acre-ft/yr (tables 1 and 2). Estimated long-term average recharge from stream infiltration therefore is about 15,600 acre-ft/yr (20,300 minus 4,700).

Recharge to the channel-fill deposits from subsurface inflow from the Muddy Creek Formation occurs near the mouth of Beaver Dam Wash. Evidence of the recharge can be found in water-quality data from wells and springs near the mouth of Beaver Dam Wash. Measurements of specific conductance during a seepage study on October 21, 1993, showed increases in specific-conductance values near the mouth of Beaver Dam Wash. The specific-conductance value of water from springs discharging in the channel downstream from U.S. Geological Survey gaging station 09414900, Beaver Dam Wash at Beaver Dam, Arizona, was 650 μS/cm, and specific conductance was 860 μS/cm at the mouth of the wash (Enright, 1996, table 5).

An estimate of the amount of recharge from subsurface inflow derived from the Muddy Creek Formation can be obtained using the formulas

$$Q_1C_1 + Q_2C_2 = Q_3C_3 \text{ and} \quad (3)$$

$$Q_1 + Q_2 = Q_3, \quad (4)$$

where

Q_1 is the subsurface flow,

C_1 is the specific-conductance value for ground water in the channel-fill deposits upstream of U.S. Geological Survey gaging station 0944900 at well (B-41-15)29cbc, about 2.5 mi upstream from the mouth,

Q_2 is subsurface recharge from the Muddy Creek Formation,

C_2 is the specific-conductance value of water from the Muddy Creek Formation near the mouth of Beaver Dam Wash,

Q_3 is the total subsurface outflow and discharge from springs at the mouth of Beaver Dam Wash, and

C_3 is the specific-conductance value of the water at the mouth of Beaver Dam Wash.

These formulas account for the mixing of two sources of water with different values of specific conductance while retaining conservation of mass.

The subsurface flow (Q1) in Beaver Dam Wash upstream from the area where recharge to the channel-fill deposits from the Muddy Creek Formation is occurring can be calculated using Darcy's Law in the form of

$$Q = TIL \quad (5)$$

where

T is the transmissivity of the channel fill,

I is the hydraulic gradient, and

L is the cross-sectional length of the channel-fill deposits.

The results of an aquifer test done about 2.5 mi upstream from the mouth of Beaver Dam Wash, during which well (B-41-15)29cbc was pumped for 72 hours and drawdown and recovery were measured in six observation wells, indicate a transmissivity of about 35,000 ft^2/d. The hydraulic gradient, based on the altitude of water levels in wells prior to the test, was about 0.008 ft/ft and the length of the cross section was about 4,500 ft. Thus, the estimated subsurface flow (Q_1) in Beaver Dam Wash about 2.5 mi upstream from the mouth is 1.26 million ft^3/d or about 10,600 acre-ft/yr (14.6 ft^3/s). The specific conductance (C_1) of water from the well on February 27, 1994, was 535 μS/cm (Enright, 1996, table 3).

Water in the Muddy Creek Formation on the east side of Beaver Dam Wash near the mouth is of the same type and is similar in quality to water in the Virgin River. The specific conductance (C_2) of water from well (B-41-15)33bac, completed in the Muddy Creek Formation (Enright, 1996, table 3), was 2,720 μS/cm. The specific conductance (C_3) of water discharging from springs into the channel near the mouth of Beaver Dam Wash on October 21, 1993, was about 860 µS/cm (Enright, 1996, table 5), which also is assumed to represent the specific conductance of the subsurface flow from Beaver Dam Wash to the Virgin River. There was no water in Beaver Dam Wash upstream from the springs near the mouth as evidenced by a no-flow observation 5.9 mi upstream from the mouth on October 21, 1993 (Enright, 1996, table 5).

Substituting $Q_1 + Q_2$ for Q_3 in the equation $Q_1C_1 + Q_2C_2 = Q_3C_3$ and rearranging the equation results in the relation

$$Q_2 = ((Q_1C_3) - (Q_1C_1)) / (C_2 - C_3). \qquad (6)$$

On the basis of the data presented above, estimated recharge to the channel-fill deposits from the Muddy Creek Formation is ((14.6)(860) - (14.6) (535)) / (2,720 - 860), or about 2.6 ft^3/s or 1,900 acre-ft/yr. Water levels in wells completed in the Muddy Creek Formation do not fluctuate significantly (Enright, 1996, table 1); therefore, the estimated 1,900 acre-ft/yr of recharge from the Muddy Creek Formation is assumed to represent both the 1993 and the long-term average recharge.

Movement

The altitude and configuration of the water table in the semiconsolidated and unconsolidated basin-fill deposits near the lower part of the Beaver Dam Wash area is shown in figure 15. The direction of ground-water flow in the alluvial channel-fill deposits in most of the Beaver Dam Wash area generally is southeast. Near the mouth of the wash, the direction of ground-water flow is toward springs in the bottom of the wash or to the south, toward the Virgin River. Data in the upper parts of the Beaver Dam Wash area are not available.

Water-Level Fluctuations

Water levels in the channel-fill deposits fluctuate primarily in response to streamflow in Beaver Dam Wash. Water levels in the channel-fill deposits near springs in Beaver Dam Wash do not fluctuate as much as water levels in areas more distant from springs. Between February 1991 and February 1994, water levels in well (B-41-15)32dba (Enright, 1996, table 1) varied from a high of 18.07 ft below land surface in February 1993 to a low of 21.90 ft below land surface in February 1991. The well is located close to springs discharging near the mouth of Beaver Dam Wash and water-level fluctuations in the well are small.

Water levels in well (B-41-16)13ada on the flood plain of Beaver Dam Wash (Enright, 1996, table 1), which is more distant from springs in Beaver Dam Wash, varied from 51.94 ft below land surface in February 1993 to 36.74 ft below land surface in February 1994. The 15-ft rise in water levels was the result of stream infiltration during 1993 when streamflow in Beaver Dam Wash was above average (table 2). The rise in water levels may have been even greater than 15 ft because some flooding in Beaver Dam Wash occurred during January 1993, which could have caused additional water-level rises in January.

Water levels in well (B-41-15)33cab (fig. 16) have been measured about annually since 1976. Between 1976 and 1981, water levels in the well rose about 20 ft; between 1981 and 1992, water levels declined about 8 ft; and between 1992 and 1994, water levels rose again by about 8 ft. Water-level fluctuations in the well generally correspond to a hydrograph showing cumulative departure from average annual precipitation at St. George, Utah, and a hydrograph showing the annual mean discharge at U.S. Geological Survey gaging station 09415000, Virgin River at Littlefield, Arizona (Allen, Steiger, and others, 1995, fig. 35). Available water-level measurements in February of 1993 and 1994 in all wells completed in the alluvial channel-fill deposits (Enright, 1996, table 1) indicate that the water level rose on the order of about 10 ft in the channel-fill deposits in Beaver Dam Wash in 1993 as a result of above-average streamflow and resultant stream infiltration.

Storage

Recoverable ground water in storage in Beaver Dam Wash in 1993 was estimated to be about 140,000 acre-ft. This estimate is based on the 7,100 acres of channel-fill deposits (fig. 4), an estimated 100-ft thickness of saturated channel-fill deposits, and an estimated specific-yield value of 0.2 determined from lithologic descriptions reported from drillers' logs (Enright, 1996, table 2). The amount of ground water in storage in the channel-fill deposits of Beaver Dam Wash varies from year to year. Water levels in the channel-fill deposits rose an estimated 10 ft as a result of above-average streamflow during 1993. On basis of the estimated rise of 10 ft, the amount of water going into storage was about 14,000 acre-ft.

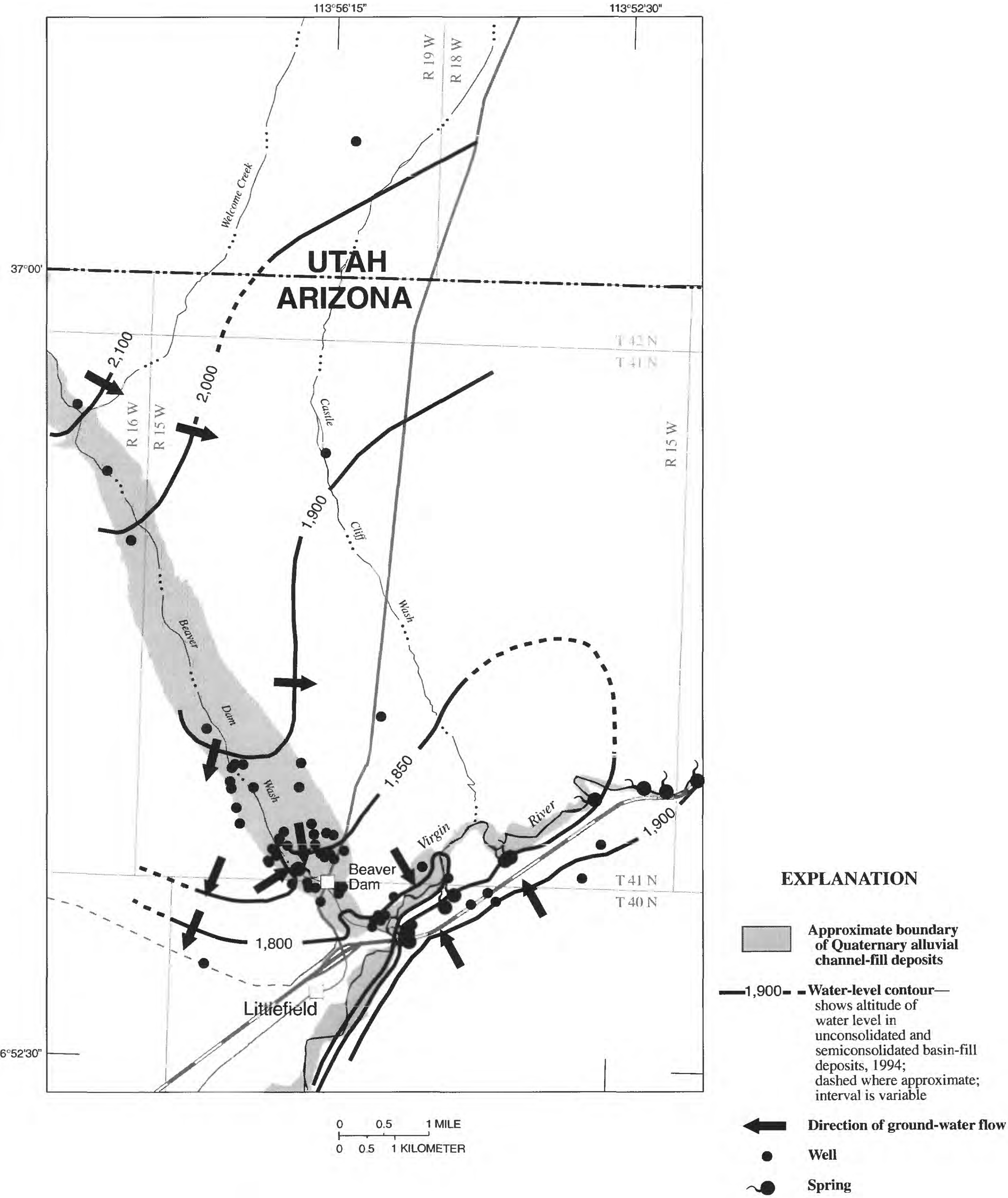


Figure 15. Altitude and configuration of the water table in the unconsolidated and semiconsolidated basin-fill deposits in the lower part of the Beaver Dam Wash area, 1994.

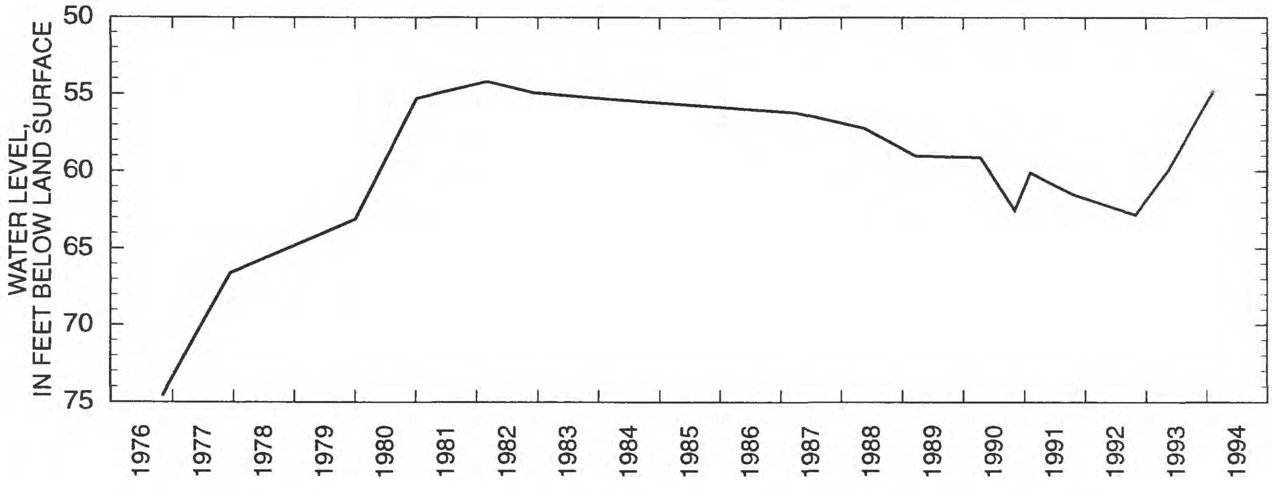


Figure 16. Water-level fluctuations in well (B-41-15)33cab in the Beaver Dam Wash area.

Discharge

Discharge from the alluvial channel-fill deposits in Beaver Dam Wash to springs, wells, evapotranspiration, and subsurface outflow was estimated to be 27,000 acre-ft in 1993, and the long-term average discharge was estimated to be 18,000 acre-ft/yr. Beaver Dam Wash gains flow from springs that discharge from the alluvial channel-fill deposits beginning about 0.5 mi upstream from the gaging station at Beaver Dam, Arizona, which is represented by low-flow discharge at site S29 in table 1, and continuing to its confluence with the Virgin River, which is represented by the low-flow discharge shown as net gain between sites S29 and S32 in table 1. The estimated discharge of these springs, based on low-flow measurements (table 1) in 1993, was 2.5 ft^3/s (1,800 acre-ft) at site S29 plus 6.5 ft^3/s (4,700 acre-ft) gain in flow between sites S29 and S32, or 6,500 acre-ft. The estimated long-term (1970-95) discharge was 6.0 ft^3/s (1.5 ft^3/s at site S29 plus 4.5 ft^3/s gain in flow between sites S29 and S32) or 4,300 acre-ft/yr. Other springs, some of which are intermittent, discharge from the alluvial channel fill to Beaver Dam Wash near its confluence with Welcome Creek (intermittent), at the Lytle Ranch near the confluence with Jackson Wash (intermittent), and at Bentley Springs (fig. 1). Most of the discharge from these springs infiltrates into the alluvial channel-fill deposits and is not considered as discharge from the alluvial channel-fill deposits.

Discharge from the alluvial channel-fill deposits to wells in the Beaver Dam Wash area was estimated to be 3,000 acre-ft in 1993. Most of the discharge from wells is used for irrigation of crops or for watering a golf course in the community of Beaver Dam, Arizona. An estimated 2,500 acre-ft was withdrawn from four large irrigation wells in 1993. The estimates of discharge are reported primarily by the well owners, but some estimates were based upon measurements of discharge. Ground-water withdrawals for watering the golf course at Beaver Dam, Arizona, determined from water-use data from St. George, Utah (Utah Department of Natural Resources, Division of Water Rights, written commun., 1994), was estimated to be 500 acre-ft. About 30 acre-ft was withdrawn for domestic use on the basis of a population of 250 and a per capita consumptive use of 110 gal/day (David Anning, U.S. Geological Survey, Tucson, Arizona, written commun., 1996). The estimated long-term discharge from wells also was assumed to be 3,000 acre-ft/yr.

Discharge from the alluvial channel-fill deposits to evapotranspiration occurs primarily near the mouth of Beaver Dam Wash where phreatophytes such as salt cedar, cottonwoods, and willows are rooted in the saturated channel-fill deposits. Substantial areas of phreatophytes also exist in Beaver Dam Wash near the confluence with Welcome Creek, at the Lytle Ranch, and at Bentley Springs (fig. 1). Floods in Beaver Dam Wash in 1993 removed substantial amounts of phreatophytes, but by 1994, new growth was observed in numerous locations in Beaver Dam Wash.

Glancy and VanDenburgh (1969, table 13) estimated evapotranspiration of ground water by phreatophytes in Beaver Dam Wash to be 750 acre-ft/yr. Eighty percent of the evapotranspiration (600 acre-ft/yr) was reported to occur in the first 1.5 mi upstream from the confluence with the Virgin River. In 1993, precipitation was much higher than average and Beaver Dam Wash was perennial during much of the year. Evapotranspiration by phreatophytes during 1993 was probably greater than reported by Glancy and VanDenburgh. Thus, discharge from the alluvial-fill deposits to evapotranspiration in 1993 was assumed to be 1,000 acre-ft/yr, and the long-term discharge was estimated to be about 800 acre-ft/yr.

Discharge from the alluvial channel-fill deposits in Beaver Dam Wash to subsurface outflow is to Virgin River alluvium at the mouth of Beaver Dam Wash and to the Muddy Creek Formation. The subsurface outflow to the Virgin River alluvium can be estimated using a water budget analysis in the lower 2.5 mi of Beaver Dam Wash. The 1993 discharge to subsurface outflow to the Virgin River alluvium was calculated as follows: 10,600 acre-ft/yr of subsurface flow in Beaver Dam Wash, as measured 2.5 mi upstream from the mouth; plus 1,900 acre-ft/yr of estimated recharge to the channel-fill deposits from the Muddy Creek Formation in the last 2 mi of the wash (see "Recharge" section); minus 1,000 acre-ft of evapotranspiration in the last 2 mi of the wash; minus 6,500 acre-ft of spring discharge in the last 2 mi of the wash; minus any flow from Beaver Dam Wash to the Muddy Creek Formation in the vicinity of the mouth. Most flow from Beaver Dam Wash to the Muddy Creek Formation probably occurs above the mouth, and for purposes of this report, flow to the Muddy Creek Formation in the lower 2.5 mi of Beaver Dam Wash is assumed to be negligible. The estimated amount of subsurface outflow to Virgin River alluvium in 1993 determined by using this budget was 5,000 acre-ft (10,600 + 1,900 - 1,000 - 6,500).

Long-term subsurface outflow to the Virgin River alluvium is assumed to be 5,000 acre-ft/yr, the same as that calculated for 1993. This assumption is based on the argument that the saturated cross-sectional area and hydraulic gradient near the mouth of Beaver Dam Wash do not change significantly because springs in the channel-fill deposits do not allow the water-level altitude to change substantially. The springs can be conceptualized as overflow controls for the ground-water system; therefore, spring discharge may change but subsurface outflow will remain fairly constant.

Subsurface outflow to the Muddy Creek Formation or the overlying post-Muddy Creek Tertiary gravels can be estimated from the ground-water budget for the channel-fill deposits in 1993 and 1970-95 (table 4). This subsurface outflow is computed as the difference between total recharge (not rounded) and the total of all other discharge elements, minus the change in storage. Estimated subsurface outflow to the Muddy Creek Formation in 1993 was about 11,000 acre-ft/yr (40,700 - 15,500 - 14,000 = 11,200), and the estimated long-term average is about 4,400 acre-ft/yr (17,500 - 13,100 = 4,400). These estimates have a high degree of uncertainty and, therefore, estimates of discharge from alluvium to subsurface outflow to the Muddy Creek Formation should be considered only approximate and should be used with caution.

Post-Muddy Creek Tertiary Gravels and Quaternary Alluvial-Fan and Tufa Deposits

Extensive deposits of post-Muddy Creek Tertiary gravels and Quaternary alluvial-fan and tufa deposits that extend to depths of several hundred feet occur near and north of the Virgin River between Beaver Dam Wash and the consolidated rocks in the Beaver Dam Mountains, as evidenced in the driller's logs of wells (C-43-19)25bbb-1 and (B-40-15)4acd. The deposits generally are unsaturated north of the Virgin River (Enright, 1996, table 2); however, post-Muddy Creek saturated gravels extend to a depth of 200 ft on the Virgin River terrace just northeast of the I-15 bridge, and a thin layer of saturated gravel occurs on the south side of the Virgin River from near the confluence with Beaver Dam Wash (fig. 5C) to near the mouth of the Virgin River Gorge. The direct-current resistivity survey (see the "Additional Information" section) indicated that the post-Muddy Creek Tertiary gravels may be as much as 1,000 ft thick near the Beaver Dam and Virgin Mountains.

Recharge to the post-Muddy Creek Tertiary gravels and Quaternary alluvial-fan and tufa deposits is from subsurface inflow from consolidated rocks near the mouth of the Virgin River Gorge. In other parts of the Beaver Dam Wash area, streams lose water where they cross permeable alluvial-fan deposits near the contact with the consolidated rocks, and the infiltrating water moves downward and recharges the underlying Muddy Creek Formation.

Water in the post-Muddy Creek Tertiary gravels and Quaternary alluvial-fan deposits on the south side of the Virgin River near the confluence with Beaver

Dam Wash and near the mouth of the Virgin River Gorge discharges to the Virgin River or to channel-fill deposits along the Virgin River. Several wetland areas along the south side of the Virgin River near the mouth of Beaver Dam Wash are dependent upon ground water discharging from the Littlefield Formation of Moore (1972, p. 22). The Littlefield Formation consists of interbedded limestone and sandstone overlying a conglomerate that caps the Muddy Creek Formation along the Virgin River near the confluence with Beaver Dam Wash (Trudeau and others, 1983). The "Littlefield Limestone Member" is a spring-deposited tufa (see "Geology and geohydrologic units" section). The tufa deposit is the result of the precipitation of calcium carbonate from numerous springs that discharge along the south side of the Virgin River near the confluence with Beaver Dam Wash.

Near the mouth of the Virgin River Gorge, springs generally discharge from post-Muddy Creek Tertiary gravels and Quaternary alluvial-fan deposits. Some discharge from Virgin River alluvium occurs, but the deposits are probably thin, and the original source is probably the underlying or adjacent Littlefield Formation (Trudeau and others, 1983).

The amount of recharge and discharge, assuming water in the deposits is in a steady-state condition, is about equal to the discharge of the springs. Trudeau and others (1983) estimated the discharge of springs at the mouth of the Virgin River Gorge at 20 ft^3/s and the discharge of the springs near the confluence of Beaver Dam Wash and the Virgin River also at about 20 ft^3/s. Recharge and discharge therefore are estimated to be about 40 ft^3/s or 29,000 acre-ft/yr.

Muddy Creek Formation

Ground water occurs in the Muddy Creek Formation throughout most of the study area where the area is underlain by basin-fill deposits. In this report, it is assumed that most of the basin-fill deposits that are saturated consist of the Muddy Creek Formation. Depth to water in the Muddy Creek Formation varies from about 21 ft above land surface at well (C-42-19)7cbc-1 at the Lytle Ranch to about 764 ft below land surface at well (C-43-19)25bbb-1 high on the flanks of the basin (Enright, 1996, table 1). Municipal wells completed in the Muddy Creek Formation yield large amounts of water at Mesquite, Nevada, about 10 mi southwest of the study area (Johnson, 1995), but the Muddy Creek Formation has not shown that capacity within the Beaver Dam Wash area. The difference between the large production capacity of the Muddy Creek Formation near Mesquite, Nevada, and the limited production capacity in the Beaver Dam Wash area is not well understood. Drillers' logs indicate the Muddy Creek Formation to be slightly coarser grained near Mesquite, Nevada, and according to Johnson (1995), fractures or faults in the Muddy Creek Formation may play an important part in the movement of water and increased production capacity.

The direct-current resistivity survey provided information on the extent, thickness, lithology, and quality of water in the Muddy Creek Formation (see "Additional Information" section). Soundings made where the Muddy Creek Formation crops out or is at shallow depth indicate that the resistivity of the unsaturated part ranges from about 25 to 100 ohm-meters and the resistivity of its saturated part ranges from about 9 to 20 ohm-meters. Values of resistivity for the saturated Muddy Creek Formation, together with results of chemical analyses of water from wells east of the wash near the town of Beaver Dam that are completed in the Muddy Creek Formation, indicate lithology and ground-water quality. Where resistivities are less than 20 ohm-meters, the Muddy Creek Formation is predominantly fine grained and contains water that has a dissolved-solids concentration greater than about 2,000 mg/L. The profiles from the entire resistivity survey indicate that most of the topographically low areas in the Beaver Dam Wash area are underlain at depth by fine-grained Muddy Creek Formation and older units saturated with poor-quality water. The extent of this area is shown in figure 3, and the area appears to widen south of profile D-D', which corresponds to the gravity low which marks the deep Mesquite structural basin.

Recharge

Long-term average recharge to the Muddy Creek Formation from stream infiltration along Beaver Dam Wash, subsurface inflow from consolidated rocks, and infiltration of runoff near the mountain front was estimated to be about 48,000 acre-ft/yr. Recharge from infiltration of precipitation on the outcrop of the Muddy Creek Formation is minimal because of low annual average precipitation and high potential evapotranspiration in the low-altitude areas where the formation is exposed at the surface.

A water-budget analysis was used to estimate the amount of recharge from Beaver Dam Wash to the Muddy Creek Formation (table 4). Recharge to the Muddy Creek Formation from stream infiltration along

Beaver Dam Wash was estimated to be about 11,000 acre-ft in 1993. Recharge from stream infiltration probably occurs in Beaver Dam Wash where alluvial channel-fill deposits are in contact with coarse, post-Muddy Creek Tertiary gravel similar to the regrade gravel of Moapa, which overlies the fine-grained Muddy Creek Formation about 40 mi west of Beaver Dam Wash (Schmidt, 1994). These outcrops of gravel were observed at several locations upstream from Beaver Dam, Arizona, and generally coincide with areas where losses of streamflow were observed during seepage studies. Recharge in these areas would be greater than in other areas of the wash where alluvial channel-fill deposits are in contact with fine-grained, lacustrine deposits of the main body of the Muddy Creek Formation. The extent of the post-Muddy Creek gravel in Beaver Dam Wash is unknown. The amount of recharge from stream infiltration was greater in 1993 than would be expected during average flow. The estimated long-term average recharge from stream infiltration is about 4,400 acre-ft/yr.

Recharge to the Muddy Creek Formation from subsurface inflow from consolidated rocks and infiltration of runoff near the mountain front was estimated to be 6,000 acre-ft/yr (Glancy and VanDenburgh, 1969, table 9). Recharge was estimated using the Maxey-Eakin method (Eakin and others, 1951), which relates recharge to precipitation and altitude. The method was developed in ground-water basins in Nevada and has been used to estimate recharge in over 200 basins. A recent 1961-90 precipitation map (Utah State Climate Center, written commun., 1995) was used to update earlier estimates of recharge. The new precipitation map yields larger recharge values (table 5) because precipitation values in given altitude zones on the new precipitation map are larger than those reported by Glancy and VanDenburgh (1969, table 9). The new estimate of long-term recharge from subsurface inflow from consolidated rocks and infiltration of runoff on alluvial fans is 44,000 acre-ft/yr (table 5).

Movement

Ground-water movement in the Muddy Creek Formation probably is from the higher-altitude areas in the northern and eastern part of the Beaver Dam Wash area and along Beaver Dam Wash, toward the lower-altitude areas in the southern and western part of the Beaver Dam Wash area and the Virgin River. Data are insufficient to determine water-table contours for the entire study area, but contours near the mouth of Beaver Dam Wash (fig. 15) indicate movement mostly away from Beaver Dam Wash, although at its mouth, movement is toward the Virgin River. Some recharge to the Muddy Creek Formation from the Virgin River may occur upstream from the mouth of Beaver Dam Wash.

Water-Level Fluctuations

Water-level fluctuations in wells completed in the Muddy Creek Formation are generally small. Water levels in the Muddy Creek Formation measured at well (B-41-15)8ada (5 mi north of Beaver Dam, Arizona) from February 1993 to February 1994 varied from a low of 383.42 ft below land surface on May 14, 1993, to a high of 380.02 ft below land surface on November 5, 1993. Water levels in the Muddy Creek

Table 5. Estimated recharge to Muddy Creek Formation from subsurface inflow from consolidated rocks and infiltration of runoff near the mountain front in the Beaver Dam Wash area

	Area (acres)	Range of precipitation (inches)	Average precipitation (inches)	Assumed percent of precipitation	Estimated recharge[1] (acre-feet per year)
	159,000	greater than 15	18.0	12	28,700
	137,000	12-15	13.5	7	10,800
	179,000	8-12	10.0	3	4,500
	52,000	less than 8	7.0	0	0
Total	527,000				44,000

[1]Based on method modified from Eakin and others (1951, p. 79-81) used with 1961-90 precipitation map (Utah State Climate Center, written commun., 1995).

Formation measured at well (B-41-15)28abd-1 (2 mi north of Beaver Dam, Arizona) from November 1992 to February 1994 varied from a low of 203.04 ft below land surface on February 4, 1993, to a high of 201.36 ft below land surface on November 17, 1992 (Enright, 1996, table 1).

Storage

The amount of recoverable ground water in storage in the Muddy Creek Formation in the Beaver Dam Wash area is estimated to be about 1.5 million acre-ft per 100 ft of saturated material. This estimate is based on about 300 mi^2 of Muddy Creek Formation with a specific-yield value of 0.08 for silt (Johnson, 1967, table 29). The 300-mi^2 area assumes that the Muddy Creek Formation underlies the post-Muddy Creek Tertiary gravels and Quaternary alluvial-fan and tufa deposits. Because of the low yield of wells completed in the Muddy Creek Formation in the Beaver Dam Wash area, it is unlikely that substantial amounts of ground water can be removed from storage.

Discharge

Ground water discharges from the Muddy Creek Formation into the alluvial channel-fill deposits in Beaver Dam Wash near its confluence with the Virgin River and to the southwest as subsurface inflow. Some seepage to the Virgin River downstream from Beaver Dam Wash may occur, but data are not available to prove this. Discharge from the Muddy Creek Formation to Beaver Dam Wash was estimated to be 1,900 acre-ft/yr (table 4). Subsurface outflow, assuming no changes in storage (steady-state conditions), can be estimated as a residual of the recharge minus the estimated discharge to Beaver Dam Wash, which equals about 46,000 acre-ft/yr.

Hydrologic Properties

The transmissivity of the unconsolidated and semiconsolidated Quaternary-Tertiary basin-fill deposits was determined from aquifer tests at wells (B-41-15)29dac (fig. 5A) and (B-41-15)29cbc (fig. 5C) and a slug test at well (C-41-19)8cdc-1 (at the confluence of Jackson Wash with Beaver Dam Wash). Well (B-41-15)29cbc is completed in the channel-fill deposits of Beaver Dam Wash. A multiple-observation-well aquifer test at the well in February and March of 1994 yielded a transmissivity value of about 35,000 ft^2/d. A 6-hour, single-well test in March 1994 at well (B-41-15)29dac, also completed in channel-fill deposits (older channel-fill deposits under a high terrace) of Beaver Dam Wash and the underlying Muddy Creek Formation, yielded a transmissivity value of about 5,000 ft^2/d. The value of 35,000 ft^2/d, determined from the test at (B-41-15)29cbc, is assumed to be more representative of the transmissivity of the channel-fill deposits because the test was much longer in duration, pumping affected a larger part of the saturated channel-fill deposits, the well was completed in a single water-bearing unit which was a younger, and likely more permeable, part of the channel-fill deposits, and a more rigorous analysis of the data was possible.

A slug test on well (C-41-19)8cdc-1, completed in the Muddy Creek Formation, yielded a transmissivity value of about 10 ft^2/d. The transmissivity value determined from the slug test is probably representative of the fine-grained parts of the formation. Gravels of Tertiary age that overlie the Muddy Creek Formation in the Beaver Dam Wash area are expected to have larger transmissivity values, but the values may still be low because of poor sorting and cementation. In addition, the Tertiary-age gravels commonly are unsaturated.

Values for specific yield and storage coefficient could not be determined from aquifer or slug tests conducted during this study. From descriptions of materials reported in drillers' logs and correlation between specific yield and grain size reported by Johnson (1967, table 29), the specific-yield value for the channel-fill deposits was estimated to be about 0.2 and the specific-yield value of the Muddy Creek Formation about 0.08.

WATER QUALITY

Ground Water

Results of water samples analyzed for this study, as well as results reported from earlier studies and laboratory analyses from the files of other agencies are reported by Enright (1996, table 3). The dissolved-solids concentration in water from wells and springs in the topographically lower part of the Beaver Dam Wash area are shown on figure 17, and water-quality diagrams showing the chemical composition of selected ground-water samples are shown in figure 18. Water in the Beaver Dam Wash area generally can be divided into two distinct water types or a combination of the two types.

Type 1 water is represented by ground water discharging from wells and springs east of Beaver Dam

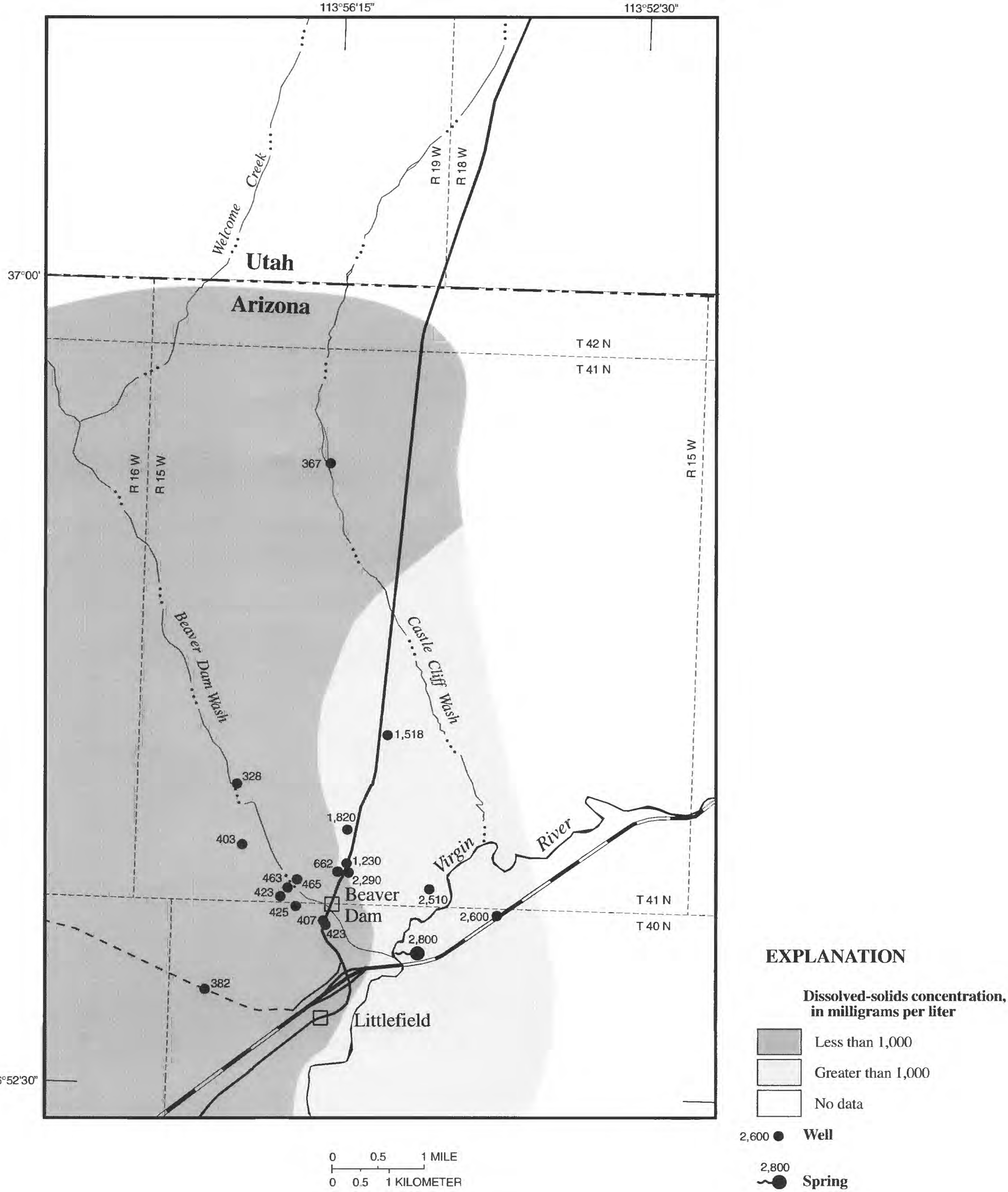


Figure 17. Dissolved-solids concentration in water from wells and springs in the topographically lower part of the Beaver Dam Wash area.

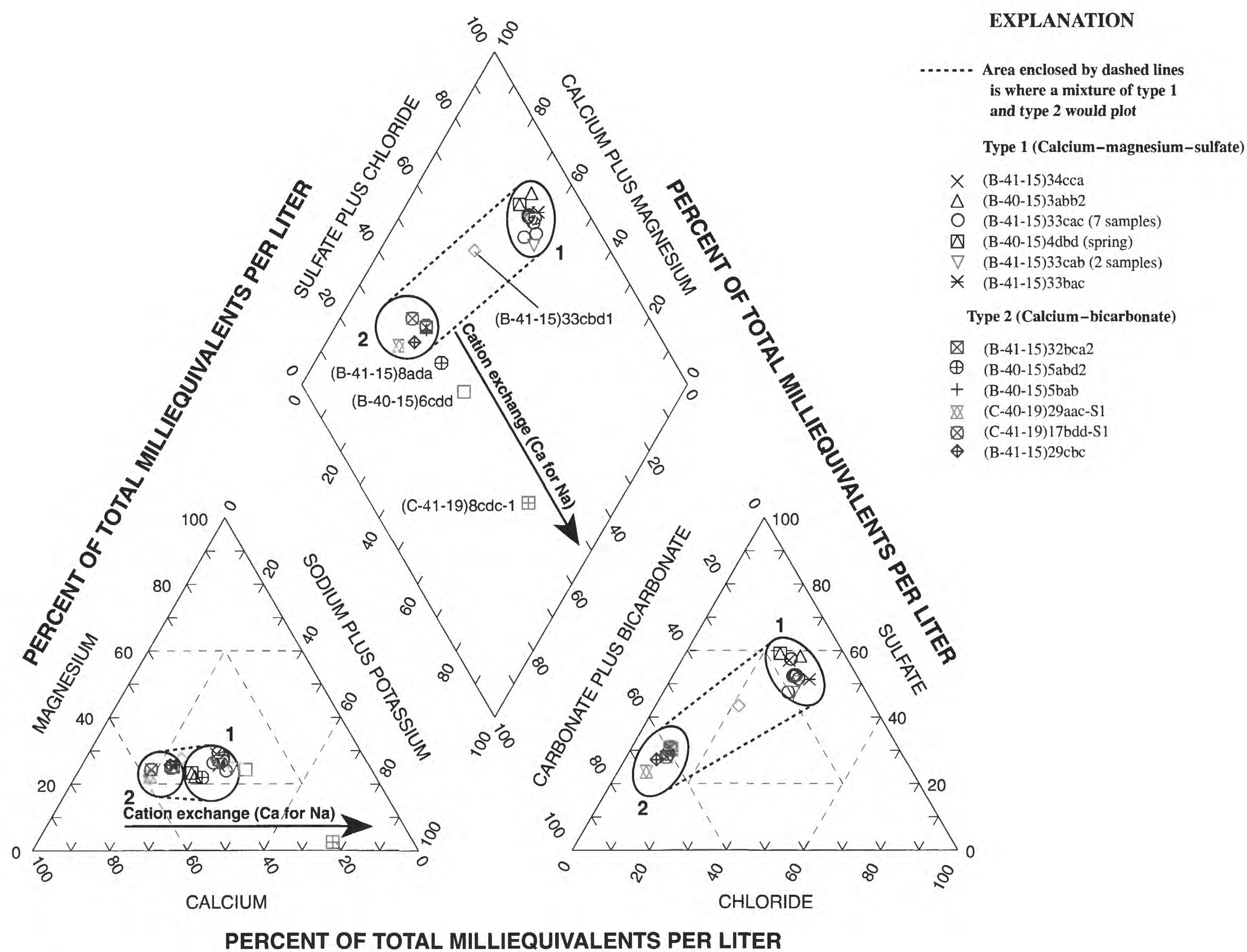


Figure 18. Chemical composition of ground water at selected sites in the Beaver Dam Wash area.

Wash near the Virgin River and is a calcium-magnesium-sulfate type with a dissolved-solids concentration generally greater than 1,500 mg/L (figs. 17 and 18). The water type and dissolved-solids concentration are similar to the type and dissolved-solids concentration of water from the Virgin River. Trudeau and others (1983) use water-quality data, isotope data, surface-water records, and discharge measurements from springs to show that the source of water discharging from springs to the Virgin River in the Virgin River Gorge, near the mouth of the Virgin River Gorge, and on the south side of the Virgin River near the confluence with Beaver Dam Wash, is the Virgin River upstream from the Beaver Dam Wash area near St. George, Utah.

Type 2 water is represented by ground water discharging from wells and springs north of the Virgin River in Beaver Dam Wash and west of Beaver Dam Wash in basin-fill deposits and generally is a calcium-bicarbonate type with a dissolved-solids concentration generally less than 500 mg/L. The water type and dissolved-solids concentration are similar to the water type and dissolved-solids concentration of surface water in Beaver Dam Wash. The boundary between the two types of water is well defined near Beaver Dam Wash, Arizona (fig. 17). Temporal data are not available to determine if this boundary changes between wet and dry years.

Ground water near the mouth of Beaver Dam Wash is a mixture of the two types. Calcium-magnesium-sulfate type water in the Muddy Creek Formation or the overlying post-Muddy Creek Tertiary gravels and alluvial-fan deposits moves from east to west and mixes with the calcium-bicarbonate type water in the channel fill of Beaver Dam Wash. This mixing is represented in figure 18 by well (B-41-15)33cbd1, where water that is a mixture plots between the two types of water represented on the water-quality diagrams.

Wells (B-40-15)6cdd, (B-41-15)8ada, and (C-41-19)8cdc-1, north of the Virgin River, do not fall within the two water types represented by the other wells and springs. These wells are completed in the Muddy Creek Formation and show an increase in sodium and a decrease in calcium when compared to the other samples. This can be explained by a cation-exchange process. The initial recharge water is similar to other ground water in the channel fill of Beaver Dam Wash, but as the water moves slowly away from the wash through the Muddy Creek Formation, calcium is replaced by sodium.

Streams

Beaver Dam Wash

Sandberg and Sultz (1985) collected data describing the general inorganic chemistry of low and high flows at a few selected sites during 1981-82, the Bureau of Land Management collected data on the inorganic chemistry during 1980-94 (Enright, 1996), and the Arizona Department of Natural Resources collected data on nutrients at several sites in the lower reach of Beaver Dam Wash during 1993-94. In the current study, emphasis was placed on the major inorganic constituents. Most of the data used for preparing the range of dissolved-solids concentration were collected as part of the seepage studies made on April 14 and 16, and October 20-21, 1993, and were supplemented with miscellaneous data collected in other years (Enright, 1996).

The range of concentration of dissolved solids in Beaver Dam Wash during the low-flow period of August through November and high-flow period of February through May is shown in figures 19 and 20. Dissolved-solids concentration during the low-flow period of August through November in Beaver Dam Wash ranged from less than 300 mg/L in the upper reach to about 600 mg/L near the mouth. In the upper reach, where the dissolved-solids concentrations are less than 300 mg/L, the principal chemical constituents are calcium and bicarbonate. In the lower reach, where the dissolved-solids concentrations are near 600 mg/L, the principal chemical constituents are calcium, magnesium, sodium, sulfate, and bicarbonate. Because most of the flow at the mouth of Beaver Dam Wash during low-flow periods is derived from springs that enter the 0.8-mi reach between sites S29 and S32, the chemical composition of the water at site S32 is essentially the same as that of the ground water in the channel-fill deposits, which is the source of most of the spring discharge and seepage to that reach of Beaver Dam Wash (see section on "Ground-Water Hydrology").

During the high-flow period of February through May, the dissolved-solids concentrations are generally less than about 300 mg/L in the upper reach above site S19 near Lytle Ranch. In the reach from about 2 mi upstream from site S19 to site S29, the dissolved-solids concentration ranged from about 300 to 400 mg/L; and from site S29 to the mouth at site S32, the dissolved-solids concentration ranged from 400 to 600 mg/L. The principal chemical constituents in water at all sites upstream of site S29 are calcium, magnesium, and

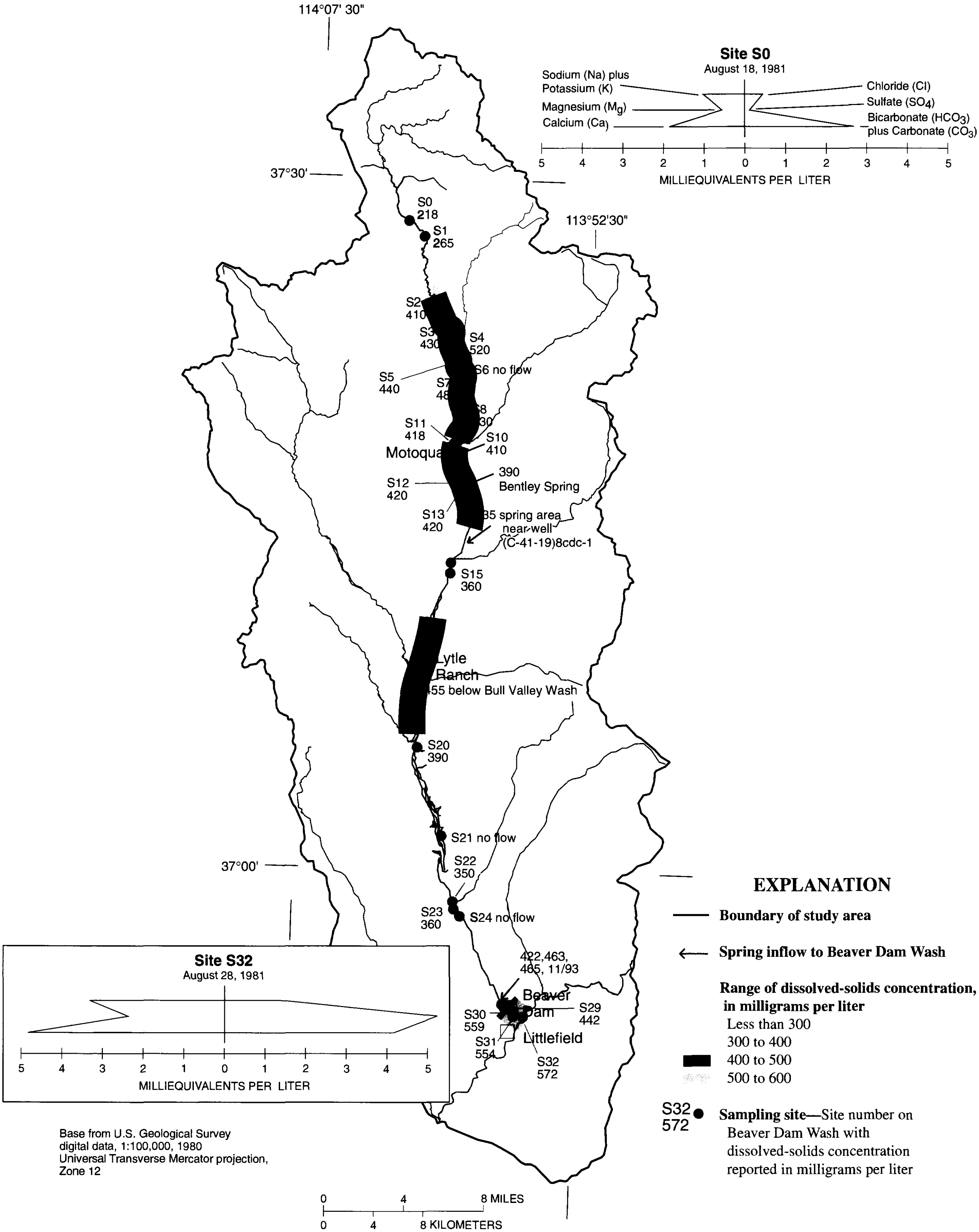


Figure 19. Range of dissolved-solids concentration and chemical composition of water in Beaver Dam Wash during the low-flow period of August through November.

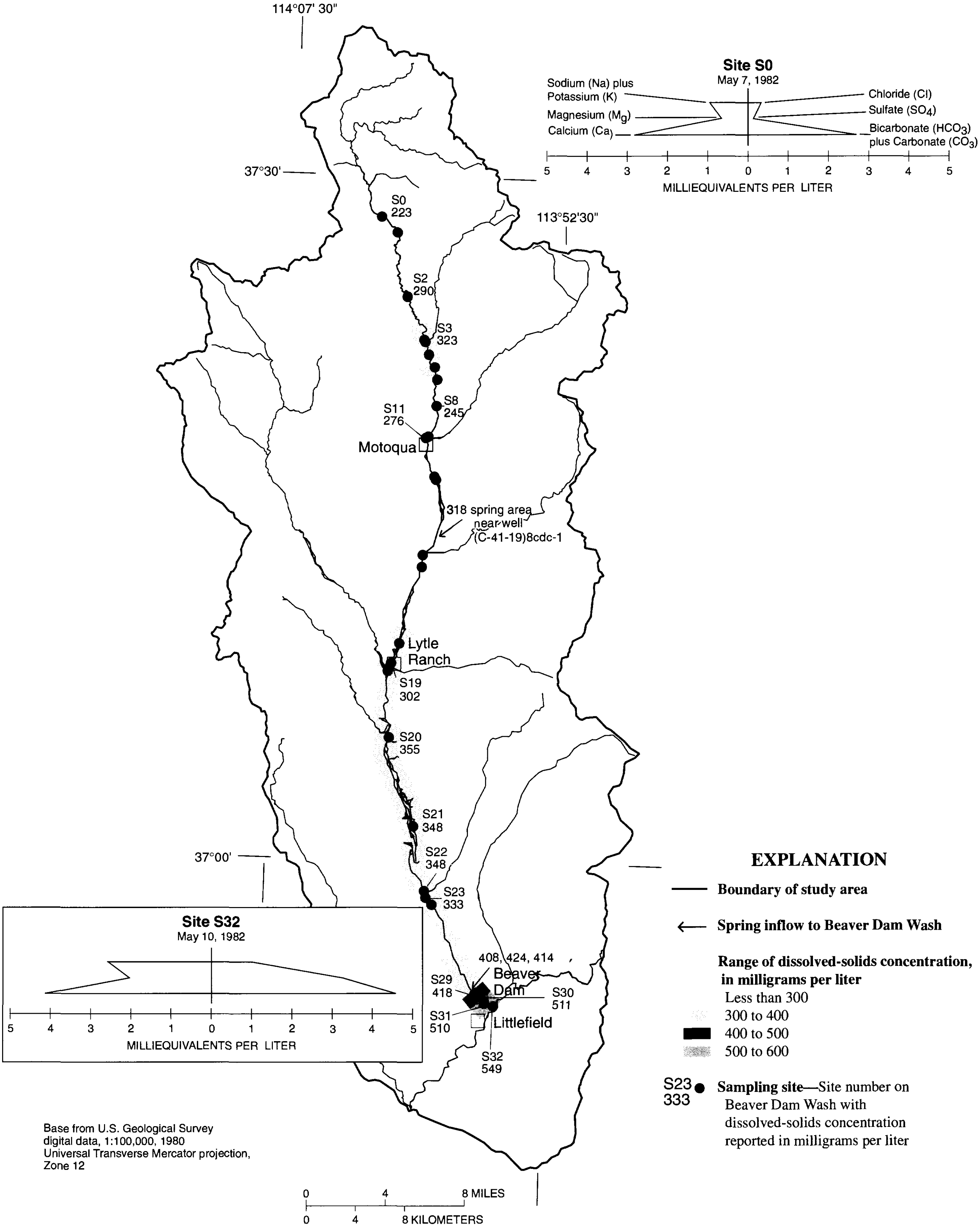


Figure 20. Range of dissolved-solids concentration and chemical composition of water in Beaver Dam Wash during the high-flow period of February through May.

bicarbonate; at site S32 (at mouth), calcium, magnesium, sodium, bicarbonate, and sulfate are the principal constituents.

Virgin River

Beaver Dam Wash discharges to the Virgin River about 0.2 mi upstream from the gaging station on the Virgin River at Littlefield, Arizona. Daily specific conductance was measured during the 1949-87 water years on the Virgin River at Littlefield, Arizona. An average ratio of dissolved-solids concentration to specific conductance was determined to be about 0.6 by comparing available results of chemical analyses with corresponding values of daily specific conductance. Using this ratio, the concentration of dissolved solids was estimated from the specific-conductance value for the 1949-87 water years.

Using the daily discharge and estimated dissolved-solids concentration at Littlefield, Arizona, the discharge-weighted average concentration of dissolved solids was computed for monthly time intervals for 1949-87 (fig. 21). The discharge-weighted average concentration of dissolved solids is the theoretical concentration that would occur if all the water for a given month was impounded and mixed and there were no evaporation or chemical changes.

The minimum concentrations of dissolved solids generally occur when the flows peak from snowmelt runoff in the spring, and the annual maximums generally occur when discharges are near seasonal lows. This is typically the case in streams fed by snowmelt runoff, which contain lower concentrations of dissolved solids than streams sustained mostly by ground-water inflow, which contain relatively higher concentrations of dissolved solids.

During 1949-87, the annual minimum concentration of dissolved solids in the Virgin River occurred about 50 percent of the time during April-May and the annual maximum occurred about 80 percent of the time during July-August. The annual minimum concentration of dissolved solids ranged from 370 to 1,270 mg/L, and the annual maximum concentration of dissolved solids ranged from 2,050 to 2,790 mg/L. The discharge-weighted average concentration of dissolved solids during 1948-87 was about 1,700 mg/L.

On the basis of the estimated range of dissolved-solids concentrations of water that discharges at the mouth of Beaver Dam Wash, the concentration of inflow from Beaver Dam Wash is about 1,300 mg/L lower than that of the Virgin River and provides some dilution to the concentration of dissolved solids in the Virgin River. Because the flow of Beaver Dam Wash is small relative to that of the Virgin River, the amount of dilution is small during most years. For example, based on long-term average discharges (1970-95) of Beaver Dam Wash at the mouth (site S32) and the flow of the Virgin River at Littlefield, Arizona, and the estimated dissolved-solids concentrations of the two sites, it was determined that the concentration of dissolved solids in the Virgin River would be decreased by about 60 mg/L. It should be noted, however, that the average flow of each stream seldom occurs concurrently because of the large variability of flow in Beaver Dam Wash and in the Virgin River and because the two streams have different seasonal flow regimes. For example, the flow of Beaver Dam Wash likely peaks about 2 months earlier than the Virgin River. The most noticeable dilution effects in the Virgin River probably occur when the flow of the Beaver Dam Wash is near a peak and the decrease in the concentration of dissolved solids is greater than 60 mg/L.

SUMMARY

The streamflows at sites S0 and S29 during 1992-95 were highly variable and probably reasonably characteristic of the range of flow in the Beaver Dam Wash basin. During the 1992 water year, the average discharge at Enterprise, Utah (site S0), was about 11 ft^3/s, which is about the same as the estimated average annual discharge for 1970-95. During the 1993 water year, the average discharge was 29 ft^3/s, or about 160 percent greater than the 1970-95 estimated average. During the 1994 water year, the average discharge was only 3.7 ft^3/s, or about 70 percent less than the 1970-95 estimated average.

The large variability of discharge at site S29 near the mouth of Beaver Dam Wash is demonstrated by the discharge values during the 1992-95 water years. During the 1994 water year, the daily mean discharge ranged from 1.4 to 11 ft^3/s and averaged 2.57 ft^3/s; whereas in 1993, the daily mean discharge ranged from 0.76 to 1,730 ft^3/s and averaged 21 ft^3/s.

Ground water is present in both consolidated rocks and unconsolidated and semiconsolidated basin-fill deposits. The alluvial channel-fill deposits of Quaternary age form the most important water-producing formation in the Beaver Dam Wash area. Wells completed in the alluvial channel-fill deposits yield large amounts of water to wells, which is used to irrigate crops and a golf course.

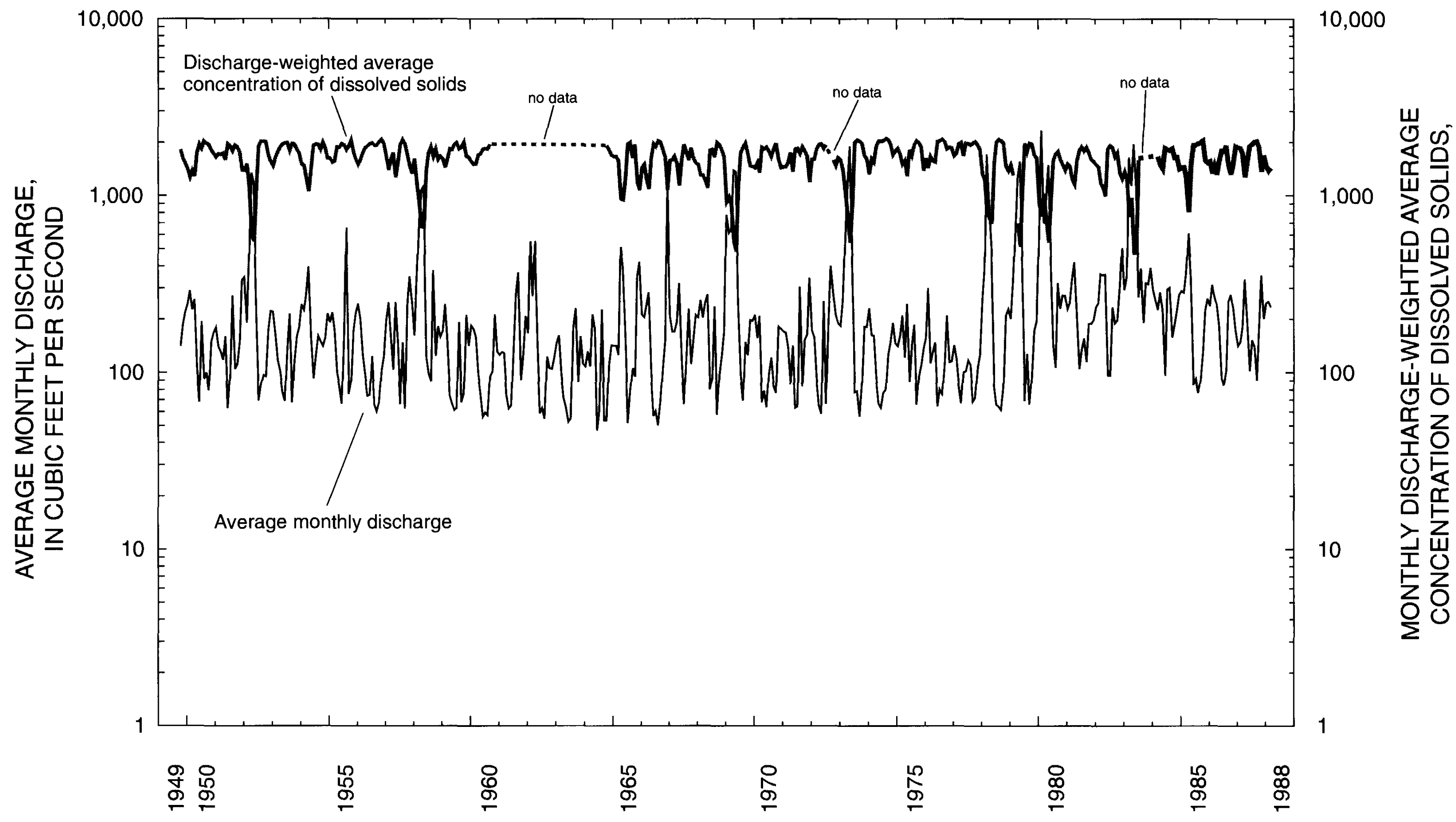


Figure 21. Monthly discharge and discharge-weighted average concentration of dissolved sollds for Virgin River at Littlefield, Arizona, 1949-88.

Recharge to the alluvial channel-fill deposits is estimated to be about 18,000 acre-ft/yr. Recharge primarily is from stream infiltration in Beaver Dam Wash, and discharge primarily is to springs and subsurface outflow to Virgin River alluvium and to the Muddy Creek Formation. Ground-water quality in the alluvial channel-fill deposits is generally good. The dissolved-solids concentration is generally less than 500 mg/L.

The Muddy Creek Formation in the Beaver Dam Wash area is composed primarily of fine-grained deposits and does not yield large amounts of water to wells. The dissolved-solids concentration of water in the Muddy Creek Formation is generally less than 500 mg/L west of Beaver Dam Wash. Water quality is poorer east of Beaver Dam Wash, where the dissolved-solids concentration of water in the Muddy Creek Formation is generally greater than 1,500 mg/L.

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ADDITIONAL INFORMATION—Geophysical Surveys

RESISTIVITY

A resistivity survey provides information on ground water because the ease with which earth materials transmit electrical current is a function of their resistivity, and resistivity is related to geohydrologic properties of earth materials, including lithology, porosity, permeability, water salinity, and water temperature.

Description of Resistivity Survey and Location of Profiles and Soundings

The resistivity method used in the Beaver Dam Wash area was direct-current soundings using the Schlumberger array. The Schlumberger array is an in-line, four-electrode array to measure voltage distributions for a known input current (Zohdy and others, 1974, p. 11). An individual resistivity sounding consists of (1) applying a voltage to a pair of electrodes (outer, current electrodes), which induces direct-current flow and an electrical field in the earth; and (2) measuring the resulting voltage at a second pair of electrodes (inner, potential electrodes). A series of measurements is made for each sounding using, at most, three potential-electrode spacings of 4 to 400 ft. The current-electrode spacing is increased for each measurement of the sounding, from a minimum of about 20 ft to as much as 24,000 ft. Resistivity values for each spacing are computed from formulas derived for the electrode geometry (Zohdy and others, 1974, p. 11).

Resistivity values as a function of depth are derived from the sounding curve with the aid of digital-computer programs (Zohdy, 1989; Zohdy and Bisdorf, 1989). Maximum electrode half-spacings for this survey ranged from 1,400 to 12,000 ft. The depth to which resistivity values were interpreted ranged from about 700 ft to about 3,700 ft. A more detailed discussion of collecting and processing the resistivity data for this survey is reported by Zohdy and others (1994).

The resistivity values from a series of soundings along a line of profile can be combined to form a resistivity cross section (Zohdy, 1993). The cross section can then be interpreted in terms of changes in geohydrologic properties along the line of profile. For the survey in Beaver Dam Wash, it was assumed that most of the variation in resistivity resulted from sediments being unsaturated or saturated, from variations in the clay content of sediments, and from salinity of ground water.

Five northeast-southwest profiles of resistivity were spaced fairly evenly across the southern half of the Beaver Dam Wash area, and the few soundings done between the five profiles were used to prepare a sixth north-south profile (fig. 3). A total of 44 soundings were made—the 5 northeast-southwest profiles included 36 soundings, the sixth north-south profile included 6 soundings from the first 5 profiles and 7 additional soundings, and 1 sounding (no. 23) was not included in any of the profiles. The resistivity survey was done where the unconsolidated sediments in the Beaver Dam Wash area are the thickest, as inferred from gravity data (Baer, 1986, fig. 2; Bohannon and others, 1993, fig. 8). The profiles could be located only along existing roads because of the rough terrain (most of the tributaries to Beaver Dam Wash and the wash itself are deeply incised into a gently sloping alluvial surface, and many areas on the western side of the wash are inaccessible because of a lack of roads) and because most of the drainage is habitat for an endangered species. The eastern Mohave desert tortoise (*Gopherus agassizii*) is especially prevalent on the alluvial slopes on the eastern side of Beaver Dam Wash, and the Bureau of Land Management restricts off-road travel in much of the area.

Profile A-A' is located roughly along Interstate 15 at the southern end of the project area and is about 7 mi long. Profile B-B' is about 5 to 8 mi to the northwest of A-A' and is about 9 mi long. The eastern half of profile B-B' is along a road down to the wash; the western half is along a powerline on the western side of the wash. Profile C-C' is a short 2 1/2-mi profile along a road down to the wash and is only on the eastern side of the wash. Profile D-D', about 10 mi long, is along the right-of-way for a power transmission line and the Kern River natural-gas pipeline. Profile E-E' is an almost east-west profile that crosses D-D' and is along a road extending east of Lytle Ranch. This profile is only 4 mi long and is only on the eastern side of the wash. A sixth profile, F-F', about 25 mi long, was constructed approximately north-south using soundings in the first five profiles; some intermediate soundings, especially between A-A' and B-B' and between B-B' and D-D'; one sounding north of the other profiles; and two soundings south of the other profiles. One other sounding, no. 23, was made just north of the eastern end of profile B-B'; an interpretation from the sounding curves of resistivity versus depth for this sounding, as well as for all other soundings, is given by Zohdy and others (1994, appendix 2). In addition to the resistivity profiles (figs. 22-27), maps of resistivity at depths of 33, 66, 160, 330, 660, and 1,640 ft were prepared (fig. 28).

Hydrogeologic Interpretation of Resistivity Data

The initial resistivity soundings were made at the western end of profile B-B' (fig. 3) to determine the resistivity of the Muddy Creek Formation. The Muddy Creek Formation crops out just north of the western end of profile B-B' (Moore, 1972, pl. 1), and the top of the formation probably is at shallow depths (less than about 90 ft) at soundings 1 through 4 and 39 (fig. 3). The section along profile B-B' (fig. 23) and the individual sounding curves (Zohdy and others, 1994, app. 2) indicate that the unsaturated part of the Muddy Creek Formation in the study area has resistivity values of about 25 to 100 ohm-meters and that the saturated part has resistivity values of about 9 to 20 ohm-meters. The one exception to this range in values is at sounding 4, where the saturated Muddy Creek Formation may have resistivity values as great as 40 to 50 ohm-meters, possibly because the upper part of the saturated zone contains good-quality water as a result of flood-flow recharge from Sand Hollow Wash. Estimated values of resistivity less than about 20 ohm-meters indicate that the Muddy Creek Formation is predominantly fine grained and is saturated with poor-quality water, which contains more than about 2,000 mg/L of dissolved solids.

Using the 20-ohm-meter estimate for the saturated part of the Muddy Creek Formation, most of the topographically low areas within the Beaver Dam Wash area are inferred to be underlain at depth by fine-grained Muddy Creek Formation and older formations saturated with poor-quality water. The extent of this area is shown in figure 3. The area appears to widen south of profile D-D', which corresponds to the gravity low that marks the deep Mesquite basin. At six soundings (4, 17, 19, 22, 30, and 31), however, the upper part of the saturated Muddy Creek Formation has resistivity values that range from about 20 to 80 ohm-meters. These values may represent locally fresher water, resulting from recharge, in the upper Muddy Creek Formation. On profile D-D', sounding 30 is in the channel of Beaver Dam Wash and sounding 31 is 1.3 mi to the west. The wash is influent at this location and freshwater recharge could be the cause of the higher resistivity values at these soundings. The higher resistivity values in the upper part of the saturated zone in the Muddy Creek Formation at sounding 4 on profile B-B' (fig. 23), as mentioned previously, possibly result from ephemeral recharge from Sand Hollow Wash. The higher resistivity values at soundings 17, 19, and 22 on profile A-A' (fig. 22), 0.6 to 2.4 mi west of Beaver Dam Wash and near its mouth, also might result from recharge from the wash.

Several soundings indicate relatively high resistivity values (24 to more than 1,000 ohm-meters below about 100 ft) and thus indicate that fine-grained Muddy Creek Formation, saturated with poor-quality water, is not present. These soundings are mostly along the east side of the surveyed area—soundings 5, 6, and 23 at or near the east end of profile B-B' (fig. 23), soundings 40 and 41 at the east end of profile E-E' (fig. 26), and soundings 27 and 28 on profile F-F' (fig. 27). In addition, sounding 38 south of the Virgin River on profile F-F' (fig. 27) also does not indicate any material with resistivity values of 20 ohm-meters or less. Two other soundings on the west side of the surveyed area, 34 and 35 on the west end of profile D-D' (fig. 25), also indicate the presence of little, if any, fine-grained Muddy Creek Formation saturated with poor-quality water.

The high resistivity values at depth were initially assumed to indicate consolidated rock and (or) basin-fill deposits containing fresh water. The high-resistivity intervals include the interval from about 35 to 1,100 ft at sounding 5, where resistivity values ranged from about 420 to 1,000 ohm-meters; the interval from about 60 to 630 ft at sounding 6, where resistivity values ranged from about 460 to 1,300 ohm-meters; and the interval from about 36 to 520 ft at sounding 23, where resistivity values ranged from about 180 to more than 1,700 ohm-meters. Subsequent seismic surveys, described below, and test drilling at sounding 23 indicated that this material was unconsolidated and that at least its upper part is probably aggradational gravels of post-Muddy Creek Formation age and alluvial-fan deposits of younger Quaternary age. At sounding 23, a test well, (C-43-19)25bbb-1, was drilled to a depth of 818 ft. The borehole-resistivity log of the well indicated material of high resistivity (on the order of several hundred ohm-meters) to a depth of 465 ft—this material likely is post-Muddy Creek Tertiary gravels and Quaternary alluvial-fan deposits. From 465 to about 760 ft, resistivity-log values ranged from about 20-30 ohm-meters to about 90 ohm-meters, and this

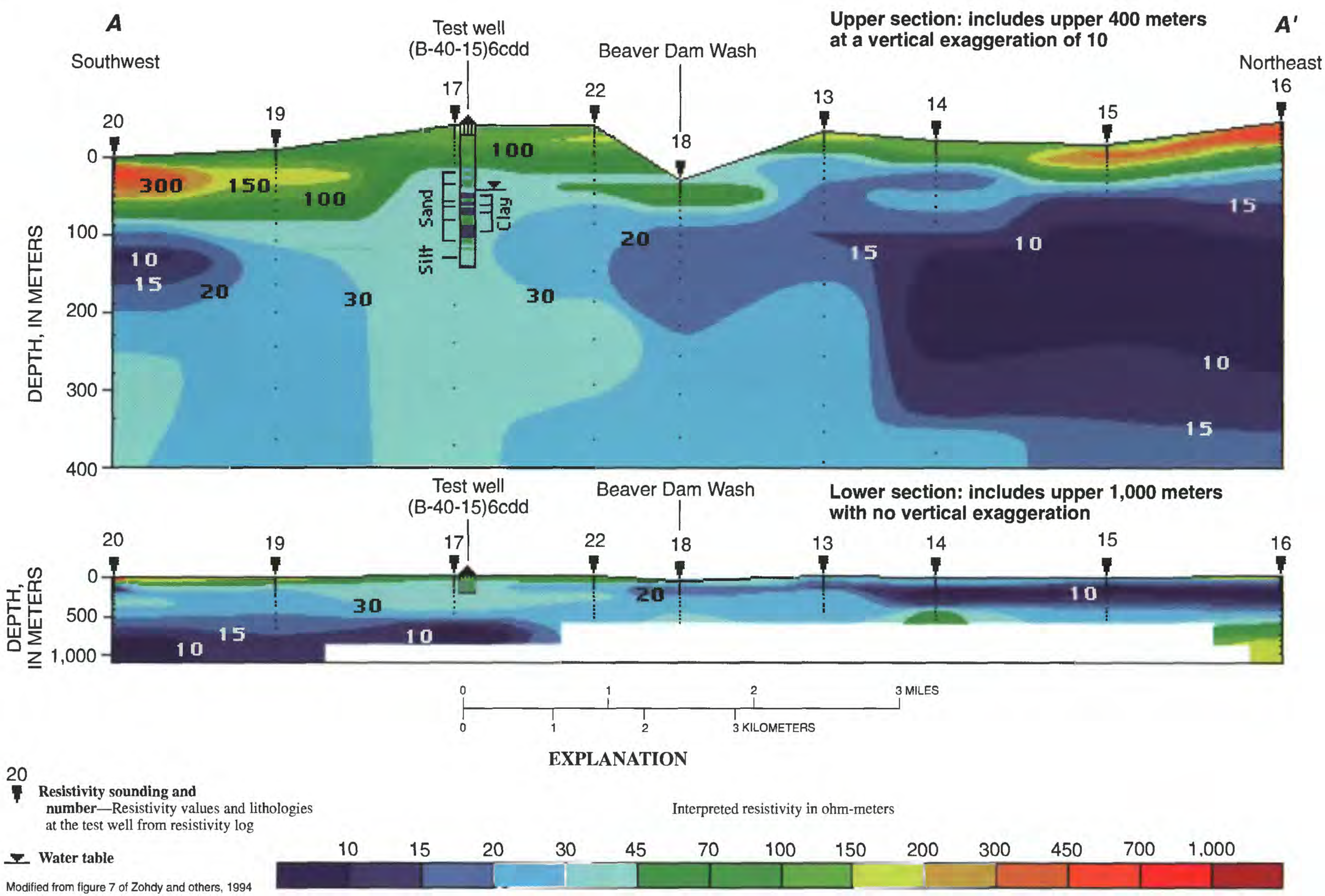


Figure 22. Resistivity values along profile A-A' in the Beaver Dam Wash area.

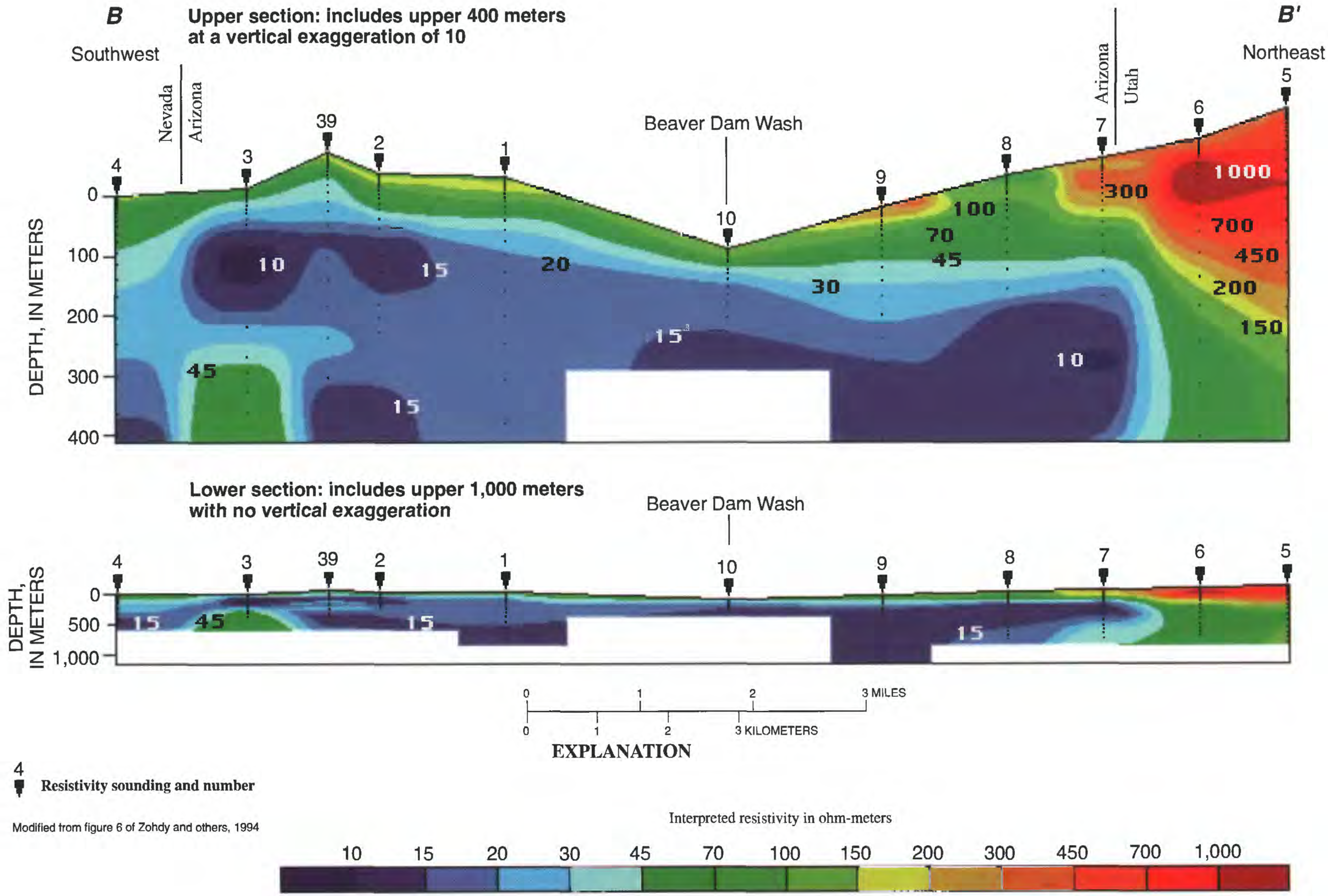


Figure 23. Resistivity values along profile B-B' in the Beaver Dam Wash area.

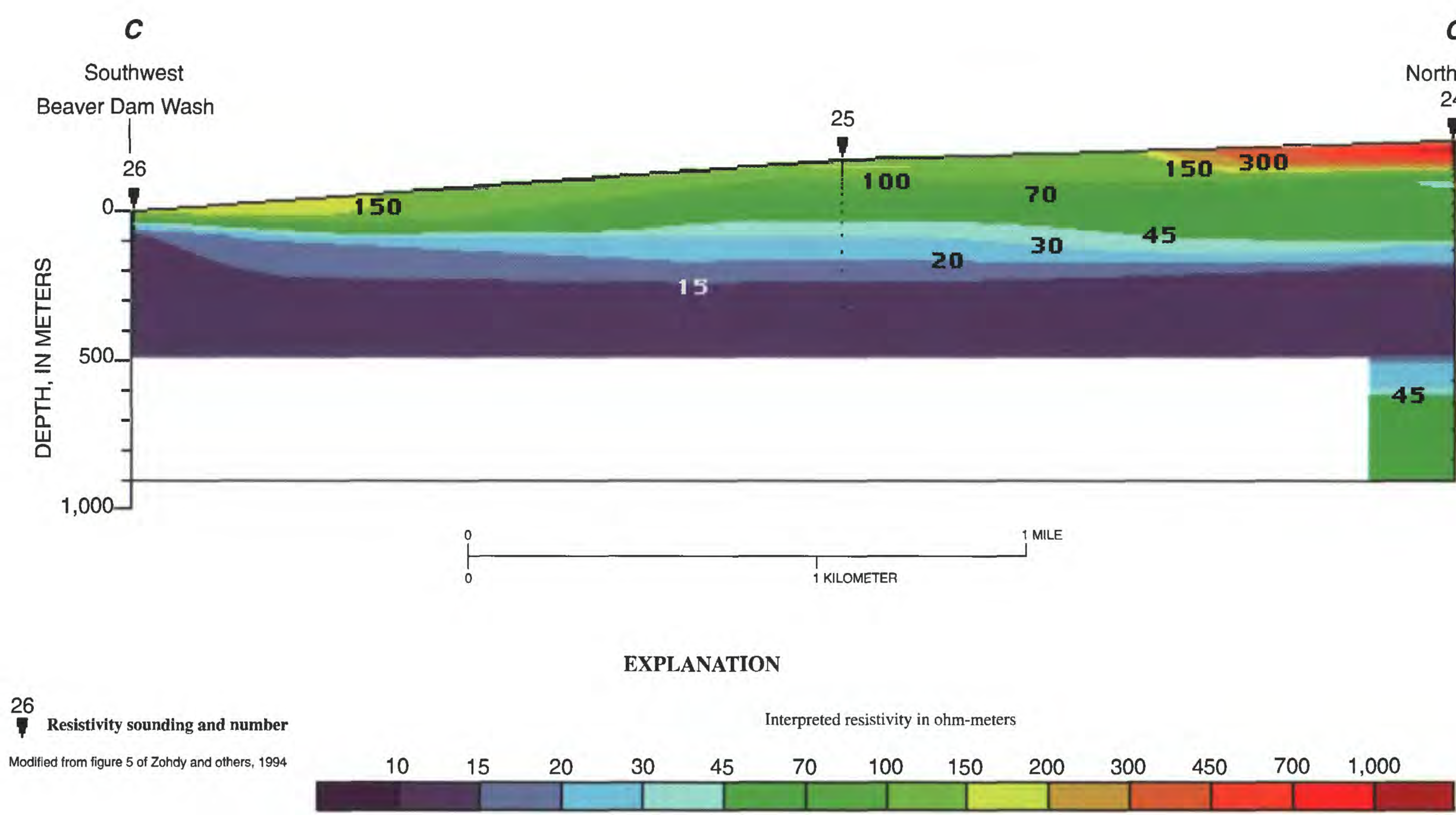


Figure 24. Resistivity values along profile C-C' in the Beaver Dam Wash area.

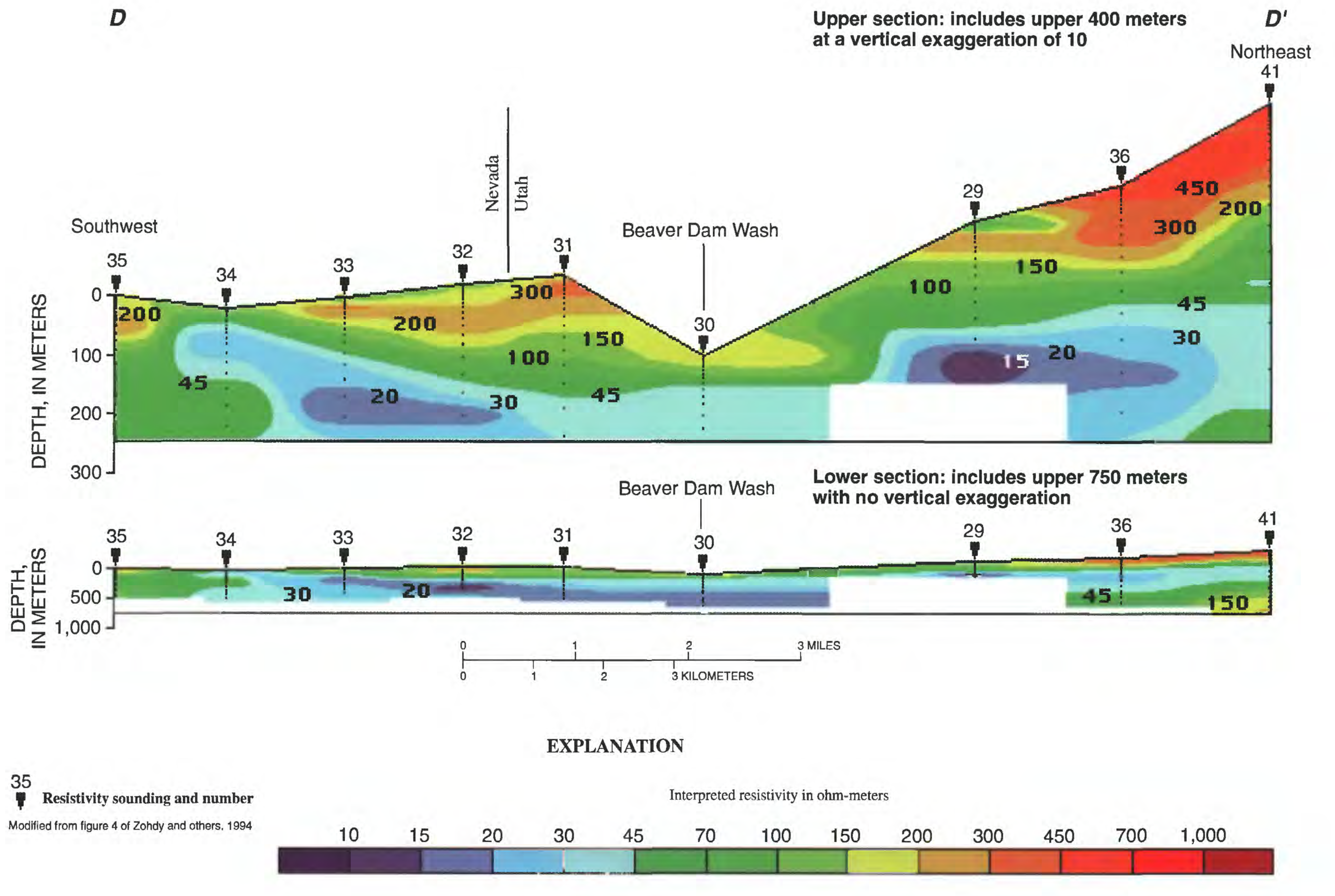


Figure 25. Resistivity values along profile D-D' in the Beaver Dam Wash area.

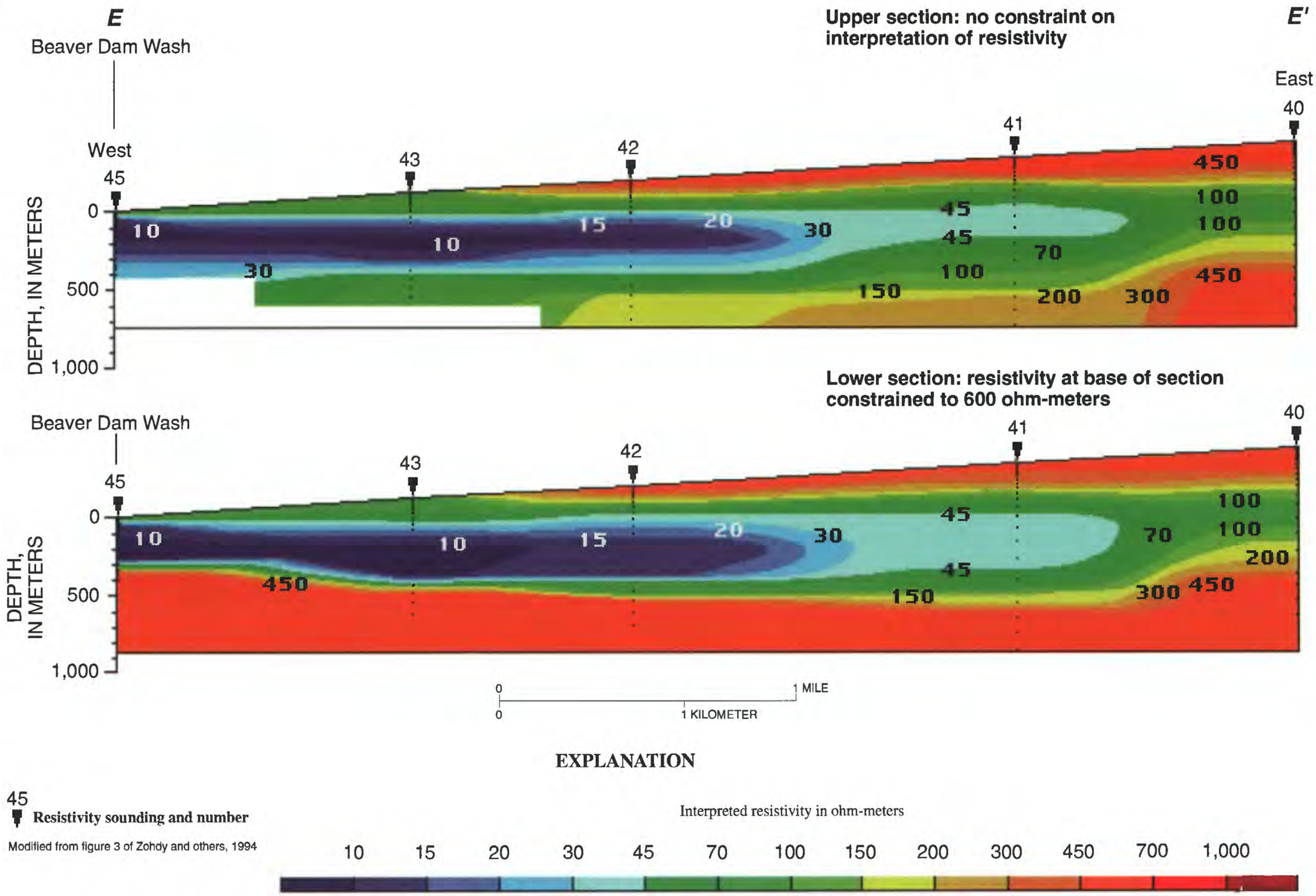


Figure 26. Resistivity values along profile E-E' in the Beaver Dam Wash area.

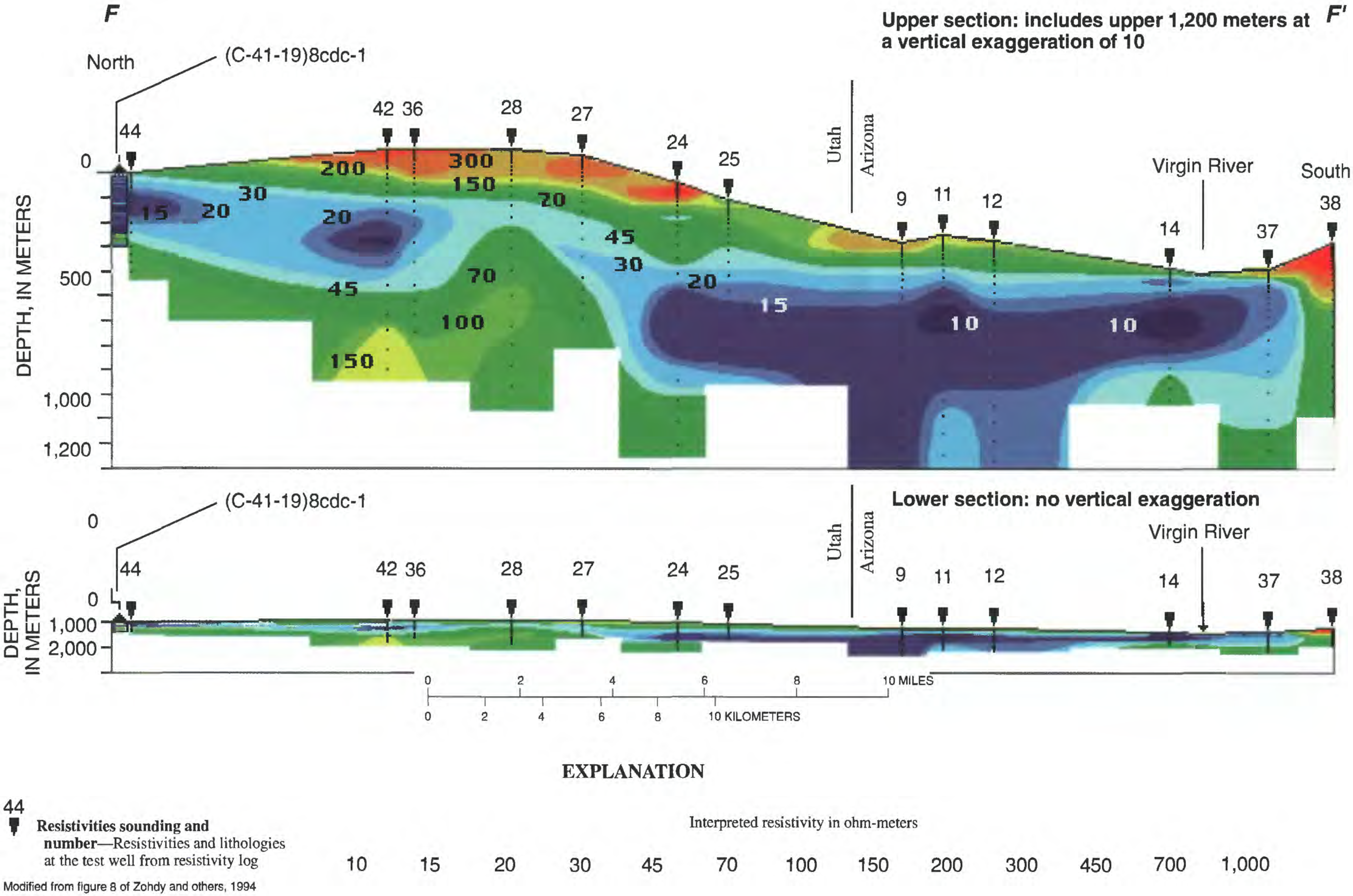
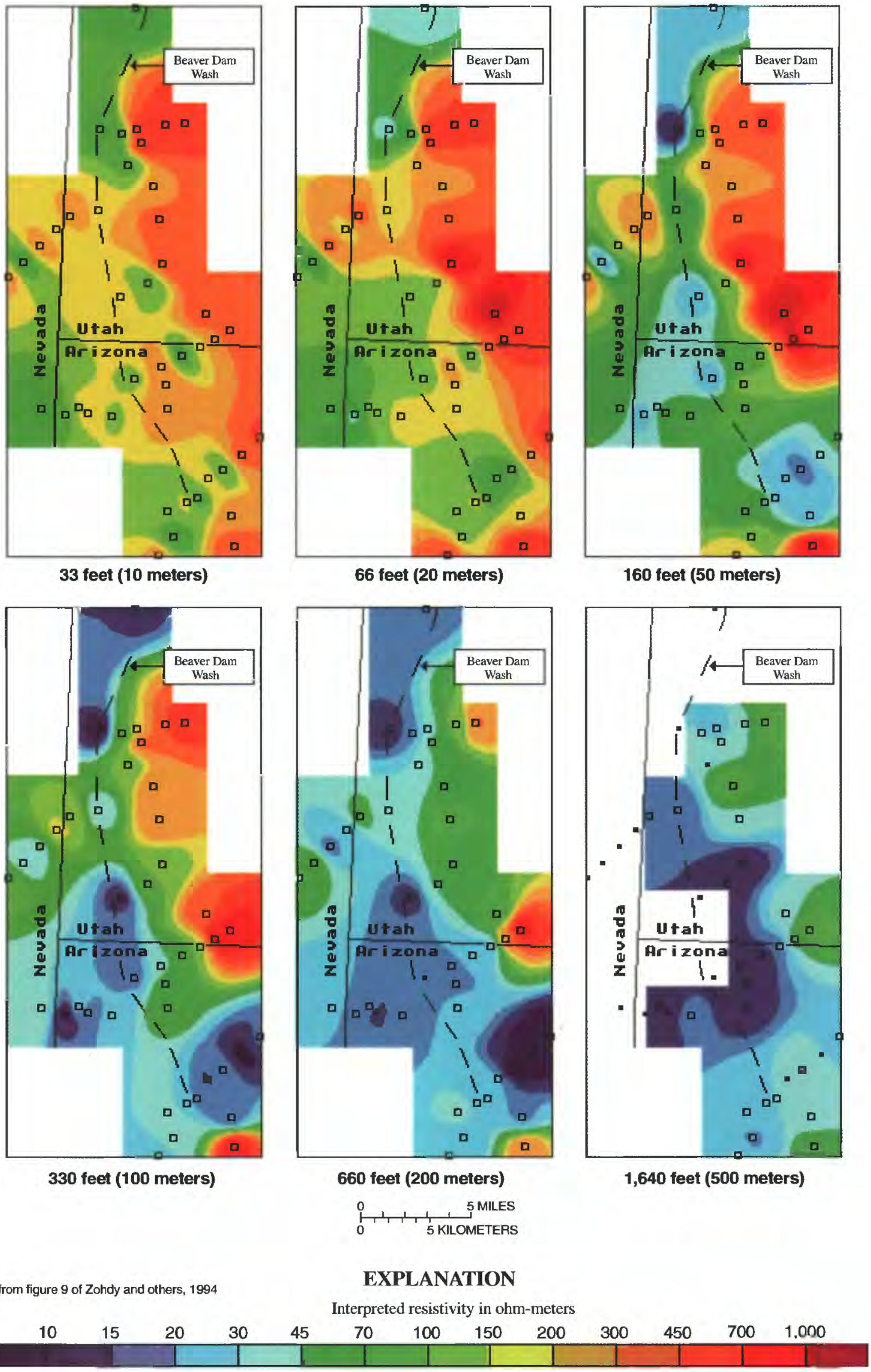


Figure 27. Resistivity values along profile F-F' in the Beaver Dam Wash area.



Modified from figure 9 of Zohdy and others, 1994

Figure 28. Resistiviy values at depths of 33, 66, 160, 330, 660, and 1,640 feet in the Beaver Dam Wash area.

material likely is unsaturated Muddy Creek Formation. Below about 760 ft, the water level in the well is in the saturated Muddy Creek Formation, with resistivity-log values of about 20 to 40 ohm-meters. Although the test well penetrated some coarse-grained and potentially permeable material down to about 300 to 400 ft, this silt-to-gravel-sized material was unsaturated. Lower in the well, the Muddy Creek Formation, although slightly more resistive than in the lower parts of the basin, still is predominantly fine grained. The potential yield of the saturated part of the Muddy Creek Formation was estimated by air-lift pumping, but the production was less than 1 gal/min.

The high-resistivity values representing material in the upper part of the basin-fill deposits at resistivity soundings 27 and 28 (fig. 27) and 40 and 41 (fig. 26) on the western flanks of the Beaver Dam Mountains (about 30 to 600 ohm-meters between depths of about 100 and 1,100 ft), and at sounding 38 (fig. 27) on the northeastern flank of the Virgin Mountains (about 100 to 1,000 ohm-meters between depths of about 100 and 1,100 ft), probably represent mostly coarse-grained and unsaturated post-Muddy Creek Tertiary gravels and alluvial-fan deposits. At soundings 34 and 35, at the west end of profile D-D' (fig. 25), some of the high resistivity values at depth may indicate consolidated rock. Sounding 35 is less than one-half mile southeast of an outcrop of limestone of late Paleozoic age (Stewart and Carlson, 1978), which probably is the material with resistivity greater than about 50 ohm-meters below depths of about 500 ft at sounding 34 and about 120 ft at sounding 35.

Resistivity Profiles

The six resistivity profiles show resistivity values versus depth and indicate large-scale geohydrologic features. However, most of the depth and thickness figures estimated from the resistivity data and reported in this section were derived from the sounding curves for individual resistivity soundings (Zohdy and others, 1994) and not from the resistivity profiles, which are less accurate. Profile A-A' (fig. 22) shows resistivity values across the southern end of the study area. At shallow depths, to a maximum of about 300 ft, the high values indicate unsaturated Muddy Creek Formation and younger material. Lower resistivity values, below about 160 to 300 ft, indicate saturated Muddy Creek Formation. Resistivity values in the upper part of the saturated zone, above a depth of about 1,600 ft, are much lower east of Beaver Dam Wash than they are to the west. East of the wash, resistivity values generally are less than 15 ohm-meters; on the western side of the wash, resistivity values generally are more than 20 ohm-meters. These values indicate that the Muddy Creek Formation is finer grained and (or) probably contains poorer-quality water east of the wash, and possibly correlate with previous observations that the deepest part of the Mesquite basin is in the southeastern corner of the study area and also that this probably has been a topographic low since the time the Muddy Creek Formation was deposited.

Data on ground-water quality also support the inference of poorer-quality water east of the wash. Wells east of the wash at Beaver Dam, Arizona, generally yield water with a dissolved-solids concentration greater than 2,000 mg/L; to the west, test well (B-40-15)6cdd (at sounding 17) yielded water containing 382 mg/L of dissolved solids (fig. 17). The resistivity and geologic logs indicate that the well penetrated the Muddy Creek Formation from about 140 ft to its total depth of 599 ft, and that this interval was about 60 percent clay and silt and 40 percent sand and gravel. Below the water table at about 270 ft, the saturated Muddy Creek Formation consisted of about 65 percent clay and silt and 35 percent sand and gravel. These data indicate that the higher resistivity values at soundings 17, 19, and 22 are not caused by coarser material, but by better-quality water. The resistivity log of the well also indicates that the largest resistivity contrast is between the post-Muddy Creek gravels of Tertiary age, which occur from near the land surface to 140 ft where resistivity values range from about 20 to 500 ohm-meters; and the unsaturated Muddy Creek Formation, for which values range from about 20 to 95 ohm-meters. In the saturated part of the Muddy Creek Formation, values range from about 7 to 120 ohm-meters.

Resistivity data from profile A-A' indicate that in the southeastern corner of the study area, fine-grained unconsolidated material was deposited within about 1 mi or less of the mountain front; apparently little or no coarse-grained strata of the Muddy Creek Formation occurs in this area. Data from the sounding curve of sounding 16 (Zohdy and others, 1994, p. 44), about 1 mi west of the consolidated rock of the mountain front, indicates that between depths of about 250 to 1,700 ft, deposits have a resistivity value of less than 20 ohm-meters, which indicates they are predominantly fine grained and possibly contain poor-quality water. It is not known why so little coarse-grained material was deposited close to the mountain front.

Profile B-B', which crosses the Utah/Arizona and Arizona/Nevada borders (fig. 23), indicates very high resistivity values on its eastern end, probably representing coarse-grained material deposited along the flanks of the Beaver Dam Mountains, some of which may be the same age as the Muddy Creek Formation. The sounding curve of sounding 6 (Zohdy and others, 1994, p. 34) shows especially high resistivity values, ranging from 50 to more than 1,000 ohm-meters, to depths of more than 2,000 ft, and from 110 to more than 1,000 ohm-meters to depths of about 3,000 ft. As discussed previously, test well (C-43-19)25bbb-1 was drilled to a depth of 818 ft at sounding 23, 1.4 mi north-northwest of sounding 6. Based on the resistivity log, this test well penetrated material with a resistivity value greater than 1,000 ohm-meters, probably post-Muddy Creek gravels of Tertiary and Quaternary age, to a depth of 465 ft. The well penetrated unsaturated Muddy Creek Formation, with resistivity values of from 10 to 150 ohm-meters, from 465 to about 760 ft; and saturated Muddy Creek Formation, with resistivity values from 10 to 30 ohm-meters, from about 760 to 818 ft. Sounding 23 near the test well, similar to sounding 6, indicated high-resistivity material down to at least 500 ft. Although the high-resistivity material indicated by sounding 6 is thicker than that at sounding 23, the magnitude and pattern of variation of its resistivity are similar. Together with the test-well information, this indicates that the high-resistivity material at sounding 6 is unsaturated sand and gravel.

Along profile B-B', resistivity values for the Muddy Creek Formation from depths of about 300 to about 1,300 ft generally are higher west of Beaver Dam Wash than they are to the east. This pattern is similar to the change in resistivity across the wash on profile A-A', but less pronounced. These higher resistivity values also indicate that recharge from Beaver Dam Wash moves into the Muddy Creek Formation and travels west. As mentioned in the discussion of profile A-A', relatively high resistivity in the upper part of the saturated Muddy Creek Formation, indicated by sounding 4 at the west end of B-B', indicates some recharge from Sand Hollow Wash, possibly from infrequent flood flows.

Profile C-C' is entirely on the eastern side of Beaver Dam Wash (fig. 24) and indicates that low-resistivity Muddy Creek Formation underlies the entire section below depths from about 160 ft at sounding 26 in the wash to about 1,100 ft at soundings 24 and 25. Because of the large thickness of material with a resistivity value greater than about 45 ohm-meters, some of this material might be below the water table and might consist of permeable, coarse-grained, post-Muddy Creek Formation deposits saturated with fresh water. However, sounding 23, about 3 mi to the southeast of soundings 24 and 25, indicated material with a resistivity value of 50 ohm-meters to depths of 1,600 ft, and test well (C-43-19)25bbb-1 and its borehole-resistivity log at sounding 23 showed that the water table was at 760 ft in low-resistivity Muddy Creek Formation. The similarity of the sounding curves at soundings 23 and 24 indicates that fine-grained material of low permeability, probably containing poor-quality water, occurs at sounding 24.

Profile D-D' extends northeast-southwest across Beaver Dam Wash (fig. 25), mostly along or near a transmission line/pipeline right-of-way. All of the soundings, except 41 on the northeastern end of the profile and 35 on the southwestern end, indicate that low-resistivity Muddy Creek Formation occurs at depth. The thick, high-resistivity material at the northeastern end of the profile and just west of Beaver Dam Wash probably consists of post-Muddy Creek Tertiary gravels and Quaternary alluvial-fan deposits, with some unsaturated Muddy Creek Formation. The thickness of the post-Muddy Creek Formation deposits probably ranges from about 800 ft at the northeastern end of the profile to about 300 ft west of Beaver Dam Wash.

Profile E-E' is entirely east of Beaver Dam Wash and extends east of Lytle Ranch (fig. 26). The three soundings on the eastern end of the profile, 40, 41, and 42, indicate consolidated rock at depths that range from about 1,800 to 2,900 ft. Post-Muddy Creek Formation deposits east of Beaver Dam Wash extend from the land surface to depths of about 400 to 1,200 ft; the thickness of the Muddy Creek Formation ranges from about 1,000 to 1,700 ft.

Profile F-F' extends approximately north-south along and up to 2.5 mi east of Beaver Dam Wash (fig. 27). Overall it shows that from sounding 24 south, the Muddy Creek Formation is thick and includes mostly material with a resistivity of 20 ohm-meters or less, which indicates predominantly fine-grained material probably saturated with water containing 2,000 mg/L or more of dissolved solids. This also is the area of low gravity shown by Blank and Kucks (1989, pl. 2) and designated the Mesquite basin. From sounding 27 north, the Muddy Creek Formation interval is thinner and includes more material with a resistivity greater than 20 ohm-meters, which indicates a coarser-grained material possibly containing water with a dissolved-solids concentration less than 2,000 mg/L. The lack of low-resistivity material at sounding 28 may represent a structural high.

At sounding 44, at the northern end of profile F-F', high-resistivity material at a depth of about 1,000 ft (Zohdy and others, 1994, p. 20) is interpreted as consolidated rock. Because limestone of Paleozoic age crops out about 1 mi west (Hintze, 1980), it is possible that this high-resistivity material is limestone. A seismic-refraction line at sounding 44 (line 4, described in the section "Hydrologic Interpretation of Seismic Data") indicated high-velocity material, interpreted as consolidated rock, at a depth of about 500 ft. Test well (C-41-19)8cdc-1 was drilled to a depth of 979 ft at a location about 1,000 ft north of sounding 44. This test well was drilled to determine the geohydrologic characteristics of the alluvial channel-fill deposits and of the Muddy Creek Formation at a location outside of the Mesquite basin and to penetrate the limestone to try to determine if it could yield water to wells. The borehole and driller's log of the test well indicated that consolidated rock was penetrated somewhere between 805 and 940 ft, with the strongest indication of rock at 940 ft. The driller's log reports that this material is shale, but the shale probably is underlain by higher-resistivity limestone, as indicated by data from sounding 44.

Maps of Resistivity at Selected Depths

Maps of resistivity values at depths of 33, 66, 160, 330, 660, and 1,640 ft are shown in figure 28. Although the maps were constructed on the basis of data that are not evenly spaced over the entire area, and thus should be used with caution, they do indicate some general features of the area. All the maps show higher resistivity values along the eastern and southern sides of the surveyed area, which indicates coarser-grained, more resistive material derived from the Beaver Dam Mountains and Virgin Mountains. The generally high resistivity values, 45 ohm-meters or more, over most of the area at depths of 33 and 66 ft are characteristic of the post-Muddy Creek Formation deposits of Tertiary and Quaternary age. Unsaturated Muddy Creek Formation may be indicated by resistivity values of 45 to 100 ohm-meters at depths of 33 and 66 ft in the southwestern part of the area. At a depth of 160 ft, the relatively widespread occurrence of material with resistivity values of 20 to 100 ohm-meters indicates unsaturated Muddy Creek Formation. At depths of 330 ft, and especially at 660 and 1,640 ft, the widespread occurrence of material with resistivity values of less than 20 ohm-meters indicates saturated Muddy Creek Formation with water containing about 2,000 mg/L or more of dissolved solids. In the southern half of the surveyed area, the area that coincides with the Mesquite basin, resistivity values at depths of 160 to 660 ft tend to be the lowest in its southeastern corner, possibly a result of the deposition of fine-grained material in the deepest part of the Mesquite basin and (or) inflow of ground water of poor quality from the Virgin River Gorge area. At a depth of 1,640 ft, however, the lowest resistivity values are on the western side of the surveyed area, with slightly higher values in the southeastern corner.

Thickness of Quaternary Alluvial Channel-fill Deposits

Six resistivity soundings, from north to south numbers 44, 45, 30, 26, 10, and 18 (fig. 3), were done in the channel of Beaver Dam Wash and can be used to estimate the thickness of the alluvial channel-fill deposits of Quaternary age. The thickness ranged from about 30 ft at sounding 44 to 130 ft at sounding 30. The deposits were about 70 ft thick at sounding 45, 110 ft at sounding 26, 100 ft at sounding 10, and 90 ft at sounding 18. At test well (C-41-19)8cdc-1, located 1,000 ft north of sounding 44, the thickness was estimated to be 39 ft, although a seismic-refraction line (discussed in more detail later) indicated the channel-fill deposits were 160-220 ft thick. The test well was located at the side of the channel, where the channel-fill deposits may be thinner. Thus, although the most definitive resistivity data indicate a channel-fill thickness of about 30 ft, the data also could be interpreted to indicate a thickness of 100 to 150 ft. The channel-fill deposits at the mouth of Beaver Dam Wash, near sounding 18, were estimated to be about 70 to 90 ft thick on the basis of drillers' logs of several wells in the area (fig. 5C) and agrees with the thickness estimated from resistivity data.

Determined from individual sounding curves in the report by Zohdy and others (1994), estimated resistivity values of the saturated channel-fill deposits range from about 50 ohm-meters to almost 300 ohm-meters, although about 10 ft of fill at sounding 18 had resistivity values between 30 to 45 ohm-meters. The saturated Muddy Creek Formation below the channel-fill deposits had resistivity values of 47 ohm-meters or less. These values are higher than those of the saturated Muddy Creek Formation away from the channel of Beaver Dam Wash, generally estimated to be 20 ohm-meters or less. The higher resistivity values under the channel-fill deposits probably result from recharge of fresh water. The interval of Muddy Creek Formation under the channel-fill deposits that was affected by recharge (with resistivity values ranging from about 20-30 to 47 ohm-meters) ranged from about 30 to 70 ft in thickness.

SEISMIC REFRACTION

A seismic-refraction survey provides information on ground water because the velocity of artificially generated pulses of energy through earth materials is related to the elastic properties of the materials, which can be related to such geohydrologic properties as density, porosity, lithology, and degree of saturation. In addition, energy waves refract or bend at interfaces between layers with different elastic properties and can indicate the depth to these interfaces. Seismic-refraction surveys can determine the depth to consolidated rock under unconsolidated basin-fill deposits and can indicate whether unconsolidated deposits are sand and gravel by a lower velocity or silt and clay by a higher velocity. Seismic data also can indicate whether materials are dry, by a lower velocity, or saturated, by a higher velocity.

Description of Seismic-Refraction Survey and Location of Velocity Profiles

For the Beaver Dam Wash study, seismic-refraction surveys were done along seven lines (fig. 3) selected to obtain additional information (1) where resistivity soundings had indicated the presence of high-resistivity and possibly coarse-grained material to depths indicating that the deposits might be saturated with fresh water, and (2) where a test well was planned. All seismic lines were located where resistivity data also had been collected. The seismic data provided information used to estimate depth of the top of the saturated interval, depth to the top of the Muddy Creek Formation, and depth to consolidated rock.

An aggregate total of about 110 pounds of explosives was used as the energy source for the seismic survey. Seismic lines had a total of 24 geophones on 2 spread cables. Each cable had a geophone connector every 100 ft and a total of 12 geophones. The end geophones of the 2 cables also were separated by 100 ft, which made a continuous layout of all 24 geophones. The seismograph used for the survey was a Geometrics 2415F 24-channel, signal-enhancement model. Preliminary interpretation of the data was done soon after the completion of the survey to provide information to use in selection of test-hole sites. Final interpretation was done using a personal computer-based program, SIPT (Rimrock Geophysics, Inc., 1988-93).

Seismic lines 1 and 2 were located on the northeastern end of resistivity profile B-B' (fig. 3). In this area, high resistivity values (more than 150 ohm-meters) were indicated to depths of about 300 to 1,200 ft, which indicates coarse-grained sediments to these depths that possibly are saturated with fresh water. Seismic data were collected to determine whether this material was unconsolidated sediment or consolidated rock. Line 3 was located on the southwestern half of resistivity profile A-A', where resistivity data indicate material in the Muddy Creek Formation was coarse-grained and (or) saturated with better-quality water than that in Muddy Creek Formation sediments under most of the rest of profile A-A'. This location was selected as the site for a test well, and seismic data were collected to supplement the resistivity data and to estimate depth to the water table.

Seismic line 4 was located at the northern end of resistivity profile F-F' (fig. 3) and in the channel of Beaver Dam Wash. This location was selected as a site for a test well to determine the characteristics of the unconsolidated deposits in the northern end of the area where these deposits had substantial thickness. Information needed included age of the material (Muddy Creek Formation or younger), water-yielding potential, water quality, and depth to consolidated rock and its geohydrologic properties. Seismic data were collected to obtain information on the lithology of the unconsolidated deposits and the depth to consolidated rock.

Seismic lines 5 and 6 were located on resistivity profile C-C' (fig. 3). Resistivity data from nearby soundings indicated moderately resistive material (more than 45 ohm-meters) to depths of about 700 to 1,200 ft that is moderately coarse-grained, unconsolidated, and possibly saturated with fresh or slightly saline water. Seismic data were collected to supplement and verify the resistivity data and to estimate the depth to the water table. Line 7 was centered on resistivity sounding 42 on resistivity profile E-E' (fig. 3), near the northeastern end of profile D-D'. At sounding 42, the sounding curve (Zohdy and others, 1994, p. 71) indicated moderately to highly resistive material (60 to more than 500 ohm-meters) to depths of 700 ft that is moderately coarse- to coarse-grained, unconsolidated, and with its lower part possibly saturated with fresh to slightly saline water. Seismic data were collected to supplement and verify the resistivity data and to attempt to estimate the depth to the water table.

Hydrologic Interpretation of Seismic Data

Velocity profiles from seismic-refraction lines 1 and 2, located adjacent to each other between resistivity soundings 5 and 7 on the northeastern end of resistivity profile B-B' (fig. 3), are shown in figures 29 and 30. Both profiles show three velocity layers. The shallowest layer on both profiles extends from the land surface to depths of about 20 to 135 ft and has a velocity of 3,500 to 3,800 ft/sec. This layer may consist of alluvial-fan deposits of Quaternary age. The intermediate layer on both profiles extends to maximum depths of 360 to about 580 ft, and its base is deeper to the west. This layer has velocities of 5,800 to 6,000 ft/sec and may represent post-Muddy Creek gravels of Tertiary age. The deepest layer on both profiles, with velocities of about 8,700 to 8,900 ft/sec, is below depths of 360 to 580 ft. This layer may represent Muddy Creek Formation; it likely is unsaturated because the water level is at a depth of about 760 ft in test well (C-43-19)25bbb-1, which is near resistivity sounding 23, 1.4 mi to the north-northwest of seismic-refraction lines 1 and 2, where the land-surface altitude is about 80 to 240 ft higher. In addition, the velocity of the deepest layer is faster than would be expected if the layer were composed of saturated material similar to that of the intermediate layer, which indicates that the deepest layer has a different lithology.

The velocity profile for seismic-refraction line 3, located at sounding 17 on resistivity profile A-A' (fig. 3) and lithologic cross section B-B', is shown in figure 31. The profile shows two velocity layers. The upper layer extends from the land surface to depths of 150 to 225 ft and has a velocity of 2,400 ft/sec. This layer probably represents post-Muddy Creek gravels of Tertiary age and younger deposits. Test well (B-40-15)6cdd, drilled at the center of line 3, penetrated about 140 ft of post-Muddy Creek deposits, unsaturated Muddy Creek Formation from 140 to 270 ft, and saturated Muddy Creek Formation below 270 ft. The velocity profile indicates a thickness of about 160 ft for post-Muddy Creek deposits at the test-well site, close to the 140 ft indicated by the test-well data. The lower layer at line 3 was below depths of 150 to 225 ft and had a velocity of 6,700 ft/sec. This layer probably is Muddy Creek Formation, the upper 130 ft of which is unsaturated.

The velocity profile for seismic-refraction line 4, located at the northern end of resistivity profile F-F' at sounding 44 (fig. 3), is shown in figure 32. This profile shows three velocity layers. The upper layer extends from the land surface to depths of 160 to 220 ft and has a velocity of 4,700 ft/sec. This layer at least partly represents alluvial channel-fill deposits of Quaternary age. Test well (C-41-19)8cdc-1, about 700 ft northwest of the seismic-refraction line, indicated only 39 ft of alluvial channel-fill deposits; but the test well is located at the side of the channel, so the alluvium in the center of the channel may be thicker and the upper velocity layer may represent this material. The intermediate layer extends from depths of 160 to 220 ft to depths of 440 to 1,000 ft and has a velocity of about 10,000 ft/sec. This layer represents saturated Muddy Creek Formation, although some of it may represent weathered consolidated rock. The deepest layer, which extends below depths of 440 to 1,000 ft, has a velocity of more than 17,000 ft/sec, which is characteristic of consolidated rock. The top of this layer is progressively deeper from northeast to southwest along line 4. At the part of the seismic-refraction line closest to the test well, the depth to this layer is about 500 ft, whereas the test well penetrated consolidated rock at 940 ft. The velocity profile shows that the top of the deepest layer has considerable relief, which may account for the difference between the depth to consolidated rock indicated by the test hole and that from the seismic-refraction line. However, since consolidated rock (green shale) crops out about 1 mi to the west of the seismic line and test well, a reasonable inference would be that consolidated rock would be shallower northwest of the seismic-refraction line, rather than deeper. Therefore, the data from the seismic-refraction line does not correlate well with the test-well data.

The velocity profiles for seismic-refraction lines 5 and 6, located about 0.6 mi apart along resistivity profile C-C' (fig. 3), are shown in figures 33 and 34. Both of the profiles show two velocity layers. Line 5, which is centered at resistivity sounding 24, has an upper layer from the land surface to depths of about 20 ft to 330 ft with a velocity of 4,200 ft/sec and a lower layer with a velocity of about 5,500 ft/sec. Line 6, which is located at resistivity sounding 25, has an upper layer from the land surface to depths of about 150 to 250 ft with a velocity of 4,400 ft/sec and a lower layer with a velocity of about 8,000 ft/sec. The upper layer on both profiles probably represents post-Muddy Creek deposits, mostly gravels of Tertiary age; the lower layer probably represents unsaturated Muddy Creek Formation. How-

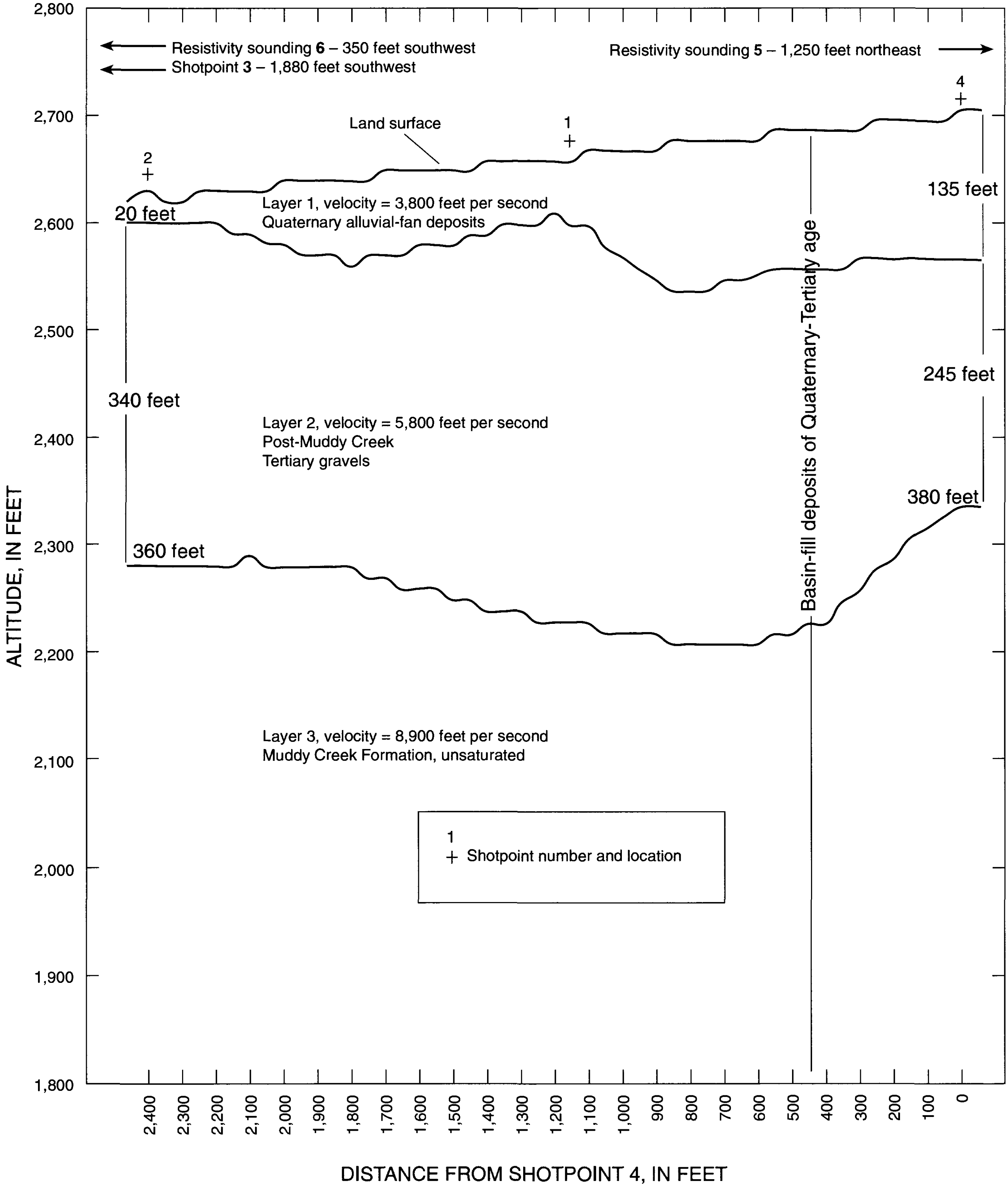


Figure 29. Velocity profile from seismic-refraction line 1, Beaver Dam Wash area.

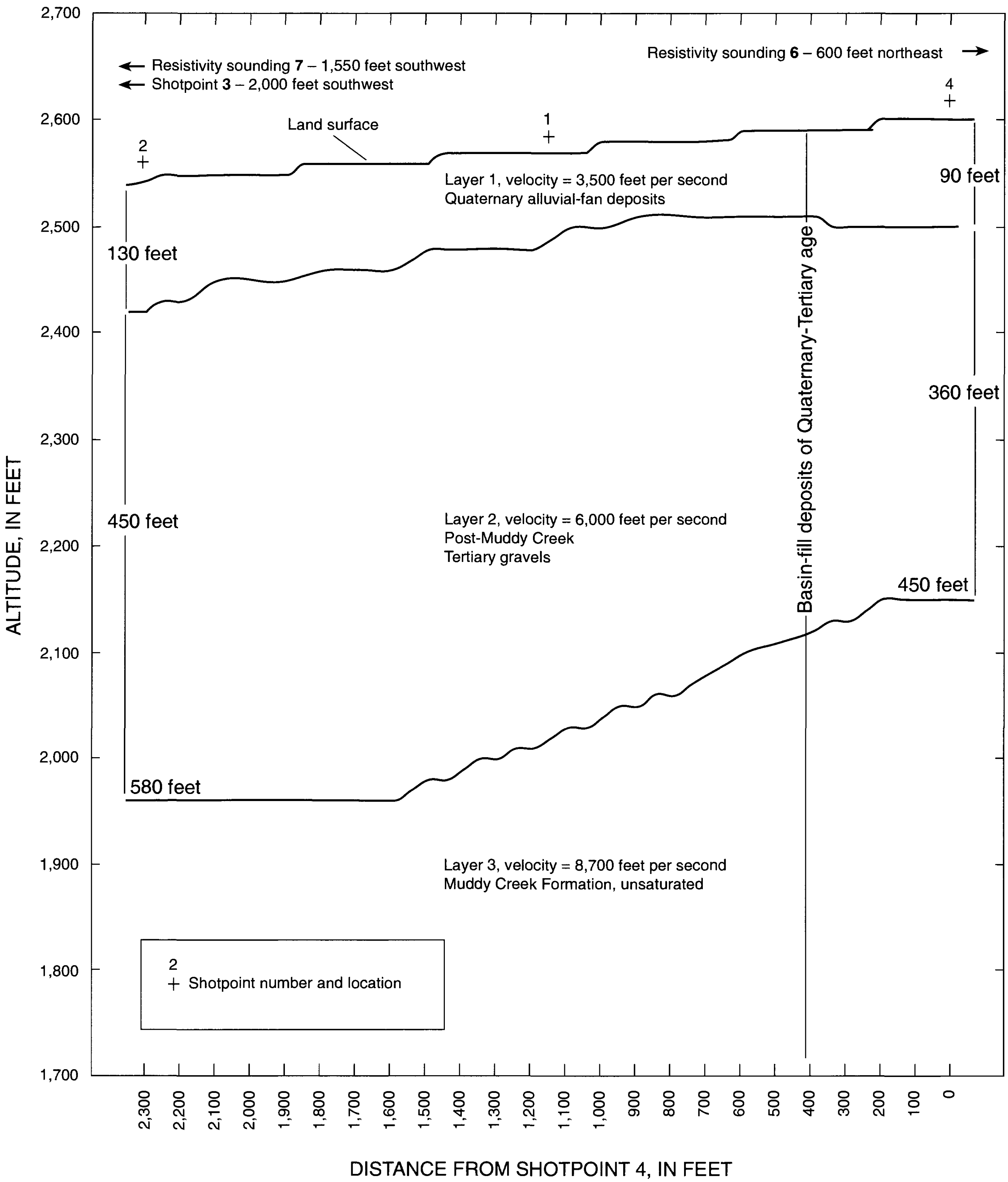


Figure 30. Velocity profile from seismic-refraction line 2, Beaver Dam Wash area.

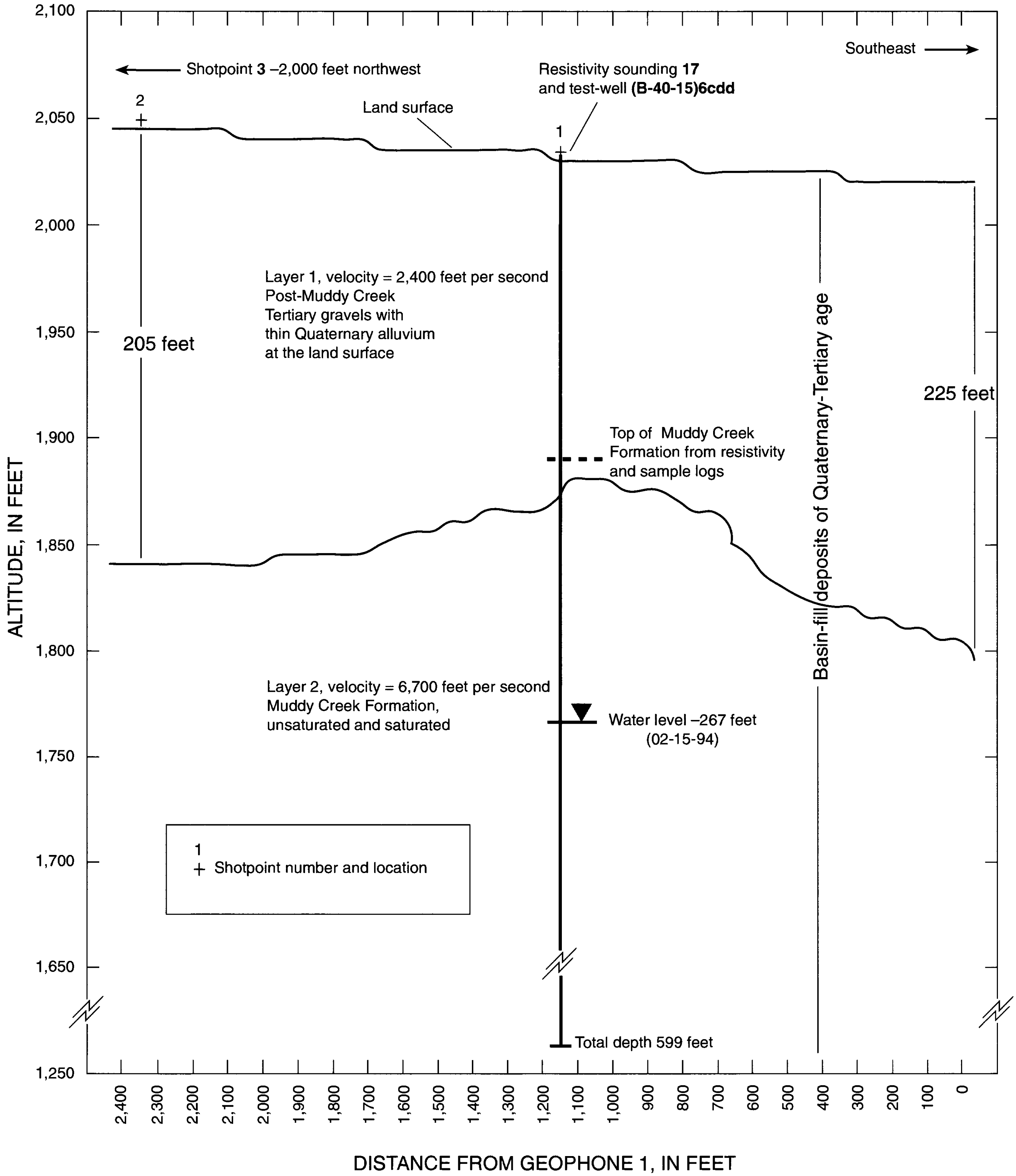


Figure 31. Velocity profile from seismic-refraction line 3, Beaver Dam Wash area.

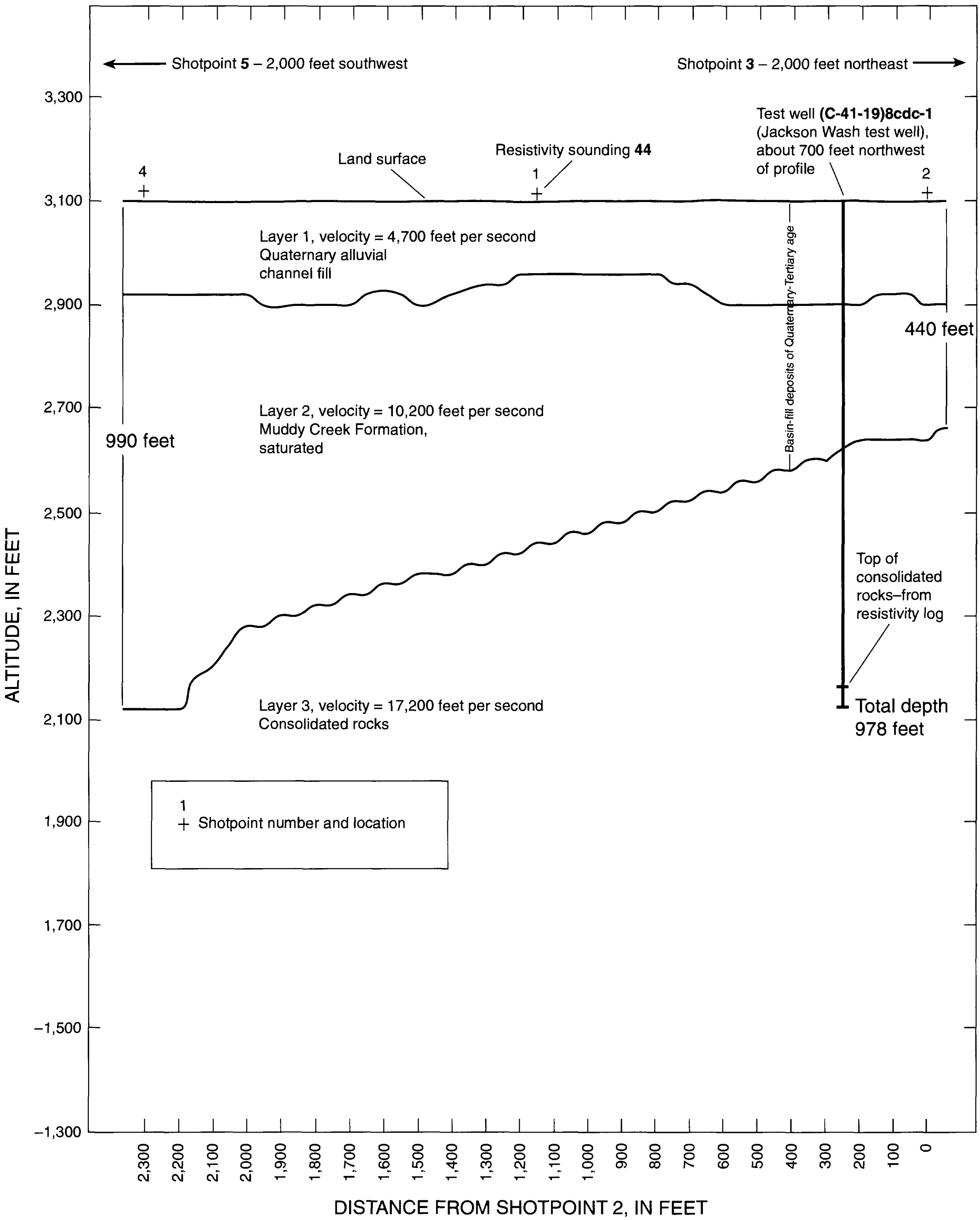


Figure 32. Velocity profile from seismic-refraction line 4, Beaver Dam Wash area.

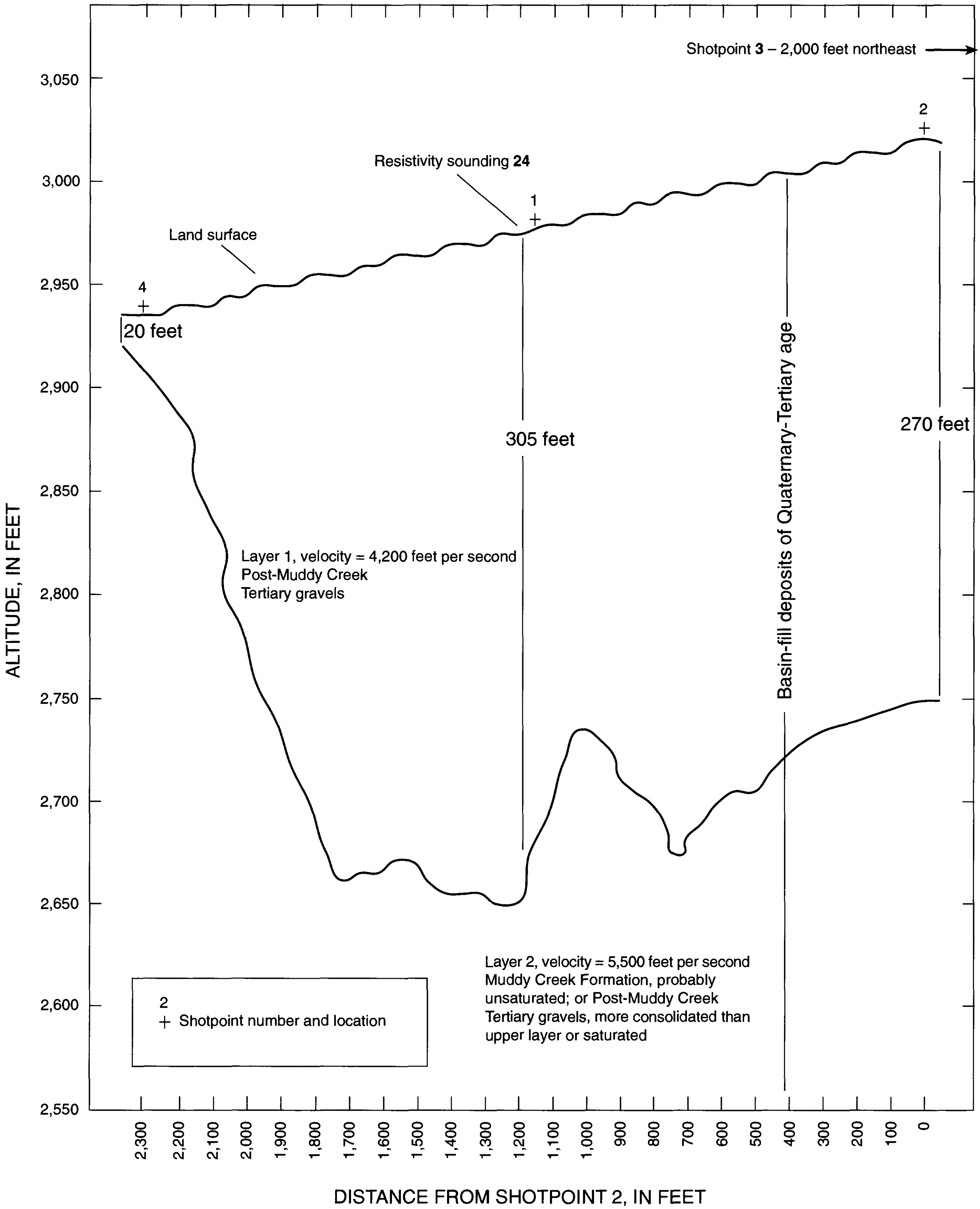


Figure 33. Velocity profile from seismic-refraction line 5, Beaver Dam Wash area.

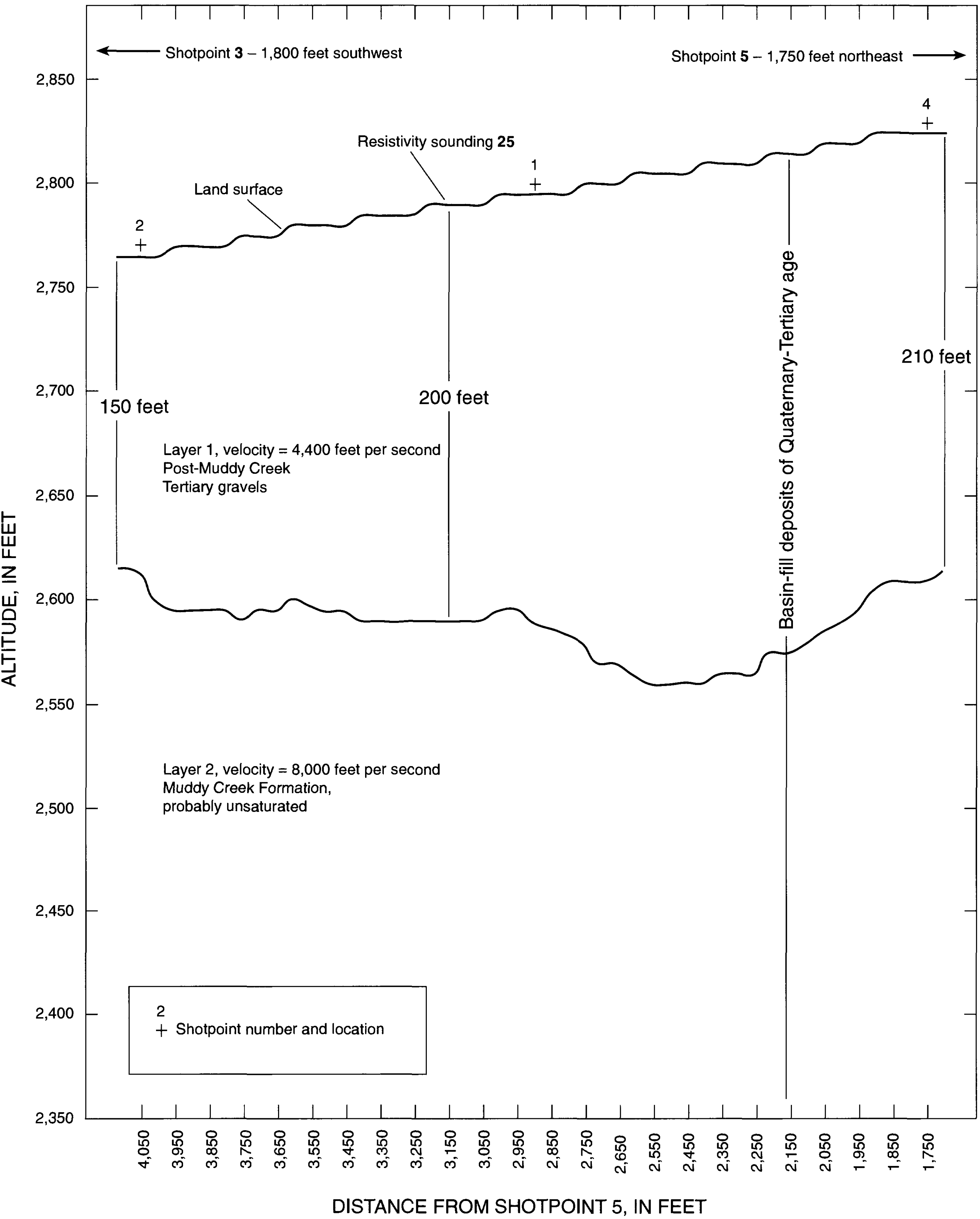


Figure 34. Velocity profile from seismic-refraction line 6, Beaver Dam Wash area.

ever, the lower layer on the profile for line 6 could represent slightly more consolidated post-Muddy Creek deposits. It is also possible, especially for line 6, that the lower layer represents saturated sediments, possibly post-Muddy Creek gravels of Tertiary age, saturated with fresh water. Because test well (C-43-19)25bbb-1 at sounding 23, 3 mi to the southeast of line 6, didn't encounter permeable material containing water, it is unlikely that permeable material containing fresh water occurs at line 6.

The velocity profile for seismic-refraction line 7, centered at resistivity sounding 42 on profile E-E' and F-F' (fig. 3), is shown in figure 35. The profile shows four velocity layers. The uppermost layer, layer 1, generally extends from the land surface to depths of 50 to 110 ft and has a velocity of about 4,900 ft/sec. Layer 1 likely represents alluvial-fan deposits of Quaternary age, but it may also be the uppermost, least-consolidated part of the deposits represented by layer 2. Layer 2 generally extends from depths of 50 to 110 ft to depths of 425 to 600 ft and has a velocity of 5,900 ft/sec. Layer 2 likely represents post-Muddy Creek gravel deposits of Tertiary and Quaternary age. Layer 3 extends from depths of about 425 to 600 ft to depths of about 1,650 to 1,850 ft and has a velocity of about 8,100 ft/sec. Layer 3 probably represents the Muddy Creek Formation, most of which, because of its depth, probably is saturated. Resistivity data from sounding 42 indicate that the water table is at a depth of about 700 ft. The change in velocity from layer 2 to layer 3 possibly represents the velocity change from unsaturated to saturated conditions, but more likely it represents a lithologic change from post-Muddy Creek deposits to Muddy Creek Formation. It is also possible that the water table approximately coincides with the top of the Muddy Creek Formation and that layer 3 is entirely saturated Muddy Creek Formation. Layer 4 is below depths of about 1,650 to 1,850 ft and has a velocity of 12,000 ft/sec. This layer likely represents consolidated rock. Resistivity data from soundings 42 and 43 (3/4 mi west of 42) indicate that the upper surface of consolidated rock is at depths of 1,500-2,200 ft.

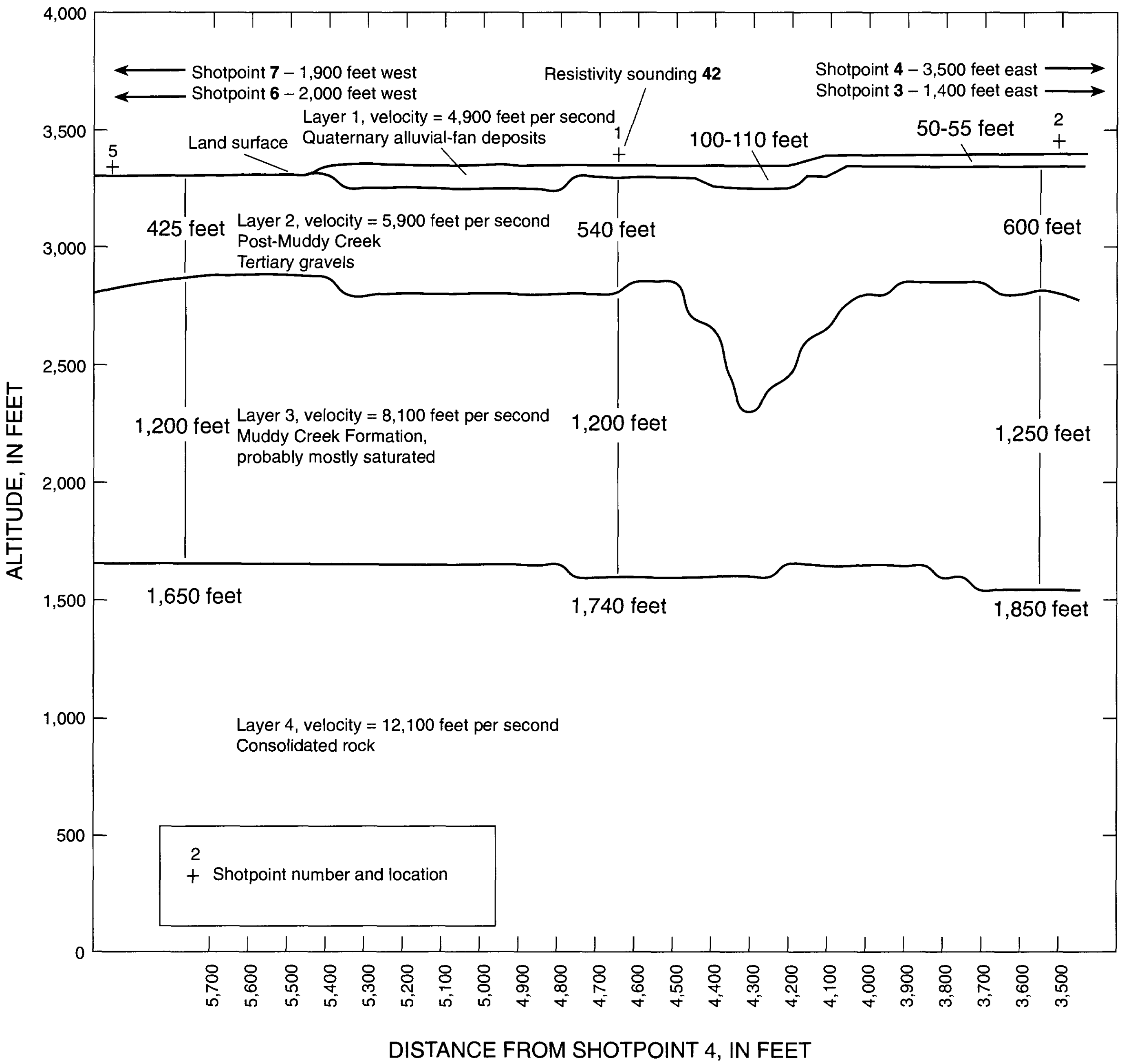


Figure 35. Velocity profile from seismic-refraction line 7, Beaver Dam Wash area.

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