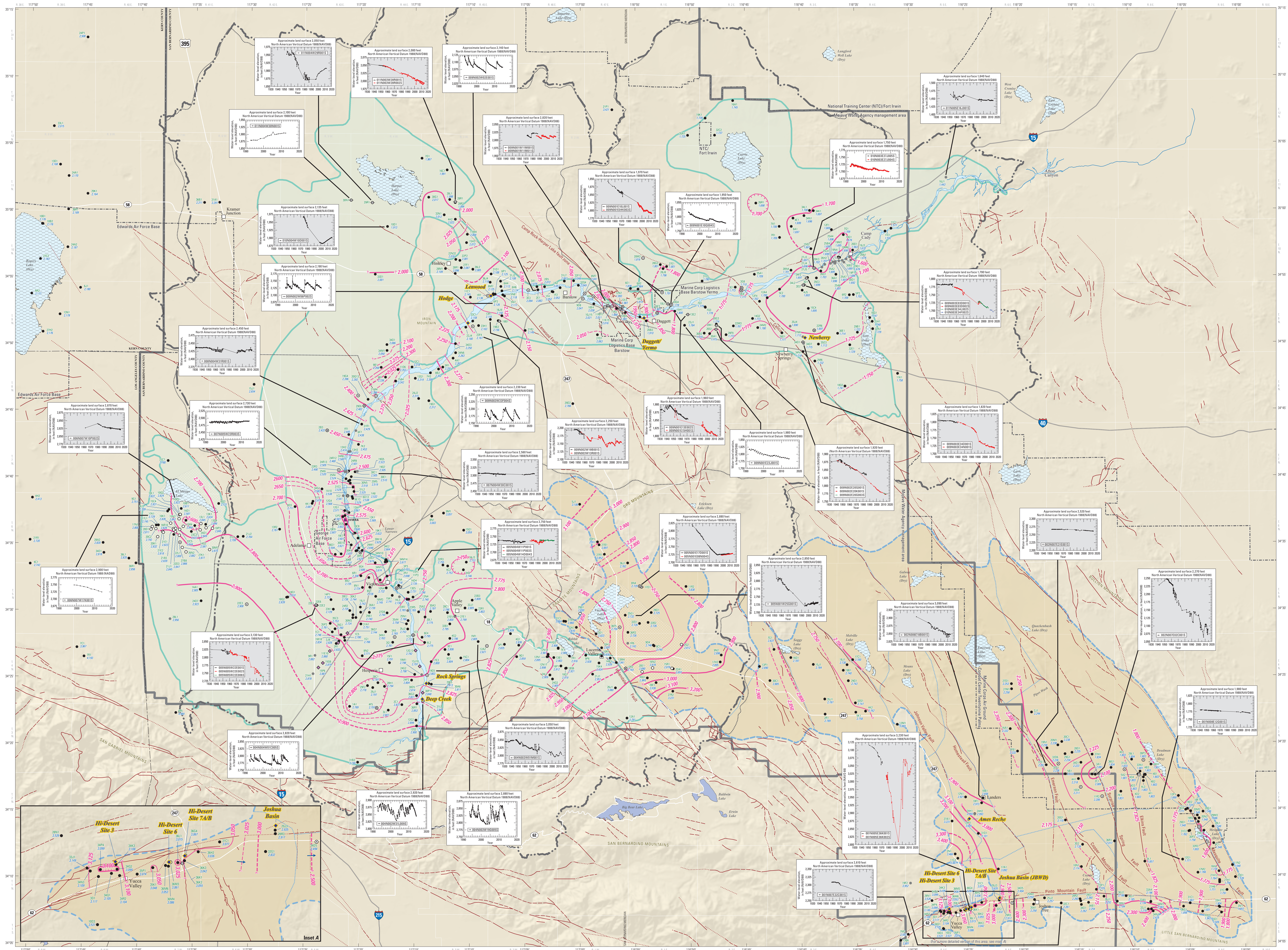


Base from U.S. Geological Survey and other Federal and State digital data, various scales
Universal Transverse Mercator Projection, zone 11.
North American Datum of 1983

SCALE 1:170,000

10 5 0 10 MILES

10 5 0 10 KILOMETERS

NORTH AMERICAN VERTICAL DATUM OF 1988

Faults modified from Schaefer, 1979; Bortugno, 1986; Londquist and Martin,1991; Cox and Wilshire, 1993; J.C. Matti and G.I. Dixon, U.S. Geological Survey, written commun., 1994; Nishikawa and others, 2003
GIS database by Sally F. House; digital cartography and cartographic production by Donna L. Knifong

EXPLANATION

Boundaries

- **Mojave River drainage basin**
- **Mojave River groundwater basin (approximate)**
- **Morongo groundwater basin (approximate)**
- **Morongo groundwater basin subbasin (approximate)**
- **Mojave Water Agency management area**
- **Mojave Water Agency management area subarea**

Perched water table

Military installation

Faults

- Location accurate
- Approximately located
- Concealed

Water-table contour—Shows elevation of water table (spring 2014). Contour interval, in feet, is variable. Contour is querried where uncertain. Thick contours indicate100-foot contour interval. North American Vertical Datum of 1988 (NAVD 88).

- Location approximate
- Location uncertain
- Depression—hachures point into depression

Generalized direction of groundwater flow

11C1 / 1,582 — **Well**—Top number is abbreviated State well number. Bottom number is elevation of water level, in feet above NAVD 88 (spring 2014).

3G93 / 1,710 — **Water-level record may contain pressure-transducer data**—Top number is abbreviated State well number. Bottom number is elevation of water level, in feet above NAVD 88 (spring 2014).

26N2 / 2,886 — **Well with perched water level**—Top number is abbreviated State well number. Bottom number is elevation of water level, in feet above NAVD 88 (spring 2014).

34D1 — **Well with historical data shown on a hydrograph**

3A1 / 2,100 — **Multi-depth well**—Well shown is most shallow and was used to generate water-table contours. Top number is abbreviated State well number. Bottom number is elevation of water level, in feet above NAVD 88 (spring 2014).

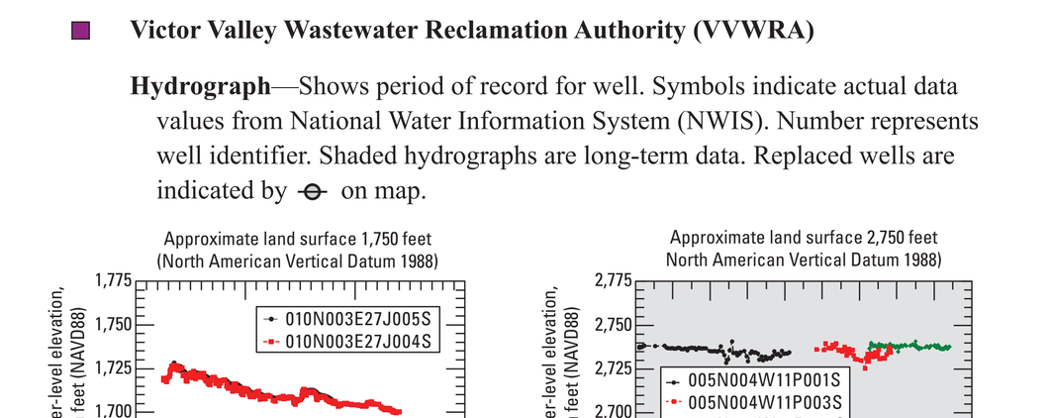
3A1 / 2,100 — **Multi-depth well with pressure-transducer data**—Well shown is most shallow and was used to generate water-table contours.

11E10 / 2,861 — **Westbay® well**—Top number is abbreviated State well number. Bottom number is elevation of water level, in feet above NAVD 88 (spring 2014).

Lenwood — **Artificial-recharge site and name**

Victor Valley Wastewater Reclamation Authority (VVWRA)

Hydrograph—Shows period of record for well. Symbols indicate actual data values from National Water Information System (NWIS). Number represents well identifier. Shaded hydrographs are long-term data. Replaced wells are indicated by ⊖ on map.



2014 WATER TABLE

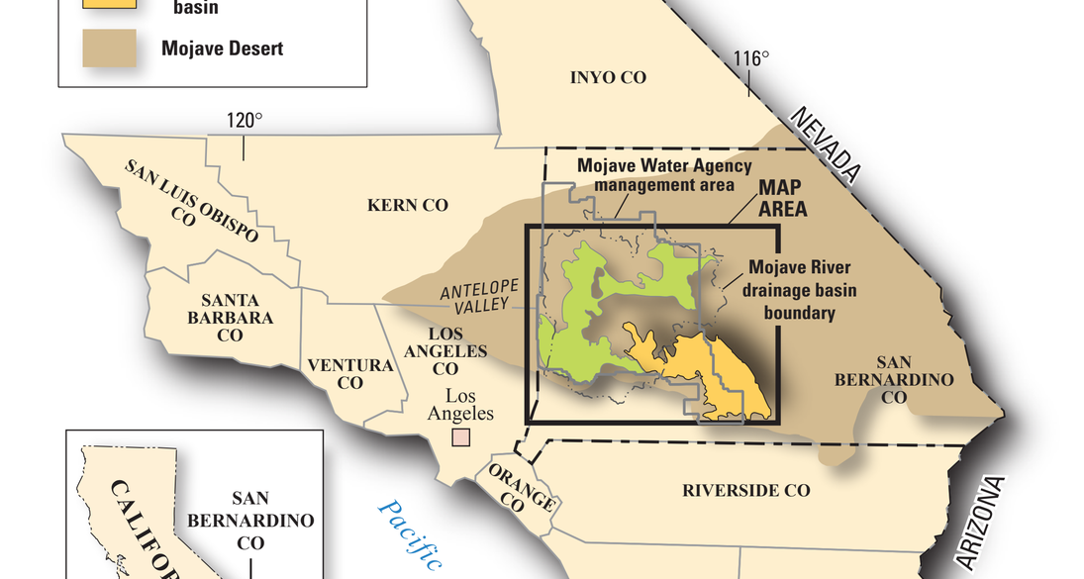
Data for static water levels measured in about 610 wells during March–April 2014 by the U.S. Geological Survey (USGS), the Mojave Water Agency (MWA), and other local water districts were compiled to construct this regional water-table map. This map shows the elevation of the water table and general direction of groundwater movement in and around the Mojave River and Morongo groundwater basins. Water levels recorded by the USGS and MWA staff were measured and compiled according to the procedures described in the Groundwater Technical Procedures of the U.S. Geological Survey (Cunningham and Schalk, 2011). Water-level data submitted by cooperating local water districts were collected by using procedures established by the corresponding agency and were compiled according to the procedures described in the Groundwater Technical Procedures of the U.S. Geological Survey (Cunningham and Schalk, 2011). All data were compared to historical data for quality-assurance purposes. Water-level contours from the 2012 water-level map (Teague and others, 2014) were used as a guide to interpret and shape the 2014 water-level contours in areas where 2014 water-level data were not available; these contours are shown as dashed (approximate) on this water-table map. Water-level data and contours are shown for the Warren subbasin in the Morongo groundwater basin in greater detail on inset A.

The water table is the surface at which the fluid pressure in the pores of a porous medium is exactly atmospheric (Freeze and Cherry, 1979). The water table is defined by the level of the water surface in wells that just penetrate the top of the water body (Lohman, 1972). The water-level measurements used for the water-level contour maps are from wells that have more than one perforated interval in the saturated zone of the groundwater basins. Although these wells can have different perforated zones, the measured water levels from the zones were within about 10 feet (ft) and, therefore, reasonably represent the water-table elevation. Water levels measured from the perched-groundwater zones were not used to construct the water-level contours.

As part of a groundwater-observation network, the USGS, in cooperation with local water agencies, water districts, the military, and private landowners, has constructed many multiple-well monitoring sites. These sites consist of a cluster of two or more observation wells completed at different depths in a single borehole, each typically screened across a 20-foot interval (Huff and others, 2002). Data from the shallowest well of a multiple-well site were used for the regional water-table maps.

BACKGROUND

The Mojave River and Morongo groundwater basins are approximately 80 miles north and 40 miles northeast of Los Angeles, respectively, in the southwestern part of the Mojave Desert in southern California (fig. 1). The Mojave River and Morongo groundwater basins together have an area of about 2,400 square miles. The climate of these basins is typical of the Mojave Desert region of southern California. Most areas of the basin floor receive 4 to 6 inches of precipitation each year, although annual precipitation can be greater than 40 inches in the southern and eastern San Bernardino and the San Gabriel Mountains (Lines, 1996). Recharge of the groundwater system from direct infiltration of precipitation is minimal.



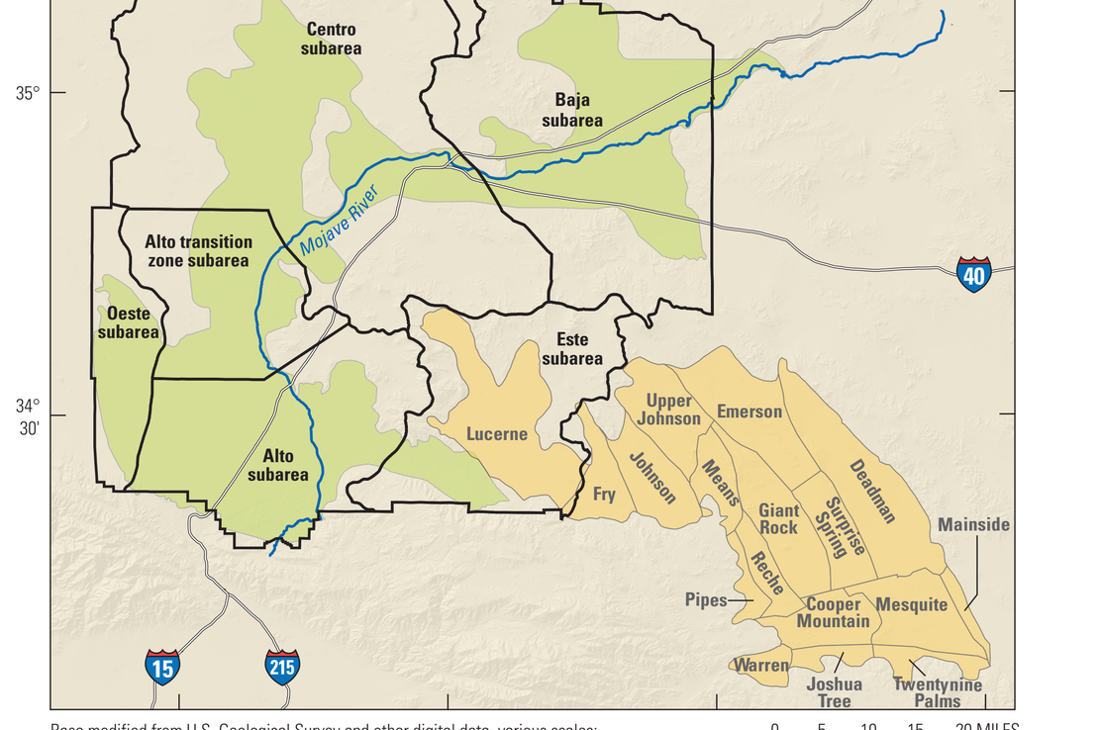
Base modified from U.S. Geological Survey and other Federal and state digital data, various scales; Albers Equal Area Projection; North American Datum of 1983

Figure 1. The Mojave River and Morongo groundwater basins, San Bernardino County, California.

Surface water in these basins is minimal and normally is limited to ephemeral flow during winter and spring storms and discharge from perennial springs in some areas of the Morongo groundwater basin. The major source of surface water is the Mojave River; however, its flow is unpredictable and not a dependable source for water supply because most of the 100-mile river channel is usually dry. The lack of notable surface-water resources has resulted in the use of groundwater as the primary water source for private, agricultural, and municipal supply. Because of increasing urbanization, demands on local water supplies have created overdraft conditions in some areas of the desert basins. Greatly lowered water levels have the potential to induce or renew land subsidence in the Mojave River and Morongo groundwater basins.

MOJAVE RIVER GROUNDWATER BASIN

The Mojave River groundwater basin has an area of approximately 1,400 square miles that extends from the San Bernardino and the San Gabriel Mountains in the south to north of Harper and Coyote Lakes (dry). The groundwater basin is bordered on the west by Antelope Valley and shares its southeastern boundary with the Morongo groundwater basin. For water-management purposes, the Mojave River groundwater basin was divided into five subareas, partially based on the Mojave River drainage basin boundary: Oeste, Alto, Este, Centro, and Baja (fig. 2).



Base modified from U.S. Geological Survey and other digital data, various scales; Albers Equal Area projection; North American Datum of 1983

Figure 2. The Mojave Water Agency subareas and the Morongo groundwater subbasins of the Mojave River and Morongo groundwater basins, respectively.

The primary sources of groundwater recharge in the Mojave River groundwater basin are intermittent streamflow, usually during January through March, in the Mojave River and sporadic releases of imported water from the California State Water Project (SWP). The basin has received SWP water at the Rock Springs recharge site (near well 4N/3W-29E5), southeast of Hesperia, since 1994; at the Hodge recharge site (near well 9N/3W-23D2) since 1999; at the Lenwood recharge site (near well 9N/3W-1R7) since 1999; at the Yermo/Daggett recharge site (near well 9N/1E-20B3) since 2003; and at the Newberry Springs recharge site (near well 9N/3E-22R7) since March 2006 (Brian Hammer, Mojave Water Agency, written commun., April 2006).

MORONGO GROUNDWATER BASIN

The Morongo groundwater basin has an area of about 1,000 square miles and is bounded by the Ord and Granite Mountains to the north, the Bullion Mountains to the east, the San Bernardino Mountains to the southwest, and the Little San Bernardino Mountains to the south. The Morongo groundwater basin contains 17 subbasins: Lucerne, Fry, Johnson, Upper Johnson, Means, Pipes, Reche, Emerson, Giant Rock, Copper Mountain, Surprise Spring, Deadman, Mesquite, Mainside, Warren, Joshua Tree, and Twentynine Palms (fig. 2). The Morongo groundwater basin is recharged by infiltration of flow in ephemeral stream channels and, since 1995, by SWP water supplied to ponds at three Hi-Desert Water District recharge sites (near wells 1N/5E-36M5 and 1N/5E-34Q1) in the Warren subbasin.

GEOHYDROLOGY

The boundaries of the Mojave River and the Morongo groundwater basins generally are defined by the contact between the water-bearing, unconsolidated deposits and the surrounding and underlying, non-water-bearing, consolidated igneous and metamorphic rocks. The groundwater system in the Mojave River Basin consists of two interconnected unconfined aquifers—a floodplain aquifer and an underlying and surrounding regional aquifer, which are part of the Basin and Range aquifers in southern California. The most productive aquifer is the floodplain aquifer, which is composed of permeable, young, river deposits of Holocene age and older river deposits of Pleistocene age. This aquifer is as much as 200 ft thick and yields most of the groundwater pumped from the Mojave River Basin (Stamos and others, 2001). The most widespread aquifer in the area is the regional aquifer; it is composed of unconsolidated older alluvium and fan deposits of Pleistocene to Tertiary age. In some places, the regional aquifer also consists of partly consolidated to consolidated sedimentary deposits of Tertiary age. The regional aquifer is as much as 1,000 ft thick. Other geologic units, such as bedrock and lake deposits, commonly contain groundwater, but they are not considered reliable sources of groundwater in the study area.

The Mojave River and Morongo groundwater basins are separated by the Helendale Fault, which acts as a barrier to groundwater flow near Lucerne Valley. The regional aquifer in the Morongo groundwater basin consists of continental deposits of Quaternary and Tertiary age that are as much as 10,000 ft deep (Moyle, 1984). For a more comprehensive description of the geohydrology of the groundwater basins, the reader is referred to Stamos and others (2001).

Perched groundwater has been identified in four areas of the Mojave River and Morongo groundwater basins. Perched groundwater is unconfined groundwater separated from an underlying body of groundwater by an unsaturated zone (Lohman, 1972). The approximate areas of perched groundwater are near El Mirage Lake (dry) and northeast of the city of Adelanto in the Mojave River groundwater basin and the Lucerne Valley (Jill Densmore, U.S. Geological Survey, written commun., 1999) and Mesquite (dry) Lake (Mendez and Christensen, 1997) in the Morongo groundwater basin.

GROUNDWATER MOVEMENT

Groundwater flows perpendicular to water-level contours from areas of higher hydraulic head to areas of lower hydraulic head (downgradient). Water-table contours in the vicinity of faults indicate that some faults in the study area are barriers to groundwater flow. The barrier effect of the faults is probably caused by compaction and deformation of water-bearing deposits immediately next to the faults and by cementation of the fault zone by mineral deposits from groundwater (Londquist and Martin, 1991).

The southern part of the Helendale Fault, near the town of Lucerne, is an effective barrier to subsurface flow. The water-table map indicates that the direction of groundwater movement on the east side of the Helendale Fault is toward Lucerne (dry) Lake; therefore, groundwater east of the Helendale Fault in this area is considered to be in the Morongo groundwater basin. Groundwater-flow patterns in the Lucerne Lake area have changed little since 1916–17, the time of the first available data (Schaefer, 1979). West of the Helendale Fault, groundwater is considered to be in the Este subarea of the Mojave River groundwater basin, and the water-table gradient is relatively flat.

MOJAVE RIVER GROUNDWATER BASIN

In most subareas of the Mojave River groundwater basin, groundwater generally flows northward and eastward. In the Este subarea, however, the flow is northward and westward. The amount of subsurface flow across the boundary between the Alto and Este subareas was estimated by Stamos and Predmore (1995). Hardt (1971) estimated that the transmissivity of the aquifer materials near the boundary of the Alto and Este subareas ranged from 5,000 to 10,000 gallons per day per foot. The width of the boundary is about 4 miles, and the hydraulic gradient was determined from the water-table map in 1992 (Stamos and Predmore, 1995) to be 0.0025 foot per foot. On the basis of these estimates, the approximate subsurface flow in 1992 from the Este subarea to the Alto subarea was 300 to 600 acre-feet per year. Available data in the southwestern part of the Mojave River groundwater basin were insufficient to estimate the quantity of flow across the Oeste/Alto subarea boundary.

The water-table contours indicate that subsurface flow crosses the northern part of the Helendale Fault from the Alto subarea to the Centro subarea along the Mojave River. Water-level data from multiple-well monitoring sites, as well as historical data, indicate that this fault restricts subsurface flow in the regional aquifer, but not in the overlying alluvial aquifer (Hardt, 1971). Groundwater moving into the Centro subarea flows either to the north, away from the Mojave River toward Harper (dry) Lake, or to the northeast through a narrow gap in the consolidated rocks on the south side of Iron Mountain. Steep water-level gradients between the Helendale Fault and Iron Mountain indicate the probable presence of subsurface faults or shallow geologic structures that impede subsurface flow to Harper Lake. On the east side of Iron Mountain, groundwater flows from the Mojave River northwest to Harper Lake and also northeast toward the city of Barstow.

Groundwater from the Centro subarea crosses the Camp Rock-Harper Lake fault zone and enters the Baja subarea east of Barstow. In the fault zone, the water-table gradient is marked by abrupt, step-like changes in the water-table gradient, decreasing in elevation as water flows eastward. Water-level data from multiple-well monitoring sites indicate that the fault zone impedes groundwater movement both in the shallow alluvial aquifer and in the underlying regional aquifer. East of the Camp Rock-Harper Lake fault zone, the water-table gradient is relatively flat where groundwater flows northeastward through the Baja subarea. As groundwater enters the middle of the Baja subarea, however, it is impeded by the Calico-Newberry Fault, as indicated by more than a 50-foot drop in the water table on the west side of the fault. Water-level data from multiple-well monitoring sites on both sides of the Calico-Newberry Fault indicate that, as in the Camp Rock-Harper Lake fault zone, groundwater flow is impeded in both aquifers.

Subsurface flow through the Baja subarea is affected by low-permeability deposits present at shallow depths in two locations. Near Camp Cady, fine-grained, unconsolidated deposits near the surface that are associated with ancient Manix Lake (California Department of Water Resources, 1967) cause an abrupt change in the water-table gradient as groundwater flows toward Afton Canyon. At Afton Canyon, low-permeability deposits at shallow depths below the Mojave River restrict subsurface flow, forcing groundwater to the surface before it exits the Mojave River groundwater basin.

MORONGO GROUNDWATER BASIN

In the Morongo groundwater basin, groundwater generally flows eastward and northward from the San Bernardino Mountains. From Pipes Wash, flow is eastward toward localized depressions in the water table at Deadman and Mesquite (dry) Lakes. Groundwater pumping by the U.S. Marine Corps Air/Ground Combat Center in the Surprise Spring subbasin has created a groundwater depression that has changed the direction of groundwater movement locally. From washes along the northern front of the San Bernardino Mountains, flow is northeastward to the pumping depression in the Lucerne subbasin and to the Soggy, Melville, and Means (dry) Lakes. As groundwater moves eastward through the Morongo Basin, subsurface flow across faults is impeded, resulting in a step-like decrease in water levels. Groundwater leaves the basin across the Mesquite Fault in the southeastern part of the basin and, ultimately, moves eastward.

Other patterns indicated by the contour lines and supported by previous findings are (1) northward flow from the Little San Bernardino Mountains to the Pinto Mountain Fault (Lewis, 1972), (2) minor flow southward from the San Bernardino Mountains into Warren subbasin (Lewis, 1972), and (3) southward flow into Lucerne subbasin from the Ord Mountains (Schaefer, 1979). Rates of groundwater movement in areas of the basin unaffected by pumping are low—generally a few feet per year (French, 1978).

Groundwater depressions are present in the areas of the greatest historical and current pumpage: Warren, Lucerne, and Surprise Spring subbasins. Construction of water-table contours in Warren subbasin was difficult because water levels varied considerably. The variability could be due to the presence of faults that separate the area into small isolated compartments, incomplete recovery of the water table in the public-supply wells at the time of measurement, even though pumping had ceased 24 hours prior to measurement, or both.

Perched water in the Mainside subbasin (under Mesquite Dry Lake) is approximately 130 ft above the regional water table. Movement of this water seems to be southeastward, similar to that of the regional groundwater below it. The probable source of this perched water is spreading ponds that are used for sewage-water treatment.

LONG-TERM AND SHORT-TERM WATER-LEVEL CHANGES

Historical water-level data from the National Water Information System (NWIS) database were used in conjunction with data collected for this study to construct 35 water-level hydrographs to show long-term (1930–2014) and short-term (1990–2014) water-level changes in the Mojave River and Morongo groundwater basins. Water-level changes between the spring of 2012 and spring of 2014 were determined by comparing water levels measured in the same well during both periods.

Long-term (1930–2014) water-level changes are depicted by 25 water-level hydrographs (shaded) for the Mojave River and the Morongo groundwater basins. Wells for three hydrographs (wells 5N/5W-22E6, 11N/4W-29R1, and 11N/4W-30N1) were destroyed or were unable to be measured in 2014, but are shown to provide information from previous versions of this report.

Data from more than one well were combined in hydrographs to show water-level changes during long periods in particular subareas. Combining data from multiple wells on a single hydrograph was done when a well went dry as a result of a decline in the water table or when it could no longer be measured, and data from a nearby well were used to continue the record. Data from the different wells are shown by using different colored data points on the hydrographs.

MOJAVE RIVER GROUNDWATER BASIN

The long-term hydrographs for the Mojave River groundwater basin showed that water levels east of the Mojave River in the Alto subarea have declined almost 50 ft since 1917 (well 4N/3W-1M1) and more than 60 ft in the eastern part of the Harper Lake region of the Centro subarea since the 1930s (wells 11N/3W-28R1, -28R2). Water levels southwest of Harper Lake (dry) in the Centro subarea (well 10N/4W-10D1) have increased from 2001 to 2014 because of a sustained reduction in groundwater pumping since the early 1990s (Mojave Water Agency Watermaster, 2015). In the Baja subarea, water levels have declined more than 105 ft since the late 1940s (wells 9N/2E-20Q1, -20K1, and -20G3).

Twelve short-term hydrographs were constructed from data collected in the Mojave River groundwater basin between 1990 and 2014. Most hydrographs show data from wells along the Mojave River and record the effects of seasonal recharge and discharge along the river; artificial recharge; and evapotranspiration, which is minimal during the winter months. These short-term hydrographs show that there has been sporadic recharge to the floodplain aquifer from intermittent stormflows in the Mojave River in the Alto (wells 4N/3W-19G5, -31L9, and 4N/4W-01C5) and Centro (wells 9N/2W-02E1, -06P2, and 9N/3W-23F4) subareas since 1992, but recharge from stormflows in the Baja (wells 9N/1E-10Q4 and 10N/3E-27J4) subarea has been minimal. In the Alto transition zone, the groundwater levels near well 7N/5W-23R3 have increased slightly as a result of recharge from treated wastewater that is discharged by the Victor Valley Wastewater Reclamation Authority (VVWRA) about 4 miles upstream.

MORONGO GROUNDWATER BASIN

All of the long-term hydrographs for the Morongo groundwater basin showed varying declines in water levels since the wells were first measured. Water levels have declined more than 45 ft in the middle of the Joshua Tree subbasin since the late 1950s (well 1N/7E-32C1), about 55 ft in part of the Reche subbasin since 1963 (well 2N/6E-18B1), about 100 ft near Lucerne Lake (dry) in the Lucerne subbasin since the early 1950s (well 5N/1W-25G1), and about 155 ft in the eastern part of the Surprise Spring subbasin since 1952 (well 2N/7E-2C1). Between 1951 and the early 1990s, water levels in the Warren subbasin (wells 1N/5E-36K1 and -36K2) decreased by as much as 300 ft, but have risen substantially since 1994 in response to artificial recharge with imported water through the use of ponds at the Hi-Desert Water District recharge site (Stamos and others, 2013; fig. 3).

WATER-LEVEL CHANGES 2012–2014

Water-level data exist for 479 wells in the Mojave River and Morongo groundwater basins for 2012 and 2014. Overall, water levels in wells along the Mojave River in the Alto subarea and the Alto transition zone have remained constant (Teague and others, 2016), because of the infiltration resulting from surface flow through the Lower Narrows (10261500) and the treated wastewater discharged by the VVWRA. Data from the Centro and Baja subareas showed that most wells had groundwater-level decreases. A small pumping depression (not shown on the map because of scale), created by efforts to pump and treat contaminated groundwater near Hinkley in the Centro subarea, likely decreases flow of groundwater to the north from Hinkley (Dennis Maslonkowski, CH2MHill, written commun., Jan. 28, 2013). In the Baja subarea, water levels declined between 0.5 and 5 ft in most wells. Several wells in the Baja subarea north of the Mojave River showed water-level increases. These increases are likely due to a reduction in pumpage in that area since 1994 (Mojave Water Agency Watermaster, 1995; Mojave Water Agency Watermaster, 2015).

A majority of the wells in the Morongo groundwater basin had water levels within 5 ft of those recorded in 2012. In the Deadman, Mesquite, and Mainside subbasins, the water-level increases can be attributed either to fluctuations in pumpage or to a possible reduction in pumpage (Li and Martin, 2011). The greatest water-level increases continue to be observed in the Warren subbasin, where artificial-recharge operations in Yucca Valley (fig. 3) and a reduction in groundwater pumpage (Stamos and others, 2013) have caused water levels to rise more than 250 ft (well 1N/5E-36K2) since 1994.

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