U.S. Department of the Interior U.S. Geological Survey

The U.S. Geological Survey (USGS) and the Bureau of Land Management (BLM) initiated a cooperative study through the Southern Nevada Public Land Management Act (Bureau of Land Management, 1998) to install six wells in the carbonate-rock and basin-fill aquifers of Clark County, Nevada, in areas of sparse groundwater data. This map uses water levels from these new wells, water levels from existing wells, and altitudes of spring discharge points to update a regional potentiometric map of the carbonate-rock aquifer and provide evidence to interpret the direction of regional groundwater flow. This potentiometric surface map is accompanied by drilling and borehole geophysical logs, wellconstruction information, lithology, water chemistry, and water levels from the newly drilled wells.

Carbonate-Rock Aquifer and Regional Groundwater Flow

The carbonate-rock aquifer in Clark County consists of thick sequences of Paleozoic-age limestone and dolomite with thinner beds of shale, sandstone, and quartzite that are deformed and extended. Mountain blocks of carbonate rock, separated by intermountain basins, thicken westward from the Muddy Mountains toward the Las Vegas and Sheep Ranges (Dettinger and others, 1995; Prudic and others, 1995; Harrill and Prudic, 1998; Heilweil and Brooks, 2011). Groundwater in the aquifer flows through fractures and faults associated with regional deformation and through small-scale brittle fractures.

The aquifer is primarily recharged through fractures in high-precipitation areas that are in high-altitude mountain ranges near groundwater divides. Regional discharge is from springs and riparian areas at low altitudes in major drainage basins. Discharge from springs at the regional scale is generally constant and less transient than from springs discharging from more localized flow systems (Toth, 1963). Active groundwater withdrawals (or pumping) can affect local spring discharge, producing fluctuations not characteristic of discharge from natural regional springs. Parts of three groundwater flow systems compose the carbonate-rock aquifer in Clark County: (1) the Colorado System, (2) Death Valley System, and (3) Mesquite Valley System (Harrill and others, 1988). In Clark County, groundwater flow in the Colorado System is principally to the southeast, discharging at the headwaters to the Muddy River. Flow in the Death Valley System is principally to the west, discharging to springs in Amargosa Valley and Death Valley (Faunt and others, 2010). Localized flow in the Mesquite Valley System discharges by evapotranspiration from phreatophytes and evaporation on the valley playa (Glancy, 1968).

Groundwater flow directions and gradients are presented on potentiometric maps by Bedinger and Harrill (2010) and Brooks and others (2014). Both studies used available groundwater levels, spring altitudes, and discharge data to classify groundwater and springs as regional or local. Bedinger and Harrill (2010) generalized hydrogeologic and geologic characteristics as proxy data to define regional hydraulic heads, which are described as water levels that are (1) lower than the water table in areas of recharge, (2) above the altitude of intermediate and regional discharge areas, and (3) below the altitude of non-discharging dry playas. Brooks and others (2014) developed a regional-scale numerical groundwater flow model to evaluate groundwater availability in the Great Basin. The published potentiometric contours, representative of the carbonate-rock aquifer, were based on water-level observations from wells

completed in basin fill and carbonate rock. These studies were conducted at a regional scale and included relatively few direct observations

Selected Existing Hydrogeologic Data

from wells in Clark County, which are completed in carbonate rock.

Water levels, water chemistry, lithology, and construction data from monitoring wells were compiled from the USGS National Water Information System (NWIS) database (U.S. Geological Survey, 2016) and from Thomas and others (1996), and compared to information obtained from the six new wells. Sites near production wells were excluded from this selection because of the potential for pumping related drawdown to affect water levels, and monitoring wells were excluded if screened across multiple intervals. Wells were selected if they were screened in the carbonate-rock aquifer or in the basin-fill aquifer at depths greater than 500 feet. It is assumed that basin-fill wells at this depth are in hydraulic connection with the carbonate-rock aquifer (Prudic and others, 1995). In Clark County, 24 wells completed in carbonate rock, 28 wells completed in deep basin-fill deposits, and 5 springs were selected from the USGS NWIS database (table 1) and included in this report.

Table 1. Existing monitoring wells representative of the carbonate-rock and basin-fill aquifers in Clark County, Nevada.

[ID, identifier; USGS, U.S. Geological Survey; NWIS, National Water Information System; mm/dd/yyyy, month/day/year; NGVD 29, National Geodetic Vertical Datum of 1929; CR, carbonate rock; BF, basin fill; —, no data]

Map ID	USGS site ID	USGS NWIS site name	Site type	Well depth (feet)	Hole depth (feet)	Contributing aquifer	Date of water-level measurement (mm/dd/yyyy)	Water level, in feet below land surface	Water-level altitude, in feet above mean sea level (NGVD 29)
1	361816115241301	212 S19 E59 18AAC 1	Well	542	542	CR	09/01/1964	417.00	3,484
2	363500115400001	161 S16 E56 16 1 Indian Springs Sewage Co	Well	550	590	CR	06/01/1963	54.00	3,146
3	362846114495501	216 S17 E64 09DDCD1 CRYSTAL 2	Well	565	565	CR	08/21/2000	254.94	1,815
4	364741114532801	210 S13 E63 26AAAA1 USGS-MX CE-DT-5	Well	628	628	CR	08/13/1999	349.81	1,820
5	360016115361501	163 S22 E57 29DABC1 USBLM NDOT 01	Well	660	660	CR	09/07/2010	306.15	3,917
6	364743114533101	210 S13 E63 23DDDC1 USGS-MX CE-DT-4	Well	669	669	CR	10/15/2015	356.27	1,819
7	363212115240301	212 S16 E58 23DDD 1 USFWS SBH-1	Well	720	720	CR	05/28/2015	575.20	2,891
8	362531114524201	216 S18 E64 07BB 1 WELL (REPORT R50)	Well	793	793	CR	11/29/1956	226.40	1,819
9	355829115150601	212 S23 E60 03DBCB1 TORTOISE CENTER	Well	800	800	CR	03/19/1990	555.00	2,150
10	361736114531601	215 S19 E63 13DCAA1 EBM-3	Well	900	1,241	CR	02/20/2004	578.73	1,810
11	363308114553001	217 S16 E63 09DDAB1 USBLM SHV-1	Well	920	920	CR	10/01/2015	833.69	1,815
12	363332115244001	212 S16 E58 14A 1 USFWS DR-1	Well	930	960	CR	05/28/2015	813.40	2,760
13	364604114471301	219 S13 E64 35DCAD1 USGS-MX CE-DT-6	Well	937	937	CR	11/01/2002	456.00	1,819
14	364830115512601	160 S13 E55 19 1 TW- 3	Well	1,127	1,860	CR	08/25/2015	1,103.00	2,381
15	363407115215301	212 S16 E59 08 2 USGS - Cow Camp	Well	1,403	1,403	CR	07/29/2015	1,330.30	2,856
16	362507114572701	216 S18 E63 05AADB1	Well	1,979	2,007	CR	03/01/2002	755.00	1,811
17	360946115421401	162 S20 E56 33CCAA1 TROUT CANYON 01	Well	718.5	720	CR	01/05/2015	467.30	4,794
18	364451114585001	210 S14 E62 01ADBD1 CSVM-5	Well	1,780	1,783	CR	09/20/2011	1,081.20	2,048
9	362700114564401	216 S17 E63 21DCCC1 HV-1	Well	2,480	2,480	CR	06/20/2000	882.00	1,820
20	361811115404401	212 S19 E56 15ABBD1	Well	660	660	CR	01/26/1981	214.40	8,500
21	364738114534001	210 S13 E63 26AABD1 CSV-RW-2	Well	710	720	CR	09/14/2011	383.40	1,819
22	364728114531001	210 S13 E63 25BDBB1 CSVM-1	Well	1,040	1,060	CR	09/21/2011	341.90	1,819
23	364529114492401	219 S13HE64 33DBBC1 UMVM-1	Well	1,200	1,200	CR	04/22/2003	247.00	1,831
24	363943114552301	210 S15 E63 03BBCC1 CSVM-2	Well	1,400	1,425	CR	09/20/2011	750.70	1,822
25	360201115204701	212 S22 E59 15DAAB1	Well	532	532	BF	03/14/1990	267.21	2,823
26	363201115333801	211 S16 E57 28B 1 Hwy95 Cons 1	Well	550	550	BF	04/22/1963	98.00	3,083
27	360247115224401	212 S22 E59 09CBDB1 HUMANE	Well	570	570	BF	01/21/2009	354.80	2,898
28 29	363452115405101 363447115404601	161 S16 E56 08BAAC1 USAF Well 3 161 S16 E56 08BAAD1 USAF Well 106-2	Well Well	600 604	600 604	BF BF	07/29/2015 07/29/2015	68.00 63.15	3,062 3,067
30	363255115515801	161 S16 E54 24BCBA1 Army 2	Well	627	658	BF	08/17/2015	495.20	3,318
31	355015115102601	166 S24 E61 20DDAC1 HIDDEN VALLEY	Well	640	640	BF	12/03/1956	605.00	2,423
32	354454115205401	164A S25 E59 27AACA1 JAIRPORT	Well	650	650	BF	12/11/2008	280.90	2,499
33	361136115101401	212 S23 E61 03BCC 1 Sky Harbor Airport	Well	650	650	BF	04/18/2011	215.36	2,160
34	360941115104801	212 S20 E61 32CDC 1	Well	665	665	BF	04/18/2011	18.47	2,077
35	355923115174201	212 S22 E60 32CB 1	Well	700	700	BF	08/06/1979	460.00	2,420
36	360826115020001	212 S21 E62 10ACAA1 Nevada Power Company	Well	715	715	BF	04/20/2011	21.94	1,683
37	364601114514301	210 S13 E64 31DADA1 USGS CSV-1	Well	765	765	BF	07/31/2009	346.91	1,813
38	361939115154801	212 S19 E60 04DAB 2 NV Division of Forestry	Well	780	780	BF	04/21/2011	77.51	2,376
39	364127114553001	210 S14 E63 28AACD1 USGS CSV-3	Well	780	780	BF	09/20/2011	594.00	1,820
10	355947115163501	212 S22 E60 33BB 1	Well	785	785	BF	12/10/1976	585.00	2,120
11	360931115083802	212 S21 E61 03ABB 2	Well	807	807	BF	04/18/2011	9.08	2,005
12	361843115161001	212 S19 E60 09BCC 1	Well	830	830	BF	04/28/2011	155.76	2,354
13	361233115021501	212 S20 E62 15BBAB1 USAF Nellis 12 (C)	Well	1,000	1,000	BF	04/27/2011	124.71	1,691
14	361346115115901	212 S20 E61 06CBDD1 CNLV Desert Aire	Well	1,000	1,000	BF	04/27/2011	60.72	2,150
15	361400115040901	212 S20 E62 05CAAA1 CNLV Wilshire	Well	1,000	1,000	BF	10/01/2015	62.56	1,806
46	361303115140301	212 S20 E60 11CAAA1 LVVWD W028	Well	1,003	1,003	BF	01/18/2007	202.05	2,085
47	361232115061001	212 S20 E61 13ABDB1 CNLV Diana Terrace	Well	1,230	1,230	BF	10/01/2015	11.83	1,845
48	361626115090701	212 S19 E61 21DDB 1 CNLV Regional Park 1	Well	1,300	1,300	BF	09/01/2015	40.72	2,119
49	360809115252601	212 S21 E58 12DDDD1 RED ROCK WASH	Well	503	503	BF	11/07/2008	400.54	3,288
50	364014114315301	220 S14 E67 31DACD1	Well	387	620	BF	03/19/1987	116.00	1,574
51	364912114041201	222 S13 E71 09BDCA1 PS27	Well	1,450	1,493	BF	07/08/1994	84.00	1,573
52	364044114165201	222 S14 E69 33ABC 1 D & HA	Well	880	880	BF	03/10/1985	37.26	1,341
53	362239114263501	215 S18 E67 12DDAD1 ROGERS SPRING	Spring	_	_	CR	_	_	1,576
54	362321114252601	215 S18 E68 07ABBA1 BLUE POINT SPRING	Spring	_	_	CR	_	_	1,562
55	09419625	CORN CK SPGS AT NATIONAL FISH & WILDLIFE HDQRS, NV		_	_	CR	_	_	2,930
56 57	09415910 362450115442001	PEDERSON SPGS NR MOAPA, NV 161 S18 E55 01DACC1 COLD CREEK SPRING	Spring Spring	_	_	CR CR	— —	_	1,811 6,324

Groundwater monitoring wells were installed at six locations in Clark County. Criteria for selecting drill sites included (1) the carbonaterock aquifer was relatively close to the surface, (2) there were no nearby groundwater withdrawals, and (3) access for drilling equipment was possible on existing roads. Drilling techniques were dependent upon borehole advancement rate and lithology. Mud rotary drilling was predominantly used when drilling through unconsolidated material consisting mostly of sand, gravel, and cobbles. At all sites, the drill penetration rate through unconsolidated material was relatively consistent and progressed rapidly with this technique. When penetration rate slowed in denser rock

units, air-hammer drilling was used. A change in drilling method allowed for consistent downward progress and limited drill time and cost.

Spontaneous potential (SP), natural gamma, caliper, and resistivity (borehole, 16- and 64-inch normal) wireline geophysical logs were obtained at each newly drilled borehole. The SP logs measure the voltage between the borehole and an electrode at the surface and are used to identify permeability changes and boundaries between formations at depth. Natural gamma logs show formation radiation intensity, which is generally higher for clay-rich rocks and sediments that tend to emit elevated levels of radiation from natural decay of uranium and thorium to potassium-40. Caliper logs measure borehole diameter and can indicate the presence of fractures along the borehole wall. Resistivity logs record the electrical resistivity of the formation and can indicate higher-porosity transmissive zones. These logs are used together to provide

information on the subsurface geology. Drill cuttings (chips of broken geologic material brought to the surface by drilling fluids) were washed and analyzed. These cuttings, borehole geophysical data, and observations made during drilling provide an indication of the subsurface geologic characteristics at each new drill site. Borehole geophysical logs, drill penetration rate, and subsurface lithology are presented with the study area map. Wells were constructed of steel or polyvinyl chloride (PVC) well casing ranging from 4.5 to 6.625 inches in diameter. Vertically slotted screens were installed in water-bearing zones interpreted from borehole geophysics. A summary of well-construction information for each of the newly drilled wells is shown in table 2.

Table 2. Summary of well construction information for newly drilled wells in Clark County, Nevada.

[USGS, U.S. Geological Survey; NWIS, National Water Information System; ID, identifier; NDWR, Nevada Division of Water Resources; OD, outside dimension; DCR, depth to consolidated rock; WP, water production; gpm, amount of water pumped from well in gallons per minute; SCH, schedule; PVC, polyvinyl chloride; CR, carbonate rock; BF, basin fill; MR, mud rotary; AH, air hammer; >, greater than; —, no data; NA, not applicable]

interval depth

site ID ID log ID depth depth (OD), in (feet) (feet) material (feet) completic inches		(gpm)	(hours)
BW-01 364204114454501 A 109838 1,928 1,926 4.500 1,786 1,926 SCH 80 PVC 595 CR	MR/ AH	3 to 5	24
362454115270201 112697 905 890 6.625 336 417 808 889 SCH 40 steel 65 CR LSC-01 B	MR	150	6
(nested) — — 210 2.250 190 210 SCH 80 PVC — BF	MR	0 (dry)	0 (dry)
RB-01 362135114285401 C 113526 975 973 6.000 810 952 SCH 40 steel 755 CR	MR/ AH	>150	3
BUFPKTS-01 362352114414501 D 114409 1,200 1,198 4.500 988 1,198 SCH 40 steel 221 CR	MR	20	10
IVPH-01 354849115225001 E 115275 1,295 1,290 4.500 1,065 1,275 SCH 40 steel 38 CR	MR/ AH	30	10
JM-01 362901115220001 F 121811 1,103 1,080 4.500 200 300 SCH 40 steel NA BF	MR	50 to 75	50

Table 3. Total dissolved solids and concentrations of major ions in water samples collected from new wells in Clark County, Nevada. [mm/dd/yyyy, month/day/year; mg/L, milligrams per liter; <, less than; CR, carbonate rock; BF, basin fill]

Well name	Date (mm/dd/yyyy)	Total dissolved solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Carbonate (mg/L)	Bicarbonate (mg/L)	Principal contributing aquifer
BW-01	04/30/2010	616	60.8	24.4	101	11.0	56.3	195	< 1.0	264	CR
LSC-01	06/14/2012	249	45.1	28.2	5.0	1.46	2.90	21.4	< 1.0	246	CR
RB-01	04/09/2014	2,980	399	135	272	18.5	312	1,570	< 1.0	145	CR
BUFPKTS-01	04/10/2014	234	7.6	4.8	72.4	5.68	17.9	20.6	8.4	166	CR
IVPH-01	04/11/2014	499	67.1	38.2	53.9	3.33	105	86.4	< 1.0	210	CR
JM-01	03/14/2013	283	35.7	28.5	33.4	1.82	5.85	19.0	< 1.0	299	BF

representative water sample.

Water-quality samples for major-ion chemistry and the stable isotopes of water in Clark County, Nevada. deuterium, δ^2 H, and oxygen, δ^{18} O) were collected at each new well site, and results of analysis were compared to existing values from springs and wells near the drill sites. Total dissolved solids (TDS) and concentrations of calcium (Ca), magnesium VSMOW, VsMOW, Vienna Standard Mean Ocean Water; ‰, per (Mg), sodium (Na), potassium (K), chloride (Cl), sulfate (SO₄), carbonate (CO₃), mil (parts per thousand)] and bicarbonate (HCO₃) were measured by the USGS National Water Quality Laboratory (NWQL), in Denver, Colorado (table 3). Deuterium (δ^2 H) and oxyge $(\delta^{18}O)$ isotopes were analyzed by the USGS Radiogenic Isotope Facility in Denve Standard three-well-casing volumes were purged from each well, and water samples were collected with a submersible pump except at two sites (wells IVPH-01 and BUFPKTS-01) where samples were obtained through bailing.

A 20-foot-long bailer was used to purge water from the well and collect a

Table 4. Isotopic ratios of deuterium (δ^2 H) and oxygen $(\delta^{18}0)$ in water samples collected from new wells drilled

),	mm (parts per mousand)								
en	Well name	δ²Η (‰)	δ ¹⁸ (%						
ver,	BW-01	-97.49	-12.8						
344	LSC-01	-103.00	-13.9						
er	RB-01	-91.70	-12.3						
	BUFPKTS-01	-82.50	-11.2						
	IVPH-01	-92.30	-12.7						
	JM-01	-95.67	-13.0						

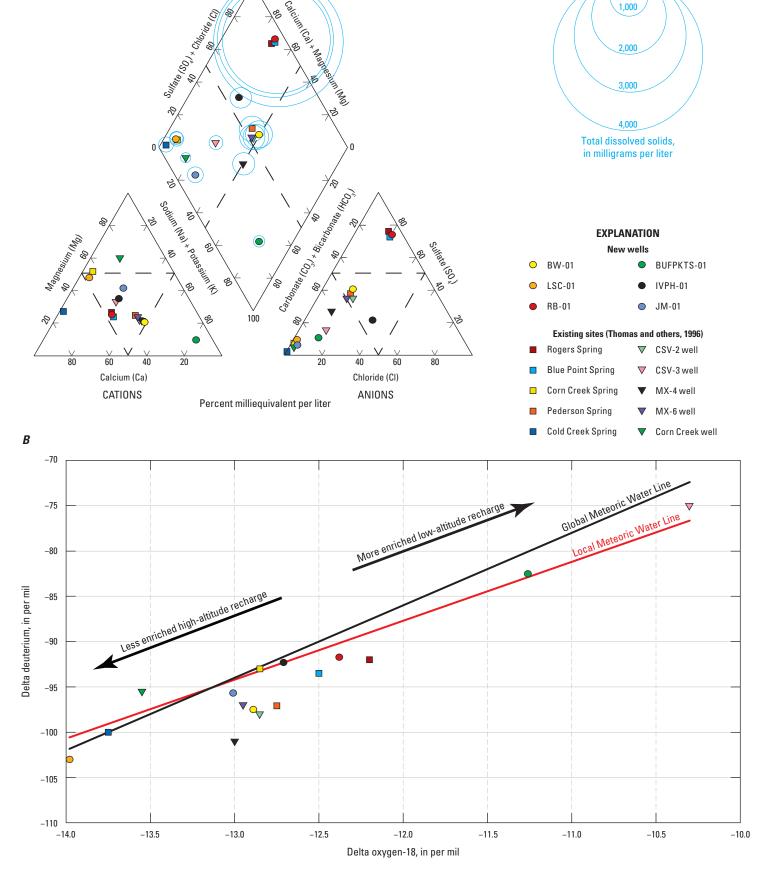


Figure 1. A, Total dissolved solids and major-ion concentrations in water samples collected from wells and springs associated with regional groundwater flow, and B, isotopic ratios of delta deuterium (δ^2 H) and delta oxygen-18 (δ^{18} O) in samples collected from new and reference wells and springs in Clark County, Nevada (Global Meteoric Water Line [δ^2 H = $8 \times \delta^{18}$ O + 10; Craig, 1961], and Local Meteoric Water Line [δ^2 H = $6.5 \times \delta^{18}$ O - 9.7; Friedman and others, 1992]).

Major-ion chemistry is important to an understanding of the migration of water through a groundwater flow system. A Piper diagram (fig. 1A) can be used to evaluate the chemical characteristics of groundwater and the effects of chemical processes occurring between minerals and water. Groundwater samples from newly drilled wells show similar major-ion chemistry to previously sampled wells and springs (Thomas and others, 1996) that are assumed to represent groundwater from the regional carbonate-rock aquifer. Isotopic ratios of δ^2 H and δ^{18} O in water samples collected from wells drilled for this study and in samples previously collected from wells and springs, are compared to the Global Meteoric Water Line (GMWL) and a Local Meteoric Water Line (LMWL) on figure 1B. This plot provides a comparison of recharge from low-altitude and high-altitude precipitation sources to waters from previously published data (Thomas

Water levels from newly drilled wells were measured periodically from 2009 to 2015 and stored in the USGS NWIS database (https://waterdata.usgs.gov/nwis). These data were quality assured, which included evaluating measurements for temporal irregularity and adjustments due to known borehole deviation. Water levels were relatively stable throughout the duration of this project except for well BW-01, which experienced a decline of approximately 3 feet from January 2010 to May 2013, and a subsequent recovery of approximately 1 foot from

Variations in borehole direction during drilling (drift) are common and can require corrections to water-level measurements. Borehole drift was monitored, and deviation was measured where drift was detected during the drilling of all new wells. The borehole at well BUFPKTS-01 was the only site that needed correction because borehole drift occurred above the depth of the static water level. The water level for this well was corrected using the equation from Elliott and Fenelon (2010):

is the measured depth, is the measured depth to the top of the correction interval, is the difference in the true vertical depth between the top and bottom of the correction interval,

is the difference in the measured top and bottom of the correction interval, and

is the corrected vertical depth to the top of the interval over which the correction

water-level contours parallel and intersect surface-water features.

Well test data

is the corrected vertical depth,

Groundwater levels from the six wells drilled for this project and wells fitting the criteria described in the section "Selected Existing Hydrogeologic Data," were compiled and used to construct a groundwater-level map representing the regional potentiometric surface of the upper carbonate-rock aquifer in Clark County, Nevada, in 2009–2015. Data used to construct the potentiometric surface are published separately as a USGS data release (Wilson, 2019). This map is similar to the regional potentiometric surface shown on previous maps by Bedinger and Harrill (2010) and Brooks and others (2014). In general, the potentiometric surface on this map follows the overlying land-surface topography. Higher topographic altitudes typically have higher groundwater altitudes, hydraulic gradients generally are steep near mountain ranges and low (flatten) in basins, and

In the Las Vegas and Sheep Ranges, and the Spring Mountains, mountain block recharge contributes to and directs regional groundwater flow in Water-level contours generally indicate groundwater flow to the east, terminating at discharge points along the Las Vegas Wash in Las Vegas

A low water-level gradient near Moapa Valley indicates slow groundwater movement toward the Muddy River and Lake Mead. A low water-level gradient in northeast Clark County indicates that groundwater in this area flows toward the Virgin River.

Valley, and the Muddy River near Moapa Valley.

Summary and Conclusions

During 2009 and 2015, the U.S. Geological Survey in cooperation with the Bureau of Land Management installed six new wells in Clark County, Nevada. The wells were installed to address the spatial gaps of wells completed in the carbonate-rock aquifer. This map describes new and existing water-level and hydrologic data used to (1) develop a potentiometric map, and (2) provide additional supporting evidence for the direction of regional groundwater flow in the upper carbonate-rock aquifer in Clark County. Results from this study indicate that the Spring Mountains and the Las Vegas and Sheep Ranges provide primary recharge to the groundwater system in western Clark County. Additionally potentiometric contours indicate eastward groundwater flow in much of Clark County that terminates at springs along Las Vegas Wash, the Muddy River, and the Virgin River. Previous maps by Bedinger and Harrill (2010) and Brooks and others (2014) show similar water-surface altitudes and gradients. This study introduces new water-level measurement sites that cover data gaps and support previous regional water-surface interpretations. Additionally, comparison of lithologic descriptions, geophysical logs, and groundwater chemistry from the six wells drilled during this study to existing data, substantiates that water levels in the new wells represent the regional carbonate-rock

0 40 80 120 0 4 8 12 16 0 20 40 60 80 -50 -25 0 25 50 0 50 100 150 0 30 60 90 120

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200–300 feet: 250 Steel vertically slotted

0.030-in. casing 300

0-1,103 feet: 5

0.030-in. casing 850

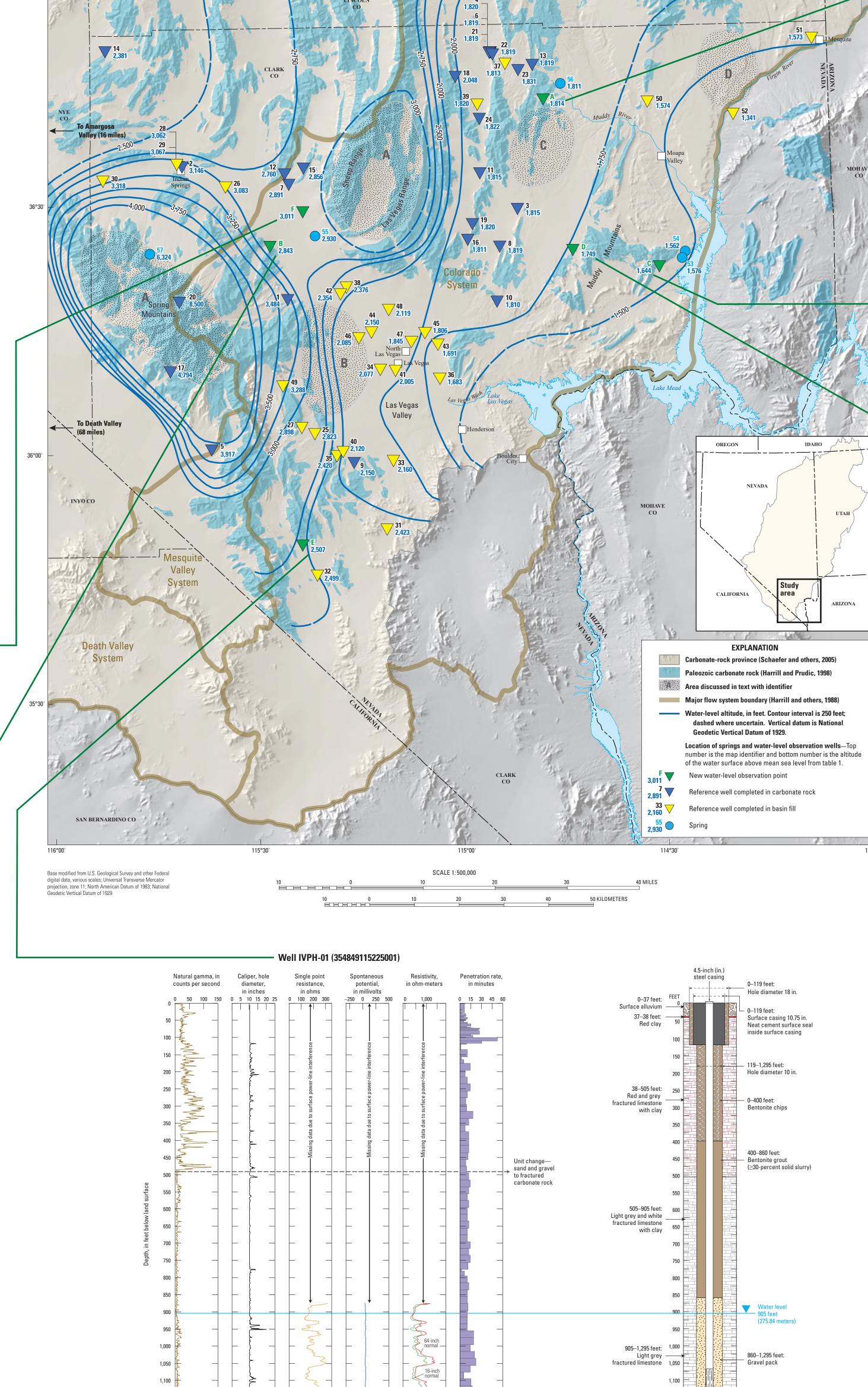
Alluvial material (subangular

to sub-rounded cobbles and gravels of carbonate rock) — 0–100 feet:

100-480 feet:

Hole diameter

Bentonite grout (≥30-percent solid

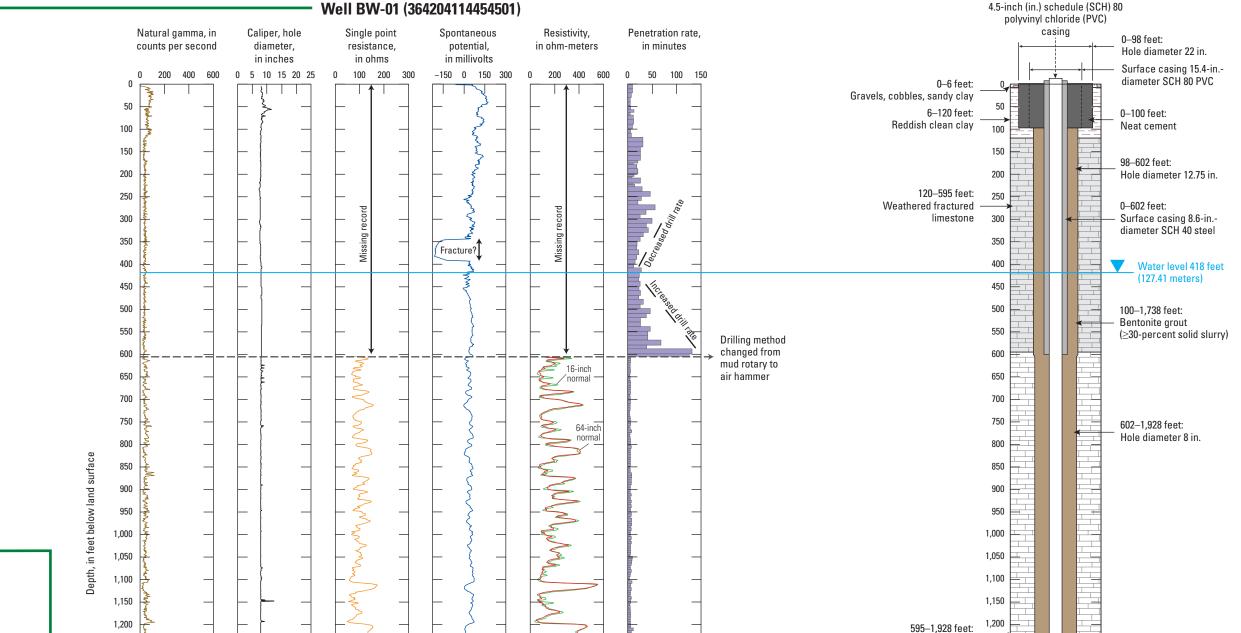


1,065-1,275 feet:

Steel vertically slotted —

0.030-in. casing 1,250

[≥, greater than or equal to



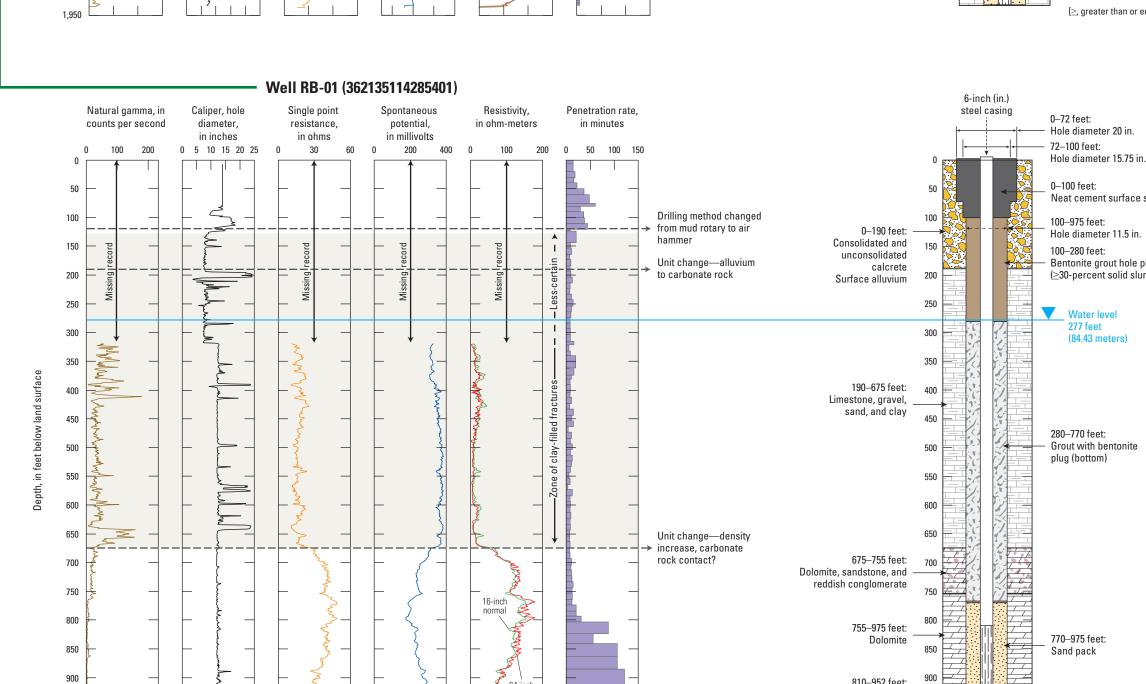
Scientific Investigations Map 3434

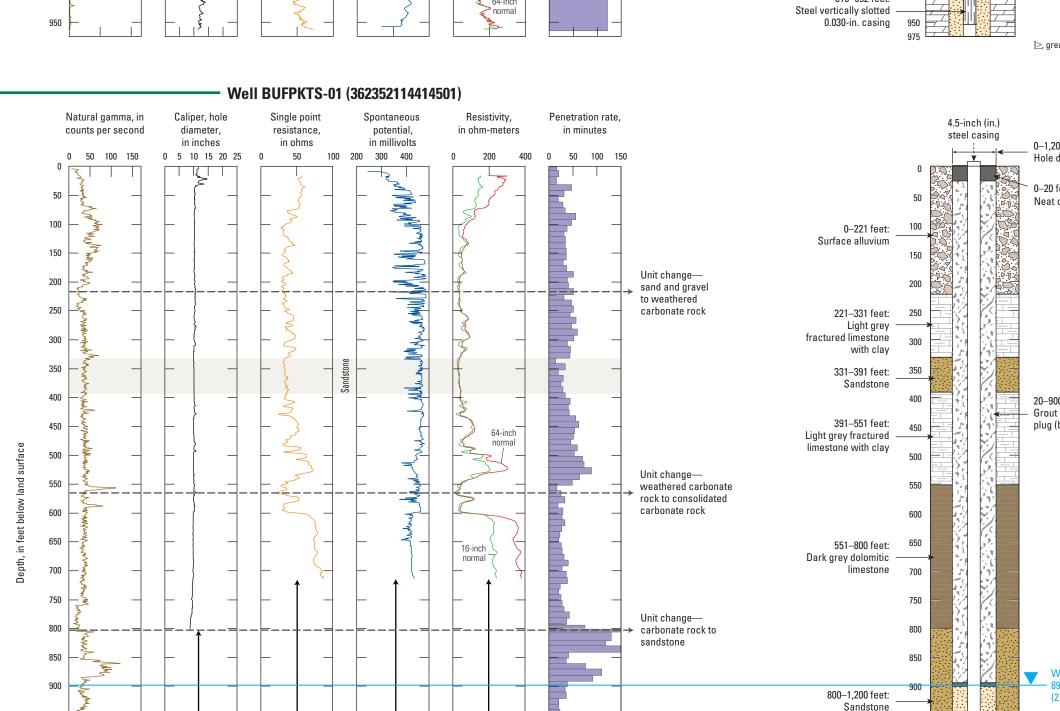
Fractured limestone

PVC vertically slotted

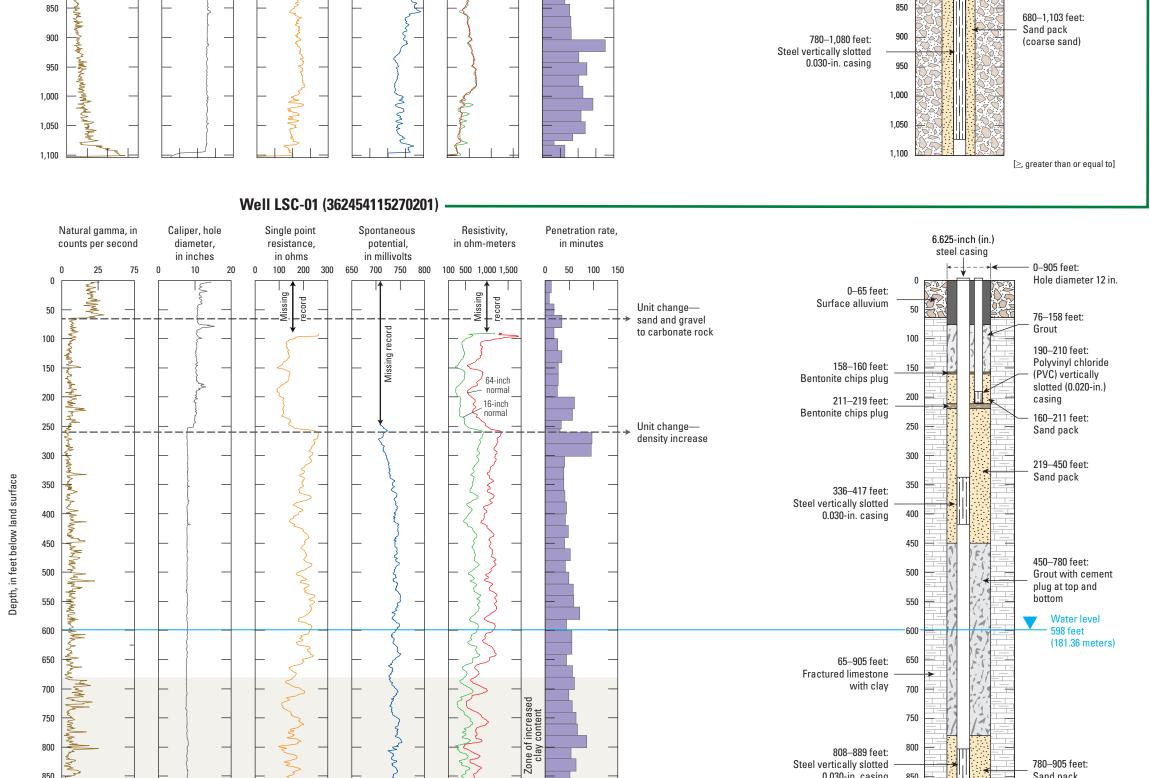
Gravel pack (coarse sand)

decreased resistance





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Sand pack

Sand pack (coarse sand)

Steel vertically slotted -

0.030-in. casing ,