Distribution of Carbonate-Rock Aquifers and the Potential for Their Development, Southern Nevada and Adjacent Parts of California, Arizona, and Utah

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 91-4146

Prepared in cooperation with the
STATE OF NEVADA,
LAS VEGAS VALLEY WATER DISTRICT, and
the CITY OF NORTH LAS VEGAS

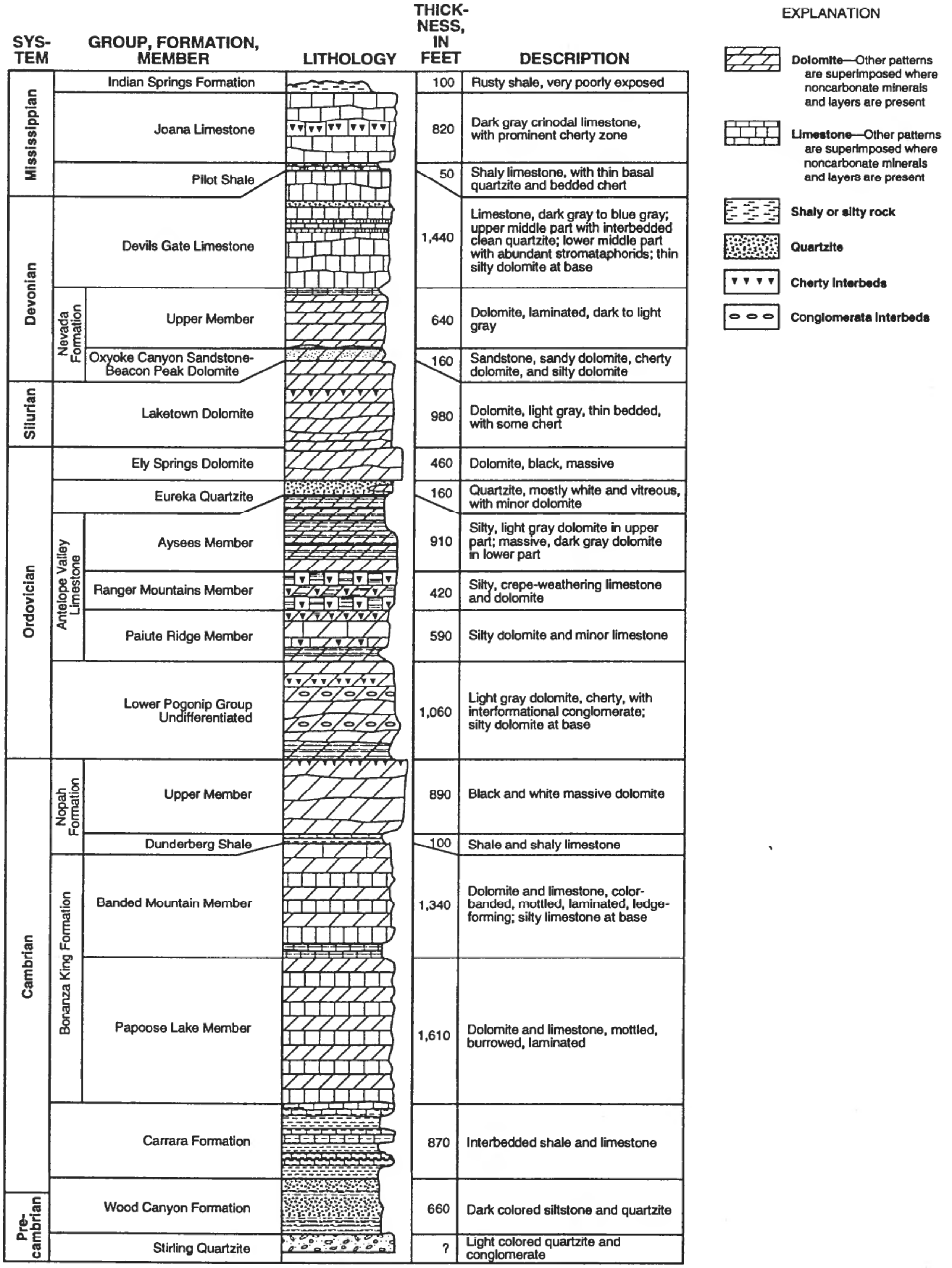

Figure 2. Paleozoic-rock section as exposed in Sheep Range (modified from Guth, 1980, pl. 3). Rocks shown range from latest Precambrian (older than 570 million years) through Mississippian (about 330 million years old).

Table 1. Construction data and aquifer-test results for wells in carbonate-rock aquifers and noncarbonate (clastic) rocks of Nevada

Site designation: Local name or USGS identification, preceded by: MX, constructed for studies of MX Missile-Siting Water Resources Program; NCAP, constructed for present study; NTS, constructed for studies associated with Nevada Test Site (but not necessarily located there); Prv., privately constructed.
Age: p∈, Precambrian; ∈, Cambrian; ∈O, Cambrian-Ordovician; O, Ordovician; S, Silurian; D, Devonian; M, Mississippian; IP, Pennsylvanian; ρIP, Permian-Pennsylvanian.
Rock-unit name: LS, limestone.
Lithology: C, predominantly noncarbonate clastics; D, predominantly dolomite; L, predominantly limestone. Multiple abbreviations are listed in order of predominance.
[--, no data available; <, less than]

Site No.	Site designation	Degrees, minutes, seconds: Latitude	Degrees, minutes, seconds: Longitude	Rocks tested: Age	Rocks tested: Rock-unit name	Rocks tested: Lithology	Well construction: Depth (feet below land surface): Shallowest opening	Well construction: Depth (feet below land surface): Deepest opening	Well construction: Total open interval (feet)	Well construction: Casing or open-hole diameter (inches)
	Wells completed in Carbonate Rock									
1	Prv. S23 E60 24BB	35 56 17	115 13 20	IP	Bird Spring	L	540	700	160	12
2	Prv. S23 E61 09BC	35 57 50	115 10 10	M	Monte Cristo	D	400	520	120	8
3	Prv. S18 E63 34CA	36 20 28	114 55 36	IP	Bird Spring	L	754	1,205	451	6
4	Prv. S17 E50 23BB2	36 27 54	116 19 02	∈	Bonanza King	D	0	140	140	14
5	NCAP S16 E58 23DD (SBH1)	36 32 12	115 24 03	O	Pogonip	L	654	694	40	6
6	NTS Tracer No.1	36 32 12	116 13 47	∈	Bonanza King, Carrara	D,L	625	830	205	9.9
7	NTS Tracer No.3	36 32 12	116 13 47	∈	Bonanza King, Carrara	D,L	620	807	187	5.5
8	NTS Tracer No.2	36 32 12	116 13 47	∈	Bonanza King, Carrara	D,L	659	828	169	6.2
9	NCAP S16 E58 14A (DR1)	36 33 32	115 24 40	D	Guilmette, Simonson	L,D	870	930	60	8
10	NTS S16 E56 08 (#2)	36 34 43	115 40 37	IP	Bird Spring	L	54	575	521	14
11	NTS TW-4 (66-75)	36 34 54	115 50 08	∈	Nopah	D	737	1,490	753	7.6
12	NTS Army 1 (67-68)	36 35 30	116 02 14	∈	Bonanza King, Nopah	L	785	1,946	1,161	10.7
13	NTS TW-10 (67-73)	36 35 31	115 51 04	∈	Bonanza King	L	1,020	1,301	281	8.6
14	Prv. S15 E67 09DD	36 38 19	114 29 43	ρIP	--	L	360	420	60	8.6
15	NTS TW-F (73-66)	36 45 34	116 06 59	S	--	D	3,137	3,400	253	8.6
16	MX CE-DT-6	36 46 04	114 47 13	IP	Monte Cristo	L	457	937	480	12
17	NCAP S13 E65 28B (CSV2)	36 46 50	114 43 20	IP	Bird Spring	L	391	480	89	8
18	MX CE-DT-5	36 47 41	114 53 28	M	Monte Cristo	L	353	628	275	20
19	MX CE-DT-4	36 47 43	114 53 31	M	Monte Cristo	L	352	669	317	10
20	NTS TW-3 (75-73)	36 48 30	115 51 26	O	Pogonip	L	1,105	1,853	748	7
21	NTS UE25P#1 (75-57)	36 49 38	116 25 21	S	Lone, Robert Mtn.	D	4,255	5,922	1,667	6.7
22	MX CE-VF-2	36 52 27	114 56 51	IP	Bird Spring	L,D,C	860	1,009	149	10
23	NTS WW-C-1 (79-69)	36 55 07	116 00 34	∈	Carrara	L	1,545	1,650	105	16.7
24	NTS WW-C (79-69a)	36 55 08	116 00 35	∈	Carrara	L	1,544	1,701	157	10.8
25	NTS TW-E (83-69)	37 03 21	115 59 42	O	Pogonip	L	1,780	2,620	840	10.8

Table 1. Construction data and aquifer-test results for wells in carbonate-rock aquifers and noncarbonate (clastic) rocks of Nevada--Continued

		Degrees, minutes, seconds		Rocks tested			Well construction			
							Depth (feet below land surface)			
Site No.	Site designation	Latitude	Longitude	Age	Rock-unit name	Lithology	Shallowest opening	Deepest opening	Total open interval (feet)	Casing or open-hole diameter (inches)
26	NTS U3cn-5 (84-68d)	37 03 35	116 01 30	D	--	D,C	2,821	3,026	205	6
27	NTS UE-16D	37 04 12	116 09 51	IP	Tippipah	L	753	2,119	1,366	7
28	NTS TW-D (84-67)	37 04 28	116 04 30	M	Eleana LS, Shale	L,C	1,772	1,882	110	10.8
29	NTS TW-1 (87-62)	37 09 29	116 13 23	D	Devils Gate, Nevada	D	3,700	4,198	498	7.6
30	NTS WW-2 (88-66)	37 09 58	116 05 15	O	Pogonip	L	2,550	3,422	498	6.6
31	MX DL-DT-3	38 05 31	114 53 42	M	--	L	853	2,395	1,542	8.8
32	MX-CV-DT-1	38 07 58	115 20 46	D	Guilmette	D	803	1,837	1,034	10
33	MX N07 E63 14ABC	38 28 19	114 51 58	IP	--	L	230	435	205	10.8
34	prv. N08 E43 24AA	38 32 41	117 05 41	∈O	--	L,C	160	340	180	6
35	MX SV-DT-2	38 55 21	114 50 36	IP	Ely LS, Chainman	L,C	500	2,447	1,947	6
36	Prv. Fad Shaft	39 30 20	115 59 05	∈	Hamburg LS, Shale	L,C	1,025	2,465	1,440	120
37	Prv. N22 E57 25CD	39 44 27	115 30 43	D	Devils Gate	L	480	583	103	12.8
38	Prv. N36 E62 18	41 00 13	115 00 39	D	Guilmette	L	140	220	80	6
39	Prv. N37 E63 06BA	41 07 29	114 53 56	P	Ely LS	L	555	595	40	6
					Wells completed in Noncarbonate rock (clastic)					
40	NTS TW-5 (68-60)	36 37 46	116 18 22	∈	Carrara	C	735	800	65	7
41	NTS UE16F	37 02 08	116 09 24	M	Eleana	C	1,293	1,414	121	9.6
42	NTS UE-17A (84-64A)	37 04 25	116 09 58	M	Eleana	C	745	1,190	215	4.5
43	NTS UE-15D (89-68)	37 12 33	116 02 29	p∈	Johnnie	C	1,773	5,940	4,167	4.5

Table 1. Construction data and aquifer-test results for wells in carbonate-rock aquifers and noncarbonate (clastic) rocks of Nevada--Continued

Specific capacity: Estimated by dividing constant pumping rate by final drawdown, except values estimated by Winograd and Thordarson (1975), which are based on drawdown at 100 minutes.
Estimated transmissivity: From capacity: based on specific capacity using method of Theis and others (1963). From drawdown: based on regular measurements of drawdown in pumped well using method of Cooper and Jacob (1946). From recovery: based on regular measurements of recovery in pumped well using method of Cooper and Jacob (1946). From other data: based on other methods and data noted in footnotes.
Hydraulic conductivity: Value estimated from transmissivity divided by total open interval, followed by: C, transmissivity estimated from specific-capacity data used to calculate hydraulic conductivity; D, transmissivity estimated from drawdown data used; O, transmissivity estimated from other data used; R, transmissivity estimated from recovery data used.

Site No.	Rate pumped (gallons per minute)	Draw-down (feet)	Specific capacity (gallons per minute per foot)	Test duration (minutes)	Estimated transmissivity (feet squared per day) From capacity	From drawdown	From recovery	From other data	Hydraulic conductivity (feet per day)	Reference
					Wells completed in Carbonate Rock					
1	17	90	0.19	240	32	--	--	--	0.2	(C) Driller's report dated 11/81
2	121	91	1.33	120	270	--	--	--	2.2	(C) Driller's report dated 06/73
3	72	282	.26	480	53	--	--	--	.12	(C) Driller's report, permit 50316
4	537	40	13.25	1,350	3,700	--	--	[a]3,500	25	(O) Dudley and Larson, 1976, tables 3 and 4
5	24	9	26.7	600	7,600	(b)	37,000	--	940	(R) Present study
6	100	8	13	60	2,800	--	--	--	14	(C) Johnston, 1968, p. 21-32, 44
7	100	2	60	60	16,000	--	--	--	84	(C) do.
8	94	1	140	60	36,000	--	--	--	210	(C) do.
9	14.5	11	1.3	1,638	320	450	100	--	7.5	(D) Present study
10	500	50	10	--	2,100	--	--	--	4.1	(C) U.S. Corps of Engineers, written commun., 1942
11	154	40	4.5	2,000	530	1,500	3,000	--	2.0	(D) Winograd and Thordarson, 1975, table 3
12	455	85	6	3,000	800	5,200	11,500	--	4.5	(D) do.
13	400	91	4.8	3,000	1,100	2,700	7,100	--	9.5	(D) do.
14	225	137	1.64	960	400	--	--	--	6.7	(C) Drillers report dated 11/85
15	58	2	29	--	[c]8,000	--	--	--	30	(C) Winograd and Thordarson, 1975, table 3; Thordarson and others, 1967, p. 14
16	472	42	11.4	3,963	3,200	12,600	[d]53,000	--	26	(D) Present study
17	101	30	3.4	1,320	860	1,600	7,000	--	18	(D)
18	3,400	11	309	42,441	98,000	250,000	--	[e]100,000	900	(D) Berger and others, 1988, p. 30-39; Bunch and Harrill, 1984, p. 33
19	540	3	154	4,600	45,000	200,000	--	[f]760,000	630	(D) Berger and others, 1988, p. 24-29; Bunch and Harrill, 1984, p. 33; Morin and others, 1988, p. 587
20	30	48	.7	1,000	80	510	--	--	.7	(D) Winograd and Thordarson, 1975, table 3
21	500	49	10.2	6,080	3,500	[g]1,200	--	--	0.71	(D) Winograd and Thordarson, 1975, table 3
22	77	13	5.9	830	1,600	2,800	7,800	--	19	(D) Present study
23	300	59	5.1	100	800	--	--	--	8	(C) Winograd and Thordarson, 1975, table 3
24	456	.8	570	240	130,000	--	--	--	860	(C) Claassen, 1973
25	[h]12	130	.08	340	19	--	11	--	.01	(R) Winograd and Thordarson, written commun., 1965

Table 1. Construction data and aquifer-test results for wells in carbonate-rock aquifers and noncarbonate (clastic) rocks of Nevada--Continued

Site No.	Rate pumped (gallons per minute)	Draw-down (feet)	Specific capacity (gallons per minute per foot)	Test duration (minutes)	Estimated transmissivity (feet squared per day): From capacity	From drawdown	From recovery	From other data	Hydraulic conductivity (feet per day)	Reference
26	76	172	.4	3,000	90	320	--	--	1.6	(D) Winograd and Thordarson, 1975, table 3
27	570	43	13.3	1,440	3,700	--	8,600	--	6.3	(R) Dinwiddie and Weir, 1979, p. 4-6, 15
28	22	49	.45	89	80	--	11	[i]13	.11	(O) Thordarson and others, 1962, p. 31-37
29	98	135	.8	500	130	880	470	--	.94	(R) Winograd and Thordarson, 1975, table 3
30	60	180	.4	5,000	94	170	710	--	.35	(D) do.
31	106	2	53	6,400	17,000	--	--	--	11	(C) Bunch and Harrill, 1984, p. 36; Ertec Western, written commun., 1985
32	95	63	1.5	1,380	350	--	--	--	.34	(C) Bunch and Harrill, 1984, p. 32; Ertec Western, written commun., 1985
33	225	118	1.9	210	390	--	--	[j]2,400	1.7	(C) Bunch and Harrill, 1984, p. 31; driller's log 22581
34	35	4	8.75	10,080	2,700	--	--	--	15	(C) Driller's report dated 01/86
35	100	124	.8	200	190	130	530	--	.3	(R) Bunch and Harrill, 1984, p. 105; Ertec Western, written commun., 1985
36	3,600	270	13.3	43,200	3,200	2,200	2,100	[k]3,200	1.5	(D) Stuart, 1955, p. 2-4
37	550	560	.98	240	190	--	--	--	1.8	(C) Driller's log 22217
38	30	75	.4	180	80	--	--	--	1	(C) Driller's log 20511
39	15	80	.19	300	40	--	--	--	.9	(C) Driller's log 20972
					Wells completed in Noncarbonate Rock (clastic)					
40	<5	126	<.04	--	<7	--	--	--	<.1	(C) Thordarson and others, 1967, p. 14
41	--	--	--	100	--	--	--	[l]1	.01	(O) Dinwiddie and Weir, 1979, p. 16-19
42	20	493	.04	120	8	--	1.2	--	.006	(R) Weir and Hodson, 1979, p. 4, 6, 8, 11
43	78	294	.27	2160	40	80	--	--	.02	(D) Thordarson and others, 1967, p. 20

[a] Estimated from drawdowns at nearby well S17 E50 23BB1.

[b] Influence of barometric pressure was greater than drawdown.

[c] Estimate based on airline measurements. Estimated storage coefficient, 0.013.

[d] Pump has no foot valve, making recovery difficult to analyze.

[e] Estimated from drawdowns at MX well CE-DT-4 (site 19). Estimated from drawdowns and recoveries at several wells. Estimated storage coefficient, 0.14. Storage-coefficient estimates range from 0.0014 to 0.00075.

[f] Estimated from borehole flowmeter test during present study. Estimated from slug test. Recovery took 100 minutes.

[g] Galloway (1986) estimated storage coefficient of 0.0003 using tidal fluctuations of water levels in well.

[h] Drawdown may be influenced by caving of overlying tuffs.

[i] Estimated using method of Skibitzke (1963).

[j] Estimated from drawdown in nearby observation well.

[k] Estimated from drawdowns and recoveries at several wells. Storage-coefficient estimates range from 0.0014 to 0.00075.

[l] Estimated from slugtest. recovery took 100 minutes.

Table 2. Data from drill-stem tests on petroleum-exploration wells. Compiled from McKay and Kepper (1988, table 2, appendices A and B)

Age: ∈, Cambrian; D, Devonian; M, Mississippian; IP, Pennsylvanian; ρ, Permian; U, undifferentiated.
Lithology: C, predominantly noncarbonate clastics; D, predominantly dolomite; G, gypsum; L, predominantly limestone. Multiple abbreviations are listed in order of predominance.
Depth interval: Reported depth zone that was mechanically isolated for the test.
Duration of test: Final shut-in period. For initial shut-in time or flow times, see McKay and Kepper (1988, appendix B).
[--, no data available]

Site designation	Degrees, minutes, seconds		Rocks tested			Depth interval tested (feet below land surface)	Duration of test (minutes)	Transmissivity (feet squared per day)	Hydraulic conductivity (feet per day)
	Latitude	Longitude	Age	Rock-unit name	Lithology				
Wells completed in Carbonate Rock									
Virgin River USA 1-A	36 38 18	114 23 42	ρ	Kaibab	L,C,G	11,764-11,814	120	0.07	0.0014
Adobe Federal 19-1	38 01 03	115 17 07	M	Joana	L	7,500-7,706	120	820	4
DOC Federal 5-18	38 17 38	115 50 22	M	Joana	L	5,671-5,725	120	84	1.6
Lone Tree 1-14-43	38 22 42	115 38 09	D	Guilmette	L,D	4,372-4,430	120	6.2	.11
Adobe Federal 16-1	38 24 15	115 50 51	D	Guilmette	L,D	3,785-3,930	90	350	2.4
Grant Canyon 5	38 27 15	115 34 49	D	Guilmette	L,D	4,548-4,648	60	460	4.6
Grant Canyon 1	38 27 19	115 34 37	D	Simonson	D	4,340-4,441	60	8.5	.085
Grant Canyon 4	38 27 32	115 34 21	D	Guilmette	L,D	4,034-4,061	62	510	19
Grant Canyon 3	38 27 45	115 34 37	D	Guilmette	L,D	3,934-3,961	60	15	.56
Bacon Flat 1	38 27 51	115 35 35	D	Guilmette	D,L	5,315-5,346	--	4.2	[a].13
Bacon Flat 5	38 27 57	115 35 10	IP	Ely	L	5,595-5,795	120	.062	.00031
White River Valley 1	38 29 09	115 06 37	IP	Ely	L	4,490-4,578	120	.077	.0087
Dobbin Creek Fed A1-6	38 59 38	116 36 49	U	--	D	(b)	1,419	6.9	.056
Wells completed in Noncarbonate Rock (clastic)									
Bacon Flat 5	38 27 57	115 35 10	M	Chain-	C	6,228-6,276	180	.041	.0008
Soda Springs Unit 1	38 32 54	115 32 59	∈	man --	C	7,699-7,796	120	0.72	.0072

[a] Transmissivity is from reservoir engineer's report. Reported hydraulic conductivity was 0.31 foot per day, but a transposition of numerals is suspected.
[b] Transmissivity and hydraulic conductivity are averages from three tests, in depth intervals 3,200-3,480, 3,600-3,660, and 3,650-4,034 feet.

Table 3. Thickness of basin fill and carbonate rocks penetrated by selected wells

Site No. (fig. 18)	Well name	Thickness penetrated (feet) Basin fill	Thickness penetrated (feet) Carbonate rocks	Total well depth (feet below land surface)
Wells Drilled During Present Study				
1	CSV-1	765	0	765
2	CSV-2	17	461	478
3	CSV-3	780	0	780
4	BHG-1	380	40	420
5	BHG-2	142	1,258	1,400
6	SBH-1	60	634	694
7	DIVIDE	200	0	200
8	OLD DRY	210	0	210
9	DR-1	182	768	950
Existing Wells				
10	CE-DT-4	30	639	669
11	CE-DT-5	110	518	628
12	CE-DT-6	420	517	937
13	CE-VF-1	714	0	714
14	CE-VF-2	850	371	1,221
15	SHV-1	250	670	[a]920
16	DDL-1	420	0	420

[a] No drilling records available.

Table 4. Information acquired from various geophysical logs

[Modified from Keys and MacCary, 1971, table 1]

Geophysical log	Information acquired
Acoustic transit time	Primary porosity, fractures, lithology
Borehole televiewer	Fractures, construction of existing wells
Caliper	Diameter of hole, fractures, construction of existing wells
Electric	True resistivity, stratigraphic correlation
Gamma-gamma density	Bulk density of rocks or sediments, total porosity, water level, lithology
Natural gamma	Clay or shale content, stratigraphic correlations
Neutron	Total porosity, location of water level, lithology
Temperature	Ground-water temperature and temperature gradients, location of water level, movement of water in well

collected at the Nevada Test Site (Winograd and Thordarson, 1975, p. C17), which averaged about 5-6 percent. Secondary porosity as estimated from the logs in zones where many fractures were present locally might constitute almost half of that total (Berger, 1992).

Aquifer Testing

Properly conducted and monitored aquifer tests can provide estimates of the capacity of aquifers to transmit and store water. The hydraulic properties that characterize these capacities are the transmissivity and storage coefficient of the aquifer, respectively.

Aquifer testing involves lowering a pump into a well to a depth below the water level, pumping water from the well at a constant rate for long periods of time while recording water-level changes in the pumped well and, if available, in any nearby observation wells. As pumping continues, water levels generally decline in the well, and the rate at which the water level declines can be used to estimate the transmissivity. After the pump is turned off, measurements are made of the recovery of water levels in the wells. The rate of recovery is used to estimate transmissivity. Measurements of declining water levels in nearby wells can be used to estimate both the transmissivity and storage coefficient of the aquifer. Because of the high cost of drilling in the carbonate-rock aquifers, most aquifer tests in the carbonate-rock aquifers of Nevada lack nearby observation wells. This limits the accuracy of the estimates of transmissivity and precludes estimation of storage coefficient (Heath, 1983, p. 42).

Estimates of transmissivity (and storage coefficient for one example) calculated from aquifer tests made in some of the carbonate wells during 1985-88 are given in table 5. All estimates are based on the straight-line approximations described for well CSV-2 and data presented in Berger and others (1988) or collected since that report. To facilitate comparisons among well sites, the last column in table 5 presents a normalized response of the aquifer tested in each well to 1 week of pumping at 1,000 gal/min. The responses are normalized to reflect drawdown that would occur in a 24-in. diameter production well at each site if it tapped 500 ft of water-saturated rock. The storage coefficient is assumed to be 0.1. Projections of drawdown are made by using known and estimated aquifer properties at each well together with simple mathematical solutions for drawdown given in Theis (1935). Projected drawdowns are those that theoretically would develop in addition to the rapid drawdowns that develop in the first few minutes of pumping. These early drawdowns reflect well construction, pump configuration, and other installation specific properties and may amount to more drawdown than the long-term contributions.

Table 5. Data and results of aquifer tests done during 1985-88

[--, no estimate available]

Well	Pumping rate (gallons per minute)	Pumping duration (hours)	Maximum drawdown (feet)	Calculated transmissivity (foot squared per day)	Calculated storage coefficient (fraction)	Hypothetical drawdown (feet)
CSV-2	101	22	30.1	1,600	--	27
CE-DT-4	540	77	3.7	200,000	--	.9
CE-DT-5	3,400	326.3	11.8	250,000	0.14	.7
CE-DT-6	472	66	41.6	13,000	--	17
CE-VF-2	77	14	13.0	3,000	--	47
SBH-1	24	10	.9	37,000	--	1.6

Activities Using Data from Petroleum-Exploration Wells

As part of the studies, existing data from petroleum-exploration activities in Nevada, where applicable, were used to describe the hydrology of the carbonate rocks (McKay and Kepper, 1988). In Nevada, three types of data are available for estimating the hydraulic properties of carbonate-rock aquifers: aquifer tests at water wells, natural fluctuations of water levels in wells or flow from springs, and records from wildcat oil and gas exploration. Results from tests at 39 water wells penetrating carbonate-rock aquifers (including the aquifer tests described in the preceding paragraphs) were compiled (table 1). Only one example of the use of natural water-level fluctuations is available in the literature (Galloway, 1986). Beginning with the present study, measurements of natural water-level fluctuations were made and used to augment the aquifer tests and oil-exploration tests; see Kilroy (1992) for complete details. As of 1988, over 480 wildcat oil and gas wells have been drilled in Nevada, and many penetrate carbonate rocks. Some provide useful data about the properties of carbonate-rock aquifers.

Locations of all the oil and gas exploration wells in and adjacent to the carbonate-rock province of Nevada are shown in figure 16. Individual records for each well are on file at the Nevada Bureau of Mines and Geology. Ideally, a complete well file will contain the following: application forms and completion reports, all geophysical logs (if run), and drill-stem test (DST) reports (if run). In practice, few files are complete.

Drill-stem tests are specialized hydraulic tests used by the petroleum industry to determine aquifer properties of rocks penetrated by oil-exploration wells.

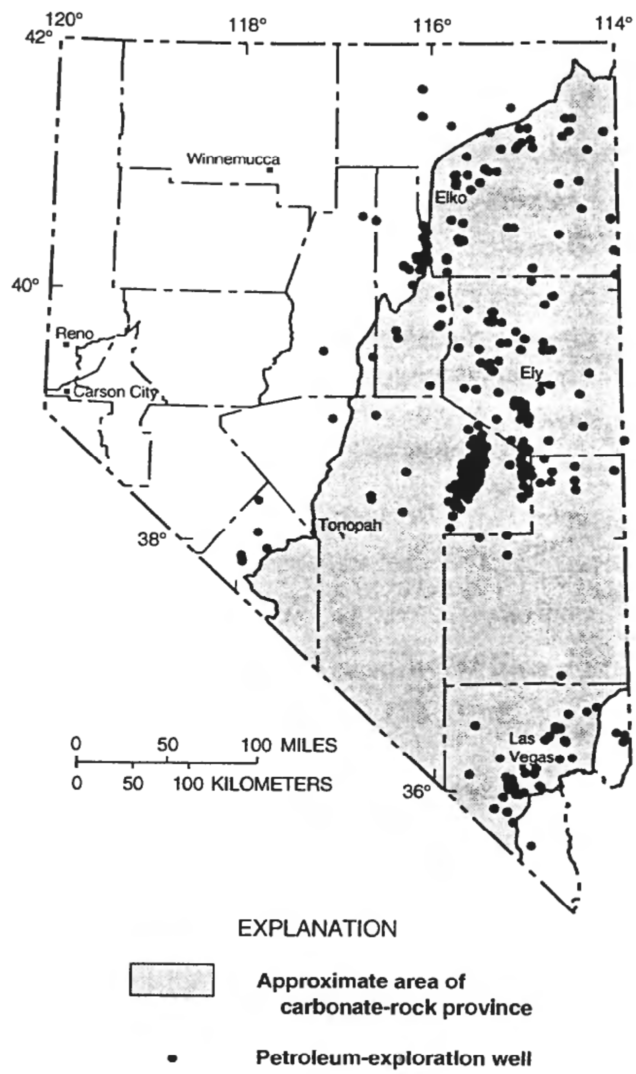

Figure 16. Distribution of petroleum-exploration wells in and adjacent to the carbonate-rock province of Nevada. Data from McKay and Kepper (1988).