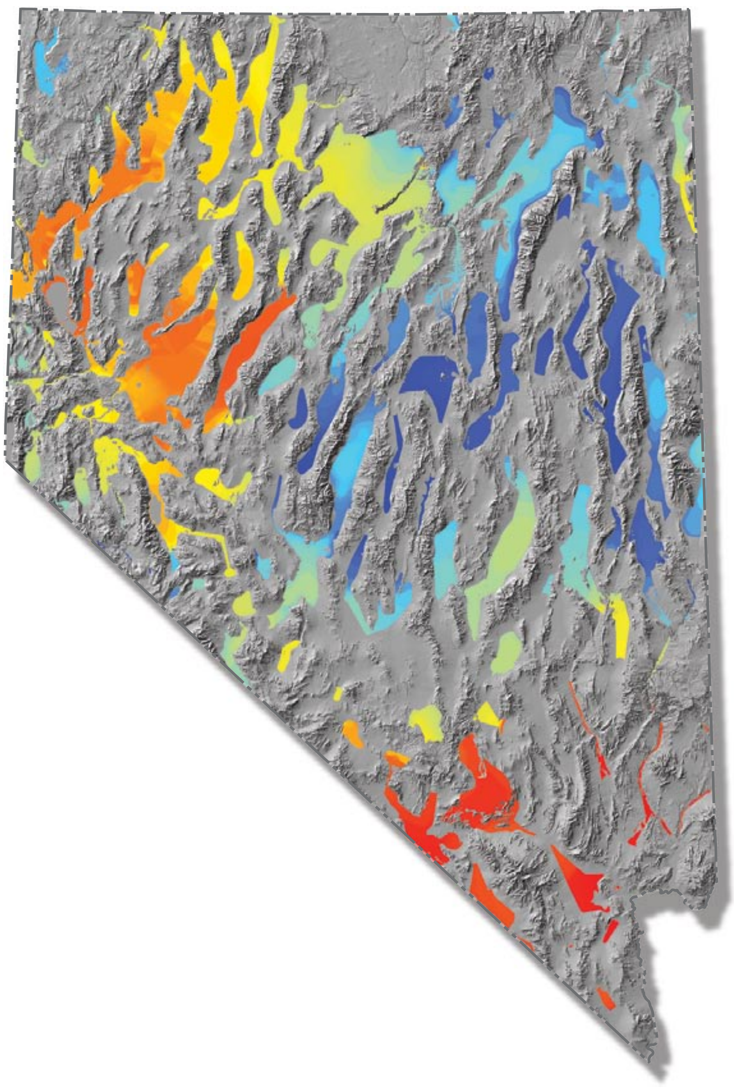
Prepared in cooperation with the
State of Nevada Department of Conservation and Natural Resources
Division of Environmental Protection

Water-Table Levels and Gradients, Nevada, 1947–2004



Scientific Investigations Report 2006–5100

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

FRONT COVER: Water-table surfaces in Nevada, 1947–2004.

Water-Table Levels and Gradients, Nevada, 1947–2004

By Thomas J. Lopes, Susan G. Buto, J. LaRue Smith, and Toby L. Welborn

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Carson City, Nevada, 2006

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Conversion Factors and Datums

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per day (ft/d)	0.3048	meter per day
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year

Datums
Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929; horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Water-Table Levels and Gradients, Nevada, 1947–2004

By Thomas J. Lopes, Susan G. Buto, J. LaRue Smith, and Toby L. Welborn

Abstract

In 1999, the U.S. Environmental Protection Agency began a program to protect the quality of ground water in areas other than ground-water protection areas. These other sensitive ground water areas (OSGWA) are areas that are not currently, but could eventually be, used as a source of drinking water. The OSGWA program specifically addresses existing wells that are used for underground injection of motor-vehicle waste. To help determine whether a well is in an OSGWA, the Nevada Division of Environmental Protection needs statewide information on depth to water and the water table, which partly control the susceptibility of ground water to contamination and contaminant transport. This report describes a study that used available maps and data to create statewide maps of water-table and depth-to-water contours and surfaces, assessed temporal changes in water-table levels, and characterized water-table gradients in selected areas of Nevada.

A literature search of published water-table and depth-to-water contours produced maps of varying detail and scope in 104 reports published from 1948 to 2004. Where multiple maps covered the same area, criteria were used to select the most recent, detailed maps that covered the largest area and had plotted control points. These selection criteria resulted in water-table and depth-to-water contours that are based on data collected from 1947 to 2004 being selected from 39 reports. If not already available digitally, contours and control points were digitized from selected maps, entered into a geographic information system, and combined to make a statewide map of water-table contours. Water-table surfaces were made by using inverse-distance weighting to estimate the water table between contours and then gridding the estimates. Depth-to-water surfaces were made by subtracting the water-table altitude from the land-surface altitude.

Water-table and depth-to-water surfaces were made for only 21 percent of Nevada because of a lack of information for 49 of 232 basins and for most consolidated-rock hydrogeologic units. Depth to water is commonly less than 50 feet beneath valley floors, 50 to 500 feet beneath alluvial fans, and more than 500 feet in some areas such as north-central and southern Nevada. In areas without water-table information, greasewood and mapped ground-water discharge areas are good indicators of depth to water less than 100 feet. The average difference between measured depth to water and depth to water estimated from surfaces was 90 feet. More recent and detailed information may be needed than that presented in this report to evaluate a specific site.

Temporal changes in water-table levels were evaluated for 1,981 wells with 10 or more years between the first depth-to-water measurement and last measurement made since 1990. The greatest increases in depth to water occurred where the first measurement was less than 200 feet, where the time between first and last measurements was 40 years or less, and for wells between 100 and 600 feet deep. These characteristics describe production wells where ground water is fairly shallow in recently developing areas such as the Las Vegas and Reno metropolitan areas. In basins with little pumping, 90 percent of the changes during the past 100 years are within ±20 feet, which is about the natural variation in the water table due to changes in the climate and recharge.

Gradients in unconsolidated sediments of the Great Basin are generally steep near mountain fronts, shallow beneath valley floors, and depend on variables such as the horizontal hydraulic conductivity of adjacent consolidated rocks and recharge. Gradients beneath alluvial fans and valley floors at 58 sites were correlated with selected variables to identify those variables that are statistically related. Water-table measurements at three sites were used to characterize the water table between the valley floor and consolidated rock.

Water-table gradients beneath alluvial fans had a median of 0.02, a mean of 0.04, and a standard deviation of 0.05. Gradients beneath valley floors had a median of 0.005, a mean of 0.03, and a standard deviation of 0.07. Information from this and other reports suggest that the average linear velocity of ground water is roughly 10 times faster beneath alluvial fans than beneath valley floors. Contaminants may travel about 10 times faster beneath alluvial fans than beneath valley floors, depending on the physical and chemical properties of the aquifer material and contaminant.

Gradients in unconsolidated sediments adjacent to different consolidated rocks differed significantly (p-value less than or equal to 0.05), which could be related to the horizontal hydraulic conductivity of the consolidated rocks and the sediments derived from them. Spearman rank correlations were statistically significant between gradients and the horizontal hydraulic conductivity of adjacent consolidated-rock hydrogeologic units (-0.30), precipitation up-gradient of the site (0.32), distance to the alluvial-fan contact (-0.31), and distance to the consolidated-rock contact (-0.41). These relations are consistent with the general description of the water table along mountain fronts and with precipitation being the driving force for gradients.

An examination of water tables at three sites suggests it may be possible to estimate the water table where data are sparse. Kyle Canyon, in Las Vegas Valley, has few domestic wells compared to Pine Nut Creek, in Carson Valley. Vicee Canyon, in Eagle Valley, has two production wells and is the most developed of the three sites. The initial water tables at Vicee Canyon and Kyle Canyon had similar shapes and were nearly parallel to land-surface altitude. Linear regression of water-table altitude with land-surface altitude from both sites had a slope of 0.89 and an r-squared of 0.97. If this relation is valid for other hydrogeologic settings, then water-table levels in undeveloped areas could be estimated from a few measurements. Recent (2000–2004) water tables at Pine Nut Creek and Vicee Canyon are similar and are not parallel with land-surface altitude, suggesting that pumping has changed the linear relation. At Vicee Canyon, pumping has reversed the gradient so that ground water flows from the valley floor toward the mountain front. The non-linear relation would depend on the amount of pumpage, making it difficult to estimate water-table levels in developed areas. This study used existing data to characterize gradients. A study specifically designed to characterize gradients may result in stronger correlations that could be used to estimate gradients and the water table where few data exist.

Introduction

In 1999, the U.S. Environmental Protection Agency began a program to protect the quality of ground water in areas other than ground-water protection areas (U.S. Environmental Protection Agency, 2000). Ground-water protection areas surrounding currently used production wells, are protected under the wellhead and source-water protection programs, and constitute a small percentage of Nevada. Other sensitive ground-water areas (OSGWA) are large areas that are not currently, but could eventually be, used as a source of drinking water and are protected under the OSGWA program. OSGWAs do not include areas that could not be used as a source of drinking water, such as saline ground water near playas. The OSGWA program specifically addresses existing wells that are used for underground injection of motor vehicle waste; new injection wells are banned. If an injection well is in a ground-water protection area or an OSGWA, well owners must either close the well or apply for a permit. A permit is granted only if the injectate fluids meet drinking-water standards.

Nevada is a large, rural, and hydrologically complex state that lies almost entirely within the Great Basin physiographic province (fig. 1). Sparse data throughout much of Nevada makes it difficult to determine which aquifers could be sensitive to contamination. Rather than designate specific areas as an OSGWA, the Nevada Division of Environmental Protection (NDEP) will evaluate site-specific information associated with the permit application and determine if the aquifer at the site is sensitive (Nevada Division of Environmental Protection, 2003). To evaluate permit applications, NDEP needs statewide information on depth to water, altitude of the water table, and other variables that control the susceptibility of ground water to contamination and contaminant transport. The greater the depth to water, the greater the probability that contaminants will degrade or sorb to sediments before reaching ground water, which makes shallow aquifers generally more sensitive to contamination than deep aquifers. If the contaminant reaches ground water, water-table altitude is needed to determine the direction and rate of ground-water flow and to identify water supplies that could be affected.

The U.S. Geological Survey (USGS), in cooperation with NDEP, started a study in 2001 to compile information on variables that could control aquifer susceptibility and vulnerability and to estimate the potential for ground-water degradation from anthropogenic contamination. As part of the study, the USGS used available, published water-table and depth-to-water contours and other data to determine statewide water-table levels and water-table gradients. This report presents the water-table levels and gradients and is one of four reports from this study. Maurer and others (2004) describe the hydrogeology of Nevada and areas with similar horizontal hydraulic conductivity, soil permeability, precipitation, slope, and aspect. Lopes and Evetts (2004) estimated ground-water pumpage and artificial recharge for the year 2000 and compiled estimates of average annual natural recharge and interbasin flow by hydrographic area. Lopes (2006) described methods and results of evaluating the quality of Nevada's aquifers and their susceptibility to contamination.

Purpose and Scope

The purpose of this report is to present (1) statewide maps of water-table contours and water-table and depth-to-water surfaces, and (2) water-table gradients determined from water-level measurements. The report includes an assessment of temporal changes in water-table levels, an assessment of the variables that affect gradients in unconsolidated sediments, and general estimates of ground-water velocity. Published maps and data from 1947–2004 were used in the study. Potentiometric surfaces of confined aquifers were not included.

Methods

Water-table and depth-to-water contours were compiled from published reports and were used to make digital surfaces of interpolated water-table levels. Recent data were used to make previously unpublished contours for Buffalo and Diamond Valleys. Recent and historical data were used to evaluate temporal changes and characterize the water table between the valley floor and consolidated rock. Water table and gradients in different hydrogeologic settings were characterized using field measurements, site characteristics, and graphical and

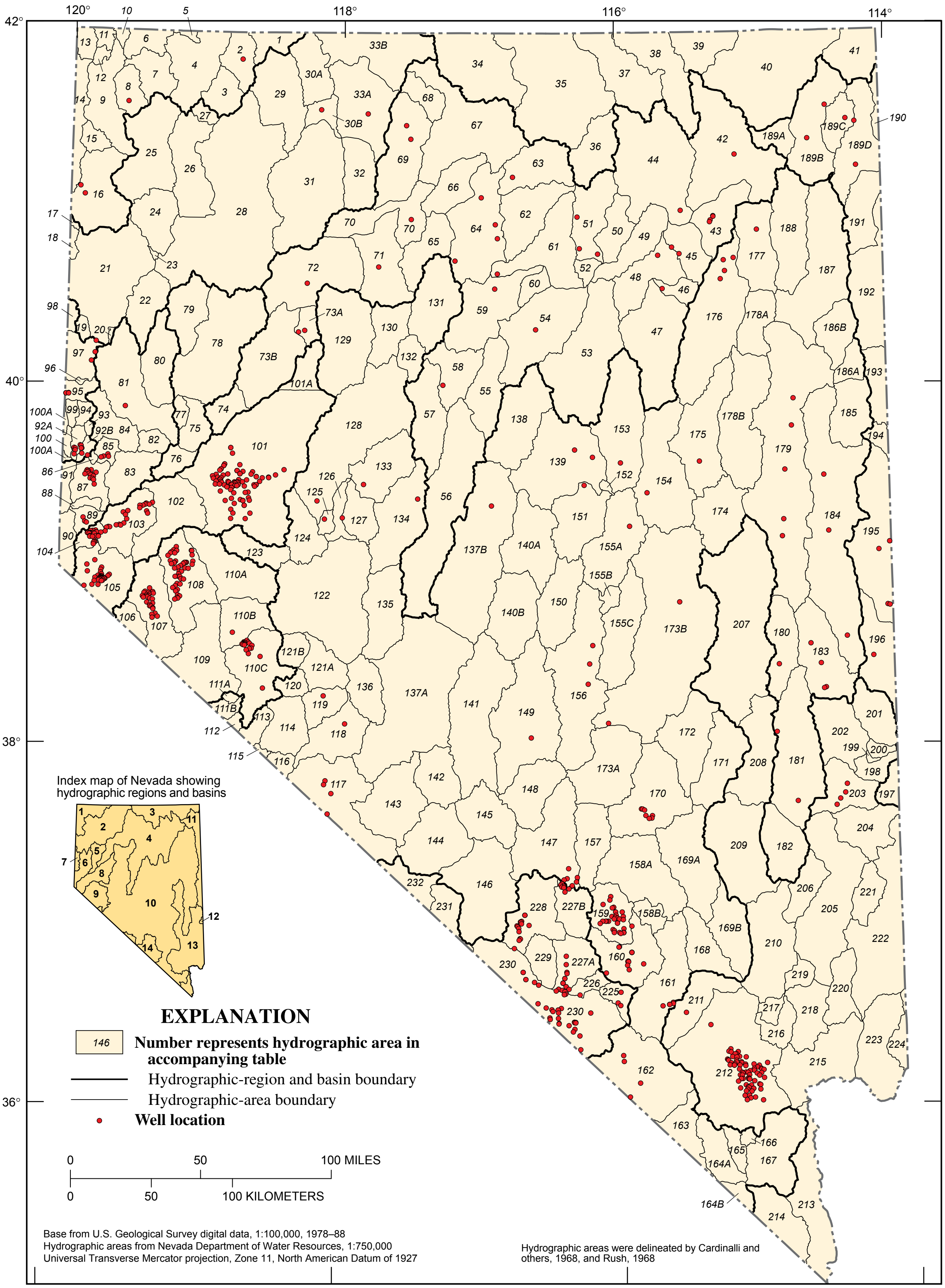

Figure 1. Hydrographic areas and locations of wells used to evaluate the accuracy of depth-to-water surfaces in Nevada.

STATE OF NEVADA--HYDROGRAPHIC AREAS

1-NORTHWEST REGION

1. Pueblo V.
2. Continental Lake V.
3. Gridley Lake V.
4. Virgin V.
5. Sage Hen V.
6. Guano V.
7. Swan Lake V.
8. Massacre Lake V.
9. Long V.
10. Macy Flat
11. Coleman V.
12. Mosquito V.
13. Warner V.
14. Surprise V.
15. Boulder V.
16. Duck Lake V.

2-BLACK ROCK DESERT REGION

17. Pilgrim Flat
18. Painter Flat
19. Dry V.
20. Sano V.
21. Smoke Creek Desert
22. San Emidio Desert
23. Granite Basin
24. Hualapai Flat
25. High Rock Lake V.
26. Mud Meadow
27. Summit Lake V.
28. Black Rock Desert
29. Pine Forest V.
30. Kings River V.
   (A) Rio King Subarea
   (B) Sod House Subarea
31. Desert V.
32. Silver State V.
33. Quinn River V.
   (A) Orovada Subarea
   (B) McDermitt Subarea

3-SNAKE RIVER BASIN

34. Little Owyhee River Area
35. South Fork Owyhee River Area
36. Independence V.
37. Owyhee River Area
38. Bruneau River Area
39. Jarbidge River Area
40. Salmon Falls Creek Area
41. Goose Creek Area

4-HUMBOLDT RIVER BASIN

42. Marys River Area
43. Starr V. Area
44. North Fork Area
45. Lamoille V.
46. South Fork Area
47. Huntington V.
48. Dixie Creek -- Tenmile Creek Area
49. Elko Segment
50. Susie Creek Area
51. Maggie Creek Area
52. Marys Creek Area
53. Pine V.
54. Crescent V.
55. Carico Lake V.
56. Upper Reese River V.
57. Antelope V.
58. Middle Reese River V.
59. Lower Reese River V.
60. Whirlwind V.
61. Boulder Flat
62. Rock Creek V.
63. Willow Creek V.
64. Clovers Area
65. Pumpernickel V.
66. Kelly Creek Area
67. Little Humboldt V.
68. Hardscrabble Area
69. Paradise V.
70. Winnemucca Segment
71. Grass V.
72. Imlay Area
73. Lovelock V.
   (A) Oreana Subarea
74. White Plains

5-WEST CENTRAL REGION

75. Bradys Hot Springs Area
76. Fernley Area
77. Fireball V.
78. Granite Springs V.
79. Kumiva V.

6-TRUCKEE RIVER BASIN

80. Winnemucca Lake V.
81. Pyramid Lake V.
82. Dodge Flat
83. Tracy Segment
84. Warm Springs V.
85. Spanish Springs V.
86. Sun V.
87. Truckee Meadows
88. Pleasant V.
89. Washoe V.
90. Lake Tahoe Basin
91. Truckee Canyon Segment

7-WESTERN REGION

92. Lemmon V.
   (A) Western Part
   (B) Eastern Part
93. Antelope V.
94. Bedell Flat
95. Dry V.
96. Newcomb Lake V.
97. Honey Lake V.
98. Skedaddle Creek V.
99. Red Rock V.
100. Cold Spring V.
   (A) Long V.

8-CARSON RIVER BASIN

101. Carson Desert
   (A) Packard V.
102. Churchill V.
103. Dayton V.
104. Eagle V.
105. Carson Valley

9-WALKER RIVER BASIN

106. Antelope V.
107. Smith V.
108. Mason V.
109. East Walker Area
110. Walker Lake V.
   (A) Schurz Subarea
   (B) Lake Subarea
   (C) Whisky Flat -- Hawthorne Subarea

10-CENTRAL REGION

111. Alkali V. (Mineral).
   (A) Northern Part
   (B) Southern Part
112. Mono V.
113. Huntoon V.
114. Teels Marsh V.
115. Adobe V.
116. Queen V.
117. Fish Lake V.
118. Columbus Salt Marsh V.
119. Rhodes Salt Marsh V.
120. Garfield Flat
121. Soda Spring V.
   (A) Eastern Part
   (B) Western Part
122. Gabbs V.
123. Rawhide Flats
124. Fairview V.
125. Stingaree V.
126. Cowkick V.
127. Eastgate V. Area
128. Dixie V.
129. Buena Vista V.
130. Pleasant V.
131. Buffalo V.
132. Jersey V.
133. Edwards Creek V.
134. Smith Creek V.
135. Ione V.
136. Monte Cristo V.
137. Big Smoky V.
   (A) Tonopah Flat
   (B) Northern Part
138. Grass V.
139. Kobeh V.
140. Monitor V.
   (A) Northern Part
   (B) Southern Part
141. Ralston V.
142. Alkali Spring V. (Esmeralda)
143. Clayton V.
144. Lida V.
145. Stonewall Flat
146. Sarcobatus Flat
147. Gold Flat
148. Cactus Flat
149. Stone Cabin V.
150. Little Fish Lake V.
151. Antelope V. (Eureka & Nye)
152. Stevens Basin
153. Diamond V.
154. Newark V.
155. Little Smoky V.
   (A) Northern Part
   (B) Central Part
   (C) Southern Part
156. Hot Creek V.
157. Kawich V.
158. Emigrant V.
   (A) Groom Lake V.
   (B) Papoose Lake V.
159. Yucca Flat
160. Frenchman Flat
161. Indian Springs V.
162. Pahrump V.
163. Mesquite V. (Sandy V.)
164. Ivanpah V.
   (A) Northern Part
   (B) Southern Part
165. Jean Lake V.
166. Hidden V. (South)
167. Eldorado V.
168. Three Lakes V. (Northern Part)
169. Tikapoo V. (Tickaboo V.)
   (A) Northern Part
   (B) Southern Part
170. Penoyer V. (Sand Spring V.)
171. Coal V.
172. Garden V.
173. Railroad V.
   (A) Southern Part
   (B) Northern Part
174. Jakes V.
175. Long V.
176. Ruby V.
177. Clover V.
178. Butte V.
   (A) Northern Part (Round V.)
   (B) Southern Part
179. Steptoe V.
180. Cave V.
181. Dry Lake V.
182. Delamar V.
183. Lake V.
184. Spring V.
185. Tippett V.
186. Antelope V. (White Pine & Elko)
   (A) Southern Part
   (B) Northern Part
187. Goshute V.
188. Independence V. (Pequop V.)

11-GREAT SALT LAKE BASIN

189. Thousand Springs V.
   (A) Herrill Siding--Brush Creek Area
   (B) Toano--Rock Spring Area
   (C) Rocky Butte Area
   (D) Montello--Crittenden Creek Area (Montello V.)
190. Grouse Creek V.
191. Pilot Creek V.
192. Great Salt Lake Desert
193. Deep Creek V.
194. Pleasant V.
195. Snake V.
196. Hamlin V.

12-ESCALANTE DESERT

197. Escalante Desert

13-COLORADO RIVER BASIN

198. Dry V.
199. Rose V.
200. Eagle V.
201. Spring V.
202. Patterson V.
203. Panaca V.
204. Clover V.
205. Lower Meadow Valley Wash
206. Kane Springs V.
207. White River V.
208. Pahroc V.
209. Pahranagat V.
210. Coyote Spring V.
211. Three Lakes V. (Southern Part)*
212. Las Vegas V.
213. Colorado V.
214. Piute V.
215. Black Mountains Area
216. Garnet V. (Dry Lake V.)*
217. Hidden V. (North)*
218. California Wash
219. Muddy River Springs Area (Upper Moapa V.)
220. Lower Moapa V.
221. Tule Desert
222. Virgin River V.
223. Gold Butte Area
224. Greasewood Basin

*Noncontributing part of the Colorado River Basin

14-DEATH VALLEY BASIN

225. Mercury V.
226. Rock V.
227. Fortymile Canyon
   (A) Jackass Flats
   (B) Buckboard Mesa
228. Oasis V.
229. Crater Flat
230. Amargosa Desert
231. Grapevine Canyon
232. Oriental Wash

Figure 1. Hydrographic areas and locations of wells used to evaluate the accuracy of depth-to-water surfaces in Nevada—Continued.

statistical techniques (Helsel and Hirsch, 1992). Statistical results were considered significant at a p-value of less than or equal to 0.05.

Water-Table and Depth-to-Water Contours

A literature search of published water-table and depth-to-water contours for Nevada produced 104 reports with maps of varying detail and scope published from 1948 to 2004 (appendix 1). Twenty-eight maps had depth-to-water contours and 90 maps had water-table contours. Two maps cover most of Nevada (Rush, 1974; Bedinger and others, 1984). However, these maps lack detail and were used only if no other information was available.

Each map was reviewed to determine which hydrographic areas (HAs) were covered. Cardinalli and others (1968) and Rush (1968) delineated 232 HAs for Nevada, based generally on drainage-area divides (fig. 1; Peltz and others, 2005). HAs are different than hydrologic units (National Atlas of the United States, 1998) and are used by the State for scientific and administrative purposes.

If multiple maps covered the same HA, a scoring system was used to determine which map to use in the study (table 1). The scoring system was designed such that the highest scores were for the most recent, most detailed maps that covered the largest area and had plotted control points. The score for each map was the sum of points for each of four criteria: percentage of hydrographic area contoured, contour interval, date of water-level measurements, and plotting of control points. Maps with the highest score were chosen for this study. Plotted control points had less weight than other criteria and were not a deciding factor because about 85 percent of the maps had plotted points. In cases where multiple maps had the same score, maps that covered multiple HAs were chosen so that contours would be consistent over as large an area as possible. Through this process, water-table contours were selected from 38 of the reports and were based on data collected from 1947 to 2004 (appendix 1). The only contours available for Honey Lake Valley (HA 97) are simulated water-table contours (Handman and others, 1990). Contours were simulated with a computer model that was calibrated to within 5 ft of the measured water-table level. Depth-to-water contours from Rush (1974) were used to estimate the water table in some HAs, such as the Carson Desert (HA 101).

If not already available digitally, contours and control points were digitized from selected maps, entered into a geographic information system (GIS), and combined with available digital contours and points to make a statewide map of water-table contours (plate 1; data can be accessed at *http://water.usgs.gov/lookup/getspatial?sir2006-5100_wanv_l*). For areas with sparse or no published contours, point measurements were retrieved from the USGS National Water Information System (NWIS) database and were plotted.

Water levels measured during spring 1996 were used to make water-table contours in Buffalo Valley (HA 131; plate 1). Water levels measured during spring 2001 were used to make depth-to-water contours in Diamond Valley (HA 153; fig. 2; data can be accessed at *http://water.usgs.gov/lookup/getspatial?sir2006-5100_dtwha153_l*). The contours were digitized and entered into the GIS. Diamond Valley has had large amounts of ground-water pumpage for agricultural use since contours were first published by Eakin (1962) (Lopes and Evetts, 2004). Comparison of 1962 contours with 2001 contours indicates that depth to water has increased tens of feet in southern Diamond Valley.

Water-Table and Depth-to-Water Surfaces

Detailed procedures of making water-table and depth-to-water surfaces are described by data can be accessed at *http://water.usgs.gov/lookup/getspatial?sir2006-5100_dtwnv_g* and *http://water.usgs.gov/lookup/getspatial?sir2006-5100_wanv_g*. Briefly, the water table between contours was estimated using inverse-distance weighting. Interpolated estimates were then converted into a gridded surface of 1,000-ft cells. A boundary was drawn around contours to limit the extent of interpolation. Where the hydrogeology, water-table contours, and literature indicated a continuous aquifer system, the boundary was drawn around contours of contiguous HAs to make a single surface. Gradational color shading of the range in water-table altitude was used to show the general direction of ground-water flow (plate 2). The same procedure was used to make a gridded surface of depth to water in HAs for which Rush (1974, data can be accessed at *http://water.usgs.gov/lookup/getspatial?nv_dtw750nv_l*) was the only information available. Some HAs, such as Smoke Creek Desert (HA 21), have only a single contour or have a single contour that extends farther than other contours in the HA. For these HAs, either a surface was not made or the extent of the surface was smaller than the extent of the contours in the HA. Therefore, plates should be compared to see what water-table information exists in an HA.

Table 1. Scoring system for selecting published water-table and depth-to-water contours used to determine water-table levels in Nevada

[**Abbreviations:** <, less than; > greater than; ≥, greater than or equal to ; ≤, less than or equal to; —, not applicable]

Criterion	Score			
	0	1	2	3
Percentage of hydrographic area contoured	—	<25	25 to <75	≥75
Contour interval, in feet	—	>20	>10 to 20	≤ 10
Date of water-level measurements	—	Pre-1975	1975-1989	Post-1989
Were control points on map?	No	Yes	—	—

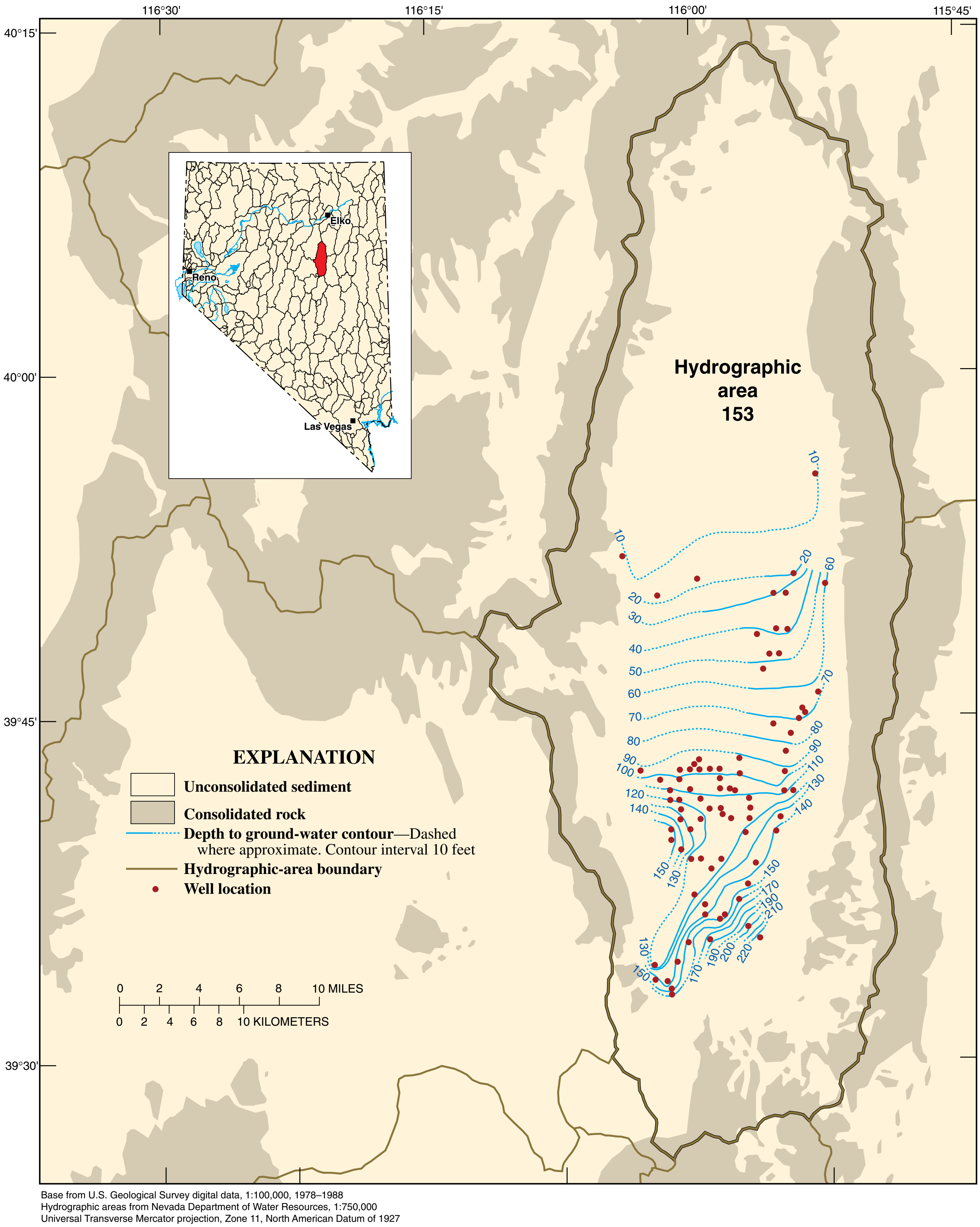

Figure 2. Depth to water in spring 2001 in the Diamond Valley hydrographic area (153), Nevada.

Most depth-to-water surfaces were estimated by subtracting the water-table altitude from the National Elevation Dataset (NED; U.S. Geological Survey, 2002) for each cell of the water-table surface (plate 3). For HAs for which Rush (1974) was the only information available, water-table surfaces were estimated by subtracting depth to water from the NED. Depth to water was assumed to be one foot where the difference between the water table and NED resulted in a negative value, which would indicate a water table above land surface. The NED is a digital-raster altitude dataset based primarily on USGS 7.5-minute digital elevation models (DEM). The vertical accuracy depends on the original source DEM, but is about 23 to 49 ft (7 to 15 m; U.S. Geological Survey, 2004). Water-resources agencies and well drillers often want to know the depth to water for a specific area. Thus, depth-to-water surfaces were shown as discrete intervals of color shading rather than gradational color shading.

The accuracy of the method used to estimate depth-to-water surfaces described above was evaluated in Mason Valley (HA 108; Huxel and Harris, 1969) and Carson Valley (HA 105; Berger and Medina, 1999), which had both depth-to-water and water-table contours. For each valley, gridded depth-to-water surfaces were made from depth-to-water contours and from water-table contours. Differences in depth to water between the two surfaces were calculated for each cell in the grid. The root mean square of differences between the cells was 20 ft (6 m) for Mason Valley and 15 ft (4.5 m) for Carson Valley. A paired t-test (Helsel and Hirsch, 1992) was used to determine if depth-to-water surfaces made from water-table contours are different than surfaces made from published depth-to-water contours. The paired t-test indicated that the two depth-to-water surfaces are significantly different for both valleys (p-value <0.01; fig. 3), but there was no consistent bias. Depth to water estimated from water-table contours was higher than that estimated from depth-to-water contours in Carson Valley and lower in Mason Valley. The largest differences between the surfaces occur near the edges of the valleys, where land-surface altitude changes abruptly. Although there are differences, the procedure produces reasonable estimates of depth to water from water-table contours.

Water-Table Gradients

The water-table gradient is the slope of the water table and is calculated as the difference in water-table altitude between two points, divided by the distance between the points. Gradients can be estimated from water-table contours (pl. 1) or from water levels measured in two wells screened in the same aquifer. Gradients are necessary to estimate ground-water flow and contaminant transport. The average linear velocity of ground water (q_x) can be estimated using Darcy's Law (equation 1), where K is horizontal hydraulic conductivity, i is gradient, and n is effective porosity (Freeze and Cherry, 1979):

$$q_x = (K \times i)/ n. \qquad (1)$$

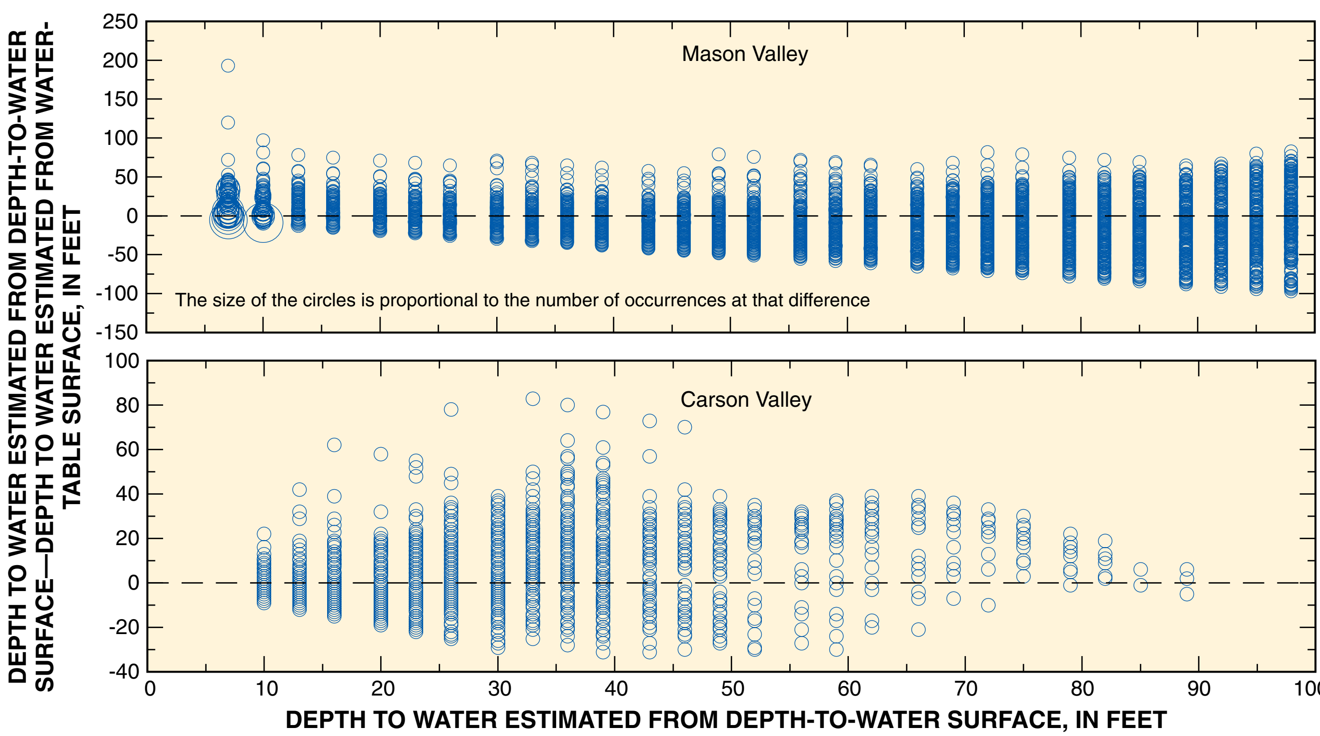

Figure 3. Differences in depth to water estimated from depth-to-water surface and water-table surfaces versus depth to water estimated from depth-to-water surfaces.

Effective porosity is the interconnected pore volume that contributes to fluid flow. Effective porosity is less than total porosity because it excludes isolated pores. The rate of contaminant transport is estimated by multiplying the average linear velocity by the retardation factor, which depends on the physical and chemical properties of the aquifer material and contaminant (Freeze and Cherry, 1979).

Gradients in unconsolidated sediments of the Great Basin are generally steep near mountain fronts and shallow beneath valley floors (Eakin and others, 1976; Maurer and others, 2004). Variables that could affect gradients in unconsolidated sediments include the source rock and texture of unconsolidated sediments, the amount of recharge and distance from recharge areas, and other variables such as the horizontal hydraulic conductivity of adjacent consolidated rocks. For example, intrusive rocks have a lower horizontal hydraulic conductivity than carbonate rocks and unconsolidated sediments (Maurer and others, 2004). Precipitation could be the same on two mountains, one composed of intrusive rocks and the other composed of carbonate rocks, but gradients in the unconsolidated sediments could be steeper near the intrusive rocks than near the carbonate rocks because of the large contrast in horizontal hydraulic conductivity.

The water table, between the valley floor and consolidated rock, and the variables that could affect the water table has not been well characterized. To identify which variables are most important, the gradient between 58 pairs of wells was correlated with the distance to the alluvial-fan contact, the distance to and horizontal hydraulic conductivity of the adjacent consolidated-rock hydrogeologic unit (Maurer and others, 2004), and precipitation upgradient of the site (Oregon Climate Service, 1997) (figs. 4, 5; table 2). This is a reconnaissance-level characterization of gradients because existing data were used in the analysis. Data in the USGS National Water Information System (NWIS) and either water-table contours or topography were used to select well pairs at the 58 sites that are roughly aligned along ground-water flow directions. However, the wells are at different depths and water levels were measured at different times. The drainage area upgradient of a site could not easily be determined, so it was approximated by a 1-mi-wide area between the site and the HA boundary.

Sixteen of the 58 well pairs are in alluvial fans and 42 are in valley floors, and well pairs are adjacent to most types of consolidated-rock hydrogeologic units in Nevada. Consolidated-rock hydrogeologic units associated with gradients were described by Maurer and others (2004). The two major hydrogeologic units in Nevada are consolidated rocks and unconsolidated sediments, which have different hydrologic properties. Consolidated rocks were subdivided into eight hydrogeologic units. In order of decreasing area covering Nevada, consolidated-rock hydrogeologic units consist of Quaternary to Tertiary age volcanic flows of (1) basaltic; (2) rhyolitic; and (3) andesitic composition; (4) volcanic breccias, tuffs, and volcanic rocks older than Tertiary age; (5) carbonate rocks; (6) Tertiary-age consolidated and semi-consolidated tuffaceous rocks and sediments; (7) clastic rocks consisting of sandstone and siltstone; and (8) intrusive and metamorphic rocks. Unconsolidated sediments were subdivided into (1) alluvial slopes, (2) valley floors, (3) fluvial deposits, and (4) playas.

Water-level measurements and linear regression were used to characterize the water table between the valley floor and consolidated rock at Vicee Canyon in Eagle Valley (HA 104), Pine Nut Creek in Carson Valley (HA 105), and Kyle Canyon in Las Vegas Valley (HA 212) (table 3). Land-surface altitude was measured to within 0.1 ft for wells at Vicee Canyon and Pine Nut Creek and estimated to within 1 to 40 ft for wells at Kyle Canyon. Kyle Canyon is associated with carbonate rocks and has fewer domestic wells than Pine Nut Creek, which is associated with Tertiary sediments. Vicee Canyon is associated with intrusive rocks, has two production wells, and is the most developed of the three sites. The initial water table prior to large pumping at Vicee Canyon and Kyle Canyon was approximated using the earliest measurements taken on multiple dates. No early water-level data were available for Pine Nut Creek. Measurements used to approximate the water table at Kyle Canyon were made from 1969 to 1990 during September to April when pumping is usually low and prior to most snowmelt. A recent (2004) measurement of a well in Kyle Canyon indicates that water levels have changed little in the area. At Vicee Canyon, water-level measurements made from 1972 to 2002 were used to approximate the initial water table.

Water-Table Levels

Water-table and depth-to-water surfaces were made for only 21 percent of Nevada because of a lack of information for 49 of 232 HAs and for most consolidated-rock hydrogeologic units (plates 2 and 3). The surfaces represent water-table levels in 40 percent of the unconsolidated sediment and 3 percent of the consolidated-rock hydrogeologic units. Water-table levels exist for the most populated HAs of Las Vegas Valley (HA 212), Truckee Meadows (HA 87), Eagle Valley (HA 104), and Carson Valley (HA 105), although most of these HAs do not have recent information.

The accuracy of the surfaces was evaluated by comparing depth to water measured at 682 wells from January 2000 to March 2004 with depth to water estimated from depth-to-water surfaces (figs. 1 and 6). The root mean square of differences between measured and estimated depth to water was 90 ft. To evaluate a specific site, more recent and detailed data may be needed. A paired t-test indicated no significant difference between measured and estimated depth to water (p-value 0.40), thus depth-to-water surfaces do not over- or under-estimate depth to water. The large differences between measured and estimated depth to water could be due to the error of the NED, temporal changes in depth to water due to natural variations and pumping, incorrectly extrapolating contours, or a combination of these explanations. For example, some water-

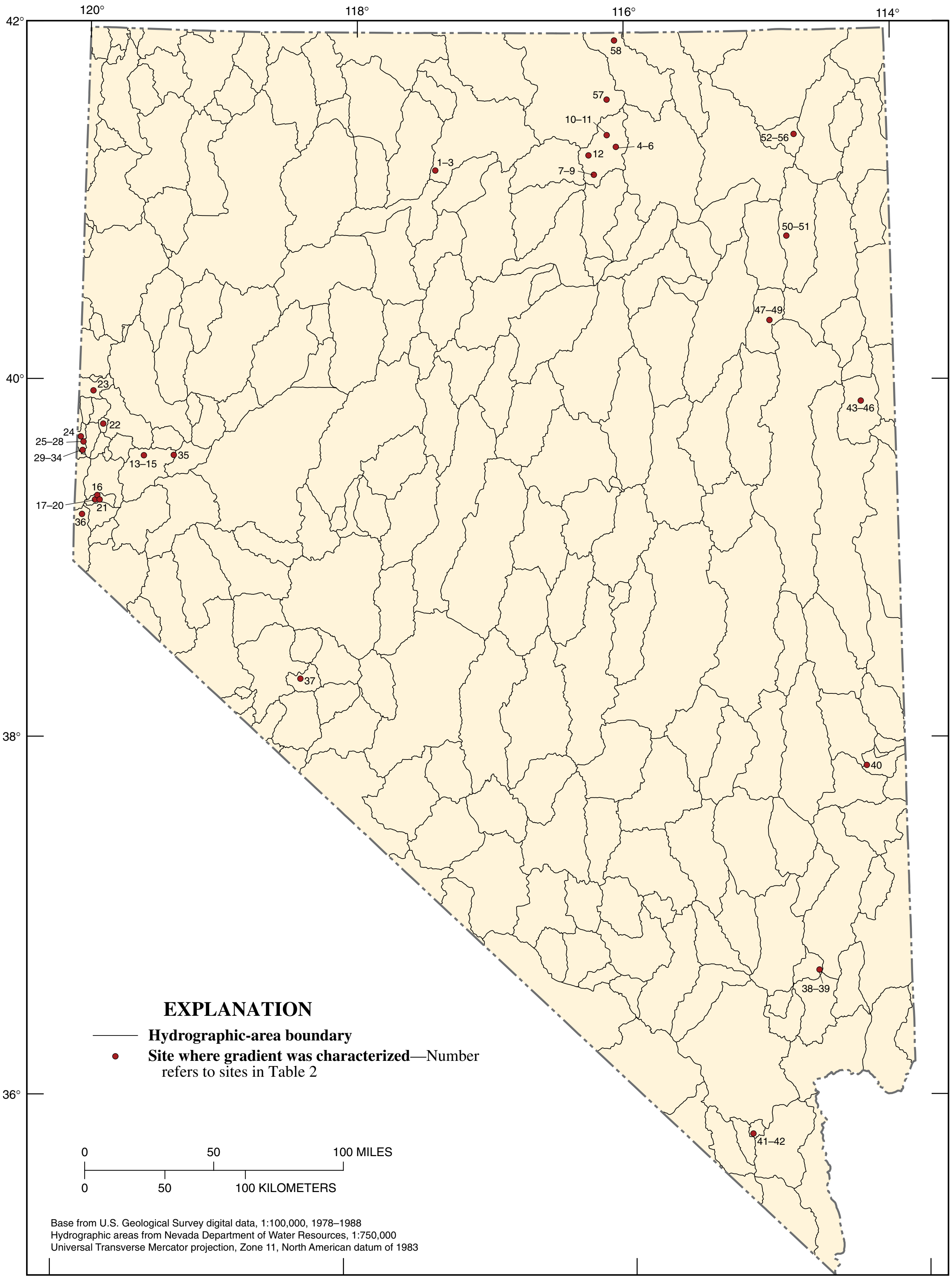

Figure 4. Sites where water-table gradients were characterized.

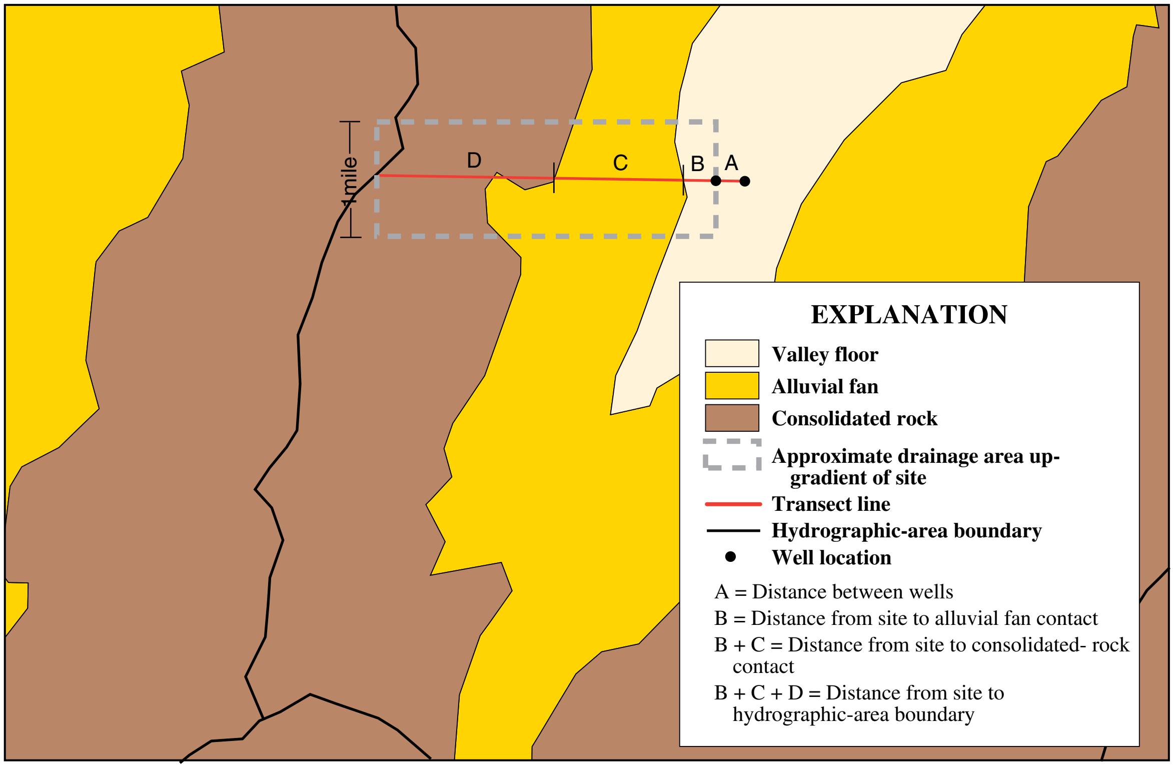

Figure 5. Variables measured at water-table-gradient sites.

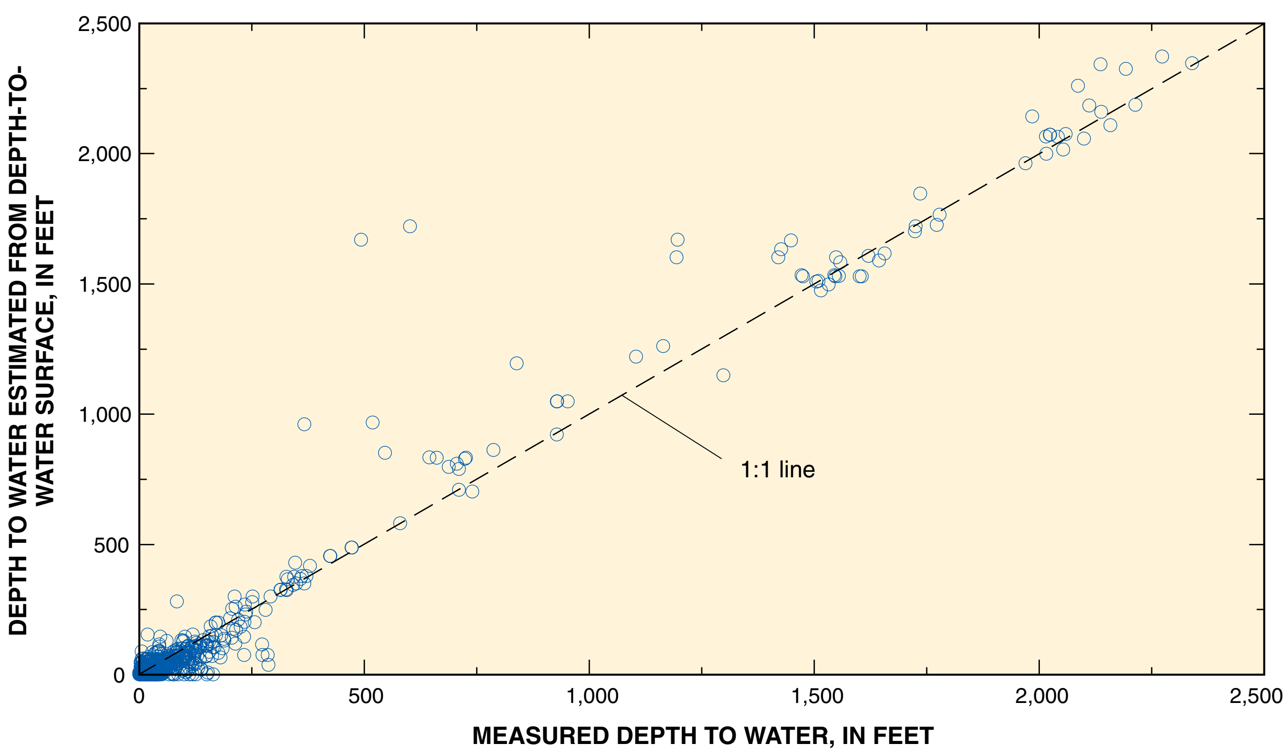

Figure 6. Depth to water estimated from depth-to-water surface versus measured depth to water.

Table 2. Information used to characterize water-table gradients in Nevada

[**Site:** Pairs of wells used to characterize gradients; locations shown on figure 4. **Adjacent consolidated hydrogeologic unit:** BTOV, breccia, tuffs, and older volcanic rocks; TS, tertiary sediments. **Hydraulic conductivity:** average horizontal hydraulic conductivity of adjacent consolidated hydrogeologic unit. **Abbreviations:** NGVD, National Geodetic Vertical Datum; —, does not apply]

Site	Down-gradient water-table altitude, NGVD 1929	Upgradient water-table altitude, NGVD 1929	Distance between wells, in feet	Gradient	Unconsolidated hydro-geologic unit of gradient	Distance from site to alluvial-fan contact, in feet	Distance from site to consoldated-rock contact, in feet	Adjacent consolidated hydro-geologic unit	Hydraulic conduc-tivity, in feet per day	Precipi-tation upgradient of site, in acre-feet per year
1	4,514	4,534	3,476	0.006	Valley floor	1,702	17,089	Clastics	9	1,633
2	4,514	4,525	2,406	.005	Valley floor	13,012	20,484	Basalt	650	1,173
3	4,520	4,534	2,374	.006	Valley floor	14,635	42,916	Clastics	9	1,003
4	5,851	5,937	2,255	.038	Valley floor	17,581	51,178	Clastics	9	4,328
5	5,619	6,482	8,798	.098	Valley floor	81,459	24,429	Clastics	9	2,736
6	5,619	6,479	14,061	.061	Valley floor	80,668	8,020	Clastics	9	3,026
7	5,797	5,857	4,546	.013	Valley floor	15,836	25,263	BTOV	300	3,753
8	5,797	5,888	7,754	.012	Valley floor	20,549	15,793	Basalt	650	4,175
9	5,786	5,892	7,685	.014	Valley floor	50,482	19,818	Basalt	650	3,956
10	5,492	5,753	4,758	.055	Valley floor	21,405	46,970	Clastics	9	4,525
11	5,673	5,711	4,973	.008	Valley floor	52,267	2,683	BTOV	300	2,436
12	5,845	6,584	3,822	.193	Valley floor	13,297	22,730	BTOV	300	4,954
13	4,253	4,285	4,992	.006	Valley floor	4,438	34,663	Basalt	650	2,543
14	4,321	4,342	10,734	.002	Valley floor	5,943	58,696	Andesite	30	4,066
15	5,049	5,083	1,875	.018	Alluvial fan	—	19,641	Intrusives	15	2,502
16	6,476	6,760	2,824	.101	Alluvial fan	—	11,903	Intrusives	15	2,246
17	5,503	5,860	4,706	.076	Alluvial fan	—	25,279	Andesite	30	1,092
18	5,385	5,488	5,536	.019	Alluvial fan	—	41,761	Andesite	30	1,297
19	5,467	6,093	6,767	.093	Alluvial fan	—	28,625	Andesite	30	2,128
20	5,347	6,108	10,403	.073	Alluvial fan	—	42,223	Andesite	30	2,662
21	5,355	5,379	1,110	.022	Alluvial fan	—	6,855	Andesite	30	791
22	5,054	5,073	7,464	.003	Valley floor	31,153	70,500	Intrusives	15	154
23	4,402	4,432	5,491	.005	Valley floor	20,047	77,106	BTOV	300	4,453
24	5,037	5,097	7,120	.008	Valley floor	0	44,956	Intrusives	15	475
25	5,036	5,041	3,771	.001	Valley floor	6,294	17,978	Intrusives	15	776
26	5,025	5,042	3,246	.005	Valley floor	13,382	19,031	Intrusives	15	1,202
27	5,032	5,042	4,556	.002	Valley floor	22,832	29,438	Intrusives	15	345
28	5,346	5,685	3,895	.087	Alluvial fan	—	45,654	Intrusives	15	4,837
29	5,030	5,055	4,214	.006	Valley floor	8,794	22,389	Intrusives	15	2,320
30	5,025	5,075	6,944	.007	Valley floor	6,481	26,624	Intrusives	15	2,300
31	5,025	5,031	3,325	.002	Valley floor	24,292	30,383	Intrusives	15	465
32	5,037	5,042	2,189	.002	Valley floor	16,095	29,605	Intrusives	15	1,091
33	5,031	5,067	7,403	.005	Valley floor	22,668	41,800	Intrusives	15	2,276
34	5,032	5,035	5,699	.001	Valley floor	19,388	26,807	Intrusives	15	415
35	4,114	4,125	807	.014	Valley floor	4,631	29,937	Basalt	650	184
36	5,256	6,346	6,742	.162	Alluvial fan	—	50,296	Intrusives	15	3,481
37	5,287	5,301	2,951	.005	Valley floor	14,475	44,218	Andesite	30	392
38	5,197	5,208	3,749	.003	Alluvial fan	—	28,966	TS	10	422
39	5,197	5,199	6,180	.0003	Alluvial fan	—	42,374	TS	10	141
40	5,114	5,220	3,187	.033	Valley floor	10,453	15,970	BTOV	300	834
41	2,428	2,431	12,144	.0002	Valley floor	39,832	55,760	Basalt	650	56
42	2,080	2,431	11,472	.031	Valley floor	37,628	54,812	Basalt	650	47
43	5,536	5,564	24,808	.001	Valley floor	91,978	151,962	Carbonates	1,650	3,286
44	5,524	5,564	23,950	.002	Valley floor	88,688	130,836	Carbonates	1,650	2,717
45	5,525	5,564	34,711	.001	Valley floor	148,223	222,981	Carbonates	1,650	3,421
46	5,528	5,564	25,497	.001	Valley floor	96,563	156,945	Carbonates	1,650	2,961
47	6,033	6,057	12,351	.002	Valley floor	34,050	53,323	Carbonates	1,650	1,458
48	6,033	6,147	10,000	.011	Valley floor	32,800	51,220	Carbonates	1,650	1,338
49	5,995	6,147	24,351	.006	Valley floor	79,871	91,282	Carbonates	1,650	1,266
50	5,596	5,679	74,254	.001	Valley floor	212,036	276,048	Carbonates	1,650	2,704

Table 2. Information used to characterize water-table gradients in Nevada—Continued

Site	Down-gradient water-table altitude, NGVD 1929	Upgradient water-table altitude, NGVD 1929	Distance between wells, in feet	Gradient	Unconsolidated hydrogeologic unit of gradient	Distance from site to alluvial-fan contact, in feet	Distance from site to consoldated-rock contact, in feet	Adjacent consolidated hydrogeologic unit	Hydraulic conductivity, in feet per day	Precipitation upgradient of site, in acre-feet per year
51	5,596	5,631	92,788	.0004	Valley floor	323,152	382,012	Carbonates	1,650	1,813
52	5,541	5,641	12,040	.008	Alluvial fan	—	94,959	Carbonates	1,650	2,252
53	5,541	5,627	16,703	.005	Alluvial fan	—	86,572	TS	10	1,759
54	5,109	5,541	15,370	.028	Alluvial fan	—	74,804	Clastics	9	956
55	5,109	5,536	14,831	.029	Alluvial fan	—	76,860	Clastics	9	1,433
56	5,109	5,617	16,203	.031	Alluvial fan	—	112,245	Carbonates	1,650	2,398
57	5,442	5,550	11,509	.009	Valley floor	10,178	62,028	Carbonates	1,650	11,372
58	6,402	6,411	5,949	.002	Valley floor	29,382	43,837	BTOV	300	4,378

Table 3. Water-table measurements for Vicee Canyon, Pine Nut Creek, and Kyle Canyon, Nevada.

[**Abbreviations:** USGS, U.S. Geological Survey; NGVD, National Geodetic Vertical Datum; —, no data; NA, not applicable]

USGS well number	Land-surface altitude, NGVD 1929	Distance from well at lowest altitude, in miles	Initial measurement			Recent measurement		
			Date of water-level measurement	Depth to water, in feet below land surface	Water-table altitude, NGVD 1929	Date of water-level measurement	Depth to water, in feet below land surface	Water-table altitude, NGVD 1929
Vicee Canyon								
391110119460602	4,724	0.00	Feb 2, 2002	4.70	4,719.30	Jan 20, 2004	5.80	4,718.20
391100119465101	4,785	.59	Sep 9, 1997	40.00	4,745.00	Jan 20, 2004	85.10	4,699.90
391110119470501	4,800	.88	Jul 17, 1975	45.16	4,754.84	Oct 15, 2003	100.48	4,699.52
391057119471901	4,860	1.10	Jul 8, 1972	94.00	4,766.00	Jan 20, 2004	162.96	4,697.04
391055119473301	4,927	1.27	—	—	—	Jan 20, 2004	232.84	4,694.16
391105119481101	5,181.5	1.86	Aug 4, 1994	139.00	5,042.50	Jan 20, 2004	140.80	5,040.70
391111119481901	5,207.5	1.98	Aug 6, 1994	96.00	5,111.50	Jan 20, 2004	95.97	5,111.53
Pine Nut Creek								
385618119422501	4,869.40	0.00	Jan 28, 2000	46.00	4,823.40	Oct 19, 2001	48.63	4,820.77
385610119415001	4,915.80	.52	Jan 28, 2000	92.50	4,823.30	Oct 19, 2001	98.64	4,817.16
385604119415001	4,897.90	.56	Jan 18, 2000	69.90	4,828.00	Oct 19, 2001	74.90	4,823.00
385554119414701	4,920.60	.65	Jan 28, 2000	96.30	4,824.30	—	—	—
385606119411501	4,949.00	1.00	Jan 18, 2000	110.20	4,838.80	Oct 19, 2001	124.36	4,824.64
385559119411801	4,932.60	1.04	Jan 18, 2000	83.40	4,849.20	Oct 19, 2001	96.70	4,835.90
385559119411301	4,938.70	1.12	Jan 24, 2000	91.00	4,847.70	Oct 19, 2001	102.86	4,835.84
385541119410601	4,957.40	1.30	Jan 6, 2000	110.70	4,846.70	Oct 19, 2001	119.79	4,837.61
385602119401301	5,005.00	1.92	NA	NA	NA	Oct 19, 2001	17.30	4,987.70
Kyle Canyon								
361939115154801	2,454	0.00	Feb 9, 1980	68.95	2,385.05	—	—	—
361924115200301	3,040	3.95	Dec 1, 1969	510.00	2,530.00	—	—	—
362004115205401	3,112	4.38	Feb 26, 1990	644.60	2,467.40	—	—	—
361922115210901	3,220	4.97	Dec 14, 1973	730.00	2,490.00	—	—	—
361907115212801	3,298	5.30	Feb 26, 1990	697.80	2,600.20	—	—	—
361937115215601	3,327	5.55	Feb 2, 2004	747.76	2,579.24	—	—	—
361816115241301	3,840	7.98	Sep 1, 1964	417.00	3,423.00	—	—	—
361622115350501	5,660	18.30	Feb 28, 1980	506.13	5,153.87	—	—	—
361607115353801	6,740	18.90	Apr 15, 1980	227.30	6,512.70	—	—	—
361544115365101	7,040	20.10	Feb 28, 1980	220.80	6,819.20	—	—	—

table contours are perpendicular to the consolidated-rock contact, which would indicate no inflow from the mountain front. Most water-table contours are based on measurements on the valley floor and may have been incorrectly extrapolated to the consolidated-rock contact. Few measurements were made on alluvial fans and near the consolidated-rock contact, presumably because there are few wells to measure in these areas.

Depth to water is commonly less than 50 ft beneath valley floors, 50 to 500 ft beneath alluvial fans, and greater than 500 ft in a few areas, such as north-central and southern Nevada (plate 3). Depth to water in unconsolidated sediments could be related to recharge, the proximity to and horizontal hydraulic conductivity of nearby consolidated rock, the amount and proximity of pumping, and whether the basin is hydraulically open or closed (Maurer and others, 2004, fig. 1).

Greasewood is a phreatophyte and a good indicator of a shallow water table. Greasewood, mapped by the Gap Analysis Program (GAP; Edwards and others, 1996), is the predominant species over 3,700 mi^2 of Nevada (fig. 7). However, greasewood also occurs in areas where it is not the predominant species. About 80 percent of the greasewood grows in areas where depth-to-water surfaces were made. In these areas, 81 percent of the greasewood is where depth to water is less than 50 ft, 10 percent is where depth to water is 50 to 100 ft, and 9 percent is where depth to water is greater than 100 ft it is unlikely that greasewood could grow where depth to water is greater than 50 ft, unless the roots are tapping into perched aquifers, which do not represent the regional water table. Greasewood growing where depth to water is greater than 50 ft also could reflect differences in resolution between GAP and the depth-to-water surfaces. In general, the presence of greasewood in figure 7 in areas for which no surface has been made indicates areas where the water table has not been mapped and where depth to water likely is less than 50 ft.

Ground-water discharge areas are areas where shallow ground water evaporates from the soil and is transpired by vegetation (Harrill and others, 1988). Ground-water discharge areas cover about 11,000 mi^2, about 10 percent of Nevada (fig. 8). However, only about 50 percent of the greasewood is within ground-water discharge areas, indicating that some ground-water discharge areas have not been mapped (fig. 8; Edwards and others, 1996). The largest areas of greasewood outside ground-water discharge areas are in the Black Rock Desert (HA 28) and Desert Valley (HA 31). Where water-table surfaces overlap ground-water discharge areas, depth to water is generally less than 100 ft. Discharge areas that do not overlap a surface indicate areas where the water table has not been mapped and where depth to water is less than 100 ft.

Temporal changes in water-table levels were evaluated for 1,981 wells with 10 years or more between the first and last depth-to-water measurements made since 1990. Temporal changes were calculated by subtracting the last depth-to-water measurement from the first measurement. Positive values of temporal change indicate the water table has dropped and negative values indicate the water table has risen. Temporal changes were related to well depth, number of years between measurements, and the first depth-to-water measurement (fig. 9). The time between measurements ranged from 10 to 102 years, with a mean of 27 years. Four wells in southern Nevada had depth to water that changed by more than ±400 ft. These four wells, not plotted in figure 9, are in Kawich Valley (HA 157; 738 ft), Yucca Flat (HA 159; 836 ft), Gold Flat (HA 147; -863 ft), and Hot Creek (HA 156; -1,592 ft).

A paired t-test between first and last depth-to-water measurements indicated that the measurements are significantly different (p-value <0.01). Depth to water has increased by an average of 5 ft. The greatest increases in depth to water occurred where the first measurement was less than 200 ft, where the time between first and last measurements was 40 years or less, and for wells 100 ft to 600 ft deep (fig. 9). These characteristics describe production wells where the water table is fairly shallow in recently developing areas such as the Las Vegas and Reno metropolitan areas. The water table has changed little in wells that are less than 100 ft or greater than 1,000 ft deep or with more than 60 years between the first and last measurements. Many of these wells are in basins with little development.

The largest increases in depth to water occurred in the Middle Reese River Valley (HA 58), Eagle Valley (HA 104), Smith Valley (HA 107), Mason Valley (HA 108), Yucca Flat (HA 159), and Las Vegas Valley (HA 212; fig. 10). Except for Yucca Flat, these HAs are areas where large amounts of ground water have been pumped for agricultural irrigation and municipal supply (Lopes and Evetts, 2004). Natural variations in water-table levels due to climate and recharge were determined using 444 measurements in HAs where pumpage during 2000 was 10 percent or less of the average annual natural recharge (Lopes and Evetts, 2004). These HAs include 2–8, 10–21, 23, 25–28, 34–44, 46, 47, 50, 53, 55, 62, 63, 68, 79–82, 94, 95, 96, 98, 99, 106, 109, 111–116, 118–121, 124, 125, 127, 130, 131, 132, 134–136, 138–141, 144, 145, 147, 148, 150, 151, 152, 155, 157, 158, 161, 168, 169, 171–176, 178–182, 184, 185, 186, 188, 189, 190, 192–197, 200, 201, 204–208, 210, 211, 217, 221, 227, 231, and 232. The change in depth to water in these HAs is normally distributed, with a mean of -1 ft and a standard deviation of 30 ft. A two-sided t-test indicated that the mean is not significantly different than zero (p-value = 0.6). Ninety percent of the changes are within ±20 ft, which is about the natural fluctuation in the water table.

Water-Table Gradients

Water-table gradients were characterized between pairs of wells at 58 sites in Nevada. The 16 gradients measured beneath alluvial fans ranged from 0.0003 to 0.2 and had a median of 0.02, a mean of 0.04, and a standard deviation of 0.05. The 42 gradients measured beneath valley floors ranged from 0.0002 to 0.3 and had a median of 0.005, a mean of 0.03, and a standard deviation of 0.07. In comparison, previ-

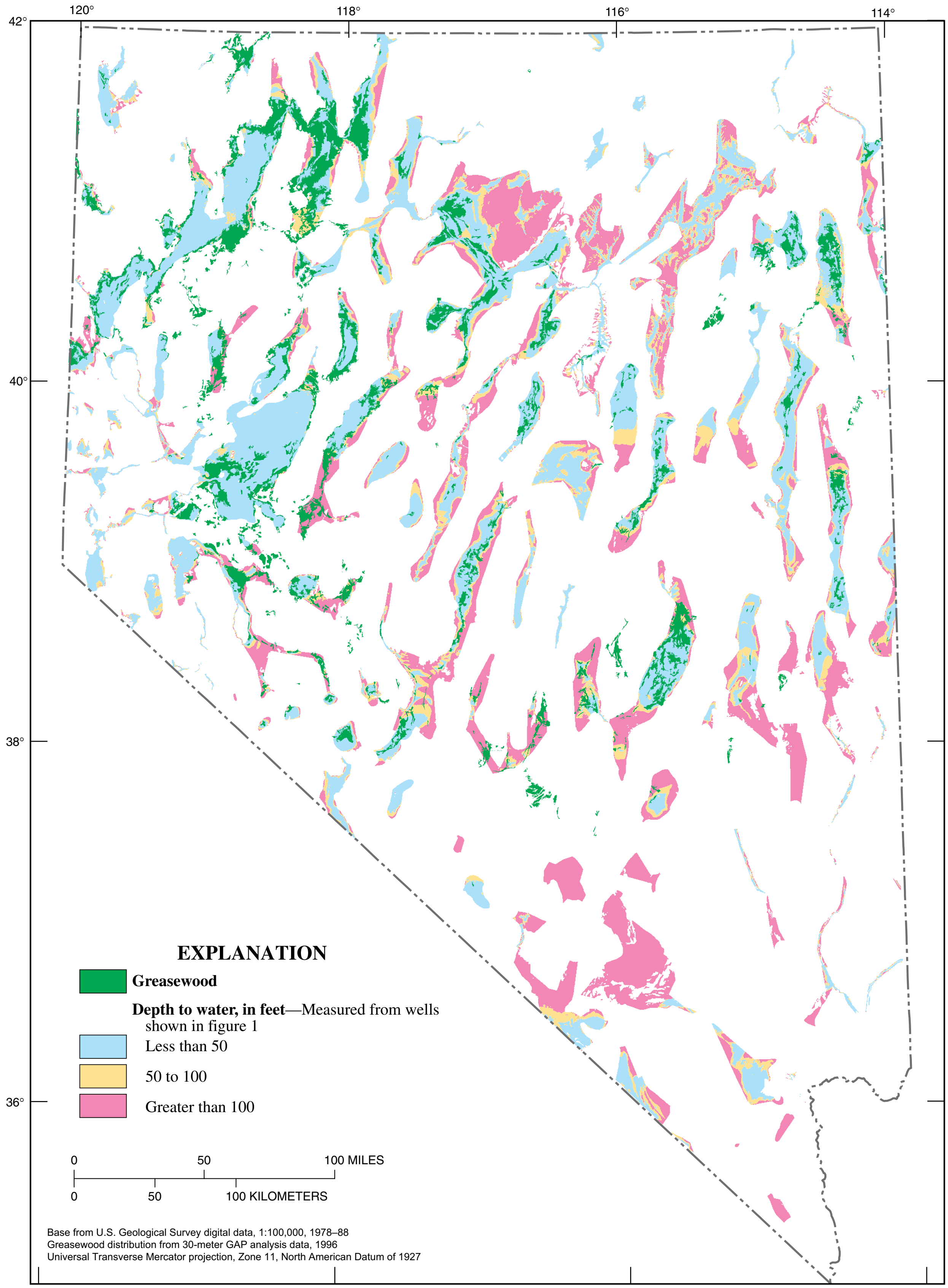

Figure 7. Depth-to-water surfaces and areas of predominantly greasewood.

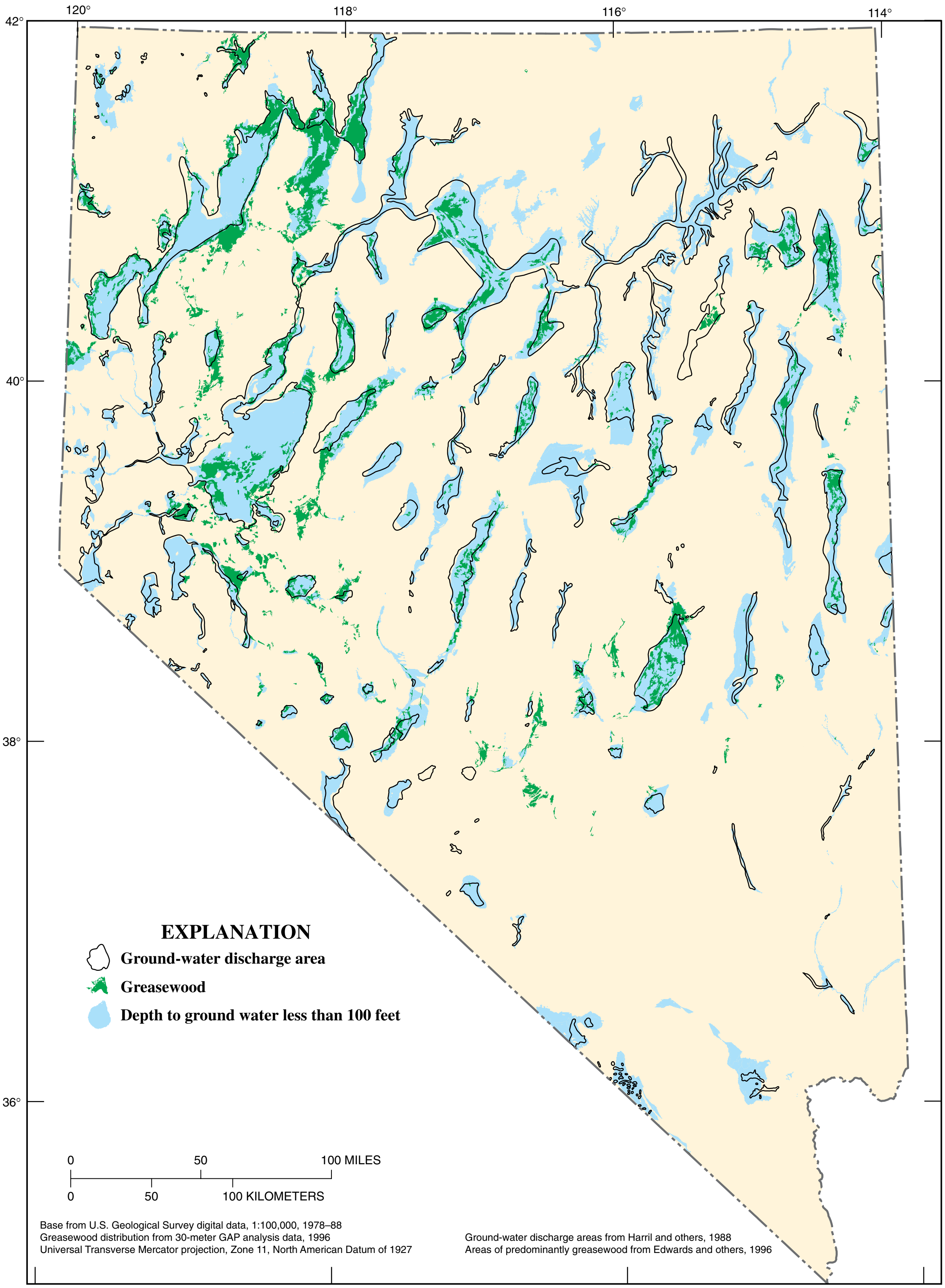

Figure 8. Ground-water discharge areas, areas of predominantly greasewood, and depth-to-water less than 100 feet.

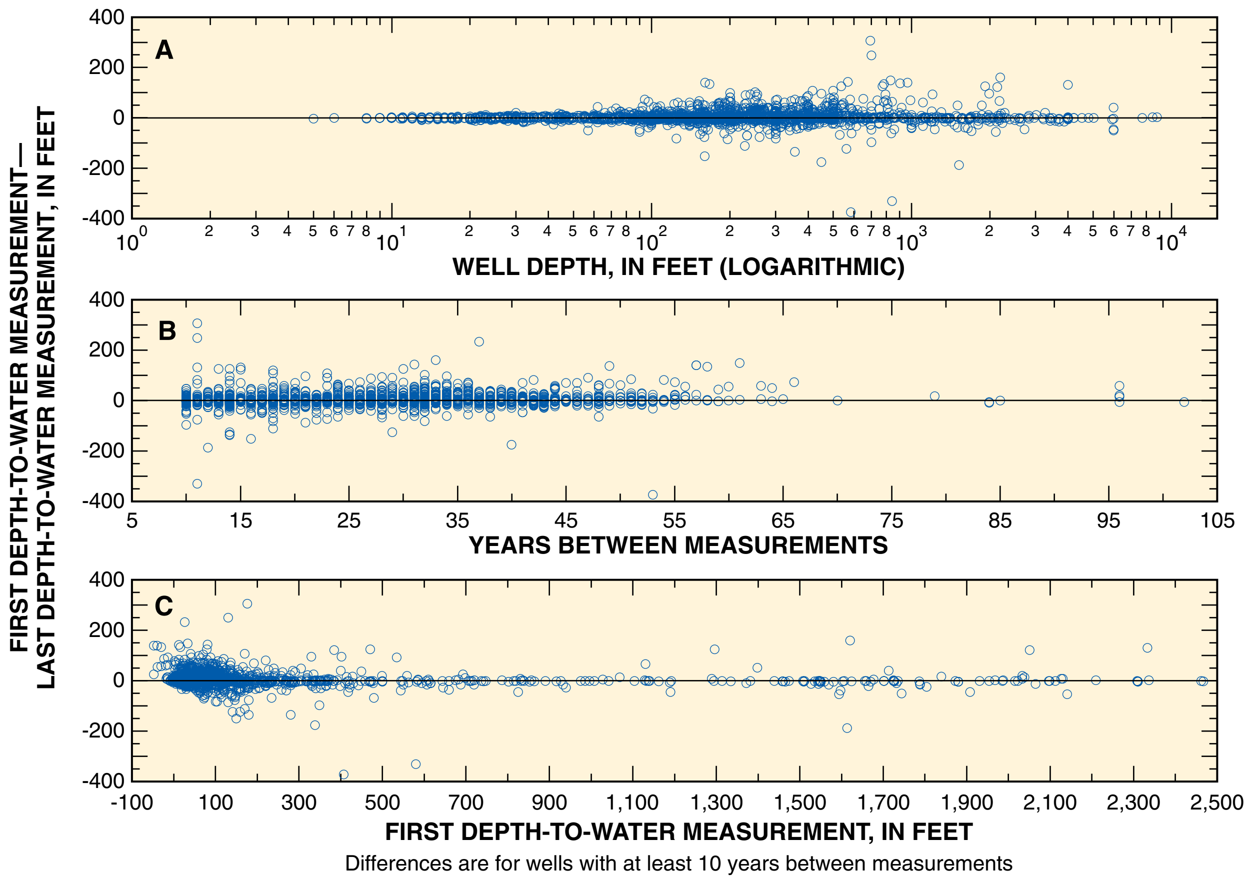

Figure 9. Differences between last and first depth-to-water measurements versus **A**, well depth, **B**, years between measurements, and **C**, first depth-to-water measurement.

ous studies in Nevada measured gradients beneath alluvial fans that range from 0.005 to 0.02 and beneath valley floors from 6 x 10 –7 to 0.002 (Handman and Kilroy, 1997, p. 61; Harrill and Preissler, 1994, p. 10; Maurer, 1986, p. 17; Prudic and Herman, 1996, p. 16; Thomas and others, 1989, pl. 2). Gradients between 26 wells in basin fill and consolidated rock and the lake-surface altitude of Lake Tahoe ranged from 0.001 to 0.120 and had a median of 0.02, a mean of 0.02, and a standard deviation of 0.03 (Thodal, 1997, p. 24).

Gradients from this study, horizontal hydraulic conductivity from Maurer and others (2004), effective porosity, and equation 1 can be used to estimate ground-water velocities in Nevada. Effective porosity is closely approximated by specific yield, which is a more commonly measured variable. Specific yield is the fraction of the saturated aquifer that drains by gravity when the water table drops. Effective porosity and specific yield exclude isolated pores and water that is too strongly adsorbed to clay and other particles to drain. Porosity and specific yield depend on variables such as particle size, degree of sorting, and depth (Cohen, 1963; Johnson, 1967). Basins that have large, flow-through rivers tend to have well-sorted sediments and higher specific yields than other basins. For example, the median specific yield of Carson Valley is 21 percent, compared to 10 to 14 percent for Paradise Valley, Smith Creek Valley, and Stagecoach Valley (Harrill and Prudic, 1998, table 7).

Alluvial fans have a median gradient of 0.02 and a mean horizontal hydraulic conductivity of about 70 ft/d and valley floors have a median gradient of 0.005 and a mean horizontal hydraulic conductivity of about 45 ft/d (Maurer and others, 2004, table 2). An effective porosity of 0.12 was used for alluvial fans and 0.2 for well-sorted sand and gravel in valley floors. Using these values in equation 1, the average linear velocity of ground water beneath alluvial fans is about 14 ft/d, compared to about 1 ft/d beneath valley floors. This indicates that contaminants travel roughly 10 times faster beneath alluvial fans than beneath valley floors, depending on the physical and chemical properties of the aquifer material and the contaminant.

Like the t-test, the two-sided Wilcoxon rank-sum test compares differences between two populations, but the Wilcoxon rank-sum test is more appropriate for small sample sizes. The Wilcoxon rank-sum test indicated that gradients beneath alluvial fans are significantly larger (p-value = 0.01) than gradients beneath valley floors, even though the largest gradients were measured beneath valley floors (fig. 11A). This

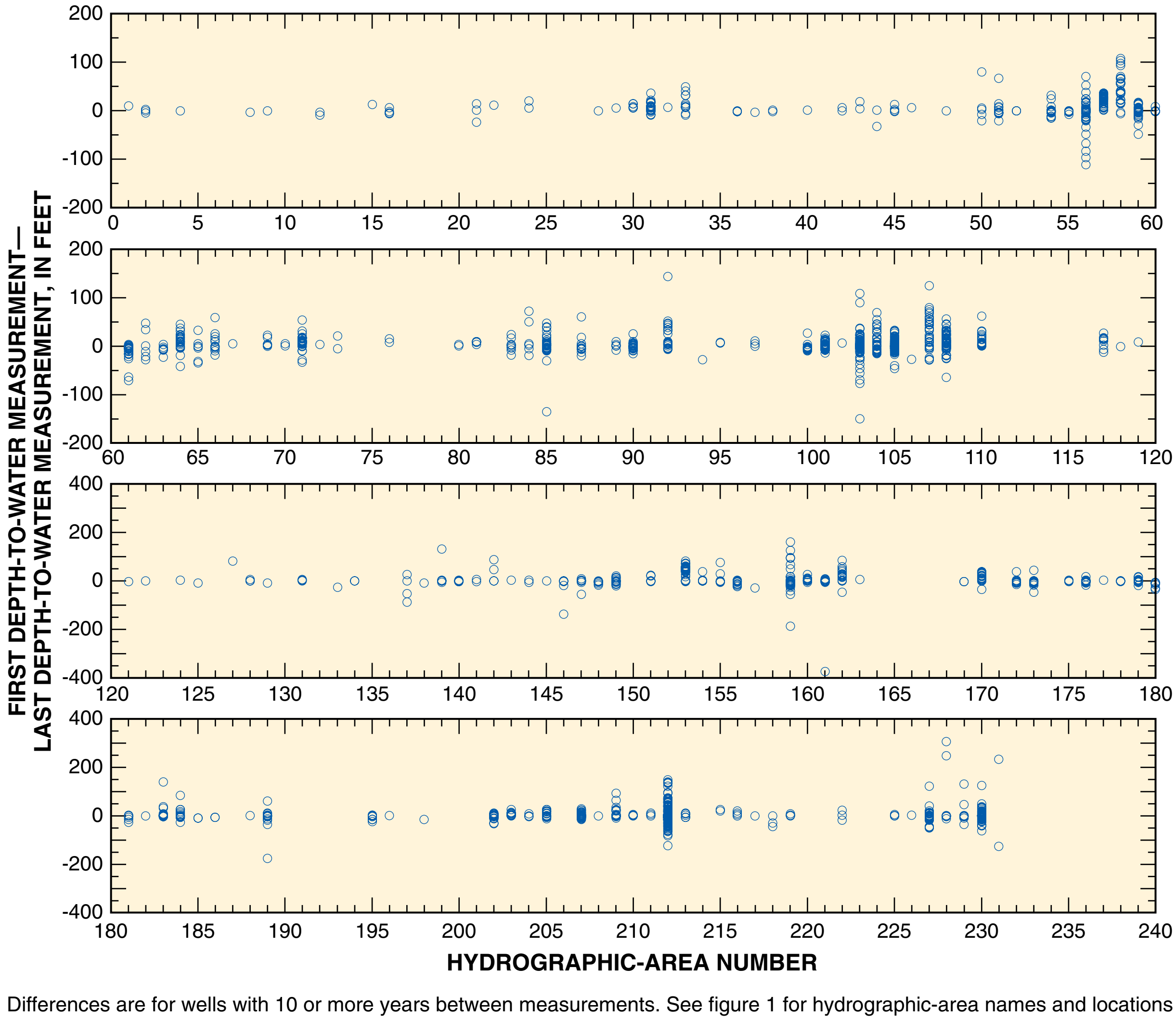

Figure 10. Differences between last and first depth-to-water measurements grouped by hydrographic-area number.

finding is consistent with the general description of the water table in Nevada. The large gradients measured in the valley floor could be due to error in location of the wells, the alluvial fan-valley floor contact, well altitude, or other reasons.

The Kruskal-Wallis rank test compares differences among more than two populations. This test indicated significant differences (p-value = 0.01) among gradients adjacent to different consolidated rocks (fig. 11B). These differences could be related to the horizontal hydraulic conductivity of the consolidated rocks and the sediments derived from them. The Spearman rank correlation is used to determine if a general but not necessarily linear relation exists between correlated variables. The Spearman rank correlation between the gradient and horizontal hydraulic conductivity of the consolidated rock was -0.30 (p-value = 0.02; fig. 12A). The inverse correlation makes hydrologic sense if gradients in unconsolidated sediments are related to the horizontal hydraulic conductivity of adjacent consolidated rocks.

Spearman rank correlations were statistically significant between gradients and precipitation upgradient of the site (0.32; fig. 12B), distance to the alluvial-fan contact (-0.31), and distance to the consolidated-rock contact (-0.41; fig. 12C). Although weak, these correlations also make physical sense. Decreasing gradients with increasing distance from the mountain front is consistent with the general description of the water table along mountain fronts (Eakin and others, 1976; Maurer and others, 2004) and with precipitation upgradient of a site being the driving force for gradients.

Prior to pumping, the water tables in Vicee and Kyle Canyons had similar shapes and were nearly parallel to land-surface altitudes (fig. 13). Linear regression of water-table altitude with land-surface altitude from both sites had a significant (p-value <0.01) slope of 0.89 and an r-squared of 0.97. This relation supports using linear interpolation of water-table contours. If this relation is valid for other hydrogeologic settings, then the water table could be estimated from a few measurements in a basin.

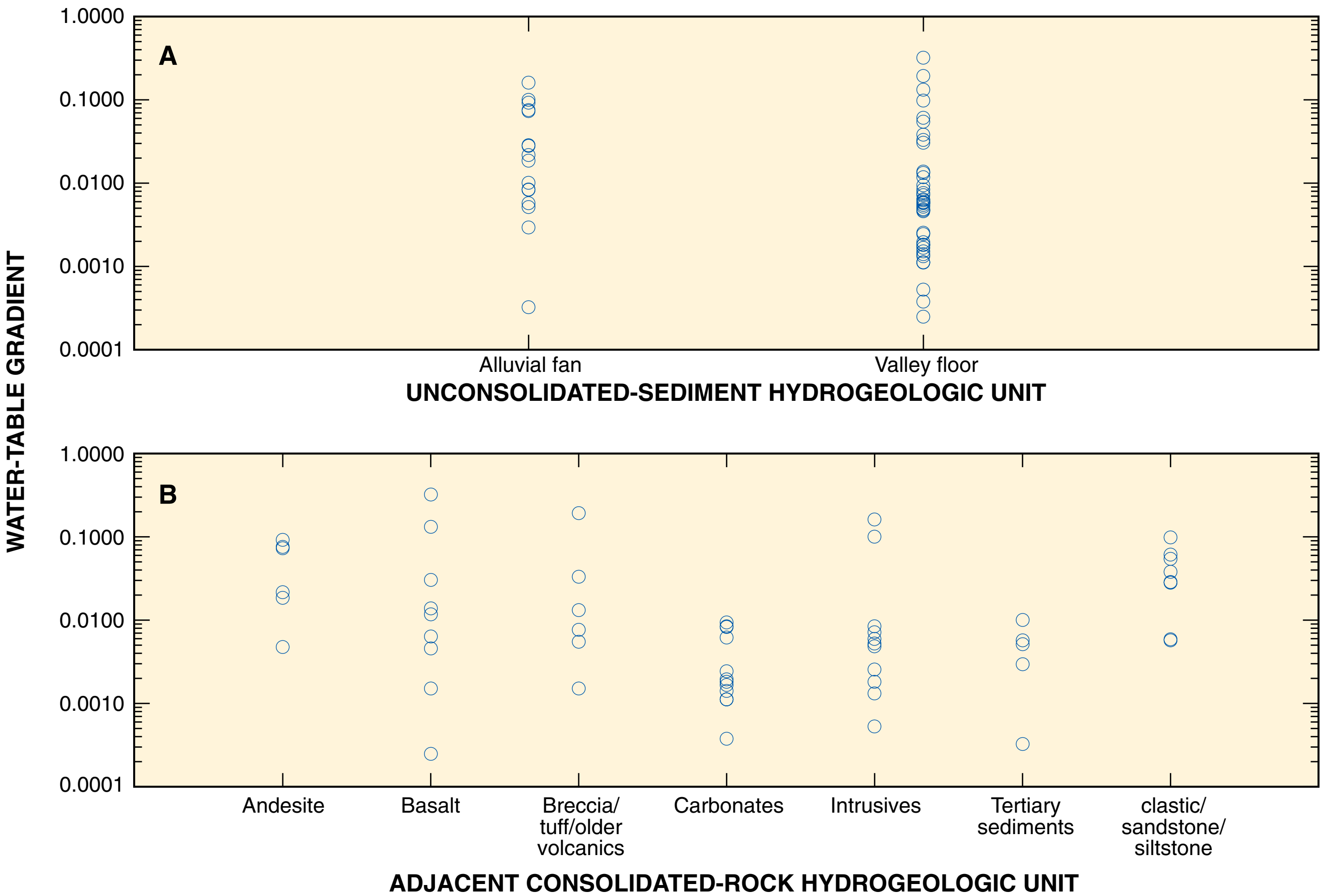

Figure 11. Ranges in water-table gradients **A**, beneath alluvial fans and valley floors and **B**, grouped by adjacent consolidated-rock hydrogeologic unit.

The recent (2000–2004) water tables at Pine Nut Creek and Vicee Canyon are similar and are not parallel to land-surface altitudes. At Pine Nut Creek, the water table is fairly flat to about one mile into the alluvial fan and then changes abruptly near the consolidated-rock contact, which is similar to the recent water table at Vicee Canyon. This similarity could be due to pumping in the alluvial fan that has lowered the water table or Pine Nut Creek has unique hydrogeologic characteristics. Production wells at Vicee Canyon have had a large effect on the water table. Recent measurements indicate that the gradient has reversed, with flow from the valley floor toward the consolidated rock. The lowest water-table altitude is at mile 1.27, between the production well drilled in 1972 and the consolidated-rock contact (fig. 13), which is consistent with pumpage near a low-flow boundary. The non-linear relation at Vicee Canyon likely depends on the amount of pumpage, which would make it difficult to estimate the water table at developed sites. This study used existing data to characterize gradients. A study specifically designed to characterize gradients may result in stronger correlations that could be used to estimate gradients and the water table where few data exist.

Summary

In 1999, the U.S. Environmental Protection Agency started a program to protect the quality of ground water in areas other than ground-water protection areas. OSGWAs are areas that are not currently, but could eventually be, used as a source of drinking water. The OSGWA program specifically addresses existing wells that are used for underground injection of motor vehicle waste. If an injection well is in a ground-water protection area or an OSGWA, well owners must either close the well or apply for a permit. NDEP will evaluate site-specific information associated with the permit application and determine if the aquifer at the site is sensitive, rather than designate specific areas as OSGWAs. To evaluate permit applications, NDEP needs statewide information on depth to water and the water table, which partly control the susceptibility of ground water to contamination and contaminant transport. In a cooperative study with NDEP, the USGS used published maps and data to make statewide maps of water-table levels and characterize water-table gradients.

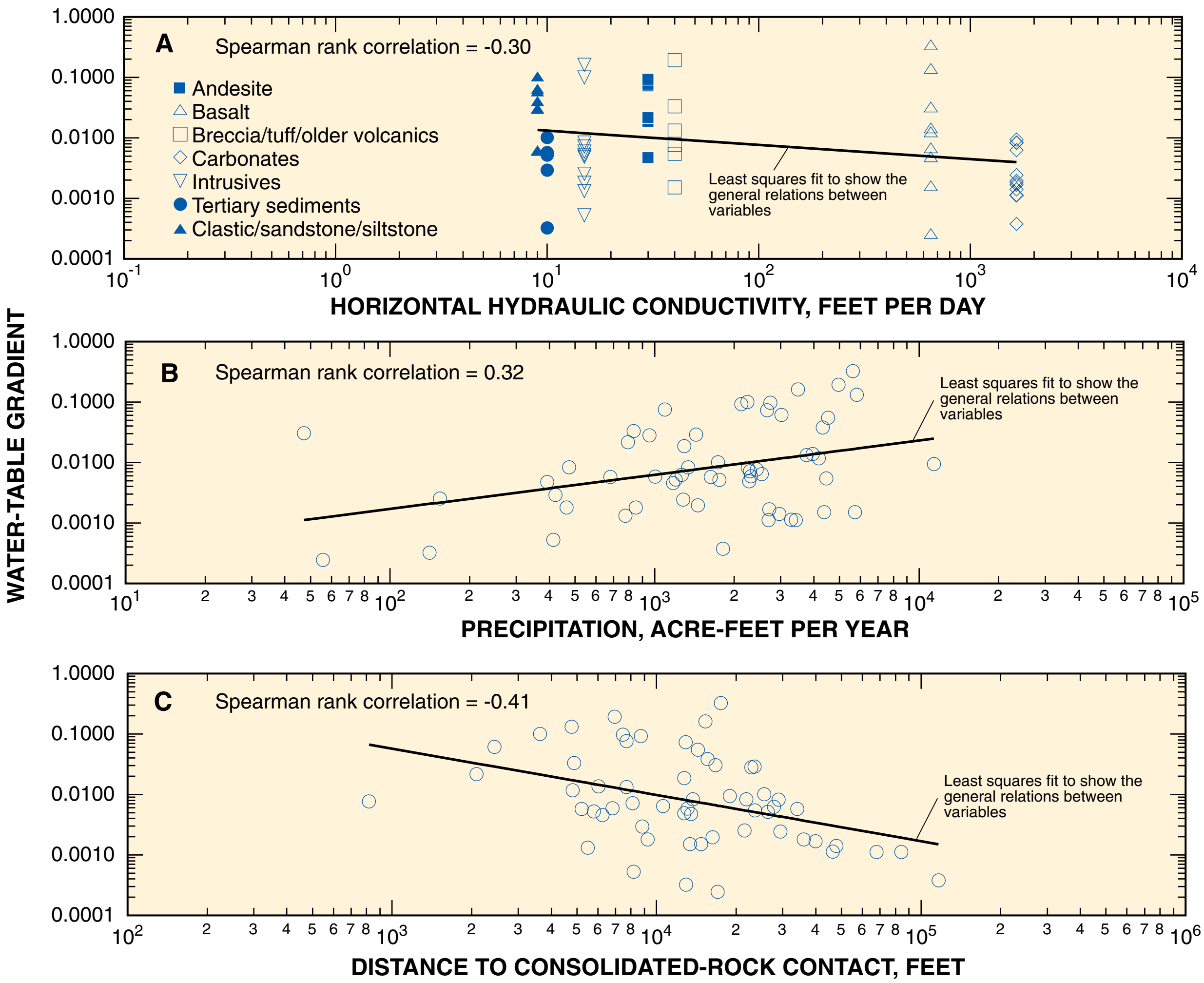

Figure 12. Water-table gradients in unconsolidated sediments versus ***A***, horizontal hydraulic conductivity of adjacent consolidated hydrogeologic unit, ***B***, upgradient precipitation, and ***C***, distance to consolidated-rock contact.

A literature search of published water-table and depth-to-water contours produced maps of varying detail and scope in 104 reports published from 1948 to 2004. Twenty-eight maps had depth-to-water contours and 90 maps had water-table contours. The most recent, detailed maps that covered the largest area and had plotted control points were chosen for this study. Where multiple maps covered the same HA, the map that covered multiple HAs was chosen. These selection criteria resulted in water-table and depth-to-water contours that are based on data collected from 1947 to 2004 being selected from 39 reports. If not already available digitally, contours and control points were digitized from selected maps, entered into a GIS, and combined to make a statewide map of water-table contours. Water-table surfaces were made by using inverse-distance weighting to estimate the water table between contours and gridding the estimates. Depth-to-water surfaces were made by subtracting water-table altitude from land-surface altitude.

Water-table and depth-to-water surfaces were made for only 21 percent of Nevada due to a lack of information for 49 of 232 HAs and in most consolidated-rock hydrogeologic units. Depth to water is commonly less than 50 feet beneath valley floors, 50 to 500 feet beneath alluvial fans, and greater than 500 feet in some areas such as north-central and southern Nevada. In areas without water-table information, greasewood and mapped ground-water discharge areas are good indicators of depth to water that is less than 100 feet. The accuracy of the surfaces was evaluated by comparing depth to water measured at 682 wells with depth to water estimated from depth-to-water surfaces. The average difference between measured and estimated depth to water was 90 feet. To evaluate a specific site, more recent and detailed data may be needed.

The greatest increases in depth to water occurred where the first measurement was less than 200 feet, where the time between first and last measurements was 40 years or less, and for wells 100 feet to 600 feet deep. These characteristics describe production wells where ground water is fairly shallow

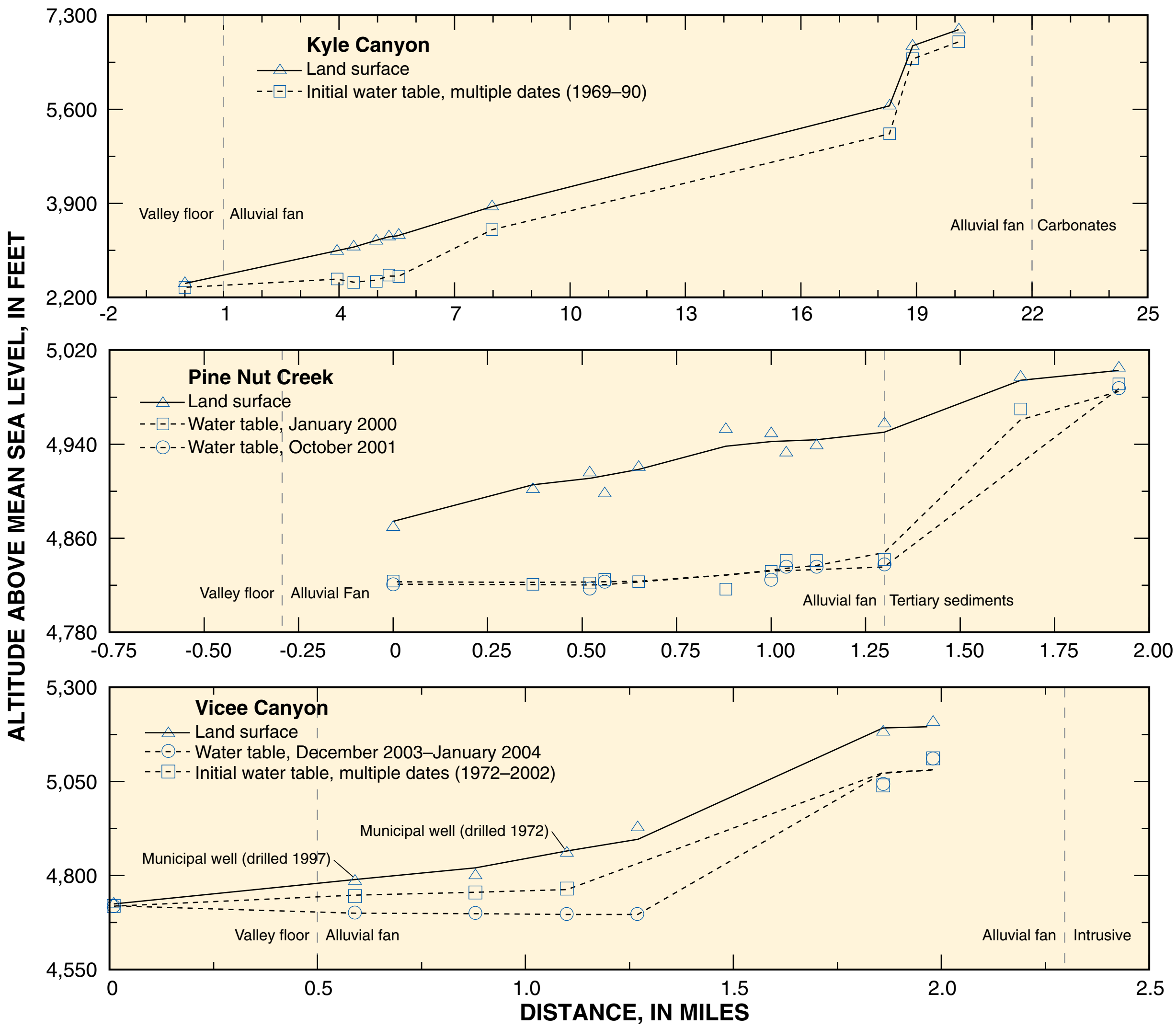

Figure 13. Water-table and land-surface altitude versus distance from the well at the lowest land-surface altitude in Kyle Canyon, Pine Nut Creek, and Vicee Canyon.

in recently developing areas such as the Las Vegas and Reno metropolitan areas. In basins with little pumping, 90 percent of the changes during the past 100 years are within ±20 feet, which is about the natural variation to expect in the water table due to changes in the climate and recharge.

Gradients in unconsolidated sediments of the Great Basin are generally steep near mountain fronts and shallow beneath valley floors. Variables that could affect gradients in unconsolidated sediments include the source rock and texture of unconsolidated sediments, amount of recharge and distance from recharge areas, and other variables such as the horizontal hydraulic conductivity of adjacent consolidated rocks. To identify important variables, gradients beneath alluvial fans and valley floors at 58 sites were correlated with the distance to the alluvial-fan contact, distance to and horizontal hydraulic conductivity of the adjacent consolidated hydrogeologic unit, and precipitation upgradient of the sites. In addition, water-level measurements were used to characterize the water table between the valley floor and consolidated rock at Vicee Canyon in Eagle Valley, Pine Nut Creek in Carson Valley, and Kyle Canyon in Las Vegas Valley.

Water-table gradients beneath alluvial fans ranged from 0.0003 to 0.2 and had a median of 0.02, a mean of 0.04, and a standard deviation of 0.05. Gradients beneath valley floors ranged from 0.0002 to 0.3 and had a median of 0.005, a mean of 0.03, and a standard deviation of 0.07. Information from this and other reports suggest that the average linear velocity of ground water is roughly 10 times faster beneath alluvial fans than beneath valley floors. Contaminants may travel about 10 times faster beneath alluvial fans than beneath valley floors, depending on the physical and chemical properties of the aquifer material and contaminant.

Gradients associated with different types of consolidated rocks are significantly different, which could be related to the horizontal hydraulic conductivity of the consolidated rocks and the sediments derived from them. Spearman rank correlations were statistically significant between gradients and the horizontal hydraulic conductivity of adjacent consolidated-rock hydrogeologic units (-0.30), precipitation upgradient of the site (0.32), distance to the alluvial-fan contact (-0.31), and distance to the consolidated-rock contact (-0.41). These relations are consistent with the general description of the water table along mountain fronts and with precipitation being the driving force for gradients.

Before large pumping in Vicee and Kyle Canyons, the water tables in both areas were similar and were nearly parallel to land-surface altitude. Linear regression of water-table altitude with land-surface altitude from both sites had a slope of 0.89 and an r-squared of 0.97. If this relation is valid for other hydrogeologic settings, then the water table could be estimated from a few measurements in a basin. The recent water tables at both Pine Nut Creek and Vicee Canyon were not parallel with land-surface altitude. This similarity could be due to pumpage in the alluvial fan that has lowered the water table or Pine Nut Creek has unique hydrogeologic characteristics. Production wells in Vicee Canyon have reversed the gradient and caused ground water to flow from the valley floor toward the consolidated rock. The non-linear relation at Vicee Canyon likely depends on the amount of pumpage, which would make it difficult to estimate water-table levels at developed sites. This study used existing data to characterize gradients. A study specifically designed to characterize gradients may result in stronger correlations that could be used to estimate gradients and the water table where few data exist.

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Plates

Plates are found in separate PDF files. Click on the desired link to view or download plate.

Plate 1. Map showing water-table contours in Nevada, 1947–2004.

Plate 2. Map showing water-table surfaces in Nevada, 1947–2004. (Lower resolution version here)

Plate 3. Map showing depth-to-water surfaces in Nevada, 1947–2004. (Lower resolution version here)

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