Prepared in cooperation with Eureka County, Nevada

Data Network, Collection, and Analysis in the Diamond Valley Flow System, Central Nevada

Open-File Report 2011–1089

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

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U.S. Department of the Interior
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KEN SALAZAR, Secretary

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations and Acronyms

ET	evapotranspiration
meq/L	milliequivalents per liter
MSAVI	Modified Soil-Adjusted Vegetation Index
NDWR	Nevada Division of Water Resources
NAIP	National Agriculture Imagery Program
NRCS	Natural Resources Conservation Service
NWIS	USGS National Water Information System
NWQL	USGS National Water Quality Lab
SSURGO	Soil Survey Geographic soils database
TM	Thematic Mapper
USGS	U.S. Geological Survey

Data Network, Collection, and Analysis in the Diamond Valley Flow System, Central Nevada

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Abstract

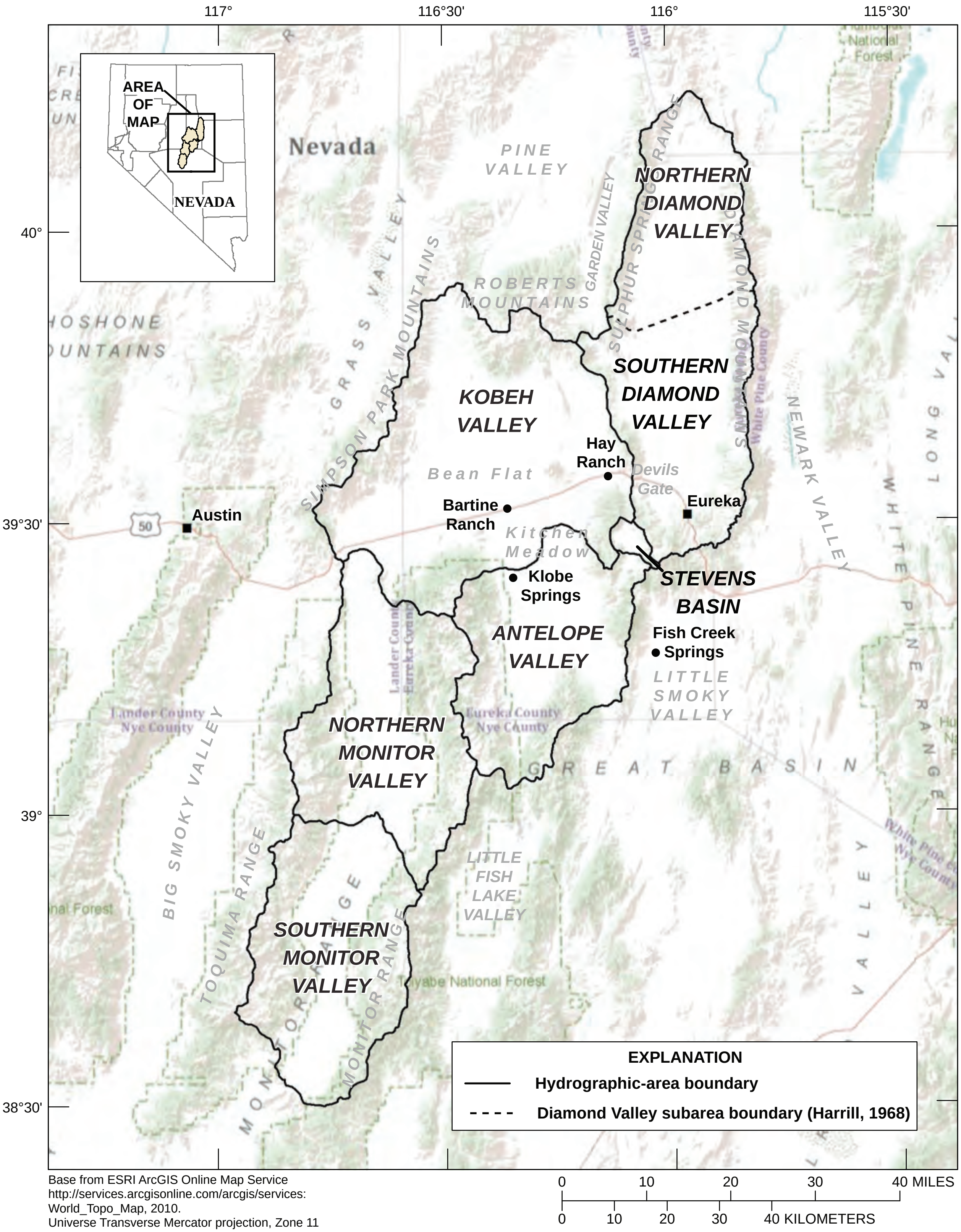
Future groundwater development and its effect on future municipal, irrigation, and alternative energy uses in the Diamond Valley flow system are of concern for officials in Eureka County, Nevada. To provide a better understanding of the groundwater resources, the U.S. Geological Survey, in cooperation with Eureka County, commenced a multi-phase study of the Diamond Valley flow system in 2005. Groundwater development primarily in southern Diamond Valley has resulted in water-level declines since the 1960s ranging from less than 5 to 100 feet. Groundwater resources in the Diamond Valley flow system outside of southern Diamond Valley have been relatively undeveloped.

Data collected during phase 2 of the study (2006–09) included micrometeorological data at 4 evapotranspiration stations, 3 located in natural vegetation and 1 located in an agricultural field; groundwater levels in 95 wells; water-quality constituents in aquifers and springs at 21 locations; lithologic information from 7 recently drilled wells; and geophysical logs from 3 well sites. This report describes what was accomplished during phase 2 of the study, provides the data collected, and presents the approaches to strengthen relations between evapotranspiration rates measured at micrometeorological stations and spatially distributed groundwater discharge. This report also presents the approach to improve delineation of areas of groundwater discharge and describes the current methodology used to improve the accuracy of spatially distributed groundwater discharge rates in the Diamond Valley flow system.

Introduction

Encompassing about 3,000 mi^2, the Diamond Valley flow system (Harrill and others, 1988) in central Nevada consists of five hydrographic areas including southern and northern Monitor Valleys, Kobeh, and Antelope Valleys, Stevens Basin, and Diamond Valley (fig. 1). Prior to groundwater development, the large discharge area in northern Diamond Valley was the terminus of the flow system. Beginning in the mid-20th century, groundwater resources in southern Diamond Valley have been developed for irrigation and mining uses. Limited groundwater development has occurred in areas of Kobeh and Antelope Valleys. Other hydrographic areas in the flow system are largely undeveloped (Tumbusch and Plume, 2006).

Future groundwater development and its effect on future municipal, irrigation, and alternative energy uses are of concern for officials in Eureka County, Nevada. To improve understanding of the groundwater resources, the U.S. Geological Survey (USGS), in cooperation with Eureka County, commenced a multi-phase study of the Diamond Valley flow system in 2005. The results of phase 1 (2005–06) are published in Tumbusch and Plume (2006). The 2006 report describes the geologic setting including water-bearing characteristics of the hydrogeologic units and the occurrence and movement of groundwater in the basin-fill aquifers. Phase 2 of the study (2006–09) focused on refining groundwater discharge estimates and developing a conceptual model of the Diamond Valley flow system. Data collection and interpretations to meet these objectives are still ongoing (2011). This report describes what was accomplished during phase 2, provides the data, and presents approaches that will be used to strengthen relations between evapotranspiration (ET) rates measured at micrometeorological stations and spatially distributed estimates of groundwater discharge. This report also presents the approach to improve delineation of areas of groundwater discharge and describes the current methodology used to improve the accuracy of spatially distributed groundwater discharge rates in the Diamond Valley flow system. Collection of hydrologic data including groundwater levels, groundwater and spring water-quality constituents, and ET rates continues during phase 3 of the study (2009–13). Using the data collected during the three phases, spatially representative distributions of groundwater discharge estimates and water-quality characteristics will be presented, as well as baseline hydrologic conditions for undeveloped areas. This information and a conceptual model of the flow system will be provided in a USGS Scientific-Investigations Report to be published at the end of phase 3.



Base from ESRI ArcGIS Online Map Service
http://services.arcgisonline.com/arcgis/services:
World_Topo_Map, 2010.
Universe Transverse Mercator projection, Zone 11
North American Datum of 1983.

Figure 1. Locations of hydrographic areas and selected geographic features of the Diamond Valley flow system, central Nevada.

Data-Collection Network

Data collected during phase 2 of the study included micrometeorological data at 4 ET stations, 3 located in natural vegetation and 1 located in an agricultural field; groundwater levels in 95 wells; water-quality constituents in aquifers and springs at 21 locations; lithologic information from 7 recently drilled wells; and geophysical logs from 3 well sites (table 1). The locations of data-collection sites are shown in figure 2. Water levels in wells are measured in the spring to early summer and most wells have data since 2005. Several wells in the study area have much longer periods of record, some going back to the mid-20th century. Seven wells were drilled during the study; three associated with the natural vegetation ET stations and four observation wells. One well is located in Antelope Valley and three wells are located in Diamond Valley. The lithology is described in drillers' logs shown in appendix A. The logs also are available in the State of Nevada Division of Water Resources well log database (State of Nevada, 2011, available at http://water.nv.gov/engineering/wlog/wlog.cfm).

Quality of Water in Aquifers and Springs

The chemical composition of water in the Diamond Valley flow system is controlled by the differences in the composition and solubility of aquifer material and the length of time that the water has been in contact with these materials. Generally, the longer the residence time the greater the concentrations of solutes. Precipitation contributes only minor amounts of solutes. Evaporation can increase concentrations of most major ions, but chemical reactions also can remove selected solutes by mineral precipitation and ion exchange. Major-ion composition and total dissolved solids affect the aesthetic properties of water, such as taste, color, and odor, and other properties, such as sodium adsorption ratio, which may adversely affect the suitability of water for crop irrigation.

Water-quality samples were collected from 21 sites—18 wells and 3 springs—during August and November 2008. Data collected included field parameters, dissolved solids and major ions, and stable isotopes (table 2). All water-quality samples and field parameters were collected using standard USGS National Field Manual methods and protocols (U.S. Geological Survey, 2010, available at http://water.usgs.gov/owq/FieldManual/index.html). Groundwater and spring samples were collected using a portable pump at all sites except two wells. Field parameters including water temperature, dissolved oxygen, pH, and specific conductance were collected using a flow-through chamber fitted with probes at wells and springs that could be sampled using a pump. Due to their small size (2-in. diameter) and limited yields, wells KW26 and AW6 were sampled using a Teflon® bailer and field parameters were measured in a beaker (table 2). Alkalinity was determined in the field by titrating 50 mL aliquots of filtered water to the inflection point at pH 4.5. Water samples were collected and stored at ambient temperature in plastic ice chests prior to overnight delivery for laboratory analyses. Samples analyzed for major ions were sent to the USGS National Water Quality Laboratory (NWQL) in Denver, Colo. Samples analyzed for stable isotopes were sent to the USGS Isotope Laboratory in Reston, Va.

Types of water can be classified based on the relative abundance of specific cations and anions, expressed in milliequivalents per liter (meq/L), and plotted as Stiff diagrams (Stiff, 1951). Stiff diagrams have three parallel horizontal axes. Concentrations, in meq/L, of sodium and potassium, calcium, and magnesium are plotted, one on each of the horizontal axes to the left of the vertical zero axis; and chloride, bicarbonate and carbonate, and sulfate are plotted, one on each of the horizontal axes to the right of the vertical axis. These six points form a polygon. The shape of the polygon indicates the water composition or type. The size of the polygon indicates the total ionic content (Hem, 1985). Figure 3 shows the Stiff diagrams for the 21 water-quality samples analyzed during phase 2 of the study.

Table 1. Site identification, location, site type, characteristics, and data type for the Diamond Valley flow system, central Nevada.

[Locations of sites are shown in figure 2. ET, evapotranpiration; SPG, spring; DW, Diamond Valley well; KW, Kobeh Valley well; AW, Antelope Valley well; MW, Monitor Valley well altitude in feet above datum; depth in feet below land surface; screened interval in range of feet below land surface; –, no data; NAD 83, North American Datum of 1983; NAVD 88, North American Vertical Datum of 1988]

Site No.	Site identification No.	Station name	Site type	Latitude NAD 83	Longitude NAD 83	Altitude NAVD 88	Depth	Screened interval	Type of available data				
									Water levels	Water quality	Hydro-graphs	Well drillers report	Geo-physical logs
ET1	395006116030101	153 N23 E53 31BBDD DV NORTH ET	ET	395006	1160304	5,901	–	–	–	–	–	–	–
ET2	393711116124501	139 N20 E51 10DDCB1 KVE ET	ET	393711	1161248	6,139	–	–	–	–	–	–	–
ET3	393553116252401	139 N20 E49 23ACCB1 KVW ET	ET	393553	1162527	6,054	–	–	–	–	–	–	–
SPG1	395412116081601	053 N23 E52 05ACCB McCloud Spring	spring	395412	1160816	6,513	–	–	–	X	–	–	–
SPG2	393316115540501	153 N20 E54 33CABC1 Four Eyed Nicks Spring	spring	393316	1155405	6,820	–	–	–	X	–	–	–
SPG3	393400116392401	139 N20 E47 26CBCC1 Goldfish Spring	spring	393400	1163924	6,684	–	–	–	X	–	–	–
DW1	400116115534801	153 N25 E54 28BCBC1	well	400116	1155351	5,814	55	20–55	X	–	–	–	–
DW2	395441116040501	153 N24 E52 36CCCA1	well	395441	1160408	5,810	–	–	X	–	–	–	–
DW3	395255116051101	153 N23 E52 11ADAA1	well	395328	1160421	5,805	98	–	X	X	–	–	–
DW4	395220115561001	153 N23 E54 18DB 1 USGS	well	395220	1155543	5,804	32	30–32	X	–	–	–	–
DW5	395147116043901	153 N23 E52 13CDBD1 TULE	well	395206	1160354	5,804	–	–	X	–	–	–	–
DW6	395100115593001	153 N23 E53 27BBBA1 USGS	well	395104	1155944	5,824	22	20–22	X	X	–	–	–
DW7	395020116030001	153 N23 E53 29CCCA1 USGS	well	395021	1160159	5,823	22	20–22	X	–	X	–	–
DW8	395008116040701	153 N23 E52 36BBDB1 SULPHUR	well	395005	1160412	5,824	–	–	X	–	–	–	–
DW9	395003116030101	153 N23 E53 31BBDD DV NORTH ET	well	395003	1160301	5,814	59	50–55	X	–	–	X	–
DW10	394717116044901	153 N22 E52 14ABDA1 VIEW WELL	well	394734	1160439	5,862	83	–	X	X	–	–	–
DW11	394703115560401	153 N22 E54 18CADD	well	394702	1155607	5,852	258	134–258	–	–	X	–	–
DW12	394657116074401	153 N22 E52 17DDAC1	well	394657	1160747	6,141	–	–	X	–	–	–	–
DW13	394654116073801	153 N22 E52 16CCCB1 ROMANO WINDMILL	well	394654	1160741	6,121	–	–	X	–	–	–	–
DW14	394520115524001	153 N22 E54 27CABB1	well	394530	1155250	5,870	94	–	X	–	–	–	–
DW15	394342114385402	153 N21HE52 35ADD 2 USBLM	well	394349	1160421	5,887	160	140–160	X	–	–	–	–
DW16	394232115545701	153 N21 E54 5DCCC	well	394234	1155459	5,882	–	–	–	–	X	–	–
DW17	394220116055002	153 N21 E52 10AAAC2 WEST DIAMOND VALLEY 2 SHAL	well	394220	1160553	6,104	375	350–370	X	X	–	–	–
DW18	394220116055001	153 N21 E52 10AAAC1 WEST DIAMOND VALLEY 1 DEEP	well	394220	1160553	6,104	499	479–499	X	X	–	X	X
DW19	394149116003201	153 N21 E53 09DBDD	well	394152	1160023	5,897	182	–	–	–	X	–	–
DW20	394112116032301	153 N21 E53 18BCCC1	well	394112	1160326	5,924	–	–	X	–	–	–	–
DW21	394056115585001	153 N21 E53 14CACC	well	394100	1155841	5,903	180	–	–	–	X	–	–
DW22	393705115574201	153 N20 E53 02DDDD	well	393704	1155745	5,967	250	120–250	–	–	X	–	–
DW23	393623115593301	153 N20 E53 10CACC1 APSW	well	393624	1155943	5,946	214	80–204	X	–	–	–	–
DW24	393534116012601	153 N20 E53 17DCAA1 GID2	well	393532	1160125	5,951	214	[a]80–214	X	–	–	–	–
DW25	393453116014201	153 N20 E53 20CBDD1 SI	well	393441	1160145	5,964	200	100–200	X	–	–	–	–
DW26	393447115570001	153 N20 E53 24DBAC1 BI	well	393447	1155703	6,081	275	210–274	X	–	–	–	–
DW27	393422116042502	153 N20 E52 26AABC2 DEVILS GATE 2 SHALLOW	well	393422	1160428	5,974	101	76–96	X	X	–	–	–
DW28	393422116042501	153 N20 E52 26AABC1 DEVILS GATE 1 DEEP	well	393422	1160428	5,974	181	156–176	X	X	–	X	X
DW29	393413116023001	153 N20 E53 30ABCC	well	393415	1160236	5,988	155	–	–	–	X	–	–
DW30	393335116005301	153 N20 E53 29DDDC1 GID1	well	393335	1160057	6,014	400	200–400	X	–	–	–	–
DW31	393327116013601	153 N20 E53 32BDCC1	well	393312	1160142	6,056	218	120–200	X	–	–	–	–
DW32	393244116024401	153 N20 E53 31CDCC1 SOUTH OF DEVILS GATE	well	393244	1160244	6,211	338	288–328	X	X	–	X	–
DW33	393143115572701	153 N19 E53 12C 1	well	393143	1155730	6,504	8	–	X	–	–	–	–

Table 1. Site identification, location, site type, characteristics, and data type for the Diamond Valley flow system, central Nevada.—Continued

[Locations of sites are shown in figure 2. ET, evapotranpiration; SPG, spring; DW, Diamond Valley well; KW, Kobeh Valley well; AW, Antelope Valley well; MW, Monitor Valley well altitude in feet above datum; depth in feet below land surface; screened interval in range of feet below land surface; –, no data; NAD 83, North American Datum of 1983; NAVD 88, North American Vertical Datum of 1988]

Site No.	Site identification No.	Station name	Site type	Latitude NAD 83	Longitude NAD 83	Altitude NAVD 88	Depth	Screened interval	Type of available data				
									Water levels	Water quality	Hydro-graphs	Well drillers report	Geo-physical logs
KW1	394514116172301	139 N22 E51 30BABB1 ROBERTS CREEK	well	394502	1161703	6,474	350	110–305	X	–	–	–	–
KW2	394327116235401	139 N22 E50 31CCAC1 RUTABAGA	well	394327	1162357	6,408	289	255–285	X	–	–	–	–
KW3	394216116101701	139 N21 E52 07BBDC1	well	394216	1161020	6,276	–	–	X	–	–	–	–
KW4	394125116223801	139 N21 E50 17BACC1 WAGON	well	394125	1162241	6,226	124	90–124	X	–	–	–	–
KW5	394059116282901	139 N21 E49 16CCBB1	well	394054	1162836	6,242	50	–	X	–	X	–	–
KW6	394036116183401	139 N21 E50 23AABD1 USGS-MX	well	394038	1161840	6,225	139	–	X	–	–	–	–
KW7	393957116103001	139 N21 E51 24DD 1 USGS-MX	well	393956	1161045	6,320	201	–	–	X	–	–	–
KW8	393954116104001	139 N21 E51 24DDDB1	well	393954	1161043	6,154	630	71–630	X	X	–	–	–
KW9	393942116245701	139 N21 E49 25BBDA1	well	393942	1162500	6,189	45	–	X	–	–	–	–
KW10	393829116322401	139 N21 E48 35DBAB1	well	393829	1163227	6,212	–	–	X	–	–	–	–
KW11	393809116105501	139 N21 E51 36DCDB2	well	393809	1161058	6,083	842	60–842	X	–	–	–	–
KW12	393808116105801	139 N21 E51 36DCDB1	well	393808	1161058	6,084	1,100	63–1,100	X	–	–	–	–
KW13	393727116160601	139 N20 E51 07DABC1 LONE MOUNTAIN	well	393727	1161609	6,144	–	–	X	–	–	–	–
KW14	393711116124801	139 N20 E51 10DDCB1 KVE ET	well	393711	1161248	6,052	43	28–43	X	–	–	X	–
KW15	393646116332901	139 N20 E48 10CABB1	well	393646	1163332	6,243	–	–	X	–	–	–	–
KW16	393610116094201	139 N20 E52 18BBBB1	well	393610	1160945	6,013	–	–	X	–	–	–	–
KW17	393558116082201	139 N20 E52 17BCAA1	well	393558	1160825	6,019	–	–	X	–	–	–	–
KW18	393554116252801	139 N20 E49 23ACCB1 KVW ET	well	393554	1162528	6,128	34	24–34	X	–	–	X	–
KW19	393546116092301	139 N20 E52 18ABDB1	well	393604	1160903	6,010	132	[a]20–125	X	–	–	–	–
KW20	393545116075101	139 N20 E52 17DBAA1	well	393545	1160754	6,039	110	85–105	X	–	–	–	–
KW21	393544116084801	139 N20 E52 17BDDA1	well	393551	1160811	6,039	90	–	X	–	–	–	–
KW22	393446116064301	139 N20 E52 21DBDA1	well	393446	1160646	6,004	–	–	X	–	–	–	–
KW23	393246116280501	139 N19 E49 04CCDC1 Solar Stock Well	well	393246	1162808	6,169	–	–	X	X	–	–	–
KW24	393129116212800	139 N19 E50 17ADDD1 Bartine Artesian	well	393127	1162136	6,110	–	–	–	X	–	–	–
KW25	393058116244501	139 N19 E49 24BBAC1	well	393054	1162446	6,263	124	–	X	–	–	–	–
KW26	393043116133201	139 N19 E51 22BCAC1 ANTELOPE VALLEY	well	393043	1161332	6,321	331	275–315	X	X	–	X	X
KW27	393022116414201	139 N19 E47 16CCCB1 Dry Creek Farm	well	393022	1164142	6,326	320	–	–	X	–	–	–
KW28	392956116332201	139 N19 E48 22BDDB1 LINCOLN WELL	well	392955	1163325	6,246	–	–	X	X	–	–	–
KW29	392849116405701	139 N19 E47 28CADD1 USGS-MX	well	392848	1164109	6,286	150	–	X	–	–	–	–
KW30	392821116425401	139 N19 E47 31AADC1 HICKISON WELL	well	392821	1164255	6,312	–	–	X	–	–	–	–
KW31	392811116340201	139 N19 E48 34BCCB1 CAMINO WELL	well	392811	1163352	6,329	146	–	X	–	–	–	–
KW32	392800116380001	139 N19 E47 36BBBA1	well	392831	1163813	6,261	102	69–102	X	–	X	–	–
KW33	392754116213201	139 N18 E50 05DADD1 USGS-MX	well	392744	1162136	6,324	167	–	X	–	–	–	–
KW34	392703116380401	139 N18HE47 01ACBB1 USGS-MX	well	392730	1163731	6,314	176	–	X	–	–	–	–

Table 1. Site identification, location, site type, characteristics, and data type for the Diamond Valley flow system, central Nevada.—Continued

[Locations of sites are shown in figure 2. ET, evapotranpiration; SPG, spring; DW, Diamond Valley well; KW, Kobeh Valley well; AW, Antelope Valley well; MW, Monitor Valley well altitude in feet above datum; depth in feet below land surface; screened interval in range of feet below land surface; –, no data; NAD 83, North American Datum of 1983; NAVD 88, North American Vertical Datum of 1988]

Site No.	Site identification No.	Station name	Site type	Latitude NAD 83	Longitude NAD 83	Altitude NAVD 88	Depth	Screened interval	Type of available data				
									Water levels	Water quality	Hydro-graphs	Well drillers report	Geo-physical logs
AW1	392847116143901	151 N19 E51 33CBAC1 USGS-MX	well	392847	1161436	6,207	160	–	X	–	–	–	–
AW2	392529116133901	151 N18 E51 22BCDC1	well	392517	1161329	6,239	135	65–130	X	–	–	–	–
AW3	392331116164201	151 N18 E51 31BCDD1	well	392331	1161645	6,204	–	–	X	–	–	–	–
AW4	392310116125001	151 N18 E51 34DCCA1 ADRANS WELL	well	392310	1161256	6,339	134	–	X	–	X	–	–
AW5	392137116094901	151 N17 E52 07CACD1 MINE WELL	well	392126	1160948	6,564	351	[b]164–351	X	–	–	–	–
AW6	391935116144901	151 N17 E51 20DDAC1 USGS-MX	well	391937	1161444	6,361	186	–	X	X	–	–	–
AW7	391855116191501	151 N17 E50 26BCCC1 USGS-MX	well	391902	1161912	6,404	160	–	X	–	–	–	–
AW8	391835116163701	151 N17 E51 27CCBC1	well	391843	1161327	6,409	272	201–267	X	–	–	–	–
AW9	391626116155902	151 N16 E51 07DADA2	well	391618	1161545	6,325	105	28–54	X	–	–	–	–
AW10	391601116213201	151 N16 E50 08DDCD1	well	391601	1162135	6,504	–	–	X	–	–	–	–
AW11	391114116185101	151 N15 E50 02CCAB1 USGS-MX	well	391147	1161849	6,470	174	–	X	–	–	–	–
MW1	392654116421401	140A N18HE47 08BBDC1	well	392654	1164214	6,302	108	–	X	–	–	–	–
MW2	392445116414801	140A N18 E47 08DBCB2 NO 4 WELL REPLACEMENT	well	392445	1164149	6,321	–	–	X	–	–	–	–
MW3	391951116413301	140A N17 E47 08ACAC1	well	391950	1164138	6,386	–	–	X	–	X	–	–
MW4	391843116364201	140A N17 E48 18CBBC1 WALDOS WELL	well	391843	1163645	6,684	–	–	X	–	–	–	–
MW5	391147116374101	140A N16 E47 35ABAB1	well	391126	1163824	6,518	180	160–180	X	–	–	–	–
MW6	391058116385501	140A N16 E47 35CBBA1 USGS-MX	well	391101	1163903	6,549	182	–	X	–	–	–	–
MW7	390608116364901	140A N15 E48 30CADD1	well	390617	1163642	6,700	350	–	X	–	–	–	–
MW8	390438116394301	140A N14 E47 03CAAD1 USGS-MX	well	390441	1164001	6,754	169	–	X	–	–	–	–
MW9	390150116403801	140A N14 E47 21DDCA1 USGS-MX	well	390151	1164045	6,810	192	–	X	–	–	–	–
MW10	385819116462301	140B N12 E46 15ADDA1 USGS-MX	well	385254	1164619	6,943	142	–	X	–	–	–	–
MW11	385229116450501	140B N12 E46 13CCBD1	well	385229	1164508	6,819	380	[c]60–380	X	–	–	–	–
MW12	384926116474501	140B N11 E46 04ADCD1	well	384923	1164742	6,850	30	–	X	X	–	–	–
MW13	384736116481801	140B N11 E46 16BDDB1 USGS-MX	well	384742	1164812	6,932	154	–	X	X	X	–	–
MW14	384524116444001	140B N11 E46 36ABBA1	well	384524	1164443	6,873	–	–	X	–	–	–	–
MW15	384354116450201	140B N10 E46 12ACAA1	well	384327	1164447	6,894	13	–	X	–	–	–	–
MW16	384005116480101	140B N10 E46 34AABD1 USGS-MX	well	384010	1164655	7,031	136	–	X	–	–	–	–
MW17	383740116434301	140B N09 E47 07DDCC1	well	383740	1164346	7,095	300	[d]100–300	X	–	–	–	–

Multiple screened intervals, ranges in feet below land surface.

[a] 20-32, 51-60, 87-93, 105-125

[b] 164-229, 317-351

[c] 60-160, 280-380

[d] 100-120, 160-240, 240-300

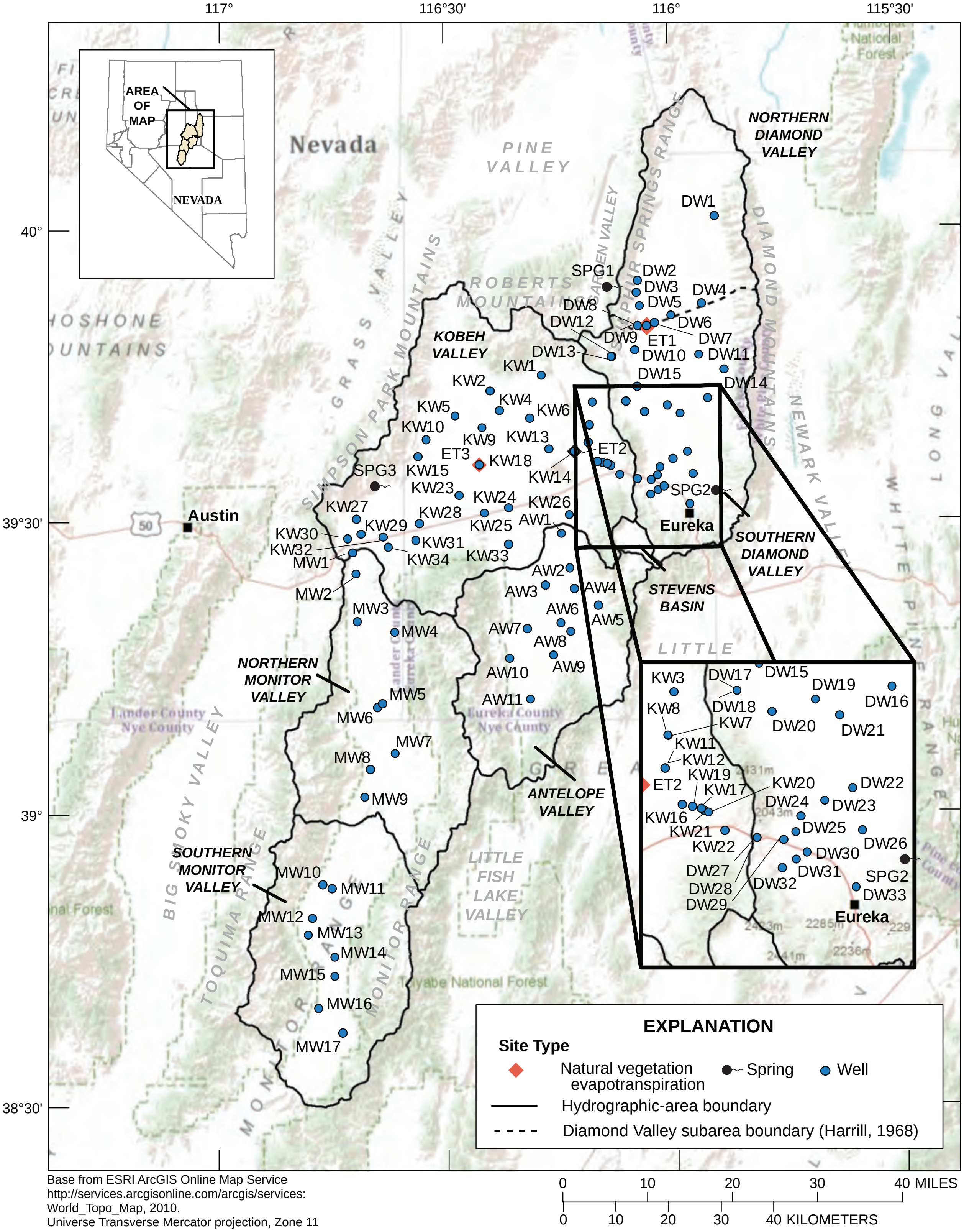


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Figure 2. Locations of data collection sites in the Diamond Valley flow system, central Nevada. Data for sites are shown in table 1.

Table 2. Selected water-quality constituents in water from wells and springs in the Diamond Valley flow system, central Nevada.

[Site number location shown in figure 2. **Abbreviations:** °C, degrees in Celsius; and µS/cm, microsiemens per centimeter <, less than; mg/L, milligrams per liter; permil, one-tenth of 1 percent; carbonate field tritration all less than 2 mg/L; –, not applicable]

Site No.	Date	Time	Temperature (°C)	Specific conductance, lab (µS/cm)	Dissolved oxygen (mg/L)	pH (field)	pH (lab)	Bicarbonate, field, tritration (mg/L)	Hardness (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
SPG1	11-03-08	13:45	11.0	590	4.9	7.0	7.9	290	260	61	26.0
SPG2	08-07-08	9:00	11.0	420	7.8	7.6	8.0	270	180	64	6.0
SPG3	08-05-08	10:00	15.0	1,800	1.3	7.0	7.6	170	870	260	53.0
DW3	11-03-08	16:15	16.5	590	–	7.8	8.3	310	250	58	25.0
DW6	11-05-08	15:20	10.5	1,300	0.6	8.2	8.2	480	170	40	17.0
DW10	08-07-08	13:30	13.5	820	1.9	7.4	8.1	360	240	56	24.0
DW17	11-04-08	14:40	12.5	1,000	1.9	7.8	7.6	280	300	45	45.0
DW18	11-04-08	16:00	10.5	1,000	1.4	8.2	7.7	280	300	46	45.0
DW27	08-06-08	9:30	12.5	1,100	4.6	7.4	7.9	350	260	56	28.0
DW28	08-06-08	8:00	18.0	830	2.3	7.0	8.1	370	280	67	28.0
DW32	11-05-08	14:00	10.0	390	5.3	7.4	8.1	230	200	45	21.0
KW7	11-06-08	10:15	13.5	440	0.4	7.6	8.0	190	140	33	14.0
KW8	11-06-08	13:00	13.0	430	2.7	8.2	8.4	160	160	43	12.0
KW23	08-06-08	12:30	13.0	600	6.2	7.6	8.1	300	120	42	4.9
KW24	08-06-08	15:30	16.5	310	0.8	8.2	8.6	130	13	4.3	0.6
KW26	11-05-08	10:40	10.5	450	–	7.9	7.6	180	120	25	14.0
KW27	08-05-08	12:30	16.0	280	5.8	6.8	7.7	120	61	19	3.2
KW28	08-05-08	15:00	13.0	290	3.2	7.2	8.1	110	85	28	3.8
AW6	11-06-08	15:15	12.5	520	0.6	7.6	7.5	280	210	56	18.0
MW12	08-04-08	15:00	11.5	480	2.5	7.2	7.7	190	100	34	3.6
MW13	08-04-08	10:30	11.5	120	6.3	6.5	7.7	66	36	12	1.7

Site No.	Date	Time	Sodium (mg/L)	Potassium (mg/L)	Chloride (mg/L)	Sulfate (mg/L as SO_4)	Fluoride (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Total dissolved solids (mg/L)	delta deuterium (permil)	delta oxygen-18 (permil)
SPG1	11-03-08	13:45	33.0	2.1	24.0	43.0	0.3	240	350	-121.8	-15.33
SPG2	08-07-08	9:00	14.0	0.9	6.7	8.8	0.2	220	240	-117.3	-15.26
SPG3	08-05-08	10:00	88.0	1.2	17.0	890.0	3.0	140	1,500	-128.6	-16.48
DW3	11-03-08	16:15	34.0	7.6	24.0	42.0	0.4	250	370	-122.7	-15.87
DW6	11-05-08	15:20	220.0	21.0	200.0	7.7	0.6	390	760	-118.5	-14.86
DW10	08-07-08	13:30	71.0	9.9	54.0	63.0	0.3	290	470	-121.6	-15.58
DW17	11-04-08	14:40	120.0	3.3	16.0	300.0	0.7	230	660	-133.8	-16.28
DW18	11-04-08	16:00	120.0	3.3	16.0	300.0	0.7	230	680	-133.5	-16.35
DW27	08-06-08	9:30	140.0	12.0	120.0	96.0	0.2	280	650	-123.3	-15.84
DW28	08-06-08	8:00	70.0	8.5	54.0	55.0	0.3	300	430	-123.2	-15.88
DW32	11-05-08	14:00	7.6	1.2	4.3	18.0	[1]0.07	190	210	-121.7	-15.80
KW7	11-06-08	10:15	37.0	8.1	10.0	48.0	0.5	150	280	-141.2	-17.88
KW8	11-06-08	13:00	27.0	5.8	20.0	45.0	0.3	130	310	-136.8	-17.02
KW23	08-06-08	12:30	91.0	6.4	16.0	37.0	0.8	240	410	-121.4	-15.73
KW24	08-06-08	15:30	56.0	9.0	6.6	22.0	3.2	110	230	-128.5	-16.65
KW26	11-05-08	10:40	48.0	6.3	28.0	22.0	0.5	150	280	-132.1	-16.94
KW27	08-05-08	12:30	27.0	5.3	15.0	18.0	0.2	98	210	-123.8	-16.29
KW28	08-05-08	15:00	24.0	6.3	16.0	23.0	0.2	92	230	-124.6	-16.02
AW6	11-06-08	15:15	27.0	9.0	14.0	25.0	0.6	230	370	-123.0	-16.17
MW12	08-04-08	15:00	54.0	7.0	30.0	38.0	0.4	150	340	-110.2	-14.38
MW13	08-04-08	10:30	11.0	1.1	1.3	2.5	<0.12	54	97	-116.5	-15.65

[1] Value was estimated by U.S. Geological Survey laboratory.

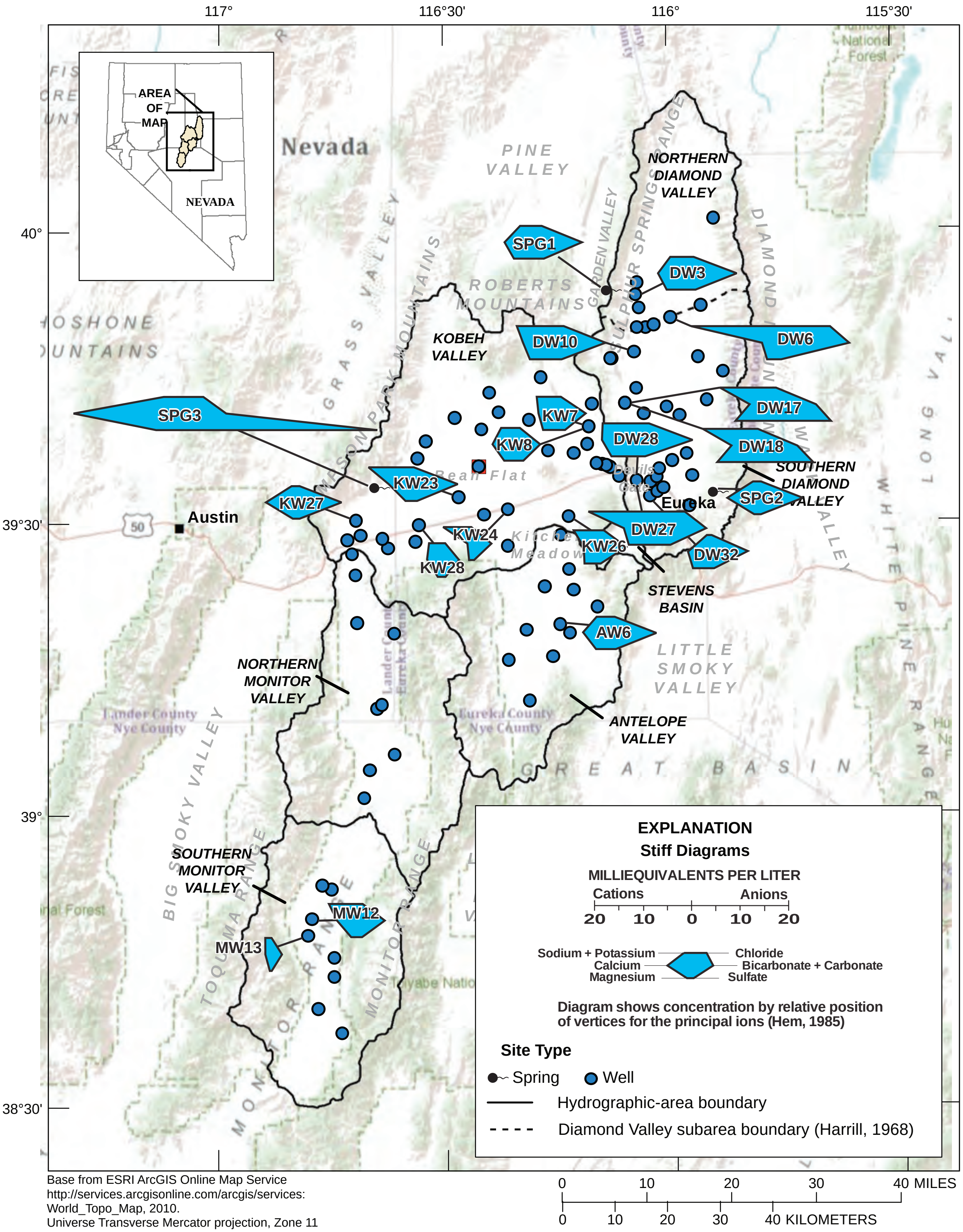

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Figure 3. Relative concentration and water types in aquifers and springs in the Diamond Valley flow system, central Nevada.

Temporal Changes in Groundwater Levels

Previous study phases established a groundwater level network that includes more than 40 wells in Monitor, Kobeh, and Antelope Valleys, and 100 wells in Diamond Valley. Most water levels were collected by the USGS and Nevada Division of Water Resources (NDWR) personnel prior to the irrigation season. Water-level data were compiled from the USGS National Water Information System (NWIS) and the State's databases. Temporal changes in groundwater levels were investigated. Temporal declines in groundwater levels exceeding 10 ft in the Diamond Valley flow system coincide with areas of groundwater development. Groundwater development in southern Diamond Valley began in 1949; by 1964, more than 200 irrigation wells had been drilled (Harrill, 1968). Net annual pumpage estimates from 1950 to 1965 increased two orders of magnitude (from 220 to 12,000 acre-ft). Net annual pumpage increased from 40,000 acre-ft in 1975 to 58,500 acre-ft in 1985 and decreased by 10,000 acre-ft by 1990 (Arteaga and others, 1995). Groundwater development primarily in southern Diamond Valley has resulted in water-level declines since the 1960s. Water-level declines in southern Diamond Valley ranged from less than 5 to 100 ft (fig. 4). The difference between water levels measured in 2005 and 2010, in areas outside southern Diamond Valley, changed by less than plus or minus 5 ft (point data, fig. 5). Except for two wells, inter-annual water-level changes, during the period from 2005 to 2010, were less than 15 ft and less than 10 ft in most wells (hydrographs, fig. 5). Groundwater resources in the Diamond Valley flow system outside of southern Diamond Valley have been relatively undeveloped (fig. 5).

To explore temporal changes in water levels across the Diamond Valley flow system, hydrographs for selected wells were constructed to provide visual comparisons across the area. The hydrographs span the period from 1960 through 2010 (figs. 4 and 5). The six representative hydrographs shown in figure 4 illustrate the long-term water-level declines in southern Diamond Valley. The mean yearly water-level decline ranged from about 1 to slightly more than 2 ft. Water levels were not collected during 1990 through 1996; however, water levels were nearly the same in 1989 and 1997. To evaluate recent trends, water levels collected during March for the years 1997–2010 were inspected. During 1997–2010, all six hydrographs exhibited persistent declines that likely were caused by groundwater withdrawals. Except for well DW29 (figs. 2 and 4), the inter-annual variability, as a result of climatic differences, is masked by pumping effects.

Hydrographs in figure 5 illustrate the general widespread stability of water levels outside of southern Diamond Valley. Water-level patterns and magnitudes were compared for 1973–89 and 2005–10. Precipitation data from the Eureka gage is shown in figure 6. The period from 1973 to 1989 reflects a wetter period with an annual mean of 13.06 in. The period from 2005–10 reflects a drier period with an annual mean of 9.76 in. The long-term mean for 1965–2010 is 11.89 in. For both periods, the typical year-to-year groundwater-level fluctuation ranges from about 1 to 2 ft, but occasionally water levels fluctuate by more than 5 ft (fig. 5). Most hydrographs do not exhibit discernible trends or consistent water-level patterns; fluctuations likely are related to variable local climatic conditions. During 1960–2010, water levels at wells KW32 and DW7 declined slightly. Water levels at well KW32 typically ranged from 47 to 51 ft below land surface during the wet period (1973–89) and from 51 to 56 ft below land surface during the dry period (2005–10). Water levels at well DW7 had the smallest inter-annual fluctuations but were about 2 ft lower during the dry period than the wet period.

Historical Groundwater Budgets

Several water-resources investigations present groundwater budgets for the hydrographic areas that make up the Diamond Valley flow system (Eakin, 1962; Rush and Everett, 1964; Harrill, 1968). These investigations were completed prior to extensive groundwater development in southern Diamond Valley. Components of a natural groundwater budget for a particular hydrographic area include recharge from precipitation, subsurface inflow, groundwater discharge by evapotranspiration, and subsurface outflow (table 3).

Estimates of groundwater recharge from precipitation were derived using the Maxey-Eakin Method (Maxey and Eakin, 1949; Eakin and others, 1951; Watson and others, 1976, p. 336) and the precipitation map of Nevada (Hardman and Mason, 1949). The method empirically related recharge to annual precipitation by adjusting "recharge efficiencies" to generate a balance between recharge and estimated discharge. The method assumes that higher altitudes receive greater percentages of precipitation that becomes recharge (Eakin, 1966).

Estimates of groundwater discharge were derived by assigning groundwater discharge rates reported for other locations in the Southwestern United States to groundwater discharge areas within the Diamond Valley flow system according to vegetation types, density, and depth to the water table (Eakin, 1962). Shallow groundwater is discharged to the atmosphere by transpiration from phreatophytic vegetation and evaporation from bare soil and open-water surfaces, a process collectively referred to as ET. Since the early reconnaissance investigations, the accuracy of delineating areas of phreatophytic vegetation and measuring ET rates has improved; therefore, groundwater discharge rates applied to areas mapped in previous studies likely will differ from ongoing research in the Diamond Valley flow system.

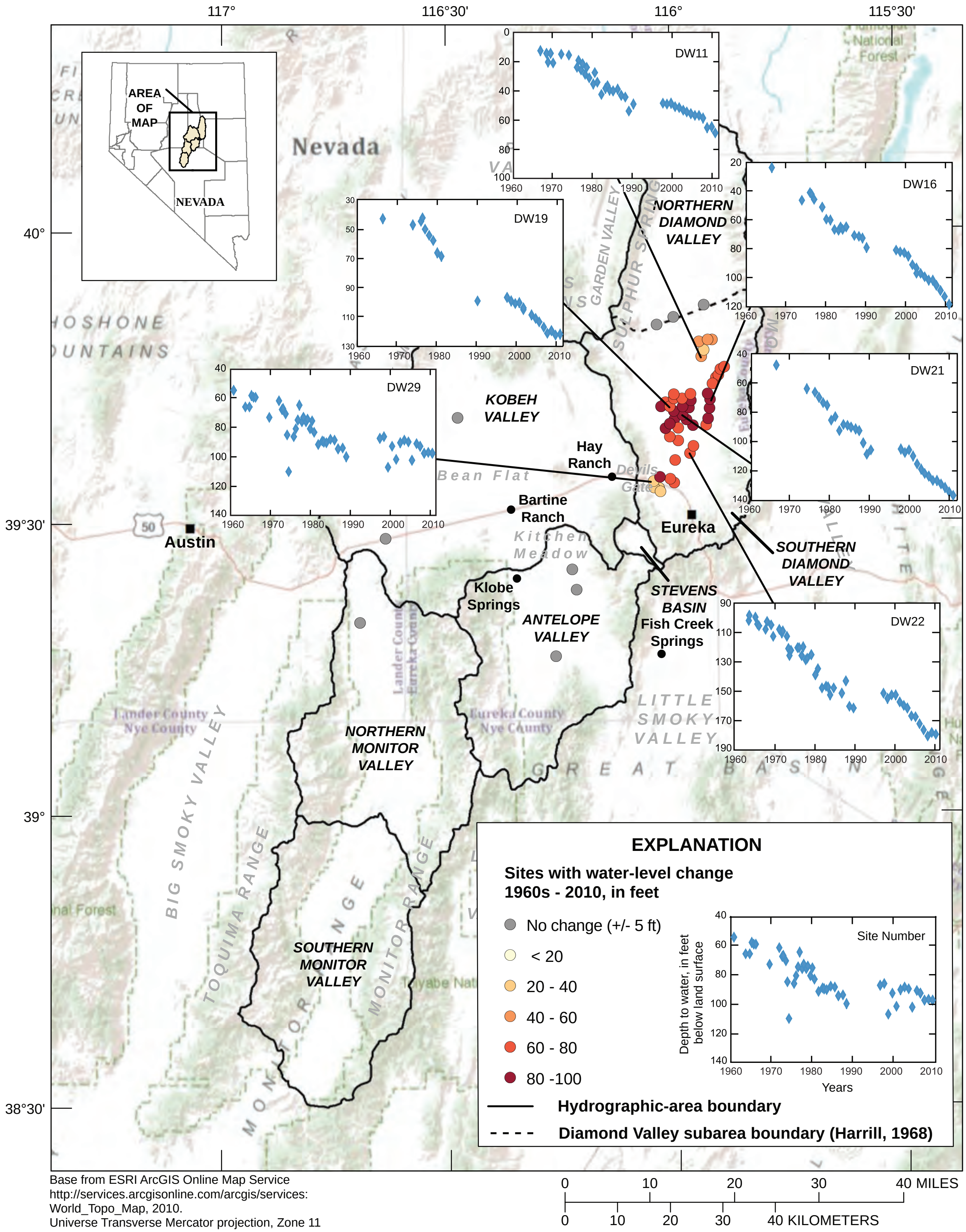

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Figure 4. Water-level changes from 1960s-2010 and period-of-record hydrographs in Diamond Valley flow system, central Nevada.

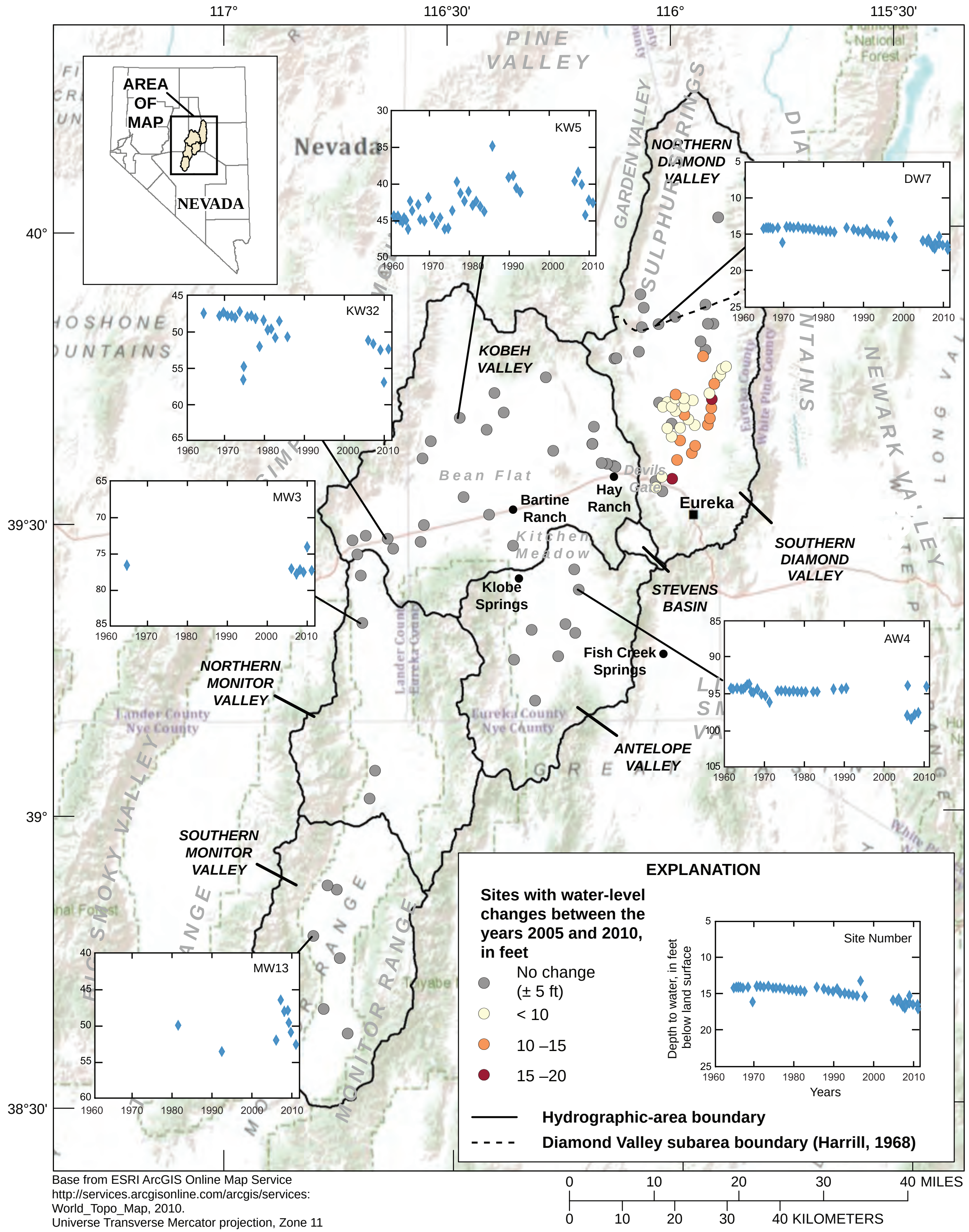

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Figure 5. Water-level changes between the years 2005 and 2010 and period-of-record hydrographs in Diamond Valley flow system, central Nevada.

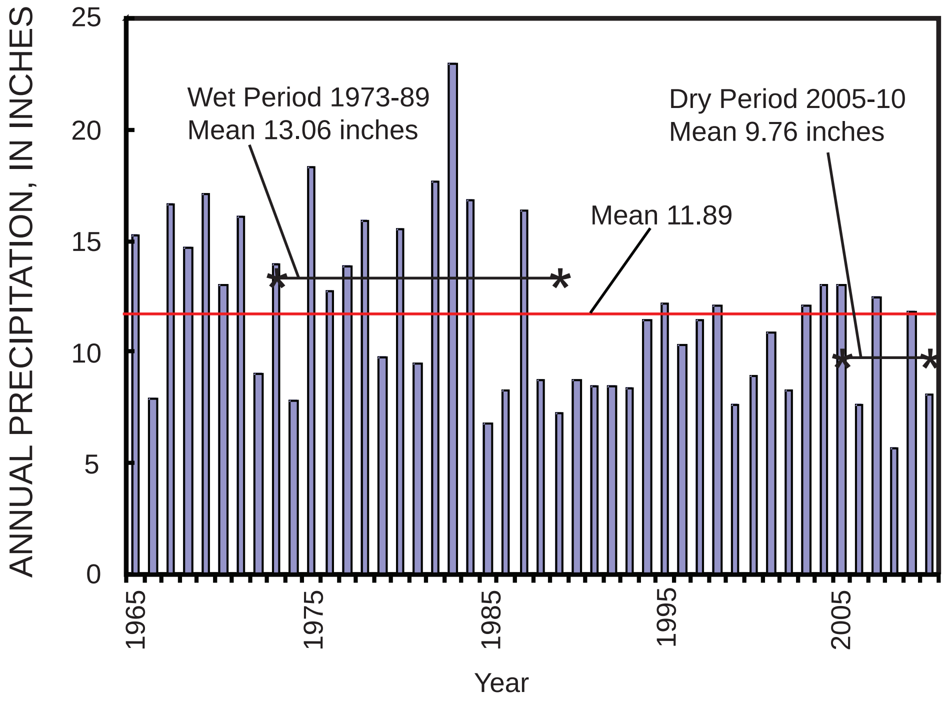

Figure 6. Annual precipitation at weather station at Eureka, Nevada, 1965–2010 and mean annual precipitation during wet and dry periods, Diamond Valley flow system, central Nevada.

Table 3. Summary of historical groundwater budgets and perennial yields for hydrographic areas in the Diamond Valley flow system, central Nevada.

[Recharge, recharge from precipitation; Phreatophytes, acreage of native vegetation; ET, evapotranspiration; ft, feet; yr, year]

Hydrographic area	Groundwater inflow			Groundwater outflow			Perennial yield (acre-ft/yr)
	Precipitation (acre-ft)	Recharge (acre-ft/yr)	Subsurface inflow (acre-ft/yr)	Phreatophytes (acres)	Discharge by ET (acre-ft/yr)	Subsurface outflow (acre-ft/yr)	
Monitor Valley Southern[1]	280,000	15,000	0	32,500	9,200	2,000	13,000
Monitor Valley Northern[1]	230,000	6,300	2,000	5,900	2,000	6,000	8,000
Monitor Valley Total[1]	510,000	21,300	–	38,400	11,200	6,000	21,000
Kobeh[1]	460,000	11,000	6,000	28,500	15,000	Trace	16,000
Antelope[1]	190,000	4,100	Trace	12,600	4,200	Trace[2]	4,000
Stevens Basin[1]	8,500	200	0	([3])	0	200	200
South Diamond Valley[4]	240,000	12,000	150	4,200	1,400	–	–
North Diamond Valley[4]	160,000	9,000	9,000	102,000	29,000	–	–
Diamond Valley Total[4]	400,000	21,000	9,150	106,000	30,000	Terminus	30,000
Diamond Valley[5]	–	16,000	–	–	23,000	–	23,000

[1] Rush and Everett (1964).

[2] 2,000 acre-ft/yr as outflow from Antelope Valley.

[3] 400 acres of bare soil, greater than 400 ft to water.

[4] Harrill (1968).

[5] Eakin (1962).

As part of the early groundwater budgets, estimates of perennial yield also were developed. The Nevada State Engineer uses perennial yield to appropriate available groundwater. The perennial yield is “ultimately limited to the maximum amount of natural discharge that can be salvaged for beneficial use” and typically is determined as the average of total discharge and total recharge. Perennial yield estimates are developed for an entire hydrographic area; therefore, only with an ideal distribution of groundwater pumping can all available discharge be salvaged. Groundwater budgets for each hydrographic area are based on those previous investigations.

Monitor Valley

Rush and Everett (1964) subdivided Monitor Valley into northern and southern parts, to facilitate the development of a groundwater budget. Even though southern and northern Monitor Valleys are comparable in size (within 2 percent), the acreage at altitudes greater than 8,000 ft in southern Monitor Valley is 50 percent more than northern Monitor Valley, increasing the percentage of precipitation that becomes groundwater recharge from about 2.7 percent in northern Monitor Valley to 5.4 percent in southern Monitor Valley. The combined groundwater recharge from precipitation is 21,300 acre-ft/yr; 15,000 and 6,300 acre-ft/yr in southern and northern Monitor Valleys, respectively. In southern Monitor Valley, groundwater inflow exceeds outflow by almost 4,000 acre-ft/yr. Groundwater outflow totals 11,200 acre-ft/yr. Groundwater discharge by ET includes about 9,000 acre-ft/yr of transpiration from about 32,000 acres of phreatophytes and about 250 acre-ft/yr of evaporation from 2,500 acres of bare soil. Additionally, about 2,000 acre-ft/yr of subsurface flow enters northern Monitor Valley from southern Monitor Valley (table 3; Rush and Everett, 1964). In northern Monitor Valley, groundwater inflow is nearly equal to outflow at about 8,000 acre-ft/yr. Groundwater discharge by ET is 2,000 acre-ft/yr from about 6,000 acres of phreatophytes and about 6,000 acre-ft/yr of subsurface outflow enters Kobeh Valley. The total estimated perennial yield for Monitor Valley is 21,000 acre-ft/yr; 13,000 and 8,000 acre-ft/yr for southern and northern Monitor Valleys, respectively.

Kobeh Valley

In Kobeh Valley, about 2 percent of the annual precipitation becomes groundwater recharge. Groundwater inflow totals 17,000 acre-ft/yr; 11,000 acre-ft/yr of recharge from precipitation, and 6,000 acre-ft/yr of subsurface inflow from northern Monitor Valley (Rush and Everett, 1964).

Groundwater outflow totaling 15,000 acre-ft/yr includes 12,500 acre-ft/yr of groundwater discharge by ET from 28,500 acres of phreatophytes and about 2,500 acre-ft/yr of spring discharge at Bean Flat, the Bartine Ranch, and the Hay Ranch. Estimated perennial yield is 16,000 acre-ft/yr, the average of total groundwater inflow and outflow (table 3).

Antelope Valley

Groundwater inflow totals 4,100 acre-ft/yr; groundwater recharge from precipitation is about 2 percent of the estimated annual precipitation of 190,000 acre-ft (Rush and Everett, 1964). Groundwater outflow is from groundwater discharge by ET and includes 3,200 acre-ft/yr from 12,600 acres of phreatophytes, and 1,000 acre-ft/yr of spring discharge at Kitchen Meadow and Klobe Springs (Rush and Everett, 1964).

The historical groundwater budget for Antelope Valley is essentially in balance (table 3; Rush and Everett, 1964). Eakin (1962) and Rush and Everett (1964) state that underflow through the alluvium from Antelope and Kobeh Valleys into Diamond Valley is small. Rush and Everett (1964) also describe faults that function as a flow barrier impeding the northward flow of groundwater from Antelope to Kobeh Valleys resulting in the spring discharge at Kitchen Meadow and Klobe Springs.

In a subsequent reconnaissance series report, Rush and Everett (1966) conclude that about 2,000 acre-ft/yr of subsurface outflow leaves Antelope Valley, discharging at Fish Creek Springs. Phase 1 water-level measurements indicate that groundwater may flow eastward from the southeastern part of Antelope Valley to Fish Creek Springs in Little Smoky Valley (Tumbusch and Plume, 2006). Refined estimates of groundwater discharge for Antelope Valley and additional water-level measurements in Little Smoky Valley may assist in determining the potential for subsurface flow to leave the Diamond Valley flow system and in determining the validity of the 2,000 acre-ft/yr imbalance for Antelope Valley. The perennial yield in Antelope Valley is about 4,000 acre-ft/yr (table 3; Rush and Everett, 1964).

Stevens Basin

Groundwater inflow is 200 acre-ft/yr (table 3). Recharge from precipitation is about 2 percent of the annual precipitation (8,500 acre-ft). Neither subsurface inflow to nor outflow from Stevens Basin is noted (Rush and Everett, 1964). Furthermore, no groundwater discharge by evapotranspiration occurs in the basin. The depth to groundwater is greater than 400 ft below land surface which is too deep for use by phreatophytic vegetation. Rush and Everett (1964) suggest that the 200 acre-ft/yr imbalance is subsurface outflow from Stevens Basin probably to Antelope or Diamond Valleys. Perennial yield for Stevens Basin is 200 acre-ft/yr (table 3).

Diamond Valley

Eakin (1962) and Harrill (1968) published groundwater budgets for Diamond Valley. Eakin (1962) estimated groundwater recharge from precipitation to be about 16,000 acre-ft/yr using a single precipitation distribution. Harrill (1968) recognized that precipitation is greater in the northern than in the southern part of Diamond Valley and developed a precipitation altitude relation for each part. Harrill (1968) estimated the total groundwater recharge from precipitation at 21,000 acre-ft/yr; 9,000 and 12,000 acre-ft/yr in northern and southern Diamond Valleys, respectively. Subsurface inflow to northern Diamond Valley from Garden Valley (outside the flow system) was hypothesized by Eakin (1962) and estimated at 9,000 acre-ft/yr by Harrill (1968). Subsurface inflow to southern Diamond Valley through Devil's Gate is considered small (150 acre-ft/yr) by Eakin (1962) and Harrill (1968). Estimates of perennial yield for northern and southern Diamond Valleys were not made by Harrill (1968).

Diamond Valley is the terminus of the flow system with no subsurface outflow; all groundwater outflow is discharge by ET. Eakin (1962) estimated groundwater discharge at about 23,000 acre-ft/yr and excluded discharge from the 50,000-acre playa in northern Diamond Valley. Eakin (1962) estimated groundwater recharge to be 7,000 acre-ft/yr less than groundwater discharge, but did not determine a reason for the large difference. Harrill (1968) estimated about 5,000 acre-ft/yr of groundwater discharges from the playa area using an annual ET rate of 0.1 acre-ft/acre. Total groundwater inflow is about the same as the groundwater outflow equaling about 30,000 acre-ft/yr (Harrill, 1968).

Groundwater Discharge and Evapotranspiration

Groundwater discharge occurs in topographically low areas of the Diamond Valley flow system where groundwater is at or near land surface. Groundwater discharges to the surface by three natural processes: (1) spring and seep flow, (2) transpiration by phreatophytic vegetation, and (3) evaporation from soil. Phreatophytes obtain water from the water table using long tap roots. Numerous USGS studies in Nevada have shown that the amount and rate of ET from areas of groundwater discharge vary with vegetation type and density, and soil characteristics. These studies have applied various remote-sensing techniques within delineated areas of potential groundwater discharge using satellite imagery in combination with field mapping to identify and group areas of similar vegetation and soil conditions. These groupings are referred to as ET units. ET rates can be measured for individual ET units with micrometeorological sensors. Various methods of relating ET rates to ET units have been applied in past studies depending, in part, on the nature of the groundwater discharge area under investigation and the number of micrometeorological stations in operation.

Potential Areas of Groundwater Discharge

Shallow groundwater may be consumed by ET in areas referred to in this report as potential areas of groundwater discharge. Potential areas of groundwater discharge are being defined and mapped using techniques similar to those described by Smith and others (2007). Preliminary potential areas of groundwater discharge boundaries were delineated from high-resolution imagery (National Agriculture Imagery Program; NAIP) and field mapping (fig. 7). NAIP images were acquired from aerial surveys conducted in October and November 2006. In general, the NAIP images facilitate straightforward boundary mapping by identifying the occurrence and extent of the phreatophytic shrubs greasewood (*Sarcobatus vermiculatus*) and rabbitbrush (*Chrysothamnus nauseous);* however, in areas where greasewood-rabbitbrush shrubland are mixed with other desert shrubs, or are very sparse, the boundary is more difficult to define. Fieldwork is ongoing to improve the accuracy of delineated potential areas of groundwater discharge boundaries.

Evapotranspiration Units

Past studies have used Landsat satellite imagery in combination with field mapping to identify and delineate ET units within potential areas of groundwater discharge throughout arid and semi-arid regions of the Great Basin (Laczniak and others, 1999; Laczniak and others, 2001; Reiner and others, 2002; Smith and others, 2007; Allander and others, 2009). ET units are defined as areas of similar vegetation type and density and similar soil characteristics where groundwater potentially is being lost to the atmosphere by evaporation or through plant transpiration (Laczniak and others, 1999, 2001, 2006). In general, the more dense and healthy the vegetation and the wetter the soil, the greater is the ET. The general characteristics of ET units range from areas of no vegetation, such as open water, dry playa, and moist bare soil, to areas with vegetation that often are dominated by phreatophytic shrubs, grasses, rushes, and reeds. Three preliminary ET units—(1) phreatophytic and other vegetation, (2) playa, and (3) undifferentiated—are delineated in the Diamond Valley flow system based on Landsat Thematic Mapper (TM) satellite imagery and the Soil Survey Geographic (SSURGO) soils database (fig. 8).

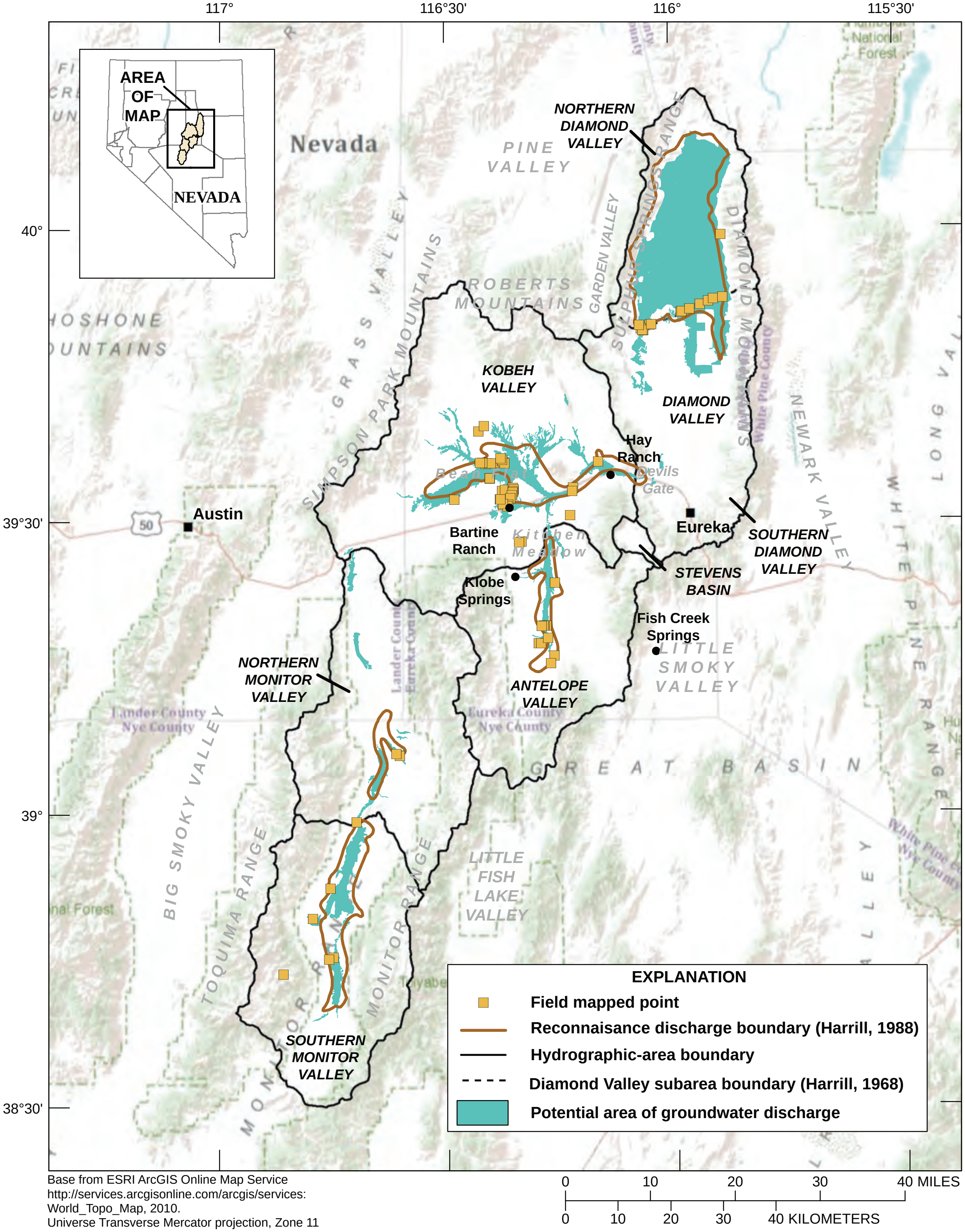

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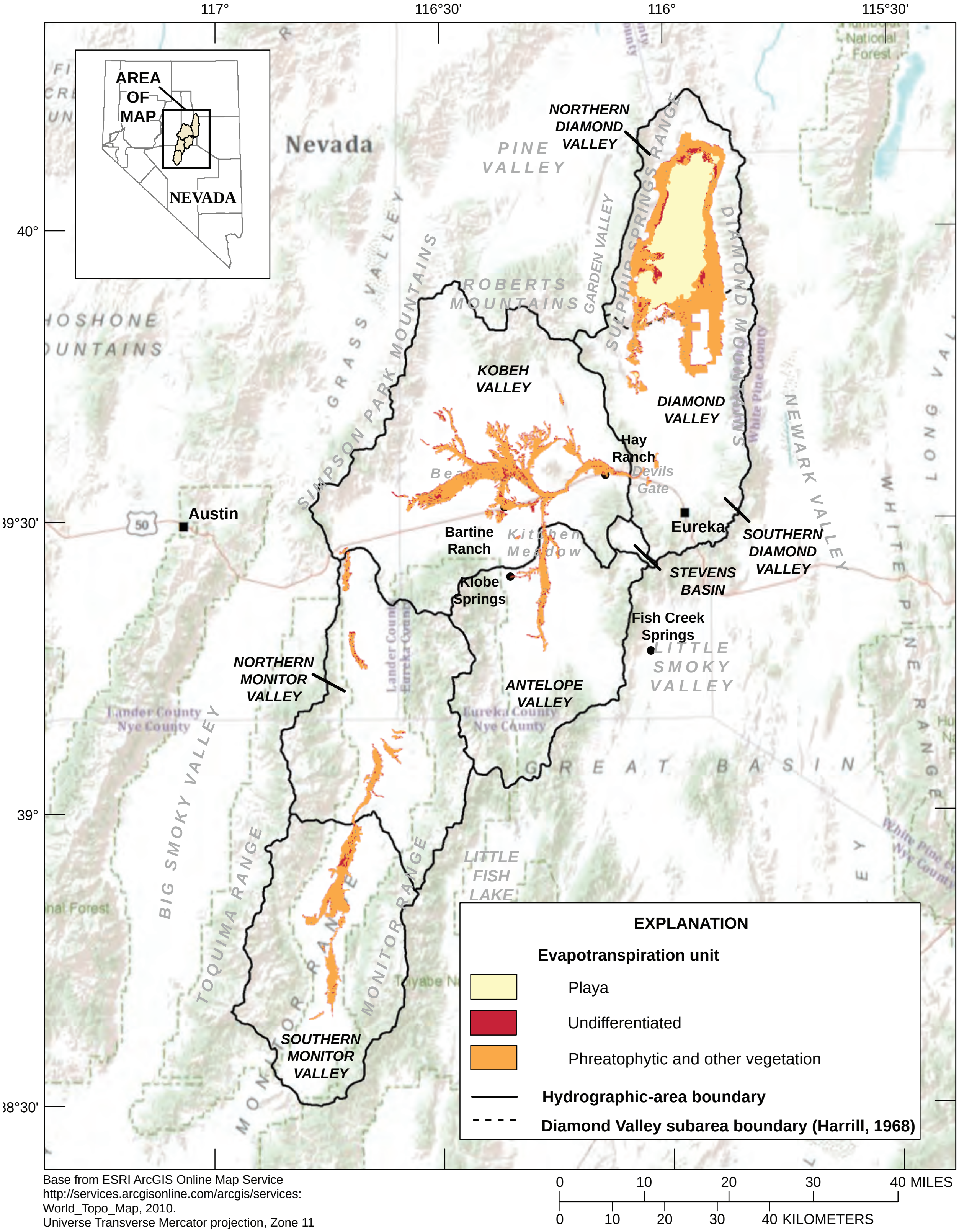
Figure 7. Locations of field-mapped points and potential areas of groundwater discharge in Diamond Valley flow system, central Nevada.



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North American Datum of 1983.

Figure 8. Preliminary evapotranspiration units in the Diamond Valley flow system, central Nevada.

The phreatophyte ET unit, comprised primarily of phreatophytic vegetation, was delineated from two Landsat scenes (Landsat scene identifiers LT50410322007181EDC00 and LT50410332007181EDC00 acquired June 30, 2007). Late June through early July is the optimum period to characterize vegetation health and vigor because solar radiation and phreatophyte transpiration are near annual maximums (Nichols, 2001; Moreo and others, 2007). Landsat images are georeferenced to allow geospatial evaluations and direct comparison with other spatially referenced datasets. Image standardization processes normalized the spectral data for differences in sun illumination geometry, atmospheric effects, and instrument calibration (Smith and others, 2007). The resulting dataset is in the physical units of percent reflectance, which is the percentage of solar energy reflected by the Earth’s surface at each approximately 100×100 ft picture element or pixel.

A Modified Soil-Adjusted Vegetation Index (MSAVI; Qi and others, 1994) value representing the health, density, and vigor of vegetation is computed for each phreatophyte ET-unit pixel. The MSAVI is particularly applicable for mapping sparse plant cover in desert landscapes because soil influences on the index are minimized. MSAVI values are dimensionless and can range from -1.0 to 1.0. MSAVI values in the phreatophyte ET unit range from 0.085 to 0.67. The distribution of MSAVI values are skewed to the low range indicating a large percentage of phreatophytic vegetation is greasewood-rabbitbrush shrubland (fig. 9).

Soil Survey Geographic (SSURGO; U.S. Department of Agriculture, 2011, at http://soils.usda.gov/survey/geography/ssurgo/) data was used to delineate the playa ET unit, which is located entirely in northern Diamond Valley (fig. 8). SSURGO is the most detailed level of soil mapping done by the Natural Resources Conservation Service (NRCS) with mapping scales ranging from 1:12,000 to 1:63,360. The dataset was converted to a raster dataset to be compatible with the Landsat MSAVI data.

A single ET-unit map was developed by layering ET units defined by the Landsat MSAVI and SSURGO soil data (fig. 8). The potential area of groundwater discharge was used to identify only those areas of the MSAVI data to be used in the final map. The resulting MSAVI dataset was compared to NAIP imagery and the field points that were collected to determine the lower detection limits of the MSAVI analysis. Pixels with MSAVI values less than 0.085 are grouped into a temporary undifferentiated ET unit. Preliminary estimates of evapotranspiration-unit acreage for each ET unit are given in table 4.

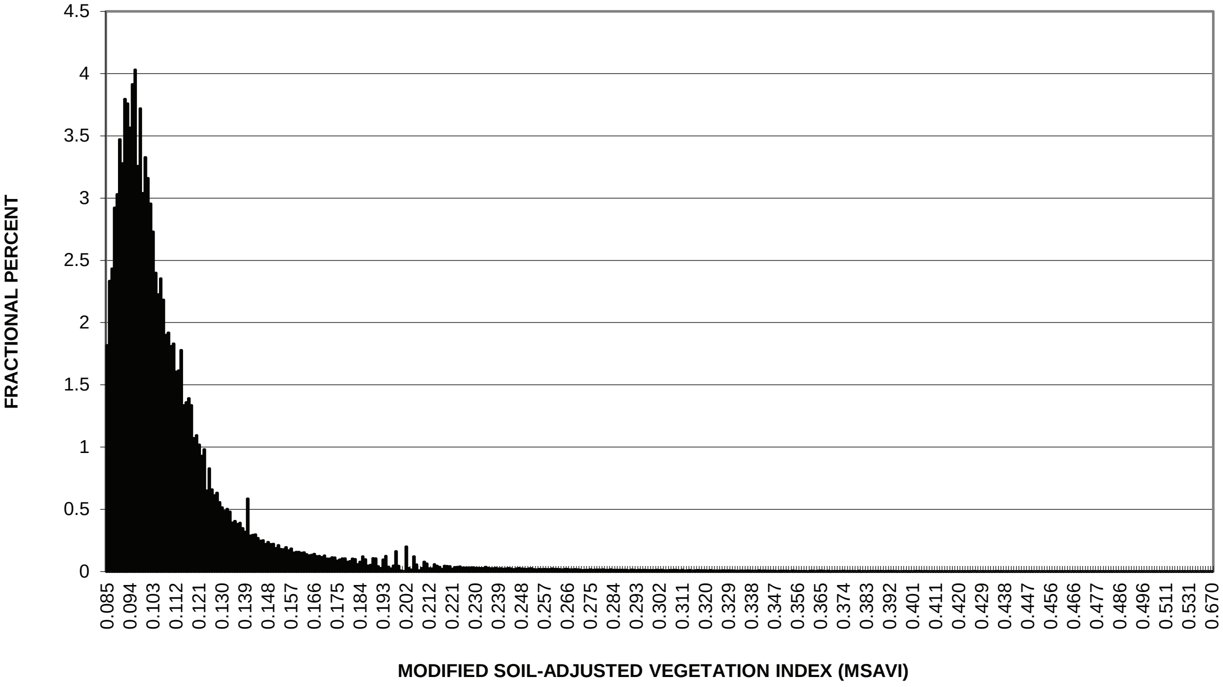

Figure 9. Fractional histogram of MSAVI values in the Diamond Valley flow system, central Nevada.

Table 4. Preliminary estimates of evapotranspiration-unit acreage delineated by hydrographic area in Diamond Valley flow system, central Nevada.

Hydrographic area	Evapotranspiration unit, in acres		
	Playa	Undifferentiated	Phreatophytic and other vegetation
Monitor Valley, South	0	1,289	16,613
Monitor Valley, North	0	950	7,811
Kobeh Valley	0	5,280	41,397
Antelope Valley	0	835	6,712
Diamond Valley	59,103	5,488	64,857

Evapotranspiration Rates

During phase 2, three micrometeorological stations were established within the phreatophyte ET unit to measure ET rates in natural vegetation (table 1 and fig. 2). Each station was instrumented with sensors designed to measure ET rates using the Bowen-ratio method (Bowen, 1926). The Bowen-ratio method does not measure latent-heat flux directly, but assumes that the proportionality between sensible- and latent-heat fluxes can be defined by the ratio between the temperature and vapor-pressure gradient. Latent heat is the energy consumed in the ET process and sensible heat is the amount of energy that heats the air directly above the soil or plant canopy. Computed ET rates were evaluated following 1 year of data collection and were significantly higher than ET rates measured in similar environments in other recent groundwater discharge studies (Moreo and others, 2007; Allander and others, 2009). For comparison, eddy-covariance sensors capable of measuring latent-heat flux directly were established and presently (September 2010) are co-located with Bowen-ratio sensors. Eddy-covariance data may then be used to adjust the Bowen-ratio data, if necessary. Following a comparison period, eddy-covariance stations (4) will be re-deployed to other sites in order to better characterize a relation between measured point estimates of ET and MSAVI.

Groundwater Discharge

Mean MSAVI values representing the ET source area at each ET site can be computed based on the relative and cumulative distribution of latent- and sensible-heat fluxes (Moreo and others, 2007, p. 16). A relation can then be developed between point ET discharge rate measurements and MSAVI (Moreo and others, 2007; Allander and others, 2009). Figure 10 shows an example of this relation. Once established, the relation between ET discharge rate and MSAVI can be used to spatially distribute groundwater discharge rates within the phreatophyte ET unit. A groundwater discharge volume can then be estimated for each hydrographic area by multiplying spatially distributed groundwater discharge rates by the number of acres within each groundwater discharge area.

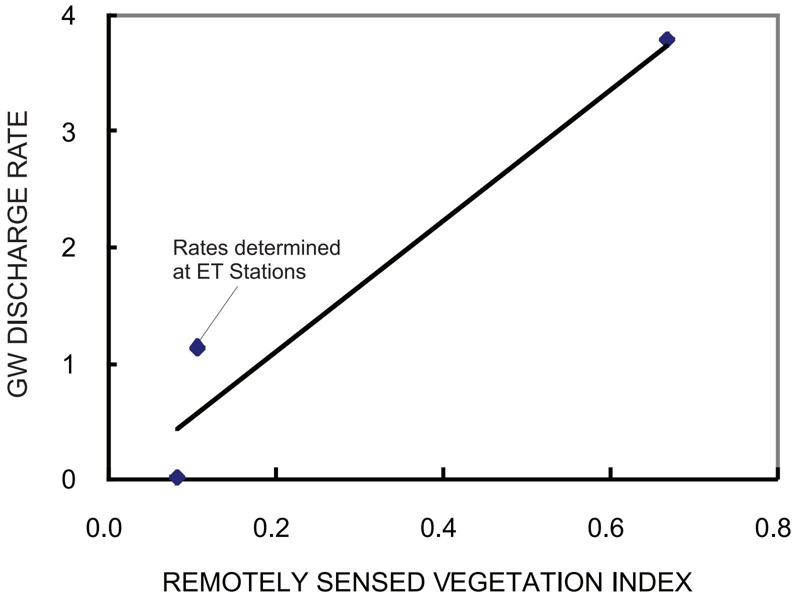

Figure 10. Example relation between remotely sensed vegetation index and groundwater discharge rate.

Continued Research in the Diamond Valley Flow System

Continued research in the Diamond Valley flow system during phase 3 is needed including the refinement of the groundwater budget, with particular emphasis on natural groundwater discharge. The ongoing work will include developing and strengthening relations between point estimates of ET (from micrometeorological stations) and spatially distributed MSAVI values by collecting ET rates over a wider, more representative range within the Diamond Valley flow system. Research efforts will focus on refining ET unit delineations as follows: (1) fieldwork is planned to eliminate the undifferentiated ET unit by determining the nature of areas where MSAVI values are low, (2) techniques are being tested to further reduce the soil influence on MSAVI, (3) Landsat images from later in the growing season will be evaluated to determine if the influence of saltgrass (*Distichlis spicata*) on MSAVI is adequately being captured by the late June through early July images, (4) inter-annual MSAVI variability will be evaluated, and (5) historical TM images and MSAVI distributions in southern Diamond Valley will be evaluated to determine whether phreatophyte distributions and densities have been affected by declining water levels. Additionally the geochemical composition of groundwater will be described for each hydrographic area, water-level changes and trends will continue to be evaluated, and a conceptual model of the flow system will be presented. A USGS scientific-investigation report that summarizes the results will be published at the end of the federal fiscal year 2013 (September 2013).

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Appendix A. Drillers' Logs for Wells Drilled as Part of Phase 2 of the Study in the Diamond Valley Flow System, Central Nevada.

Data are available in PDF format for download at http://pubs.usgs.gov/of/2011/1089/.

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