National Park Service
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Natural Resource Stewardship and Science

Groundwater Geology and Hydrology of Death Valley National Park, California and Nevada

Natural Resource Technical Report NPS/NRSS/WRD/NRTR—2012/652

ON THE COVER
The Amargosa River in the southeast part of Death Valley National Park during a flash flood in February 2005
Photography by: A. Van Luik

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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Abbreviations

mg/l	milligrams per liter
mm	millimeter
m	meter
km	kilometer
l	liter
l/min	liters per minute
ha	hectare
hfu	heat flow units
msl	mean sea level referenced to the National Geodetic Vertical Datum of 1929
yr	year
d	day

Conversions

1 meter (m) = 3.281 foot

1 kilometer (km) = 0.6214 mile

1 square kilometer (km^2) = 0.3861 square mile

1 cubic meter (m^3) = 35.31 cubic foot

1 million cubic meters (Mm^3) = 35.31 million cubic feet

1 meter per day (m/d) = 3.281 foot per day

1 meter per year (m/yr) = 3.281 foot per year

1 meter squared per day (m^2/d) = 10.76 square foot per day

1 cubic meter per day (m^3/d) = 35.31 cubic foot per day

1 cubic meter per day (m^3/d) = 264.2 gallon per day

1 cubic meter per year (m^3/yr) = 35.31 cubic foot per year

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F = (1.8 × °C) + 32

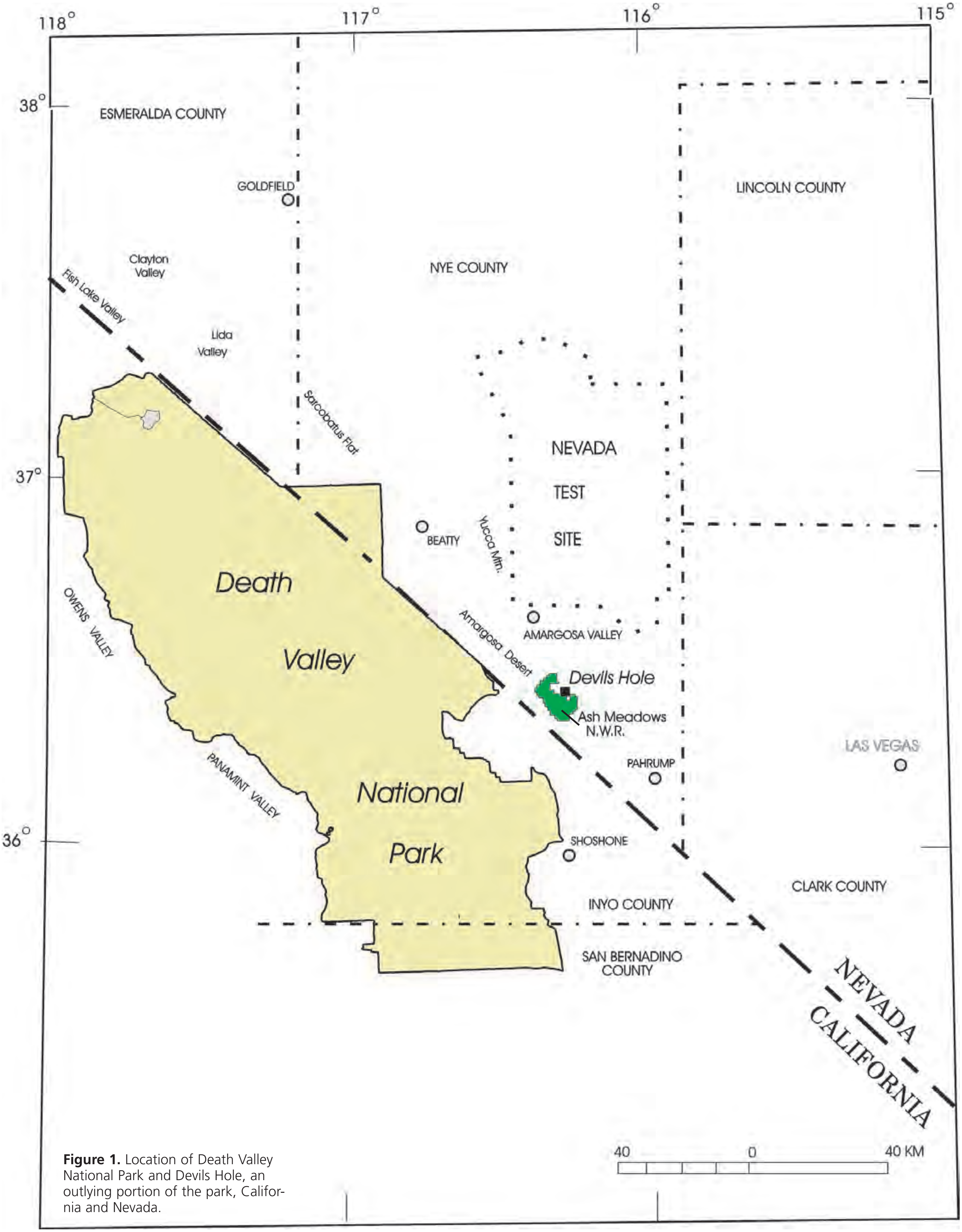


Figure 1. Location of Death Valley National Park and Devils Hole, an outlying portion of the park, California and Nevada.

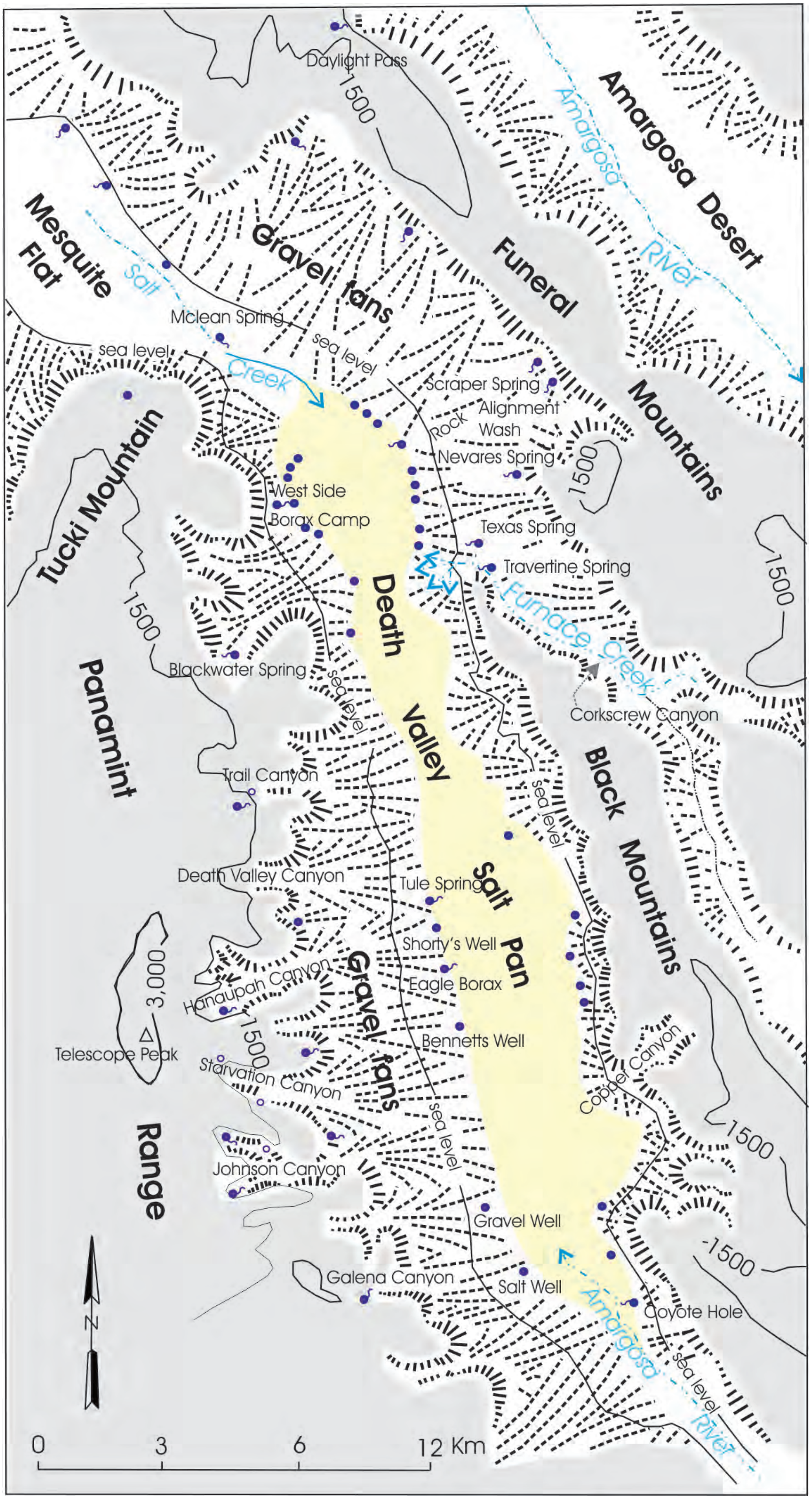
Introduction

Death Valley (fig. 1), in the southern part of the Great Basin of California and Nevada (Hunt 1967) has a fearsome reputation for heat and dryness—and rightfully so. What is lesser known is that Death Valley National Park possesses hundreds of spring-fed water resources and riparian and wetland habitats. Without these water resources, life in Death Valley would be virtually impossible. Most of these habitats are limited to areas of small springs discharging water from local sources. However, several habitats, such as Travertine Springs in the Furnace Creek area and Grapevine Springs and Staininger Spring in the Scotty's Castle area, are extensive as a result of large volumes of water discharging from the regional carbonate aquifer (Miller 1977 and Steinkamp and Werrell 2001). The Death Valley salt pan and some of the principal springs, wells, alluvial fans, and mountain ranges of Death Valley are shown in figure 2.

The hydrologic environment of Death Valley is one of contradistinction. A landscape that appears to be devoid of water, where in truth, its very shape, composition, and life are greatly dependent upon the presence and action of water above, on, and under the landscape. On close examination, it is revealed that the hydrologic environment has added the final flourish to a bedrock-dominated landscape. Water has sculpted the faulted and contorted mountains of rock and cut the arroyos through which floods transport massive amounts of sand and gravel to form the alluvial fans at the base of the mountains. The mountain fronts have been sculpted by waves at the shores of ice age lakes. Beyond the alluvial fans, dry and dusty expanses of the fine particles of silt and clay that settled from ephemeral lakes blanket the playas. Evaporation of surface and groundwater has left behind the salt flats and intricate salt formations at the Devils Golf Course. Sheets of water-deposited travertine drape the slopes below the sites of present and former springs.

The park faces significant challenges with regard to properly inventorying, studying, and managing its water resources. These challenges include, but are not limited to, (1) properly monitoring and managing the effects of new production wells and riparian area recovery associated with a new water supply, water treatment, and delivery infrastructure for the Furnace Creek headquarters complex and concession operations; (2) protection of water rights in the face of steadily increasing population growth in the region, particularly southern Nevada; (3) potential diminution of the volume of water reaching the park because of upgradient water users; (4) protection of endemic, sensitive, and threatened and endangered species that depend on water resources; and (5) concern regarding contaminant sources in the flow system from underground nuclear testing and waste storage upgradient from the park.

Figure 2. Map of Death Valley showing some of the principal springs, wells on the valley floor, alluvial fans, mountain ranges, and other geographic features. Contours are in meters above sea level. After Hunt 1975.



Background and Acknowledgements

In addition to personal observation and study, the authors have drawn extensively on the scientific studies made over many years by scientists of a multitude of diverse disciplines, as well as narratives and stories of early travelers, prospectors, miners, and Native Americans. Our thanks go first to all those who have contributed to the rich body of knowledge of Death Valley. Many, but by no means all of them, are listed in the extensive bibliography at the end of this report. We wish to thank many colleagues who have encouraged and assisted us in our work in Death Valley National Park during the past twenty years. Bill Werrell of the National Park Service, now retired, an enthusiastic supporter of this work, offered continued encouragement and support for many years during our work in the park. We also thank National Park Service personnel Mel Essington, now retired, Paul Christensen, and Douglas Threloff—all of whom provided professional assistance and knowledge of geologic, hydrologic, and biologic resources of the park. We are indebted to Donald Sweetkind, Geologic Division, and Randell Laczniak, Water Resources Division, of the U.S. Geological Survey, for valuable technical insight and critical review of the report. We extend our warm thanks and regards to Alan Riggs, U.S. Geological Survey, Water Resources Division, for his enthusiastic support for public release of the report and his thoughtful, tireless, and valuable detailed review of all phases of the report.

This report is an outgrowth of a report done under contract to the National Park Service as a phase of the park's Water Resources Stewardship Program. Our participation in this effort was done at the initiation of Terry Fisk, then-Hydrologist, of Death Valley National Park. Preparation of this report intended for public distribution was done in coordination with Jennifer Back, Hydrologist, and Dan McGlothlin, Technical Team Leader, both of the National Park Service Water Rights Branch in Fort Collins, Colorado. Final editing and formatted copy of the report was done by Gretel Enck of the National Park Service Water Resources Division in Fort Collins, Colorado.

Objectives

This report summarizes the hydrogeologic setting of Death Valley. Specific elements of this report include

(1) geologic setting of Death Valley: geologic units and structural aspects of the region that control the occurrence and flow of groundwater to and within Death Valley, the current knowledge of distribution of groundwater flow to the park, and the source and distribution of groundwater flow and occurrence within the park;

(2) hydrogeology of the Death Valley region with particular attention to the relationship to and effects of water-related activities outside the park to the water resources of Death Valley National Park. This includes potential relationships between the Death Valley flow system and adjoining flow systems; and

(3) climate and its relationship to water resources in Death Valley.

Photograph 1. Stovepipe Well in Mesquite Flat.

Hydrologic Environment of Death Valley

On a regional scale, topography controls the flow of groundwater to Death Valley. As the lowest point in the conterminous United States, Death Valley is the ultimate destination of groundwater within a large area in southeast California and southern Nevada. The contours of regional potential (plate 1) in the Death Valley groundwater flow system reveal the regional pattern of groundwater flow. Throughout the region, topographic elevation influences precipitation, evaporation, and moisture available for recharge to groundwater.

Underground, the flow of water is controlled by structure, physical properties, and lithology of the rock units. Geologic structure favors or inhibits flow of groundwater within and between rock units by controlling the attitude, position, continuity, and juxtaposition of rock units having similar or dissimilar hydrologic properties. The bedrock units that control groundwater flow have virtually no primary intergranular porosity or permeability because of a geologic history of metamorphism, deep burial and compaction, and mineral filling of voids by hydrothermal fluids. Permeability of the sedimentary bedrock units is a function of the fracturing and faulting of the brittle rocks during Cenozoic extensional tectonism and enlargement of openings in carbonate rocks by groundwater solution.

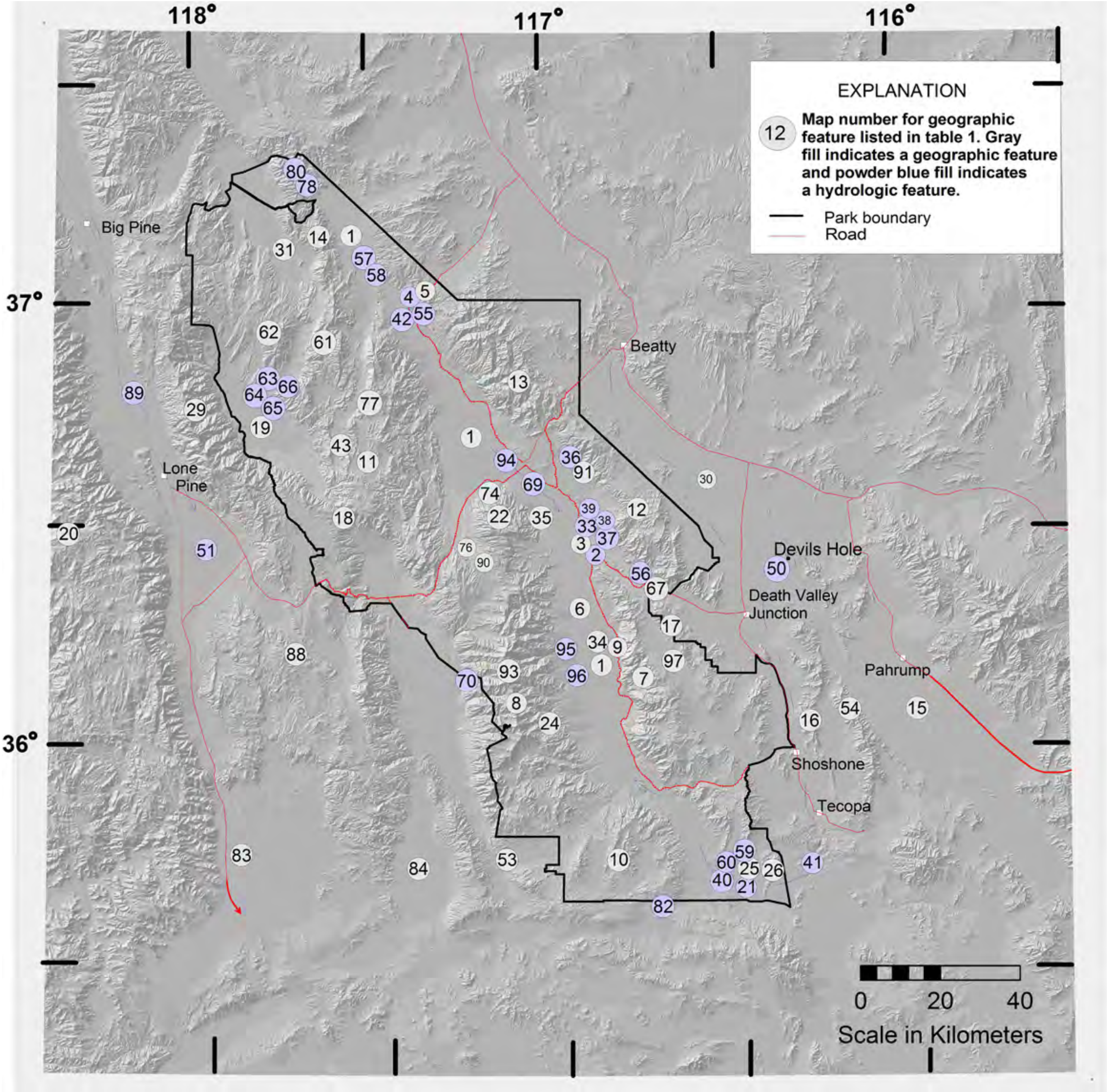


Figure 3. Map showing geographic and hydrologic features of Death Valley National Park region, California and Nevada.

Table 1. Geographic features shown in figure 3

Map #	Geographical Feature	Map #	Geographical Feature
1	Death Valley	49	Silver Lake playa
2	Travertine Springs	50	Ash Meadows
3	Furnace Creek Area	51	Owens Lake
4	Grapevine Spring and Staininger Spring	52	Silver Lake basin
5	Scottys Castle area	53	Wingate Pass
6	Devils Golf Course	54	Nopah Range
7	Black Mountain	55	Surprise Spring
8	Panamint Range	56	Navel Spring
9	Badwater	57	Sand Spring
10	Owlshead Mountain	58	Little Sand Spring
11	Cottonwood Mountains	59	Ibex Spring
12	Funeral Range	60	Superior Mine Tank B Spring
13	Grapevine Mountains	61	Dry Mountain Range
14	Last Chance Range	62	Saline Range
15	Pahrump Valley	63	Warm Spring
16	Resting Springs Range	64	Palm Spring
17	Greenwater Range	65	Lower Warm Spring
18	Hunter Mountain	66	Upper Warm Spring
19	Saline Valley	67	Travertine Point
20	Sierra Nevada	69	Salt Creek
21	Saratoga Springs	70	Warm Springs (Panamint Range)
22	Tucki Mountain	71	Three Springs west
23	Virgin Spring area	72	Tucki Spring
24	Galena Canyon (in Panamint Range)	73	Gypsum Spring
25	Ibex Hills	74	Mosaic Canyon
26	Saddle Peak Hills	76	Emigrant Canyon
29	Inyo Range	77	White Top Mountain
30	Amargosa Desert	78	Last Chance Springs
31	Eureka Valley	80	Willow Spring
32	Salt Hills	81	Klare Spring
33	Salt Spring	82	Owl Hole Spring
34	Badwater Basin	83	Indian Wells Valley
35	Cottonball Marsh	84	Searles Lake Valley
36	Keane Wonder Spring	85	San Rafael Mountains
37	Texas Spring	86	Cajon Canyon
38	Nevares Spring	87	Long Valley Geothermal Field
39	Cowcreek Spring	88	Coso
40	Amargosa River Springs	89	Owens River
41	Amargosa River	90	Skidoo Mine
42	Mesquite Spring	91	Keane Wonder Mine
43	Racetrack Playa	92	Birch Springs
44	Mojave River	93	Telescope Peak
45	San Bernardino Mountains	94	Stovepipe well
46	Barstow	95	Shortys well
47	Afton Canyon	96	Bennetts well
48	Soda Lake playa	97	Greenwater Valley

Geologic and Structural Setting of Death Valley

Depositional and Tectonic History

The depositional history and tectonic evolution of the region provides insight into the shaping of the hydrogeologic framework that controls the groundwater flow. The sedimentary and igneous rock sequences and the tectonics of Death Valley have shaped the structural framework of the region and created the geometry of permeable pathways and flow barriers that control groundwater flow. The stratigraphic and tectonic history is taken from the work of many geologists whose studies provide insight into the subject, including notably Noble (1934, 1941), Hunt and Mabey (1966), Troxel and Wright (1976, 1989), Wernicke et al. (1989), Grose and Smith (1989), Stewart (1967, 1970), Sweetkind et al. (2004), Hamilton (1988), Workman et al. (2002a and 2002b), Potter et al. (2002), and Fridrich et al. (2003a and 2003b).

Sedimentary rocks of present-day Death Valley were deposited in three geosynclinal basins; each depositional stage is imbricated with younger ones centered progressively farther west (Hunt 1967). During Middle and Late Proterozoic at least 900 meters (2,953 ft) of geosynclinal deposits accumulated in the southern part of the area that is now the Great Basin. The extent of these deposits is not known because they are deeply buried throughout most of their occurrence, but they are exposed in the Black and Panamint ranges of Death Valley (fig. 3, table 1). In Late Proterozoic though Paleozoic time a second geosyncline occupied the Great Basin, and 9,000 meters (29,529 ft) of ocean sediments were deposited. In Death Valley the lower part of the sequence is conglomerate, sand, and clay with limestone and dolomite. Dolomite and limestone sediments increase upward in the section with the first massive dolomite deposited in the Middle and Upper Cambrian. Clastic rocks make up a greater proportion of sediments toward the west. Early Mesozoic sedimentary deposition in the third geosynclinal basin overlapped the Paleozoic deposits. This sequence also contains volcanic materials. During the Middle and Late Mesozoic (Jurassic and Cretaceous) regional uplift was accompanied by igneous intrusions, folding, and faulting. Compressive forces from the west produced a series of low-angle thrust faults. The mountains formed during this tectonic activity were eroded while the geosynclinal basin centered to the north in the Great Basin continued to receive ocean sediments. In the Middle Mesozoic the Sierra Nevada batholith was formed west of Death Valley; later the folded and faulted sedimentary rocks of Death Valley were intruded by igneous stocks and laccoliths.

Erosion in Mesozoic and early Tertiary greatly subdued the topography. Beginning possibly in Oligocene and certainly by Miocene time, sediments were formed in extended broad shallow basins that existed over most of the Death Valley region before the present-day topography was developed by regional extension. Deposition continued during Middle and Late Cenozoic accompanied by episodes of regional extension involving block faulting and low-angle normal detachment faulting. Rifts developed in the main valley of Death Valley where huge blocks subsided, forming grabens that were filled with sediment from the adjacent rising blocks. The depth of the pre-Cenozoic surface beneath Death Valley is quite variable. Near Badwater the maximum depth is estimated between 4.5 and 5 kilometers (2.8 and 3.1 mi; Blakely and Ponce 2001). Volcanism accompanied the extension with basaltic lava flows and felsite-eruptions-capped plateaus.

Through geologic time, the oldest strata were deeply buried by thousands of meters of younger deposits, heated under pressure, and recrystallized. Heating and pressure formed shale from clay deposits and quartzite from sandstone. Lithification and low-grade metamorphism virtually eliminated the original interstitial porosity and permeability of the Proterozoic, Paleozoic, and Mesozoic formations. Millions of years of tectonic forces have crushed rock and imprinted the rock mass with folds, joints, faults, and fractures that have produced large blocks of tightly recrystallized rock interspersed with crushed rock strata. Some fractures and faults were opened;

some fractures filled with minerals from circulating hydrothermal fluids. The latest episode of tectonic deformation in the Tertiary and Holocene was marked by extensional tectonics producing fractures and shear zones as the crust extended, moving large crustal blocks many kilometers. The brittle rocks fractured as pressure released and the strata were folded, twisted, and faulted. Permeability of the carbonate rocks has been increased by solution of the tectonically produced openings. The various modes, environments, and sequences of tectonic deformation produced great differences in physical properties of the rocks.

Structural Features and Hydrogeologic Significance

Thrust Faults

Thrust faulting accompanied regional uplift, folding, mountain building, and erosion of the region during the Mesozoic, after the geosynclinal deposition of thousands of meters of sediments during the Late Proterozoic and Paleozoic. Thrust faulting of igneous rocks and sedimentary rocks was caused by compressive forces from the west. The thrust faulting in sedimentary sequences causes younger strata to override older strata. Thrust faults were recognized and mapped in the mountains and originally given different names in each mountain block (plate 2). Wernicke et al. (1989) recognized that the thrust faults in different mountain blocks were segments of several once-continuous thrust faults that crossed the region before the segments were separated by later mountain and basin formation during the Cenozoic. The traces of the thrust faults are offset between mountain ranges by transverse strike-slip faults that bound the massive blocks of the region. A sense of the lateral translocations of rock masses can be seen by observing the offsets of the thrust faults between mountain ranges (Wernicke et al. 1989, fig. 0–4).

The influence of thrust faults on groundwater movement depends to a large extent on the orientation of the fault zones in relation to the gradient of the potentiometric surface. Thrust-fault planes would tend to be of low permeability because of the compressive forces that created the faults. Low angle fault planes of low permeability could significantly impede vertical groundwater movement. Northeast of Death Valley near the eastern limit of the geosynclinal basin, thrust faults typically are low angle features of great lateral extent (Wernicke et al. 1989). However, the primary control on modern groundwater movement in the vicinity of thrust faults is likely to be post-thrusting tectonism and the present-day depth of burial. Mesozoic thrusting predates the regional extensional detachment movements of mountain blocks and faulting. Thrust-fault planes were subject to displacement, faulting, and folding, and the upper and lower thrust plates were subject to separation by Tertiary extensional tectonics. Andrew (1999), in studying the structure of the Panamint Range, noted that many Mesozoic structures were reactivated during Tertiary extension, producing a strong brittle fabric that would tend to be more permeable than the ductile fabric related to Mesozoic tectonic events. Extensional tectonics would tend to nullify the influence of an originally low permeability thrust-fault plane. For example, the discharge of Warm Springs (Warm Spring A, B, and C, numbered 106, 107, and 108 in the Appendix) originates as recharge at higher elevations of the Panamint Mountains, the Wheeler Pass thrust plate of Wernicke et al. (1989). Groundwater flows across the plane of the thrust fault to discharge from strata of the lower plate, the Keystone thrust plate of Wernicke et al. (1989). Permeable joint and fault networks are apparently continuous across the plane of the fault.

Regional Transverse Fault Zones

A regional dominating pattern of transverse fault zones crosses the Death Valley region from northwest to southeast (plate 2). These faults divide the region into large crustal blocks containing mountain blocks or mountain blocks and basins. The faults are typically displaced both vertically and strike-slip. From the northeast, the Death Valley region is bounded by the state-line fault that extends from Pahrump Valley to the latitude of the Grapevine Mountains. The segment northeast of the Funeral Mountain front lies beneath the Amargosa Desert. The Death Valley–Furnace Creek fault, a right-lateral strike-slip fault, borders the southwest front of the Funeral Mountains. The fault extends northwest to Fish Lake Valley in Nevada and to the western front of the Resting Springs Range where the fault zone turns and continues southward as a large normal fault. The Southeast Death Valley fault, an active right-lateral strike-slip fault with large vertical displacement, borders the western front of the Black Mountains. The Grand View fault, with right-lateral strike-slip movement, lies between the Black Mountains and the Greenwater Range. The Hunter Mountain–Panamint fault zone, composed of a linear sequence of faults with vertical and strike-slip segments, extends northwestward from the Garlock fault along the western front of the Owlshead Mountains and Panamint Range to the southern margin of Saline Valley thence northward along the eastern front of the Inyo Mountains. The Garlock fault, with a left lateral strike-slip movement, marks the southern boundary of Great Basin extension and extends from south of the Owlshead Mountains westward to the Sierra Nevada.

The hydrogeologic setting of individual regional springs, discussed later in this report, and the inflow to Death Valley do not support the conclusion that regional transverse fault zones impede the flow of groundwater to Death Valley. For example, groundwater flow across the Furnace Creek–Death Valley fault zone and into Death Valley is several tens of thousands of cubic meters per day. In areas where permeable rocks are juxtaposed across the fault zone, the absence of springs at the fault zone indicates that the fault zone is permeable. In other areas groundwater movement is inhibited by low permeability rocks downgradient from the fault. Low permeability sedimentary rocks of Tertiary age on the downgradient side of the Death Valley–Furnace Creek fault zone apparently control the emergence of Grapevine Springs, Keane Wonder Spring, and Nevares Spring. No location has been found where it can be demonstrated that the fault zone itself solely acts as a barrier to groundwater flow.

The southeast termination of the Death Valley–Furnace Creek fault zone is characterized by a southward curvature of the fault zone. This would have been an area of intense releasing pressure (Potter et al. 2002) during fault movement by virtue of the right-slip movement of the west block of the fault away from the fault plane. The fault zone here would be expected to increase permeability in the area of Pahrump Series rocks in a south trending zone parallel to the regional hydraulic gradient toward Saratoga Spring.

Normal Faults

Normal faults commonly associated with extending terrane tend to produce openings for movement of groundwater. In the Proterozoic and Paleozoic sedimentary rocks and the intrusive igneous rocks, in which primary interstitial and intercrystalline permeability is nil, normal faults are a primary cause of rock permeability.

Large vertical offsets along normal faults may juxtapose water transmitting units against low permeability units. The southwest block along the Death Valley-Furnace Creek fault is downthrown. As noted above, this normal fault movement juxtaposes the aquifer of lower Paleozoic carbonate rocks against low permeability Tertiary and Quaternary valley fill in the vicinity of Grapevine Springs and Nevares Spring (fig. 16). In contrast, the downthrown block places permeable gravel beds of the Funeral Formation in contact with the Paleozoic carbonate rocks upgradient from Travertine and Texas springs. At Ash Meadows, lower Paleozoic carbonate rocks abut low-permeability basin-fill materials across the gravity fault (fig. 18). Flow in the carbonate rocks moves in to the basin fill in local travertine and gravel aquifers and is discharged at the springs in Ash Meadows (Winograd and Thordarson 1975, Dudley and Larson 1976, Harrill and Bedinger 2005, Sweetkind et al. 2004, and Bedinger and Harrill 2006b).

Detachment Faults

Detachment faulting developed at middle crustal depths as shear zones during regional extension in the region from Oligocene to Holocene age. The detachment faults juxtapose unmetamorphosed upper plates of upper Proterozoic to Paleozoic strata astride medium- to high-grade metamorphic lower plates of basement Proterozoic and lower Paleozoic rocks. Stratigraphic units are given in table 2. Detachment faults are major tectonic features of Panamint, Grapevine, Funeral, Black, and Cottonwood Mountains of Death Valley. The blocks have been rotated, raised, and denuded as they were progressively transported westward. The lower plates of metamorphic rocks underwent doming and faulting as the plates were raised and rotated to the northwest. The upper plates of unmetamorphosed brittle upper crust broken into shingled normal faults lie across a zone of mylonite that developed during movement on the fault (Hamilton 1988).

The Grapevine and Funeral mountains preserve the upper and lower plates of the Boundary Canyon detachment, a gently south-dipping fault that juxtaposes the metamorphosed Proterozoic to lower Cambrian rocks of the lower plate against the unmetamorphosed brittle fractured upper plate Proterozoic to Paleozoic rocks (Hamilton 1988, Wright and Troxel 1993, and Sweetkind et al. 2004). In the Black Mountains, lower-plate midcrustal metamorphic rocks of the detachment underlie Cenozoic sedimentary and volcanic rocks.

A major detachment zone in Tucki Mountain preserves an upper plate of middle Proterozoic through Paleozoic rocks on the east mountain flank overlying a basal plate of Proterozoic rocks (Stirling Quartzite, Johnnie Formation, and Pahrump Group) of the ZPcc unit (fig. 4). Although the metamorphic rocks of the lower plate are of lower permeability, the rocks are cut by joints and faults that developed as the cooled, brittle plates were raised, domed, and rotated (Hamilton 1988). On the west flank of Tucki Mountain, the lower plate is overlain by Cenozoic sediments and volcanics concealing Paleozoic carbonates and clastic rocks, units ZPcc and PMc (Sweetkind et al. 2001 and Hunt and Mabey 1966). Low permeability mylonite of the detachment fault zone and the underlying lower-plate metamorphic rocks may account for the emergence of springs in the east frontal upper plate. However, springs are common through the Panamint Range, discharging from the metamorphic complex of the lower plate, intrusive rocks, and the volcanic and sedimentary rocks of Paleozoic and Cenozoic age of the upper plate.

Chaos Faulting

Noble (1941) observed a style of intricate and complex faulting in the Virgin Spring area in the southwestern part of the Black Mountains that he named Amargosa chaos. He interpreted the Amargosa chaos as part of the upper plate of a regional thrust fault he termed the Amargosa thrust. The Amargosa thrust is now recognized as a detachment fault and the chaos as an extreme product of Tertiary crustal extension that scrambled rocks during extensional tectonics of Death Valley and the Basin and Range province (Troxel and Wright 1987). Hunt and Mabey (1966) also found chaos structure in the Panamint Range associated with the Tucki Mountain detachment fault. The intricate and complex chaos faulting may provide permeable pathways for movement of groundwater.

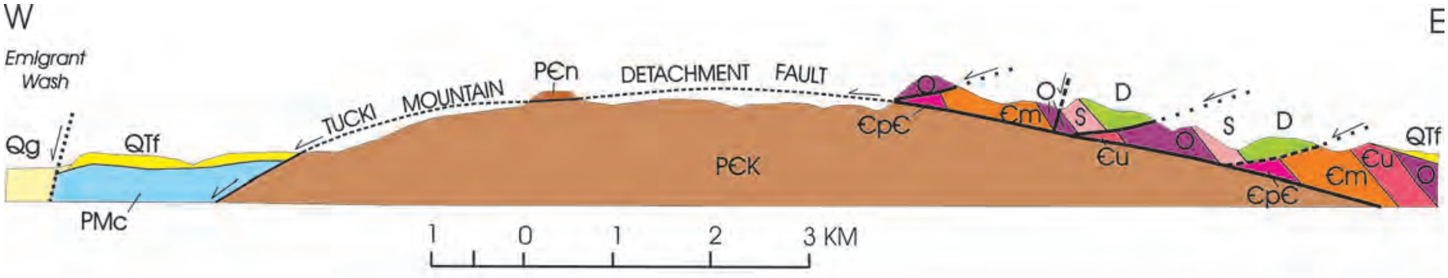
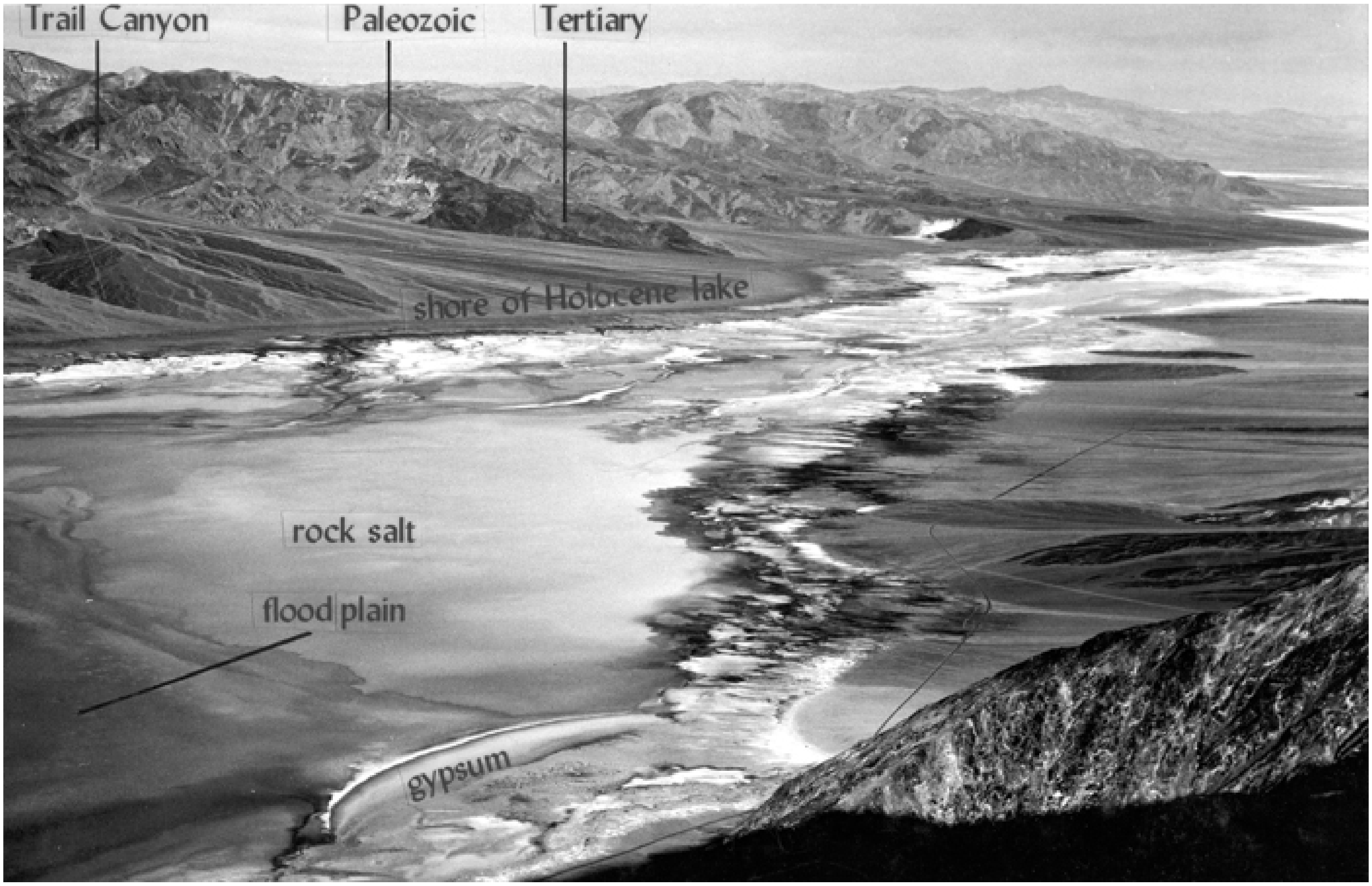


Figure 4. Section through Tucki Mountain showing the Tucki Mountain detachment fault and its branches on the east side of the mountain, the Cenozoic deposits on the west side conceal, PMc, Paleozoic carbonates. PMK, Stirling Quartzite, Johnnie Formation and Pahrump Series, undivided; pЄn, Noonday Dolomite; ЄpЄ Stirling Quartzite and Lower Cambrian; Єm Middle Cambrian; Єu Upper Cambrian; O, Ordovician; S, Silurian; D, Devonian; PMc, Paleozoic and Mesozoic carbonates; QTf, Funeral Formation; Qg, upper Pleistocene fan gravel. Vertical scale not exaggerated. From Hunt and Maybey 1966, modified after Sweetkind et al. 2001.



Photograph 2. Badwater Basin. Badwater Basin, from center to left margin of photo, viewed from Dantes View in Black Mountains, Panamint Mountains in background. Photograph from C. B. Hunt, USGS files.

Geologic Units and their Hydrologic Characteristics

The hydrogeologic groupings of geologic formations of Death Valley National Park are outlined in table 2, following the descriptions in Hunt and Mabey (1966) and Sweetkind et al. (2004). The formations are grouped into units that have similar and distinctive hydrogeologic properties. The hydrologic groupings were established by Winograd and Thordarson (1975) and generally followed by D'Agnese et al. (1997) and Sweetkind et al. (2004). The surface distribution of geologic units in the park is shown in figure 5.

Metamorphic and Igneous Basement Rocks (Xmi)

Early Proterozoic crystalline metamorphic rocks (Xmi) (the Crystalline Rock Confining Unit [XCU] of Sweetkind et al. 2004) make up the rock basement and are the oldest rocks exposed in the park. The rocks consist of metasedimentary quartzofelspathic schist, augen gneiss, and granite intrusive rocks. Hunt and Mabey (1966) ascribed a thickness of at least 900 meters (2,953 ft) to these rocks. Proterozoic basement rocks (Xmi) are exposed in the Mesozoic Wheeler and equivalent thrust plates and as metamorphic core in basal plates of Cenozoic detachment faults in the Panamint Mountains, in the southern Black mountains, and limited exposures in the Funeral Mountains (fig. 5). Hunt et al. (1966, B13) note that the metamorphic and granitic rocks are dense; they have no significant inter-crystalline permeability, but they are broken by numerous widely spaced fissures that provide channels for seepage of groundwater. At depth these fissures are believed to be closed, and the crystalline basement rocks are thought to form the lower limit of significant regional flow in the Death Valley groundwater system (Winograd and Thordarson 1975). However, local springs (fig. 20) are widely distributed in outcrops of metamorphic and igneous basement rocks, especially at higher altitudes where the greater precipitation provides recharge to the fractured rock.

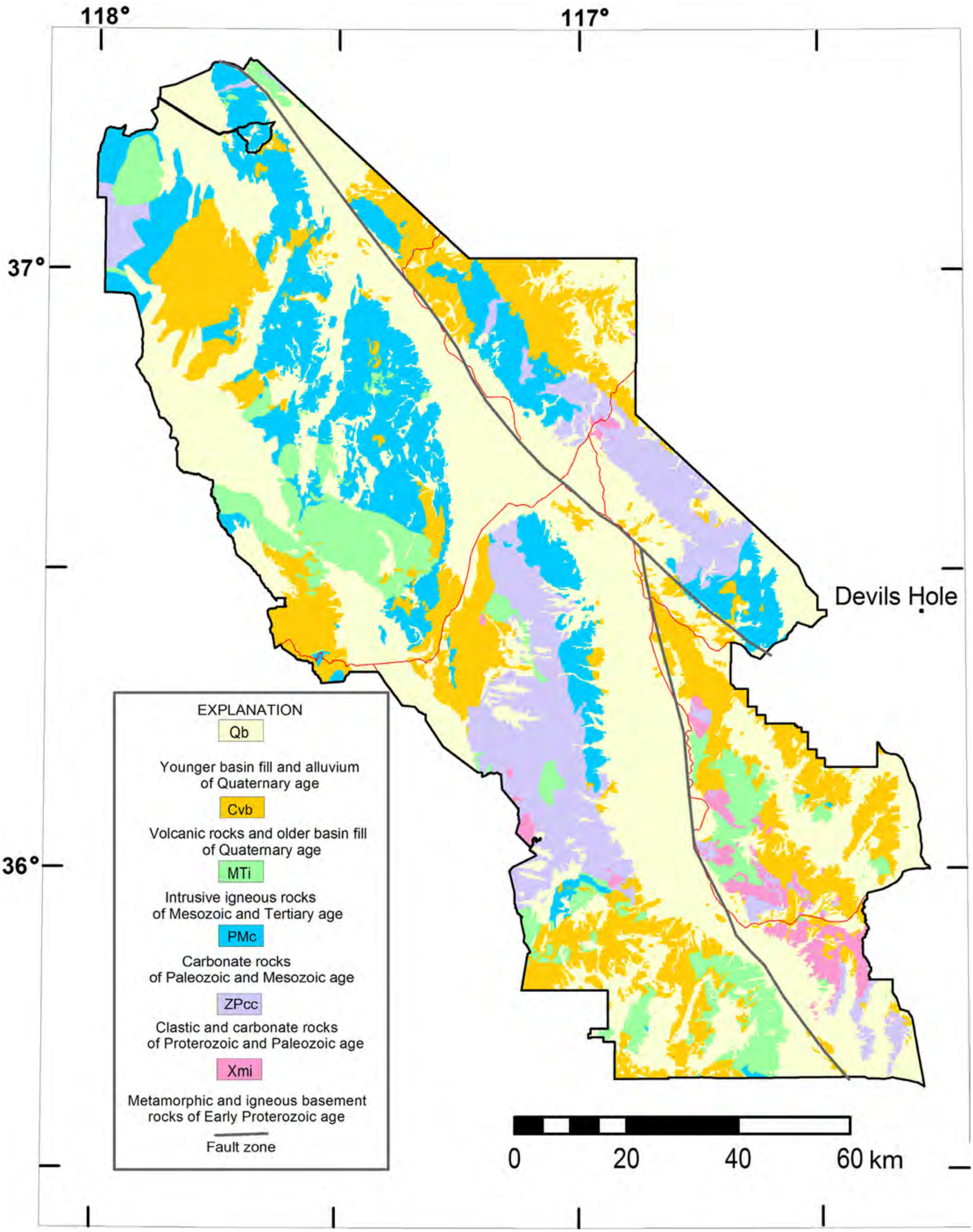


Figure 5. Generalized geologic map of Death Valley National Park. After Workman et al. 2002a.

Table 2. Geologic and hydrologic units of Death Valley

Hydrogeologic unit and and map symbol (fig. 5)	Age	Formation	Lithology and thickness	Hydrologic Properties (meters/day)
Younger Basin Fill and Alluvium (Qb)	Cenozoic (Quaternary)		Coarse- and fine-grained basin fill, evaporites, freshwater limestone, travertine spring deposits	Variable with hydraulic conductivities from $1x10^{-5}$ to $2x10^{2}$ m/d
Volcanic Rocks and Older Basin Fill (Cvb)	Cenozoic (Tertiary and Quaternary)	Artist Drive Formation, Furnace Creek Formation, Funeral Formation	Basalt, silicic to intermediate flows; alluvium, fan, lacustrine, and evaporite deposits, 900 meters	Variable with hydraulic conductivities from $1x10^{-5}$ to $2x10^{2}$ m/d
Intrusive Igneous Rocks (MTi)	Mesozoic and early Tertiary		Granite, gabbro, diorite, quartzmonzonite	Hydraulic conductivities from $1x10^{-8}$ to $1x10^{0}$ m/d
Carbonate Rocks (PMc)	Middle Cambrian through Permian	Formations at east foot of Tucki Mountain	Conglomerate, limestone, and shale, 900 meters	Hydraulic conductivities: Fractured carbonite rocks from $1x10^{-2}$ to $1x10^{3}$ m/d; Unfractured carbonate rocks from $1x10^{-4}$ to $1x10^{0}$ m/d; Quartzite $1x10^{-5}$ to $1x10^{0}$ m/d; Shale $1x10^{-8}$ to $1x10^{-1}$ m/d
		Resting Springs Shale	Conglomerate, limestone, and shale, 900 meters	
		Tin Mountain Limestone and younger limestone	Limestone, 300 meters	
		Lost Burro Formation	Limestone with some quartzite and sandstone, 600 meters	
		Hidden Valley Dolomite	Dolomite, 100–300 meters	
		Ely Springs Dolomite	Massive dolomite, 100–150 meters	
		Eureka Quartzite	Quartzite, 100 meters	
		Pogonip Group	Dolomite, minor shale and limestone, 450 meters	
		Nopah Formation	Basal shale, 30 meters; dolomite, 400 meters	
		Bonanza King Formation	Thick-bedded, massive dolomite with minor limestone and shale units, 500 meters, 900 meters	

Table 2 continued

Hydrogeologic unit and and map symbol (fig. 5)	Age	Formation	Lithology and thickness	Hydrologic Properties (meters/day)
Lower Clastic and Carbonate Rocks (ZPcc)	Middle and Upper Proterozoic and Lower and Middle Cambrian	Carrara Formation	Shale, silt, limestone, 300 meters	Hydraulic conductivities: Fractured carbonite rocks from $1x10^{-2}$ to $1x10^{3}$ m/d; Unfractured carbonate rocks from $1x10^{-4}$ to $1x10^{0}$ m/d; Quartzite $1x10^{-5}$ to $1x10^{0}$ m/d; Shale $1x10^{-8}$ to $1x10^{-1}$ m/d
		Zabriskie Formation	Quartzite, about 50 meters	
		Wood Canyon Formation	Lower basal quartzite, 500 meters; middle shaley unit, 150 meters; upper dolomite and quartzite, 120 meters	
		Stirling Quartzite	Quartzite, 600 meters	
		Johnnie Formation	Mostly shale, interbedded with dolomite, quartzite, conglomerate, 120 meters	
		Noonday Dolomite	Dolomite and limestone, 300 meters	
		Pahrump Series		
		—Kingston Peak Formation	Conglomerate, quartzite, shale, with limestone and dolomite, 900 meters	
		—Beck Spring Dolomite	Cherty dolomite, 150 meters	
		—Crystal Spring Formation	Quartzite, shale, dolomite, diabase, and chert, 600 meters	
Metamorphic and Igneous Basement Rocks (Xmi)	Early Proterozoic		Metasedimentary rocks with igneous intrusions	Hydraulic conductivities from $1x10^{-8}$ to $1x10^{-1}$ m/d

Source: Hydraulic conductivities after Waddell 1982, Bedinger et al. 1989a and 1989b, D’Agnese et al. 1997, and Belcher et al. 2001.

Photograph 3. Cambrian strata of the Last Chance Range. View of Last Chance Range from the floor of Eureka Basin shows an uninterrupted 1,000-meter (3,281-ft) sequence of Lower to Upper Cambrian strata, units ZPcc and PMc. Quartzite strata appear as light colored bands. The lower broad band is the Stirling Quartzite, the middle light colored band is the Zabriskie Quartzite, and the upper light colored band is the Eureka Quartzite. Photograph by M. S. Bedinger.

Clastic and Carbonate Rocks (ZPcc)

The Lower Clastic and Carbonate rock unit (ZPcc), equivalent to the Lower Clastic-Confining Unit (LCCU) of Sweetkind et al. (2004), consists of quartzites, shales, limestones, and dolomites. In Death Valley the Lower Clastic and Carbonate rock unit is reported by Hunt and Mabey (1966) to be 4,700 meters (15,421 ft) thick. The rocks are slightly to moderately metamorphosed where they form the upper plate of detachment faults and where intruded by igneous rocks. The lower parts of this sequence make up the lower plate of detachment faults in the middle Funeral Mountains (Hamilton 1988) and at Galena Canyon in the southern part of the Panamint Range (Hunt and Mabey 1966, A13).

The Lower Clastic and Carbonate rock unit (ZPcc) can be considered to be made up of two parts. The lower part of the stratigraphic section includes the Proterozoic rocks of the Pahrump Series composed of the Crystal Spring Formation, the Beck Spring Dolomite, and the Kingston Peak Formation. The Crystal Spring Formation is composed of basal conglomerate and quartzite grading upward to shale and thinly bedded limestone. The upper part of the Crystal Spring is thick-bedded dolomite and locally massive chert. At Galena Canyon the formation is about 900 meters (2,953 ft) in thickness and is intruded by diabase (Hunt and Mabey 1966). The Beck Spring Dolomite is a cherty dolomite with estimated thickness of 150 meters (492 ft). The Kingston Peak Formation is conglomerate, quartzite, shale, and some limestone and dolomite, at least 900 meters (2,953 ft) in thickness (Hunt and Mabey 1966).

The upper part of the Lower Clastic and Carbonate rock unit (ZPcc) includes formations of Upper Proterozoic through Cambrian. This sequence is made up of Noonday Dolomite (dolomite and limestone, 300 meters [984 ft]), Johnnie Formation (mostly shale interbedded with dolomite, quartzite, and conglomerate, 1,220 meters [4,000 ft]) and Stirling Quartzite (quartzite, 600 meters [1,969 ft]), the Lower Cambrian Wood Canyon Formation (quartzite and dolomite, 500 meters [1,641 ft]) and Zabriskie Quartzite (quartzite, more than 50 meters [164 ft]) and the

Lower and Middle Cambrian Carrara Formation (limestone and shale, 300 meters [984 ft]) (Hunt and Mabey 1966). Exposures of the Stirling Quartzite in the Panamint Mountains show open bedding joints between 8- to 30-centimeter- (3.1- to 11.8-in) thick beds and cross bedded fracture openings spaced at closer intervals. Belcher et al. (2001) reports the maximum measured hydraulic conductivity of the quartzite to be 5 meters per day (16.4 ft/d).

Exposures of the Lower Clastic and Carbonate rock unit (ZPcc) are widespread in the principal mountain ranges—Panamint Range, Funeral Mountains, Grapevine Mountains, Cottonwood Mountains, and Last Chance Range. The Lower Clastic and Carbonate rocks are the principal unit in the Ibex Hills and Saddle Peak Hills, southeast of the Black Mountains. Rocks in the exposures are porous and permeable by virtues of cracks, faults, and fractures—features that in carbonate rocks are enlarged by solution.

Over much of Death Valley flow system, this unit is deeply buried where the fractures may be closed by compression or filled with precipitated minerals. The formations comprising this unit at the Nevada Test Site (renamed the Nevada National Security Site in 2010) were considered to have negligible permeability and were called the Lower Clastic aquitard by Winograd and Thordarson (1975). However, in the Death Valley region, the Lower Clastic and Carbonate rock unit (ZPcc) is of regional importance as an aquifer. Saratoga Spring, discharging regional flow at the southeastern edge of the Death Valley playa, emerges from the Pahrump Series of this unit. Keane Wonder Spring, a regional spring, issues from the Pahrump Series in the northern Funeral Mountains. Other locations where the Lower Clastic and Carbonate rocks may contain aquifers of regional significance include the upper detachment plate between the Panamint and Cottonwood Range. A line of springs arises along the east flank of the Panamint Range bordering the central Death Valley playa. These springs are probably of local origin in the Panamint Range, but regional discharge to the Death Valley playa through the Lower Clastic and Carbonate rocks cannot be ruled out.

Photograph 4. Stirling Quartzite. Photograph of Stirling Quartzite showing fold and fault openings, bedded plane joints, and cross-bed joints and fractures. Beds are 8 to 30 centimeters (3.1 to 11.8 in) in thickness. Photograph from C. B. Hunt, USGS files.

Hunt et al. (1966, B13) note from study of exposures of the rock sequence that carbonate rocks, shale, and quartzite are dense and not intrinsically permeable, but they are broken by closely spaced fissures. The quartzites tend to be generally shattered by faulting (McAllister 1970). In places quartzites are intensely fractured to a granular texture (Hunt et al. 1966). Some fissures in the carbonate rocks are closed by secondary carbonate and others opened by solution (Hunt et al. 1966). Where the rocks in this unit are at or near the surface, they make up the principal aquifer of many upland springs. The abundant fractures in the rocks readily admit recharge in the higher elevations where precipitation is greater. Many of the upland springs are perennial with significant reservoir storage; circulation of groundwater is to depths of several tens of meters in the flow path of some springs as indicated by warmer spring temperatures.

Photograph 5. Bonanza King Formation. Bonanza King Formation showing solution channels. The Bonanza King is one of the principal groundwater-bearing formations of the Paleozoic and Mesozoic carbonate rock unit (PMc). Photograph from C. B. Hunt, USGS files.

Carbonate Rocks (PMc)

In Death Valley the succession of rocks of Middle Cambrian through Permian age is dominated by carbonate rocks with interbeds of quartzite and shale. The carbonate rock units make up the principal regional aquifer of central and east-central Nevada (Dettinger et al. 1995). North and northeast of Death Valley in Nevada, the carbonate rock succession is often separated by a great thickness of clastic rocks of Upper Devonian and Mississippian age. At the Nevada Test Site, the clastic dividing unit is the Eleana Formation having a thickness of 2,400 meters (7,874 ft; Winograd and Thordarson 1975). Where the sequence is separated by a clastic unit, the lower sequence of carbonates form the Lower Carbonate–Rock Aquifer (LCA), clastic rocks make up the Upper Clastic Confining Unit (UCCU), and the Pennsylvanian and Mississippian Limestone and dolomite make up the Upper Carbonate–Rock Aquifer (UCAQ) of D'Agnese et al. (1997) and Sweetkind et al. (2004).

In Death Valley the Middle Cambrian through Permian carbonate unit (PMc) is the primary regional aquifer conveying groundwater to Death Valley from the east through the Funeral and Grapevine Mountains and from the west through the Cottonwood and Last Chance Ranges. Stratigraphic equivalents of this unit containing a significant thickness of carbonate rocks occur in the Inyo Mountains bordering Saline Valley and Eureka Valley in the northwest part Death Valley National Park. The PMc unit is missing in the Greenwater Range and Black Mountains and the Ibex and Saddle Peak Hills. The presence of these rocks in the east facing slopes of the Panamint Range is limited to the upper plate of detachment faults where the rocks are aquifers supplying upland springs. However, in the northwestern Panamint Range (northwest slope of Tucki Mountain), the Lower Carbonate Rock Unit in the upper plate of the detachment fault may be important in transfer of regional groundwater from Panamint Valley to Death Valley playa.

In the higher mountain ranges where carbonate rocks are the predominant country rock, as in the Cottonwood Mountains and Last Chance Range, upland springs are rare except near igneous intrusions that obstruct the downward migration of infiltrating water. Upland springs are lacking in the southern Funeral Mountains in the outcrop area of the PMc unit.

Intrusive Igneous Rocks (Mti)

Mesozoic and early Tertiary igneous intrusions (MTi unit) were emplaced following thrust faulting, folding and uplift of the Proterozoic and Paleozoic sedimentary sequence of the Death Valley region and following the emplacement of the Sierra Nevada batholith. Intrusions in the Death Valley region include the large Hunter Mountain Batholith in the southern Cottonwood Mountains, batholiths in the Panamint Mountains, Black Mountains, Greenwater Range and Owlshead Mountains. The intrusive igneous rocks are called the Intrusive Rock Confining Unit (ICU) by Sweetkind et al. (2004). Many fractures and weathered zones in the igneous intrusives are open at shallow depths, and many springs discharge from igneous plutons at higher elevations in the ranges where recharge occurs, such as the Hunter Mountain batholith where saturated fractures and fault zones are intersected by deep ravines. The extent and depth of the open fractures is not well known. Indirect evidence from the temperature of springs in the Hunter Mountain Batholith indicates moderate depth of circulation of groundwater that discharges at mountain springs.

Volcanic Rocks and Older Basin Fill (Cvb)

Tertiary and Quaternary volcanics and older basin fill of Tertiary age are commonly interbedded and are mapped as a single unit in the geologic map (fig. 5).

Volcanic Rocks

Exposed volcanic rocks of Death Valley region of Oligocene to Pleistocene age are basalt flows and silicic to intermediate composition flows and tuffs (Workman et al. 2002a). Volcanic activity was contemporaneous with extensional tectonics, and volcanic materials are interbedded with sediments in basin fill.

Basalt flows are exposed at Towne Pass and in the Saline Range. Felsic and intermediate flows are exposed in the Darwin Plateau, Southern Panamint Range, Owlshead Mountains, Saline Range, Black Mountains, and Greenwater Range. Volcanics are interbedded with sediments in the Furnace Creek basin. Many of the exposed volcanic units are not of sufficient thickness to extend downward to the water table.

Older Basin Fill

Sedimentary deposits of Oligocene, Miocene, and Pliocene age include playa- and basin-filling clastic and evaporite deposits (the sedimentary part of the volcanic-sedimentary-rock unit [VSU] of Sweetkind et al. 2004). The oldest of these deposits accumulated in broad shallow basins extending over most of Death Valley National Park and adjacent areas before the present-day topography developed. In southeastern Death Valley, the deposits overlie basement rocks of the Pahrump Group (lower part of ZPcc) and crystalline igneous and metamorphic rocks (Xmi). The oldest deposits in this unit are also exposed on the east side of the Funeral and Grapevine Mountains (Reynolds 1974, Wright and Troxel 1993, and Sweetkind et al. 2004). In the park, the deposits probably reach their maximum thickness in the Furnace Creek and Death Valley basins (Fridrich et al. 2003a and 2003b). Equivalent deposits underlie younger basin fill and alluvium in the Amargosa basin and Pahrump basins. The deposition of these deposits began possibly in Oligocene and continued during Miocene extension, but before basin-range mountain building. The oldest formation in this unit is the Artist Drive Formation. Deposition continued during and after basin-range extension and mountain building. Following deposition of the Artist Drive Formation, the Furnace Creek Formation was deposited. These formations are primarily fine-grained playa sediments with interbedded, but discontinuous, lenses of sand and gravel in a fine-grained matrix: evaporites and interbedded volcanic flows and tephras. Fridrich et al. (2003a and 2003b) describe these formations as “impermeable.” During basin-range mountain building

Photograph 6 (right). View from Zabriskie Point. Badlands carved from fine-grained playa sediments of the Furnace Creek Formation viewed from Zabriskie Point. Silt and clay exposed here were deposited in one of Death Valley's Tertiary lakes, then were buried by still more sediment, compressed and weakly cemented, then folded and uplifted during the basin–range phase of extension tectonics to be exposed by erosion and weathered to form badlands of the soft rock called mudstone. Photograph by Tom Bean.

Photograph 7 (below). Salt Polygons. Salt polygons in the Badwater saltpan, snow-covered peaks of Panamint Mountains in the background. Photograph by Ray Nordeen, NPS.

the Black Mountains and Funeral Mountains were uplifted, leaving these deposits in a synclinal basin between the two mountain ranges. Excellent sequences of the Artist Drive and Furnace Creek Formation are exposed in the strata on the south limb of the syncline upturned against the Black Mountains. The formations in the synclinal basin north of Furnace Creek are covered, to a large extent, by the Pliocene and Pleistocene age Funeral Formation, a coarse-grained, post basin-range, extension-fan deposit from the Funeral Range.

The older basin-fill deposits extend northward along the western flanks of the Funeral and Grapevine Mountains. The Furnace Creek Formation underlies Cottonball Basin and Mesquite Flat and crops out at uplift in the Salt Hills between these two segments of Death Valley. Older basin-fill deposits are exposed in the valley of Death Valley Wash, Saline Valley, and Eureka Valley. Deposits making up the Miocene and Pliocene basin filling sequences in Death Valley are described by Cemen et al. (1985), Wright et al. (1999), Sweetkind et al. (2004), Greene (1997), and Fridrich et al. (2003a and 2003b).

Many deposits of older basin fill is of low permeability and act as barriers to flow beneath the aquifer of the overlying Funeral Formation. Coarse-grained sand and gravel deposits in the Funeral Formation are permeable and supply Navel Springs, Texas Spring, Travertine Spring, and the springs on Salt Creek.

Younger Basin Fill and Alluvium (Qb)

The younger basin fill and alluvium are the unconsolidated Cenozoic alluvium and basin-fill sediments and local young volcanic rocks (YAA and OAA) of Sweetkind et al. (2010). These deposits include coarse-grained alluvial stream and fan deposits, fine-grained basin playa sediments and evaporite deposits, eolian deposits, and local lacustrine limestone and spring discharge deposits.

Regional groundwater flows in the younger basin fill deposits of the Amargosa River to Death Valley basin where it may provide part of the flow of Amargosa River Valley Springs. Alluvium of Furnace Creek conveys water to the alluvial fan at the mouth of the creek. Furnace Creek alluvium is recharged by surface runoff and, near the mouth of the creek, by subsurface flow from Travertine and Texas springs through colluvial deposits. Coarse alluvial fan deposits on the east flank of the Panamint Mountains convey groundwater to the floor of Death Valley. The groundwater emerges from the fan deposits and the underlying bedrock as springs and seeps and is transpired by phreatophytes at the margin of the valley floor. The valley floor is underlain by fine-grained sediments and evaporites. The alluvial fill of Death Valley Wash, the northwest arm of Death Valley above Mesquite Flat, is not well-known, but the Holocene and Tertiary fill in the valley is shallow as determined from geophysics.

Climatic Setting of Death Valley Region

The climate of the Death Valley is one of the most diverse in the country. Climate is largely controlled by elevation which has an extreme range from –86 meters (–282 ft) at the lowest point in Death Valley to 3,368 meters (11,049 ft) at Telescope Peak in the Panamint Mountains. While basically a complex of rain shadow deserts, the region exhibits climatic characteristics associated with continentality—severe conditions of winter cold and summer heat—while also exhibiting subtropical properties such as mild warm winters (at low elevations) and summer convectional rainfall (Rowlands 1993).

The dominant source of winter precipitation is from the west or northwest from the eastern Pacific and Gulf of Alaska. Less commonly northeasterly flow of air brings dry and unusually cold temperatures to the region (James 1993). In summer the dominant air flow is from the south and southeast and less frequently from the west. This southeast flow, the so-called "Arizona Monsoon," sometimes brings convective thunderstorms that occasionally release damaging rains. Some summers a westerly flow of drier air dominates and thunderstorms are virtually non-existent (James 1993).

The relative amount of summer (June–September) precipitation ranges from 5 to 40% of the annual total and is less than 33% at all stations reported by Rowlands (1993) except Beatty, Nevada.

"Furnace Creek" was aptly named for a geographic feature in one of the hottest places on earth. Temperatures have exceeded 120°F (49°C) each month from May through September during the period of record (James 1993). Daily maximum averages in summer are in the 110°–115°F (43°–46°C) range from June through August, with nights normally cooling only into the low to mid 80s (27°–29°C). Maximum summer temperatures routinely approach 130°F (54°C). Winter temperatures at the desert floor are relatively cool with winter days typically having high temperatures reaching the mid-60s (15.5°C). Freezing temperatures at night are common during the colder winter months of December and January (James 1993). Rowlands (1993) has drawn regression equations for the three major climatic factors affecting the hydrologic environment—potential evapotranspiration, temperature, and precipitation—relating each to elevation. Relations given below from Rowlands (1993) are drawn from weather stations in and surrounding Death Valley National Park. The stations include Trona, Bishop, Deep Springs, and White Mountains (two stations) in California, outside the park, and Beatty, Goldfield, and Sarcobatus Flat in Nevada. Stations in the park include Wildrose Ranger Station, Badwater, Cow Creek, and Furnace Creek.

Potential Evapotranspiration (mm) = e (–0.00042 Alt (m) + 7.185), r2 = 0.994

Precipitation (mm) = 0.111 Alt (m) + 10.736, r2 = 0.894

Mean annual temperature (Celsius) = –0.007 Alt (m) + 23.114, r2 = 0.988

Mean July Temperature (Celsius) = –0.008 Alt (m) + 45.701, r2 = 0.988

Mean January Temperature (Celsius) = –0.008 Alt (m) + 4.448, r2 = 0.901

More current data on precipitation stations in and adjacent to Death Valley are presented in Hevesi et al. (2003). An independent evaluation of the relation between precipitation and elevation was made using 10 stations in or near the park. These data are listed in table 3. The relation between annual precipitation and altitude is shown in figure 6. The results are in general agreement with Rowland's findings.

The climatic environment of a site is influenced by topography, aspect, slope, soil characteristics, and longitude, within the overall predominating influence of precipitation, evapotranspiration, and temperature, which are controlled by elevation. These factors in varying measures affect the vegetation cover, species distribution, and recharge to groundwater. Rowlands (1993) shows that potential evapotranspiration, estimated by the Thornthwaite method (Thornthwaite 1948) is greater than 1.3 meters per year (4.3 ft/yr) at sea level. The huge moisture deficit at the playas decreases with increasing altitude as the potential evapotranspiration decreases and precipitation increases. The moisture gradient increases with increasing altitude as the potential evapotranspiration decreases and precipitation increases. Based on average annual precipitation and evapotranspiration, the elevation at which precipitation equals potential evapotranspiration occurs at 3,100 meters (10,171 ft; fig. 6). This boundary is lower during the winter months (October–May), and the opportunity for recharge of precipitation to groundwater is enhanced, especially at higher elevations, when there is greater excess of precipitation over potential evapotranspiration. The relation of temperature to elevation is shown in figure 7.

Table 3. Precipitation data for 10 stations in and near the study area

Station Name	UTM Easting[1]	UTM Northing[1]	Altitude (meters)	Average Annual Precipitation (millimeters)
Barstow	496,955	3,860,401	659	113
Barstow	496,955	3,860,401	659	113
Goldstone Echo No. 2	519,603	3,904,072	899	150
Mountain Pass	632,115	3,926,003	1,442	221
Shoshone	565,819	3,980,883	479	132
Trona	464,669	3,957,601	517	100
Wildrose Ranger Station	483,357	4,013,218	1,250	180
White Mountains 1	401,946	4,128,839	3,094	358
White Mountains 2	398,760	4,133,760	3,081	496
Deep Springs College	412,926	4,135,799	1,593	158

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.

Source: Hevesi et al. 2003 and Rowland 1993.

Figure 6 (right). Graphs of precipitation and potential evapotranspiration versus altitude in the Death Valley region.

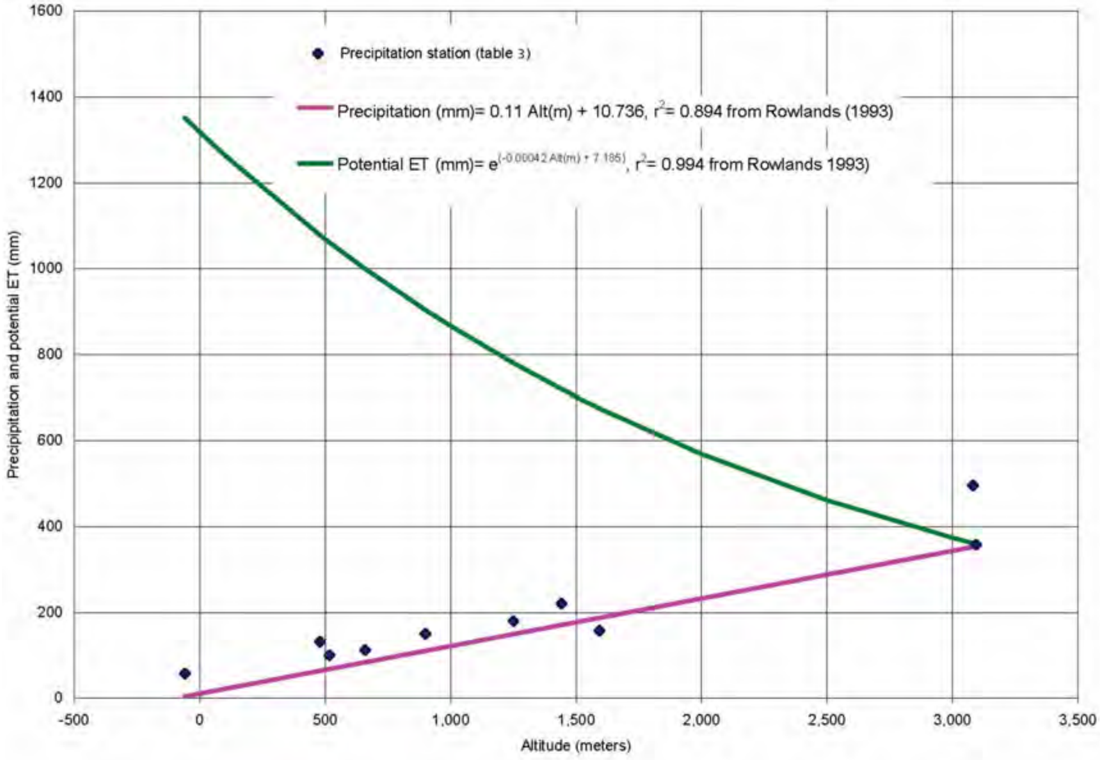
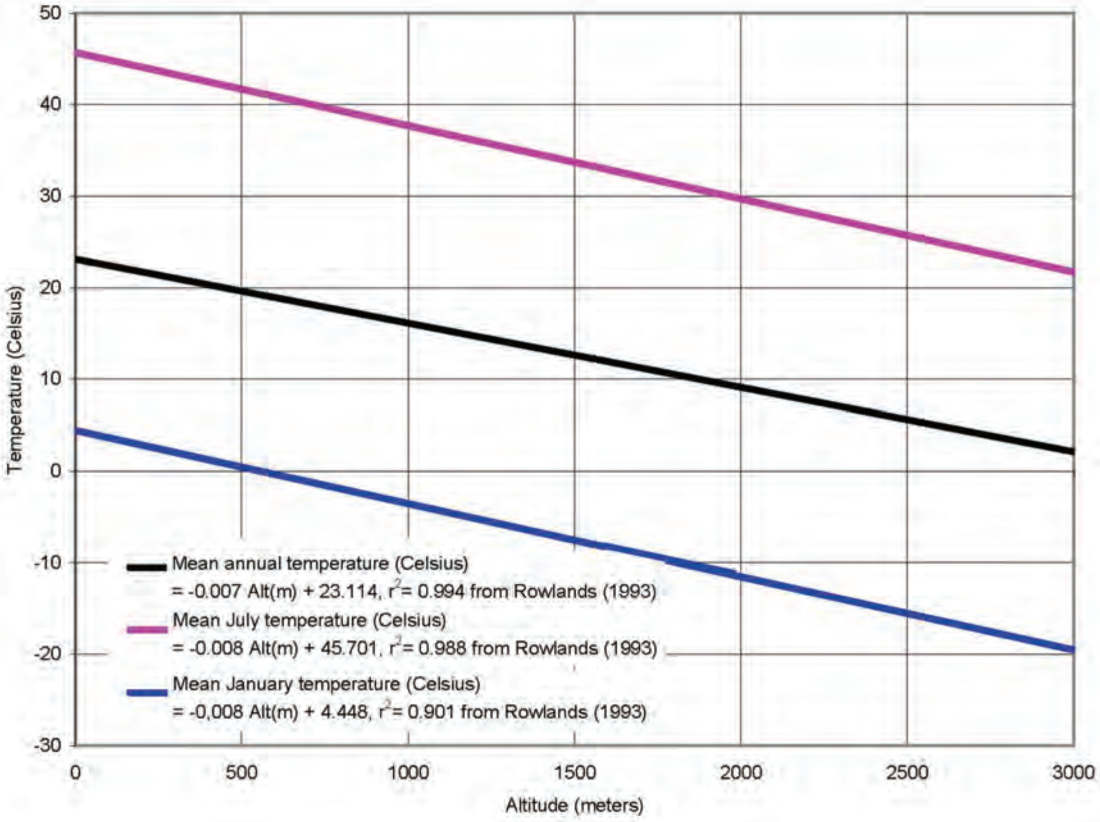


Figure 7 (below). Graphs of mean annual, mean July, and mean January temperature versus altitude in the Death Valley region.



Photograph 8. Alkali Spring. High in the Panamint Mountains, Alkali Spring supports a healthy growth of vegetation at an elevation of 2,015 meters (6,611 ft).

Vegetation

Natural vegetation cover is sparse throughout most of the region, especially at lower elevations, except for favorable areas where water is available for growth of riparian vegetation from spring discharge and shallow groundwater levels. The creosote–bursage association occupies the largest area compared to other plant associations. Woodland and forest plant assemblages are limited to the higher elevations where precipitation is greater and air temperature and potential evapotranspiration are lower (Hevesi et al. 2003). Pinion–juniper woodlands occur at elevations of about 2,000 meters (6,562 ft) and higher elevations. Limber pine and bristlecone pine associations are found on a few isolated peaks and ridges in the Panamint Range (Rowlands 1993).

Salinity of shallow groundwater, depth to groundwater, and calcium–magnesium content of soils are important ecological factors that determine the distribution of plant assemblages (Hunt and Durrell 1966). Phreatophytes, plants that consume groundwater, are principally found around the edges of the Death Valley salt pan, in Mesquite Flat, in the floodplain of the Amargosa River, and near regional and upland springs. Hunt and Durrell (1966) studied the distribution of plant species in the salt flat–fan transition zone. He identified nine phreatophytic species and related their occurrence to salinity and depth to groundwater at the edge of the salt pan. The transition from least salt-tolerant phreatophytes to most salt-tolerant is screwbean mesquite (*Prosopis pubescens*) and desert baccharis (*Baccharis sergiloides*), honey mesquite (*Prosopis julifera*), arrowweed (*Pluchea sericea*) and four-wing saltbush (*Atriplex canescens*), alkali sacaton grass

(*Sporobolus airoides*), tamarisk (*Tamarix gallica* and *T. aphylla*), inkweed (*Suaeda sp.*), saltgrass (*Distichlis spicata*, var. *stricta*), rush (*Juncus cooperi*), and finally, pickleweed (*Allenrolfea occidentalis*). Dissolved solids in groundwater grades from a minimum of 5,000 milligrams per liter (.042 lb/gal) or less where there is honey mesquite to a maximum of 60,000 milligrams per liter (.50 lb/gal) where there is pickleweed. Less tolerant phreatophytes, screwbean mesquite (*Prosopis pubescens*) and desert baccharis (*Baccharis sergiloides*), grow at higher elevations bordering the salt pan and at springs on the gravel fans. Principal xerophytes in the zone above the phreatophytes are desert holly (*Atriplex hymenelytra*) which is replaced in the zone at the south end of the valley by cattle spinach (*Atriplex polycarpa*). Above the pure stands of desert holly and cattle spinach is creosote bush (*Larrea tridentata*). Higher on the fans in the north is burroweed (*Ambrosia dumosa*) replaced in the southern part of the valley by inceinso (*Encelia farinosa*) (Hunt and Durrell 1966). A schematic representation of the effect of depth to water and salinity of soil and groundwater in the gravel fan–salt pan groundwater discharge area on the distribution of plant species is shown in figure 10.

Rowlands (1993) summarizes studies of how plant cover, plant communities, and plant species distribution in the park vary as a function of precipitation, evapotranspiration, and moisture. Density of plant cover increases in proportion to precipitation. Montane plant abundances as spindle graphs (Rowlands 1993, fig. 6) show the overlapping elevational distribution of 17 xerophytic species in order from desert holly at the lowest elevation to pinion pine at the highest elevation. Rowlands (1993, fig. 7) shows that the stratification of characteristic plant species is a function of potential evapotranspiration relating to the moisture–evapotranspiration lapse rate. A composite vertical sequence of plant species, from lower to higher elevations, from Rowlands (1993), excluding phreatophytes, halophytes, and spring assemblages, is listed here, with high altitude additions from Hunt (1975) and Arno (1984): desert holly (*Atriplex hymenelytra*); creosote bush (*Larrea tridentata*); bursage (*Ambrosia dumosa*); burrobush or cheesebush (*Hymenoclea salsola*); shadscale (*Atriplex confertifolia*); desert buckwheat (*Eriogonum fasciculatum*); desert-thorn (*Lycium andersonii*); spiny menodora (*Menodora spinescens*); Nevada ephedra (*Ephedra nevadensis*); spiny hopsage (*Grayia spinosa*); Cooper goldenbush (*Haploppapus [Ericamera] cooperi*); blackbrush (*Coleogyne ramosissima*); big sagebrush (*Artemisia tridentata*); sticky-leaved rabbit bush (*Chrysothamnus viscidiflorus*); antelope brush (*Purshia gladulosa*); green ephedra (*Ephedra viridis*); Macdougal buckwheat (*Eriogonum microthecum*); Utah juniper (*Juniperus osteosperma*); pinion pine (*Pinus monophyla*); limber pine (*Pinus flexilis*); Great Basin bristlecone pine (*Pinus longaeva*).

Because of the close relationship between plant species and the moisture gradient, zones of plant associations have been made principal criteria by some investigators for assigning estimated recharge rates. Rice (1984) placed the lower limit of recharge to coincide with the elevation of the pinion pine–juniper plant zone where precipitation is greater than 254 millimeters (10 in) and elevation is greater than 1,675 meters (5,500 ft). The lowest zone of recharge of D'Agnese et al. (1997) is coincident with the mixed-shrub transitional zone which begins at an elevation of about 1,500 meters (4,900 ft). The two vegetation zones above the mixed-shrub transitional zone, the pinon–juniper zone (1,520 to 2,440 meters [5,000 to 8,000 ft], 305 to 510 millimeters [12 to 20 in]) and the coniferous forest zones (>2,440 meters [8,000 ft], >510 millimeters [20 in]) reflecting successively greater moisture availability were given accordingly greater recharge weight.

Soils

Soils in the Death Valley region were grouped into four types by Hevesi (2002 and 2003) for use in infiltration models: (1) upland soils on the mountains and areas characterized by rugged topography, (2) valley-fill soils on alluvial fans and terraces, (3) playa soils on the valley floors and playa basins, and (4) channel soils in active stream channels. These classifications are based on the STATSGO data base of the U.S. Department of Agriculture. Hevesi (2002 and 2003) describes upland soils as usually less than one-meter (3.3-ft) thick, of coarse texture with little moisture-holding capacity, and having great permeability. Playa soils are fine-grained and characterized by a high percentage of clays or evaporites including silicified hardpans (Beatley 1976), and have much lower permeability than valley-fill and upland soils. Valley fill and soils in active channels tend to be coarse textured and more permeable than the soils of the surrounding terraces and interchannel areas of alluvial fans.

Soils of Death Valley are included in the STATSGO data base covering the United States (U. S. Department of Agriculture 1988). The STATSGO data base is a digital general soil association map developed by the National Cooperative Soil Survey. STATSGO depicts information about soil features on or near the surface of the Earth. STASGO is designed primarily for regional, multi-county, river basin, state, and multistate regional planning, management, and monitoring. It consists of a broad-based inventory of soils and non-soil areas that occur in a repeatable pattern on the landscape and that can be cartographically shown at the scale mapped. The soil maps for STATSGO are compiled by generalizing more detailed soil survey maps. Where more detailed soil survey maps are not available, data on geology, topography, vegetation, and climate are assembled, together with Land Remote Sensing Satellite (LANDSAT) images. Soils of like areas are studied, and the probable classification and extent of the soils are determined.

Hydrogeologic Setting

During the gold rush days, the vast desert region between the Rocky Mountains and the Sierra Nevada was considered a trackless wasteland—a formidable obstacle almost devoid of water that had to be carefully crossed from water hole to water hole to survive the trek to the gold fields of California. That the Native Americans who lived in the region were aware of the water holes that were essential for their survival is indicated by the names they gave the valleys reflected the presence or absence of water. Many basins having Native American names beginning in “pa” or “pah” contain water – such as Pahranagat and Panamint. These basins have groundwater near the surface or springs and marshes in the playas. Other basins having names ending in “pah” – Ivanpah and Nopah have no springs or marshes.

This great region is characterized by long high mountains of hard rock with intervening sand, gravel, and silt-filled basins with no external drainage to the sea. This very basic but significant hydrologic insight into the Great Basin was recorded prior to the 20th century by John C. Fremont who explored the northern part of the region from the Rockies to California and named the Great Basin in early 1840s. Fremont defined the Great Basin as that collection of basins with closed drainage having no outlet to the ocean. He designated the Great Basin as bounded by the Columbia River drainage on the north, the Sierra Nevada on the west and the Colorado River drainage to the south.

Using data from wet and dry valleys, discharge areas, thermal springs, and topography Bedinger and Harrill (2010) have formulated a set of guidelines for mapping the potential for regional movement of groundwater. The regional potential map, shown in plate 1, shows the direction and gradient of regional potential for groundwater movement in a part of the Great Basin and Mojave Desert. The map of the regional potential enables definition of the area contributing groundwater to Death Valley. This is the area outlined by the red line in plate 1. It is this area that Death Valley depends upon to supply water for the large springs that emerge in Death Valley and the groundwater that discharges by evapotranspiration from the valley floor.

Death Valley Groundwater Flow System

Regional Flow

The quantitative basis for establishing the concept of regional groundwater flow is grounded in the basin studies made by the U.S. Geological Survey and the State of Nevada cooperative groundwater program. Maxey and Eakin (1949), in attempting to quantify the available groundwater resources of basins, developed field methods for estimating basin recharge and discharge. They discovered, in evaluating groundwater budgets of topographically closed basins, that many basins were not closed to groundwater transfer to or from adjacent basins. Hunt and Robinson (1960) advanced the hypothesis of interbasin transfers of groundwater to Death Valley based on geochemical studies of water. Early studies such as Eakin and Winograd (1965), Eakin (1966), Eakin and Moore (1964), Mifflin (1968), Winograd and Thordarson (1975), and Mifflin and Hess (1979) recognized the importance of interbasin groundwater flow. In time, practically all basins in Nevada were studied, and estimates of recharge and discharge were made. Mifflin (1968), recognizing that thermal springs were surface manifestations of deep regional potential, mapped the first set of regional potential contours from the surface altitudes of springs in Nevada issuing at temperatures of 27°C (80°F) or greater. Harrill et al. (1988) made use of water-budget imbalances in their work in the Great Basin to interpret interbasin flow. They constructed generalized contours of the regional groundwater potential in the Great Basin. Prudic et al. (1995) simulated flow in the carbonate rock province of Nevada from the higher basins in central Nevada to the terminal discharge areas of the Death Valley and the Colorado River regional groundwater flow systems.

Photograph 9. Mud crack in floor of Eureka Basin. Groundwater discharge does not occur from the floor of Eureka Basin because the depth to groundwater is too deep for evaporation from the water table and well below the reach of phreatophytes. Recharge to the surrounding hills flows to the adjoining Saline Basin to discharge at thermal springs and to Mesquite Flat on the main Death Valley floor. Photograph by M. S. Bedinger.

Photograph 10. Amargosa River in flood. The Amargosa River in the southeast part of Death Valley National Park during a flash flood in February 2005. Photograph by A. Van Luik.

The most recent and comprehensive model of the Death Valley regional groundwater flow system was made by the U. S. Geological Survey, in cooperation with the Department of Energy (Belcher and Sweetkind 2010). The model incorporates geologic and hydrologic data in a state-of-the-science mathematical multilayered model. The model was supported by advanced geological and geophysical investigations, comprehensive studies of groundwater discharge by withdrawal and evapotranspiration, models of groundwater recharge, and hydrologic properties of rock units. Both steady and transient states of regional groundwater flow were analyzed.

Local Flow

Recharge of groundwater occurs in the mountain ranges of the Death Valley region. This local recharge supports the higher elevation springs that occur on the slopes of the mountains. In ranges where the adjacent basin does not discharge groundwater from the playa, some of the recharge becomes a part of the regional flow system. The circulation of groundwater in the ranges is superposed on the regional flow system. Higher mountain ranges that receive greater precipitation, such as Panamint Range and Cottonwood Range, contain mountainside springs and springs on the upper parts of the alluvial fans. The circulation of the groundwater above the regional flow system can be visualized as circulation cells above regional flow paths that discharge at large intermediate discharge areas and the ultimate discharge areas at Death Valley.

Surface Water Flow of the Death Valley Region

Present-Day Surface Water

Perennial surface water flow occurs only in a few stream reaches originating from spring discharge. Perennial flow and pools of water in the Amargosa River in the park originate from the Amargosa River Valley Springs that is supplied from groundwater in the alluvium beneath the river. Upstream from Death Valley, east of the park, the Amargosa River is perennial in a few reaches near Tecopa, the Franklin Well area, and Shoshone that are fed by discharge from the regional flow system. Laczniak et al. (2001) estimated groundwater evapotranspiration in these areas. Flow was observed by the authors and was reported by Miller (1977) on occasions at the Highway 127 crossing near the southern boundary of the park. These perennial and near-perennial segments of the Amargosa River and shallow groundwater supplying phreatophytes are principally discharge of regional groundwater. Along the perennial reaches, where depth to groundwater is shallow, phreatophytes consume groundwater. The perennial flow of Salt Creek above Cottonball Basin originates as spring flow. Perennial lakes at Badwater, Cottonball Basin, and Saline Valley are maintained by discharge of groundwater. Riparian wetlands are fed by spring discharge at Grapevine, Travertine, Nevares, and Mesquite springs. Some upland springs feed short stream reaches of perennial flow. Discharge of upland springs supports riparian vegetation, with many springs having pools, but no stream. Smaller springs may have no visible water, groundwater discharge being evidenced only by the presence of riparian vegetation.

Infrequent storms can cause flash floods in normally dry stream channels. Geologically, such floods are a principal geomorphic factor in building bajadas of coalescing alluvial fans along the mountain fronts. Occasionally storms can cause ephemeral lakes in the playas. Flooding along the Amargosa River and tributaries formed the ephemeral lakes in the Death Valley playa during 1969, 1993, and 2005.

Photograph 11. Shoreline Butte. Wave-cut beaches in Shoreline Butte record pluvial lake levels in Death Valley basin. Photograph by Marli Miller.

Pleistocene Streams, Lakes, and Marshes

Pleistocene lakes of the Basin and Range Province are shown in figure 8 from studies of Williams and Bedinger (1984) and Bedinger and Harrill (2006a). Death Valley, the ultimate discharge area of both surface and groundwater, was beneficiary of a large regional contributing area. The most striking divergence from today's hydrology was the chain of lakes along the east flank of the Sierra Nevada, beginning at its maximum extent with its headwaters at Lake Russel (that occupied the present-day position of Mono Lake just north of the study area), then Adobe Lake, Owens Lake, China Lake, Searles Lake (China and Searles lakes merged at high stages to form one lake), Panamint Lake, and finally Lake Manly that occupied Death Valley. Deep Springs Lake occupied a closed basin between the Owens River Valley and Death Valley. Three closed basins—Saline Valley, Eureka Valley, and the smaller Racetrack Playa—did not hold lakes. Racetrack Playa and Eureka Valley were occupied by dry playas that were probably well above the water table, as they are today. Though no shoreline terraces are present at Saline Valley as evidence of a Pleistocene lake higher than the present-day lake, it is inferred that during the pluvial the marsh was probably more extensive than today. A chain of Pleistocene lakes punctuated the pluvial Mojave River, whose watershed heads in the San Bernardino Mountains, and drained into Death Valley. Lake Manix occupied the lowland of the Mojave River valley between present-day Barstow and Afton Canyon.

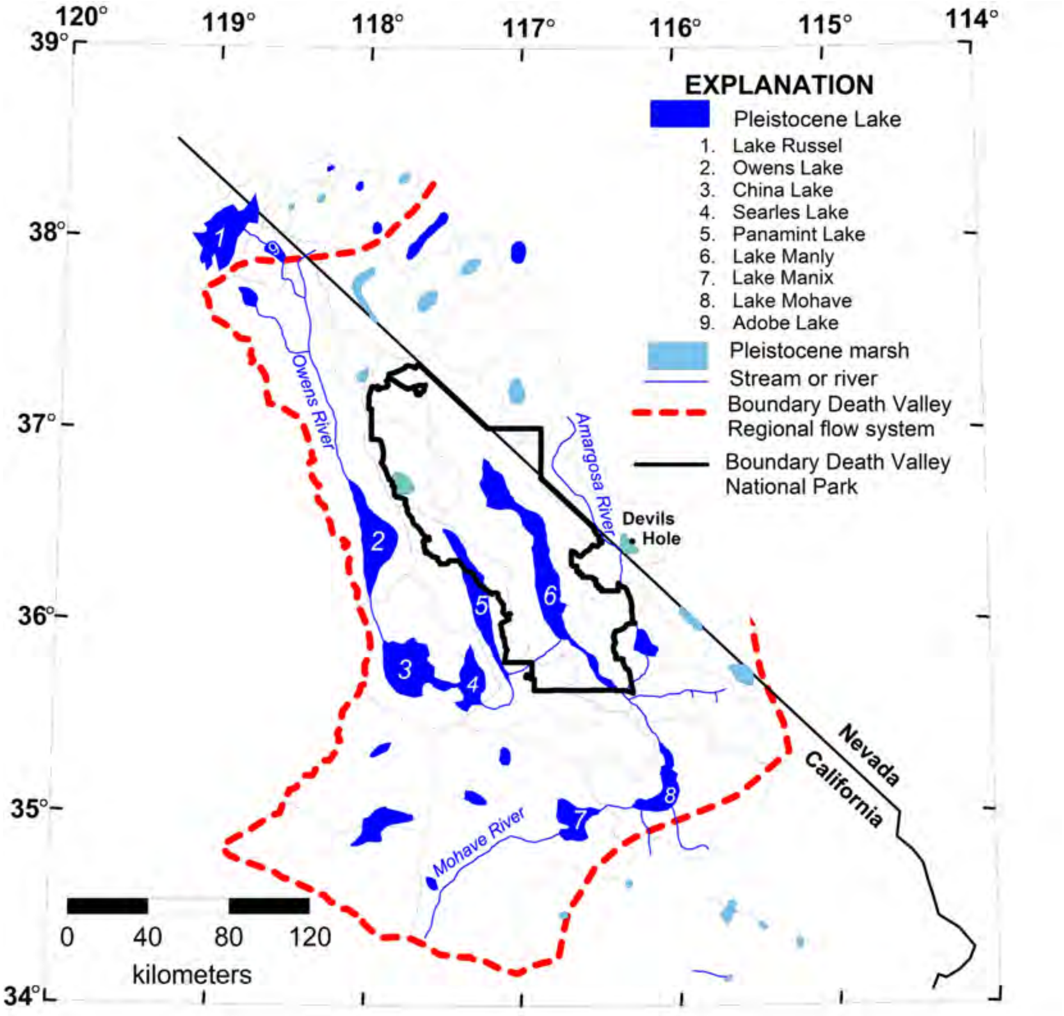


Figure 8. Map showing Pleistocene streams and lakes tributary to Death Valley. After Bedinger and Harrill 2006a.

Lake Mojave occupied the present-day Soda Lake and Silver Lake playas. The Soda Lake and Silver Lake playas are usually dry under modern conditions; however, in years of high precipitation in the San Bernardino Mountains, floods in the Mojave River sometimes fill the Soda Lake playa to depths of a few meters. Pleistocene lakes Harper, Cuddeback, Koehn, and Thompson, without apparent connection to the Mojave River, occupied shallow basins west and northwest of the Mojave River.

During the Pleistocene, the Amargosa River was, as it is today, tributary to Death Valley. In the Pliocene, Lake Tecopa, named for its location near the town of that name, occupied the present-day route of the Amargosa River until a natural dam was breached by the river. The basins of Pahrump Valley, Mesquite Valley, and Ash Meadows did not hold lakes but are inferred to have been occupied by marshes of somewhat larger extent than the early settlers found when they entered the region (Williams and Bedinger 1984).

Following the Pleistocene lake maxima, the Holocene climate has shifted toward decreasing precipitation and increasing aridity. Although there was not integrated drainage from Mono to Death Valley during the late Holocene, there were at least shallow lakes in Mono, Searles, Panamint, and Death Valley. Soda Lake Valley received flow from the Mojave River as it does under present conditions.

Inferred Groundwater Conditions under Pluvial Conditions

The location and elevations of lakes and groundwater marshes during the late Pleistocene allow us to make some inferences as to groundwater flow conditions and inter-basin hydraulic conductivities. These inferences have application to the present-day groundwater regime.

Two adjacent closed basins in California—Eureka and Saline valleys—have the greatest infiltration rates of all California basins adjoining Death Valley (J. A. Hevesi, written communication). Gale (1914) found no evidence that these basins contained lakes during the Pleistocene Epoch. During the Pleistocene, under climatic conditions of greater precipitation and less evapotranspiration than today, these basins contributed groundwater flow to Death Valley. Today groundwater discharge in Saline Valley, as is inferred during the Pleistocene, is by springs, including several thermal springs, evaporation from a saline playa lake, and transpiration by a band of phreatophytes bordering the playa. The fact that the playa of Saline Valley did not support a lake during the Pleistocene of significantly higher elevation than at present indicates that, even under conditions of greater than modern recharge, the underlying rock permeability was great enough to convey the groundwater beyond the basin. Groundwater flows from Eureka basin and Saline basin to Death Valley as shown by the regional potential map (plate 1).

Based on present-day elevations, Panamint Valley was the site of a 305-meter- (1000-ft) deep, 77,700-hectare (192,000-ac) lake having a maximum depth of about 305 meters (1000 ft), about 610 meters (2,000 ft) in elevation. At the southern end of Panamint Valley, the lake was the natural spillway—at Wingate Pass—between Panamint Valley and Death Valley. At its maximum stage the lake in Panamint Valley was 366 meters (1,200 ft) above Lake Manly in adjacent Death Valley. We can infer that the rock permeability between Panamint Valley and Death Valley is not great enough to have conveyed all the inflow from the Pleistocene lake in Panamint Valley to Death Valley. We can infer from the modern water balance of Panamint Valley, a closed basin, (recharge to the basin minus groundwater evapotranspiration) that groundwater is conveyed to Death Valley under the regional hydraulic gradient and prevailing hydraulic conductivity of the rocks.

There is a question as to what route groundwater from Panamint Valley and Saline Valley takes to Death Valley. The fact that Saline Valley did not contain a Pleistocene lake of higher level than at present reveals that the permeability of the basin rocks was too great to allow water to rise significantly in the basin. The Pleistocene water table in the playa of Saline Valley was at a maximum near its present elevation of

320 meters (1,050 ft). The Pleistocene lake elevation in Panamint Valley was more than 579 meters (1,900 ft). The outflow from Saline Valley during the Pleistocene thus could not have been by way of Panamint Valley. It is inferred that the present outflow from Saline Valley is east toward the Mesquite Flat area of Death Valley as it was during the Pleistocene.

Hunt and Robinson (1966, B40) inferred that the absence of wave-cut terraces in Pahrump Valley revealed the absence of a lake in the closed basin during the pluvial climate of the Pleistocene and reasoned that the absence of a lake indicated subsurface drainage through the Paleozoic rocks of the bounding ranges. Hunt and Robinson (1960, B28) ascribed the source of the springs at Ash Meadows and possibly springs in the Tecopa area to groundwater flow from Pahrump Valley. The hypothesis of flow from Pahrump Valley was corroborated by Malmberg's (1967, 28–33; fig. 5, plate 2) potentiometric mapping in Pahrump Valley, but the potentiometric map shows that groundwater flows southwestward toward Tecopa, directly into northeast-dipping Paleozoic carbonate strata comprising the bordering Nopah Range, rather than to Ash Meadows.

Williams and Bedinger (1984), in their map of Pleistocene lakes and marshes of the Death Valley region, inferred that closed basins that today have shallow groundwater level but that did not hold Pleistocene lakes were the sites of marshes during pluvial climate of the Pleistocene. It is further inferred that groundwater from these basins in the Death Valley flow system drained in the direction of the regional potentiometric gradient (plate 1).

Groundwater Inflow, Recharge, and Discharge

Groundwater Inflow From California

Estimates of inflow to Death Valley from desert basins in southeast California were made by a combination of water budgets for closed basins bordering Death Valley and calculations of inflow based on regional hydraulic gradient and hydraulic conductivity of the geologic materials (Bedinger and Harrill 2006a).

Water budgets (table 4) were made for several basins bordering the southern part of Death Valley basin (243). The basin numbers referred to in this report are shown on the map in figure 12. The water budgets in combination with the regional potential map indicate that most of the recharge to the basins and the inflow from the Lower Mojave Basin (269) is discharged by evapotranspiration at Soda Lake (262) playa. Probably most of the recharge to Valjean Valley (244) flows to Death Valley. Other valleys—Riggs Valley (261), Red Pass Valley (260), and Leach Valley (259)—contribute small flows based on gradient and aquifer hydraulic conductivity.

The Panamint area basins—East Pilot Knob and Brown Mountain Valley (257), Panamint Valley (255), and Darwin Plateau (254)—contribute an estimated 14,000 cubic meters per day (m^3/d; 494,340 ft^3/d) to Death Valley. In addition, inflow to the Panamint area from Lost Lake–Owl Valley basin (258) and the basins to the west of the Panamint area contribute about 2,000 m^3/d (70,620 ft^3/d) for a total estimated flow of 16,000 m^3/d (564,960 ft^3/d) to Death Valley.

An approximately equal contribution to Death Valley originates from the basins to the northwest where the high altitudes provide large amounts of precipitation. Water budgets were made for the major contributing basins: Deep Springs (250), Eureka (251), Saline (252), and Racetrack (253) valleys. Combined with a small inflow from Owens Valley (249), total flow to Death Valley from these valleys is about 15,500 m^3/d (547,305 ft^3/d).

Table 4. Summary of groundwater inflows to Death Valley basin (243) from southeast California

Bordering Area	Bordering Basins	Inflow (m^3/d)	Method of Estimating Inflow
Southern	244, 261, 260, 259	2,500	Water budgets and Darcy calculations
Panamint Area	254, 255, 257, 258	16,000	Water budgets and Darcy calculations
Northern Basins	251, 252, 263	15,500	Water budgets and Darcy calculations
Total		34,000	

Groundwater Inflow From Nevada

Regional potential for inflow to Death Valley from Nevada is indicated by the configuration of the regional groundwater potential (plate 1). The gradient is nearly perpendicular to the trend of the northeast boundary of the park. Flow across this boundary is controlled by the structural features and the distribution of geologic units. Inside the park along this boundary are the Funeral Mountains and the Grapevine Mountains. Segments of these ranges, discussed later in this report, are composed of carbonate, volcanic, clastic, and metamorphic rocks. The rocks are characteristically cut by normal faults, thrust faults, and detachment faults. The western margin of these ranges is marked by the Furnace Creek–Death Valley fault zone, a right-lateral strike-slip fault, with a downthrown southwest block, that extends from the northwest extent of the park to the Resting Spring Range southeast of the park boundary. The eastern boundary of these ranges is marked by the Stewart Valley–Pahrump fault zones, with strike-slip faults and normal fault movement, extending from Pahrump Valley northwestward to the Grapevine Mountains. The structure and lithology of segments of these ranges affect not only the distribution and nature of inflow and regional springs from the Nevada portion of the flow system, but also the distribution of springs of local origin, discussed later in this report, that occur within the ranges.

Several regional springs and spring complexes occur along the Furnace Creek–Death Valley fault zone, including Navel Spring, Sand Spring, Little Sand Spring, the Furnace Creek spring complex (Texas, Travertine, Nevares, Cow Creek, and Salt springs), the Keane Wonder Spring complex, and the Grapevine, Staininger, and Surprise spring complex. Several of these springs emerge upgradient from the fault zone and apparently emerge because of impedance to groundwater flow at or near the fault zone. In general, however, the fault zone does not appear throughout its length to impede the flow of groundwater. The flow to Nevares Spring appears to be impeded in crossing the fault zone by juxtaposition of the Funeral and Furnace Creek Formations on the downthrown southwest block of the fault zone (Bredehoeft et al. 2005). Flow to the spring appears to flow in the Paleozoic carbonate rocks on the northeast block of the fault near the discharge area. According to Fridrich et al. (2003a and 2003b), the groundwater discharging from Furnace Creek spring complex crosses the southern Funeral Mountains several kilometers southeast of the spring orifices. In transit to the discharge area, the Furnace Creek–Death Valley fault zone may provide permeable media for transmission of groundwater to the springs. The springs of the Grapevine, Staininger, and Surprise complex emerge in or near carbonate rock terrane. Sand and Little Sand springs emerge from alluvium overlying igneous intrusive rock. Sand and Little Sand springs are springs of small flow, and their source may be local recharge to alluvial deposits.

Keane Wonder Spring emerges from the upper Proterozoic and Lower Cambrian rocks of the lower plate of the detachment fault at the contact with upper plate of Tertiary sedimentary rocks. Keane Wonder Spring provides an example in which interconnected fault and fracture zones in the lower plate of a detachment fault provide conduits for groundwater flow. Other cases where igneous, metamorphic, and clastic rocks provide permeable media for groundwater movement are given elsewhere in this report and in the report on the source of groundwater to Death Valley from southeastern California (Bedinger and Harrill 2006a).

The estimated inflow to Death Valley from Nevada, about 60,000 m^3/d (2,118,600 ft^3/d), is obtained by subtracting the inflow from California (31,500 m^3/d [1,112,265 ft^3/d]) from the total regional inflow to Death Valley (90,382 m^3/d [3,191,388 ft^3/d]). The derivation of this estimate is given later in the section "Groundwater Budget for Death Valley."

Valley Floor Discharge of Groundwater

Evapotranspiration from the valley floor of Death Valley was determined by DeMeo et al. (2003) using direct field measurements and observations collected from 1997 through 2001 at selected sites. Multispectral satellite-imagery data were used to delineate areas of groundwater discharge by evapotranspiration on the valley floor. The areas of evapotranspiration were divided into five types of areas based on soil type, soil moisture, vegetation type, and vegetation density. The evapotranspiration areas, called ET units by DeMeo et al. (2003), were (1) salt-encrusted playa, (2) bare-soil playa, (3) low-density vegetation, (4) moderate-density vegetation, and (5) high-density vegetation. Annual evapotranspiration was computed from micrometeorological data which were measured continuously at six sites. The total evapotranspiration from the valley floor includes discharge of groundwater, local precipitation, and surface-water inflow. The groundwater discharge to Death Valley, determined by deducting local precipitation and surface water inflow to the valley floor from total evapotranspiration, is about 42.9 million cubic meters per year or 117,523 m^3/d (1,515 million ft^3/yr or 4,149,737 ft^3/d; DeMeo et al. 2003).

The estimate of valley floor discharge includes local and regional springs that discharge at the valley floor. The discharge of the regional springs that issue above the valley floor is not included in the valley floor evapotranspiration. The greatest portion of valley floor evapotranspiration, 47,720 m^3/d (1,684,993 ft^3/d) or about 40% of the total floor discharge, is from the bare soil and salt-encrusted playa of the Badwater, Cottonball, and Middle basins (fig. 9). Some areas where groundwater enters the valley are characterized by springs and growth of phreatophytes. In figure 9, the segments of the valley floor are shown, from south to north, (1) Saratoga–Amargosa River Valley Springs, (2) Amargosa River Valley, (3) Badwater Basin, (4) Middle Basin, (5) Cottonball Basin, and (6) Mesquite Flat.

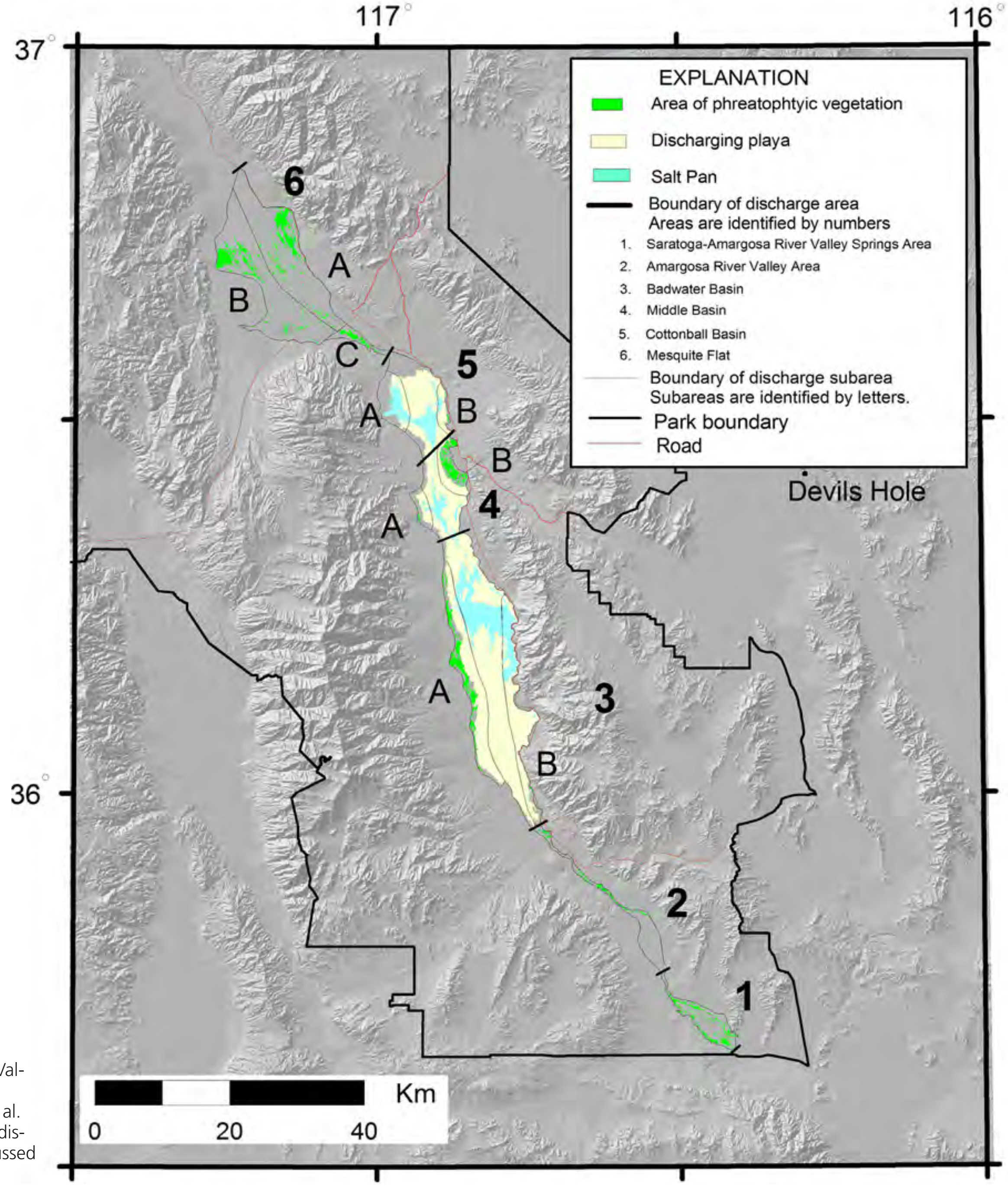


Figure 9. Map showing Death Valley floor groundwater discharge areas. Modified from DeMeo et al. 2003 (fig. 4). Numbers refer to discharge areas and subareas discussed in text.

Saratoga–Amargosa River Valley Springs

Saratoga Spring makes up a significant portion of the discharge in the Saratoga–Amargosa River Valley Springs area (fig. 9). The evapotranspiration of this area is 8,311 m^3/d (293,461 ft^3/d; DeMeo et al. 2003). The principal source of inflow for Saratoga Spring is regional flow in the Pahrump Series (of the Lower Clastic and Carbonate [ZPcc] rock unit). The two sources of groundwater for evapotranspiration from the valley floor and Amargosa River Valley Springs are regional groundwater flow that supplies Saratoga Spring and groundwater flow in the alluvium beneath the Amargosa River.

Amargosa River Valley

The Amargosa River Valley discharges groundwater by evapotranspiration principally along the incised channel upstream from the Badwater Basin (fig. 9). The groundwater discharge in this section, estimated to be 3,236 m^3/d (114,263 ft^3/d) by DeMeo et al. (2003), is thought to be derived from groundwater inflow from the Amargosa Valley Springs section of the valley floor and groundwater inflow from the Owlshead Mountains to the west and southern Black Mountains to the east. The bordering terrane in the southern Black Mountains is in the complexly faulted Amargosa chaos described by Noble (1941) and Troxel and Wright (1987). The Owlshead Mountains are underlain by igneous and volcanic rocks of relatively low elevation and are believed to provide small flow to the Amargosa River Valley.

Badwater Basin

Evapotranspiration from the Badwater Basin is about 51,687 m^3/d (1,825,068 ft^3/d; DeMeo et al. 2003). The most concentrated area of evapotranspiration is along the west margin of the valley floor at the base of the Panamint Range.

Inflow to the Badwater basin from the west is concentrated along the strip of phreatophytic growth and a line of springs on the west side of the basin at the toe of the Panamint Range fans (fig. 9, area 3A) where an estimated 18,000 m^3/d (635,580 ft^3/d) is discharged (DeMeo et al. 2003). Certainly a large part of the groundwater inflow is from recharge in the Panamint Range and infiltration of storm runoff to the alluvial fans at the front of the range. That a part of the inflow may be regional groundwater from the west is suggested by the water budget reconnaissance of the Panamint basin that reveals recharge to Panamint basin in excess of basin discharge (Bedinger and Harrill 2006a). Regional flow may also be indicated by the groundwater temperature of two wells reported by Miller (1977). One well, 16 meters (52.5 ft) in depth, at Eagle Borax Spring was measured to be 28.5°C (83.3°F); the other well near Bennetts Well, 10 meters (32.8 ft) in depth, the groundwater was measured to be 29.5°C (85.1°F).

Photograph 12. Saline Marsh and phreatophytes at Eagle Borax Spring. Groundwater discharge at Eagle Borax Spring, at the west foot of the Panamint Mountains, forms a marsh; shallow groundwater is used by phreatophytes on the edge of the salt pan on the floor of Death Valley.

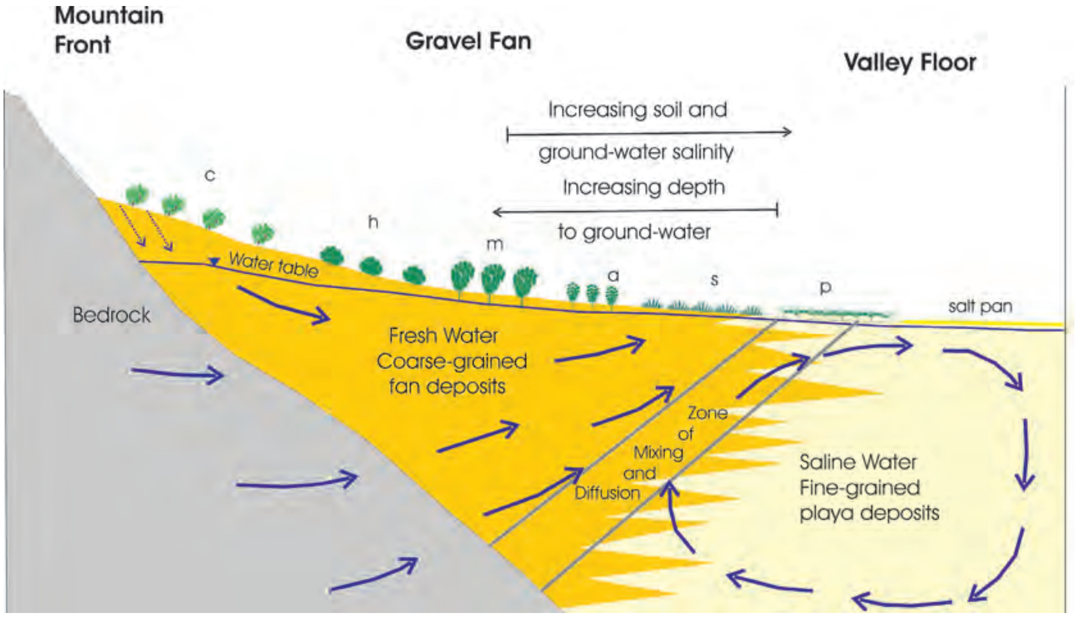


Figure 10. Composite schematic diagram of groundwater flow, groundwater and soil salinity gradients, and plant species distribution in the mountain front–gravel fan–salt pan complex of Death Valley. Groundwater inflow from recharge in the mountain range and runoff infiltration on the fan mix and diffuse with inferred density-induced circulation cells in the saline groundwater beneath the salt pan. The progression of zones of plant species reflect the soil salinity, groundwater salinity, and depth to water gradients with distance from the salt pan. Phreatophytes, in descending order of salt tolerance, include pickleweed, p; saltgrass, s; arrowweed, a; and honey mesquite, m. Xerophytes include desert holly, h, and creosote bush, c, and occupy the zones of greater depth to water on the fan above the phreatophytes. Drawing not to scale. After Miller 1977, Harrill 1995b, and Hunt 1966.

The indicated depth of flow and temperature of groundwater in these wells are near the common ranges considered to be indicative of regional flow (Bedinger and Harrill 2006a). A schematic transect from the salt pan through the gravel fan to the bedrock of the mountain range is depicted in figure 10 showing the relationships between phreatophytes, groundwater and salinity of soils, and groundwater in the discharge area.

Significant discharge occurs by phreatophytes at the foot of the Black Mountains (fig. 9, area 3B). Small springs, including Badwater Spring, are located at the toes of small fans at the base of the mountains. The inflow of groundwater is probably small and derived from recharge in the metamorphic and igneous rocks in the Black Mountains.

Middle Basin

Evapotranspiration from the Middle Basin is estimated by DeMeo et al. (2003) to be about 18,147 m^3/d (640,771 ft^3/d). Evapotranspiration from the toe of the northern Panamint Range fan (fig. 9, area 4A) is about 2,000 m^3/d (70,620 ft^3/d); there are no springs in this area. Groundwater inflow to the area is from local recharge in the carbonate and clastic rocks (ZPcc and PMc) of the Panamint Range and infiltration to the alluvial fan.

The Furnace Creek fan (fig. 9, area 4B), formed by deposition of coarse material carried down Furnace Creek by storm runoff, deserves special notice with respect to the source and the nature of the groundwater discharge at its surface. Evapotranspiration, 11,522 m^3/d (406,842 ft^3/d), is largely by phreatophytic mesquite trees along distributary channels radiating from the mouth of Furnace Creek. Ephemeral runoff contributes some recharge to the alluvial deposits of the lower reaches of Furnace Creek and the fan. The primary source is probably through surficial gravels and the alluvium of Furnace Creek that are fed by groundwater flow derived from the Funeral Formation, the source of Travertine and Texas springs.

The groundwater conditions of the Furnace Creek fan are quite different compared to the fans on the west side of the Badwater Basin. Phreatophytic growth in the distributary channels of Furnace Creek fan indicates a relatively shallow water table beneath the fan. Evapotranspiration on the west side of the basin is from the toe of the fan rather than the area up on the fan.

Photograph 13. Coyote Wells Spring. Coyote Wells Spring is a small spring at the foot of the Black Mountains looking over the Death Valley salt pan with Panamint Mountains in the distance.

Cottonball Basin

Cottonball basin is an ovoidal playa of fine silt, clay, and salt with springs and saline water pools. DeMeo et al. (2003) estimate evapotranspiration from Cottonball basin to be 10,224 m^3/d (361,009 ft^3/d). Springs issue on the west side in Cottonball Marsh at the foot of Tucki Mountain. Seventy or more small springs issue from the margin of the playa on the east side. The high salinity of the pools is not attributed to the discharging groundwater but to the solution of evaporite deposits in the playa sediments.

Evapotranspiration on the west side of Cottonball Marsh (fig. 9, area 5A) is from Salt Spring (115) and Sulfur Spring (116). Numerous small springs, East Salt Springs (240-270) and Buckboard Springs (271-312), issue from a spring area that extends along the eastern margin of Cottonball Basin (fig. 12, area 5B). Evapotranspiration occurs from the fine-grained sediments and salt crust of the playa.

Mesquite Flat

Mesquite Flat is a broad area of low-lying basin fill through which Death Valley Wash drains. The area is characterized by relatively shallow groundwater and widespread growth of phreatophytes. There are few springs in the upper, broad part of the basin. Groundwater discharge is primarily

Photograph 14 (above). Furnace Creek Fan. Radiating channels in the Furnace Creek alluvial fan are marked by growths of mesquite trees, phreatophytes that tap the shallow water table beneath the fan. Salt Creek in left foreground. Photograph by Marli Miller.

Photograph 15 (right). Salt Creek. Flow of Salt Creek is spring discharge of groundwater from Mesquite Flat. Springs are caused by uplift of Tertiary playa silts and clays of the Furnace Creek Formation at Salt Hills. The Furnace Creek Formation is exposed on the left side of stream.

by evapotranspiration, estimated by DeMeo et al. (2003) to be about 29,002 m^3/d (1,024,061 ft^3/d).

Groundwater supporting phreatophyte growth on the west side of Mesquite Flat (fig.9, area 6A) is regional flow and local recharge to the adjoining Grapevine Mountains.

Groundwater on the west side of Mesquite Flat (fig. 9, area 6B) is derived in part from local recharge in the Cottonwood Mountains. This area may be the principal discharge area for groundwater outflow from Saline Valley (Bedinger and Harrill 2006a).

In the lower part of Mesquite Flat, permeable alluvial deposits are restricted by a structural uplift of the underlying low permeability Furnace Creek Formation. A channel is incised in the Funeral Formation where it drains to Cottonball Basin. In the channel section (fig. 9, area 6C), phreatophyte growth is abundant and perennial springs discharge giving rise to Salt Creek. The discharge of Salt Creek is discussed in a later section on valley floor springs.

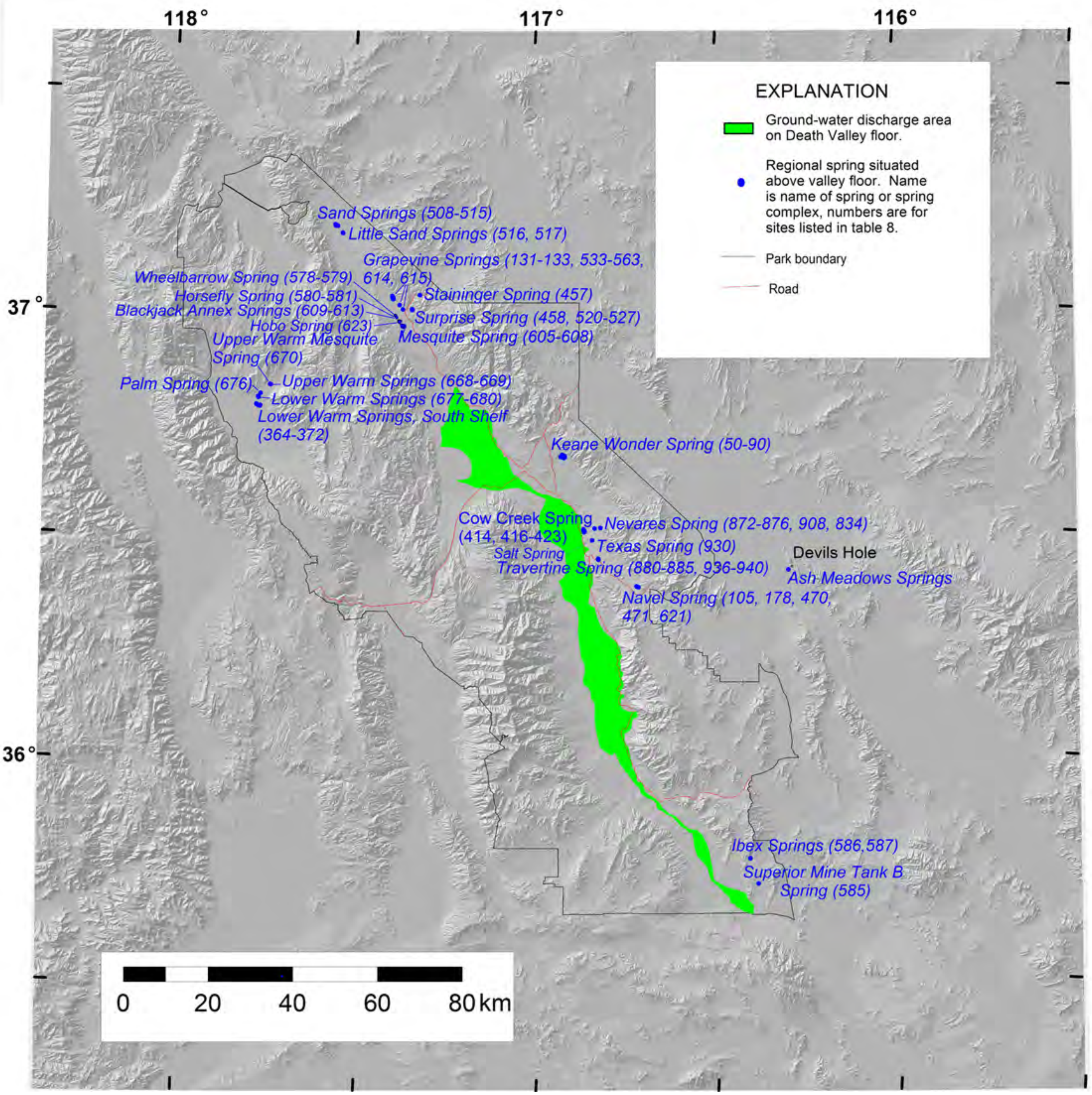


Figure 11. Map showing locations of regional springs above the valley floor of Death Valley.

Regional Spring Discharge above the Valley Floor

The regional springs that issue above the valley floor are shown in figure 11. Estimates of discharge, given in table 5, are based on flow measurements reported by Rush (1968), Miller (1977), La Camera and Westenberg (1994), Hale and Westenberg (1995), Westenberg and La Camera (1996), La Camera et al. (1996), La Camera and Locke (1997), and San Juan et al. (2004). Estimates of groundwater loss from evapotranspiration by local riparian vegetation in spring areas has been reported by Miller (1977). Laczniak et al. (2006) made evapotranspiration estimates in spring areas based on field instrumentation and aerial imagery. The total estimated groundwater discharge from the Grapevine, Staininger, Surprise, Texas, and Travertine springs was derived by R. J. Laczniak (written communication, 2006) from his observations at the spring areas including high-resolution multi-spectral imagery, micrometeorological data, discharge measurements, and evapotranspiration estimates (Laczniak et al. 2006) at the spring areas.

Table 5. Discharge of regional springs above the valley floor

Spring	Discharge spring-flow measurements and estimates. (m^3/d)	Evapotranspiration (Laczniak et al. 2006) (m^3/d)	Total Groundwater Discharge (m^3/d)
Staininger	1,035[1]	165	1,200[6]
Grapevine	2,450[1]	1,367	1,367[6]
Surprise	228[3]	30	258[6]
Texas	1,220[1]	81	1,301[6]
Travertine	4,630[1]	154	4,784[6]
Nevares	1,885[1,2]		1,885
Cow Creek, Salt	125[2]		125
Mesquite	7		7[3,4]
Keane Wonder	360		360[3]
Navel	11		11[3]
Sand	65		65
Little Sand	6		6[3]
Ibex	1.5		1.5[3]
Superior Mine Tank B	1.5		1.5[3]
Total			11,247

[1] From compilation of published and unpublished spring flow by San Juan et al. (2004). Estimates of discharge of Staininger Spring are based on measurements by Miller (1977) and Rush (1968). The estimate of Grapevine Spring is based on estimates originally made by Miller (1977) on the basis of discharge measurements made at a few accessible springs and a cursory quantification of evapotranspiration. Estimate of Texas Spring discharge is from measurements reported in La Camera and Westenberg (1994), Hale and Westenberg (1995), Westenberg and La Camera (1996), La Camera et al. (1996), and La Camera and Locke (1997).

[2] San Juan et al. (2004) from Pistrang and Kunkel (1964). San Juan et al. (2004) report the discharge of Nevares Spring by Pistrang and Kunkel (1964) includes the flow of Cow Creek and Salt Springs.

[3] National Park Service spring survey 2005.

[4] Includes Mesquite Springs (605–608) and nearby related springs (578, 579, 580, 581, 609–613, 623, and 670). (Numbers in parentheses refer to the spring number in the Appendix).

[5] Discharge reported by San Juan et al. (2004) is based on flow estimates of a few springs and an estimate of evapotranspiration by Miller (1977). The evapotranspiration estimate reported by Laczniak et al. (2006) is considered to be accurate and supersedes the estimate of Miller (1977).

[6] R. J. Laczniak (written communication, 2006).

Recharge to Death Valley

Precipitation, the source of recharge to groundwater in the Death Valley region, is closely related to elevation. The lapse rate of precipitation with altitude in the Death Valley region has been defined by Rowlands (1993) from weather station data. As the precipitation increases with altitude the potential evapotranspiration concomitantly decreases. A part of the precipitation that falls within the Death Valley hydrologic basin (basin 243 of figure 12) infiltrates and recharges the groundwater flow system. (The hydrologic basins shown on figure 12 are listed in table 6.) A part of the recharge discharges from upland springs, and a part discharges from the valley floor.

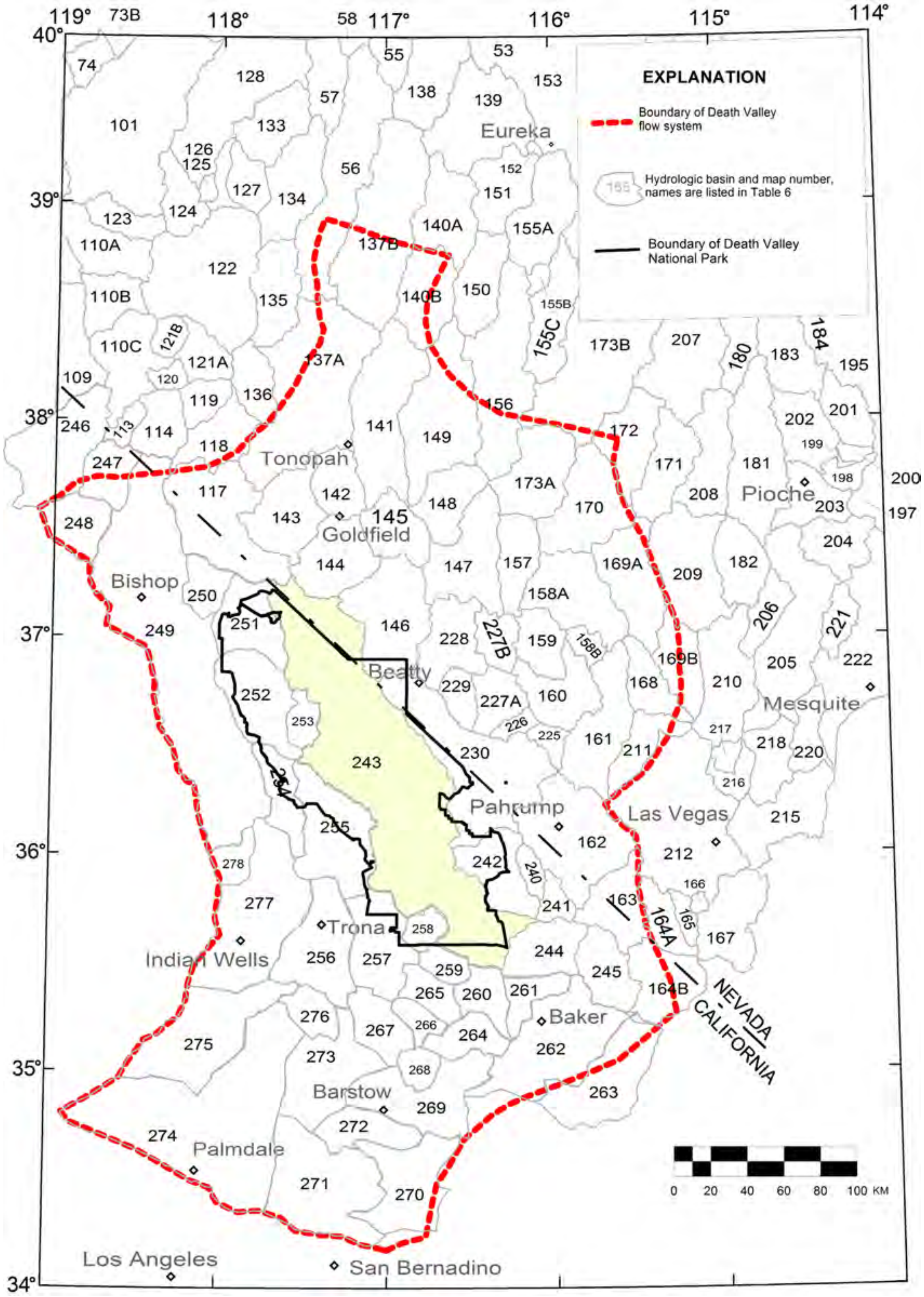


Figure 12. Map of Death Valley region showing hydrologic basins.

Table 6. Hydrologic basins in the Death Valley flow system

Number	Name	Number	Name
117	Fish Lake Valley	250	Deep Springs Valley
144	Lida Valley	251	Eureka Valley
146	Sarcobatus Flat	252	Saline Valley
147	Gold Flat	253	Racetrack Valley area
148	Cactus Flat	254	Darwin Plateau B.
158A	Emigrant Valley	255	Panament Valley
159	Yucca Flat	256	Searles Valley
160	Frenchman Flat	257	E. Pilot Knob & Brown Mt. V.
161	Indian Springs Valley	258	Lost Lake–Owl Lake V.
162	Pahrump Valley	259	Leach Valley
163	Mesquite Valley	260	Red Pass Valley
164B	Southern Ivanpah Valley	261	Riggs Valley
170	Penoyer Valley	262	Soda Lake Valley
173A	S. Railroad Valley	263	Kelso Valley
211	Three Lakes Valley (southern)	264	Cronise Valley
225	Mercury Valley	265	Bicycle Valley
226	Rock Valley	266	Goldstone Valley
227A	Jackass Flat	267	Superior Valley
227B	Buckboard Mesa	268	Coyote Lake Valley
228	Oasis Valley	269	Lower Mojave River Valley
229	Crater Flat	270	Lucerne Valley
230	Amargosa Desert	271	Upper Mojave River Valley
240	Chicago Valley	272	Middle Mojave River Valley
241	California Valley	273	Harper Valley
242	Lower Amargosa Desert	274	Antelope Valley
243	Death Valley	275	Fremont Valley
244	Valjean Valley	276	Cuddleback Valley
245	Shadow Mountain Valley	277	Indian Wells Valley
247	Adobe Lake Valley	278	Rose Valley
248	Long Valley		
249	Owens Valley		

Photograph 16. Travertine mound at Nevares Spring. Nevares Spring, issuing on the travertine mound (white) built from deposition of carbonate from the spring waters. Travertine Spring issues along a fault from the Cambrian Bonanza King Formation, shown in the background, at the foot of the Funeral Mountains. Photograph from C. B. Hunt, USGS files.

Maxey and Eakin (1949) developed an empirical relationship between elevation and recharge in the Great Basin of Nevada. Maxey and Eakin assigned recharge as a percentage of precipitation at elevation intervals beginning with three percent of precipitation at the elevation interval of 1,524 to 1,829 meters (5,000 to 6,000 ft). The Maxey–Eakin method has been justifiably criticized for its lack of precision and technical sophistication (Avon and Durbin 1994). However, during its development the Maxey–Eakin method was calibrated by balancing the recharge estimates with measurements of discharge for single closed basins and multiple basin systems with interbasin flow. During the 50 years since its development, water budgets for most of the closed basins in Nevada have been made using the Maxey–Eakin method. Recharge in many basins has also been estimated using a modified recharge–altitude relation to reflect local conditions (Miller 1977, Walker and Eakin 1963, Malmberg 1967, and Harrill 1986). Notwithstanding the imperfections and limitations, the Maxey–Eakin method retains a useful practicality. The method has been employed in several landmark quantitative regional studies of groundwater in the Great Basin (Eakin et al. 1976, Harrill et al. 1988, Prudic et al. 1995, and Dettinger et al. 1995). Further endorsement of the method is the weight accorded the Maxey–Eakin water budget analyses of basins in groundwater adjudications by the Nevada State Engineer.

D'Agnese et al. (1997) adapted the altitude interval–recharge concept of the Maxey–Eakin method to incorporate empirical recharge ratings for soil–parent rock permeability, slope–aspect, and vegetation zones. While the basin recharge estimates using the modification of D'Agnese et al. appear to be based on rational and logical technical criteria, there is no discussion by the authors of what, if any, calibration procedures were made to verify the accuracy or calibrate the method. Recharge estimates for 25 basins by D'Agnese et al. (1997, table 11) are 30% greater than Maxey–Eakin estimates for the Death Valley flow system. However, estimates for individual basin differ by multiples of -3.4 to +11. Recharge estimates for the Death Valley hydrologic basin (243) by both the Maxey–Eakin method and by D'Agnese et al. (1997) are reported to be 32,400 m^3/d (1,144,044 ft^3/d).

Studies were made to develop a basin characterization model to determine spatial and temporal variability of recharge (Hevesi et al. 2002, Hevesi et al. 2003, and Flint et al. 2004). The basin characterization model uses a mathematical deterministic water–balance approach that includes the distributed parameters of precipitation, potential evapotranspiration, soil and bedrock storage, and permeability. The basin characterization model provides for characterizing basins on the basis of characteristics that determine the temporal and spatial variability of recharge and runoff, but the basin characterization model is not deemed accurate enough to be used for assessment of water availability (Flint et al. 2004).

Table 7 summarizes the estimates that have been made of recharge to the Death Valley hydrologic basin (243) shown in figure 12. These estimates are only for direct recharge to basin 243 and do not include groundwater inflow to basin 243 from adjacent basins.

Table 7. Estimates of recharge to Death Valley

Method/Investigator	Recharge (m^3/d)
Maxey–Eakin Method/ D'Agnese et al. (1997)	32,400
D'Agnese Method/ D'Agnese et al. (1997)	32,400
Maxey–Eakin Method/ Flint et al. (2004)	27,036
Maxey–Eakin Method modified by Constants of Rantz and Eakin/ in Miller (1977) and Hevesi et al. (2003)	27,017
Basin Characterization Model, Range of various versions/ Hevesi et al. (2002) and Flint et al. (2004)	20,705 to 205,992

The results of the various versions of the basin characterization model reflect both model calculations based on mean and time series of climate factors as well as differences in computational design of the models. The basin characterization model results are presented to demonstrate a sense of the variability of recharge due to temporal climatic factors, problems inherent in conceptual modeling of mechanisms of recharge, and lack of precision and relevance of GIS factors in model application. Following the recommendation of Flint et al. (2004), basin–characterization–model results are not used directly in selecting a value for recharge to the Death Valley Basin. Accordingly, the estimates of recharge based on Maxey–Eakin method are considered the best available estimates of recharge.

Groundwater Budget Components for Death Valley

In this section we account for the groundwater flow components for Death Valley basin (basin 243, fig. 12) This accounting will provide an assessment of the source and quantity of the groundwater flow in Death Valley. Because of the approximate values for the components, we round the components to one or, at most, two significant figures.

Valley Floor Discharge: Groundwater flow to Death Valley is ultimately discharged by evapotranspiration at the valley floor. The evapotranspiration at the valley floor was estimated by DeMeo et al. (2003) as 120,000 m^3/d (4,237,200 ft^3/d).

Discharge of Regional Springs Above the Valley Floor[1]: Regional springs above the valley floor discharge is about 11,000 m^3/d (388,410 ft^3/d).

Groundwater Discharge to Death Valley Basin: As discussed in the previous section, recharge to the Death Valley basin is estimated to be about 30,000 m^3/d (1,059,300 ft^3/d). Part of this recharge is discharged from upland (non-regional) springs and does not reach the valley floor. From the small rate of flow of upland springs and the number of springs in the basin, less than 800, we estimate this total discharge to be about 1,000 m^3/d (35,310 ft^3/d).

The Total Groundwater Inflow to Death Valley Basin: The total inflow to Death Valley is valley floor evapotranspiration, 120,000 m^3/d (4,237,200 ft^3/d), plus discharge from regional springs above the valley floor, 11,000 m^3/d (388,410 ft^3/d), for a total of 131,000 m^3/d (4,625,610 ft^3/d).

The Regional Flow to Death Valley Basin[2]: This flow to Death Valley basin from beyond the boundaries of basin 243 is approximated as the Death Valley floor evapotranspiration, 120,000 m^3/d (4,237,200 ft^3/d), minus the recharge to Death Valley basin that is not discharged as upland springs, 29,000 m^3/d (936,990 ft^3/d), plus the discharge of regional springs that issue above the valley floor, 11,000 m^3/d (388,410 ft^3/d). This gives a total regional inflow of about 100,000 m^3/d (3,531,000 ft^3/d).

Flow to Death Valley Basin from California and Nevada: Regional inflow to Death Valley from California has been estimated by Bedinger and Harrill (2006a) to be about 30,000 m^3/d (1,059,300 ft^3/d). Regional inflow from Nevada is estimated as total regional inflow, 100,000 m^3/d (3,531,000 ft^3/d), minus inflow from California, or about 70,000 m^3/d (2,471,700 ft^3/d).

[1] San Juan et al. (2010) estimated groundwater inflow to Death Valley as the sum evapotranspiration from the valley floor of Death Valley (San Juan et al. 2010, fig. C-2) plus the discharge of regional springs that issue at elevations above the valley floor. San Juan et al. (2010) recognized that the method might account twice for that part of the flow of valley-margin springs that infiltrates into surficial sediments downstream from the spring orifices and flows to the valley floor. They considered this component to be small, reasoning that most of the water discharged from valley-margin springs is lost by evaporation or transpiration before reaching the sediments beneath the valley floor.

[2] San Juan et al. (2010) consider all valley floor evapotranspiration as regional flow. However, the regional springs include a minor component of local recharge and groundwater beneath the valley floor includes a component of recharge that occurs within Death Valley basin. In the present report we account for evapotranspiration at the valley floor derived from recharge within the basin. In our calculations of groundwater inflow to Death Valley, we have estimated the magnitude of these two components and separated regional flow from flow that originates in Death Valley basin.

Springs of Death Valley National Park and their Hydrogeologic Settings

Records of springs collected by National Park Service personnel date back to the 1930s. In the 1940s, Frank B. and Florence E. Welles began collecting and establishing a permanent file of spring records of Death Valley National Monument. In the late 1950s, they entered into a contract with the NPS to locate springs and compile records of all known springs in the Monument. Their report dated September 1959 was entitled Preliminary Study of Wildlife Water Resources in Death Valley National Monument. The record of each spring was entered on a standard form with provision for recording information on location; flow; vegetation; condition of springs; signs and observations of wildlife; length, depth and width of flow; and developments and maintenance. Particular emphasis was noted on use of springs by animals and activities at the springs by burros that often degraded the conditions and were considered detrimental to the needs of bighorn sheep. In the years following the Welles and Welles compilation, the unpublished records of individual springs were updated as opportunity arose, and additional springs were added to the inventory as they were discovered. In September 1988 the spring list was updated, which then contained records of 289 springs. A comprehensive survey of springs by the Great Basin Institute (Jacobs 2005) enumerates about 1000 springs in Death Valley National Park. This survey is not complete, but available data on the springs are given in the Appendix. The Great Basin Institute survey of springs is being refined. The final list of springs will probably be less than 800 because (1) the winter of 2004/2005 when the survey was made was extraordinarily wet and many ephemeral water discharge areas were improperly called springs and (2) in spring complexes, several nearby orifices will be combined as a single spring.

Various investigators have devised schemes for categorizing the origin and occurrence of springs. They may be based on topographic position, structural and geologic setting, or other criteria. Basically, springs are the surface emergence of concentrated groundwater flow, rather than the surface intersection of a widespread saturated horizon along which diffuse flow might occur, as to a lake or stream. Much of the discharge of groundwater to the Death Valley floor is not concentrated at springs but is widely dispersed as seepage from the adjacent mountain blocks and alluvial fans. Three conditions are required to produce a spring: (1) a barrier to continued subsurface flow of groundwater, (2) a conduit along which flow is concentrated, and (3) a hydraulic head to bring the groundwater to the surface.

In this report, springs of Death Valley are discussed in three categories: regional springs above the valley floor, upland springs, and valley floor springs. Regional springs originate from recharge distant from Death Valley and are conveyed by regional interbasin flow to Death Valley. Upland springs are those that occur above the Death Valley floor and have as their source infiltration of precipitation that falls in the immediate surrounding area at higher elevation. Upland springs issue from local flow systems above the regional flow system. Valley floor springs issue from the Death Valley playa or at low elevations bordering the playa. These springs may be derived from local recharge in the Death Valley hydrologic basin, regional flow, or a combination of regional and local flow.

Regional Springs Above the Valley Floor

Regional springs discharge interbasin groundwater flow. The groundwater flow to these springs also typically travels at depth beneath shallow circulation cells of groundwater. As a result of the flow at depth, the temperatures of regional springs are geothermally elevated above the ambient air temperature. The chemical and isotope signatures of the regional spring waters reflect the chemistry of the groundwater in the distant source areas and the strata of the flow system. Geochemistry has been used to support the concept of an interbasin source of regional springs in the Great Basin by many investigators including Winograd and Thordarson (1975), Thomas et al. (1996), and Steinkampf and Werrell (2001).

There is believed to be a small component of local recharge in some regional springs; for example the springs at Furnace Creek and Travertine, Texas, and Nevares springs probably discharge some groundwater from recharge in the nearby Funeral Mountains.

Regional springs that issue above the valley floor are shown in figure 11. These springs discharge at elevations a few tens of meters to a few hundred meters above the valley floor.

Keane Wonder Springs

Keane Wonder Spring, discharging about 150 L/min (39.6 gal/min), emerges from the Middle Member of the Crystal Spring Formation of the Pahrump Series (Troxel and Wright 1989), a part of the Lower Clastic and Carbonate rock unit (ZPcc). The Middle Member of the Crystal Spring Formation is described by Troxel and Wright (1989) as mostly calcite marble. Lower Clastic and Carbonate rocks (ZPcc) form the core of the northern Funeral Mountains. The spring is located near the trace of a detachment fault overlain by Tertiary rocks. The chemistry of the water (Steinkampf and Werrell 2001), topographic setting, and the spring elevation in relation to the regional hydraulic gradient indicate the source of the water is regional groundwater flow from the northeast. The low flow of the spring, absence of other regional springs in similar hydrogeologic settings of the Funeral Mountains, and the water chemistry lead Steinkampf and Werrell (2001) to surmise that the Proterozoic core of the Funeral Mountains transmits meager regional flow to Death Valley.

Saline Valley Hot Springs

Several warm springs emerge from fill in the structural basin of Saline Valley between Dry Mountain Range on the east and Saline Range on the west. Recharge for the springs could be from either adjacent range where peaks attain elevations of 2,153 meters (7,064 ft) in the Saline Range and 2,544 meters (8,347 ft) in the Dry Mountain Range. The springs, 100 to 200 meters (328 to 656 ft) above the playa lake in Saline Valley, include Lower Warm Springs (springs 677–680, Appendix), Lower Warm Springs South Shelf (364–372), Palm Spring (676), Upper Warm Springs (668–669), and Upper Warm Mesquite Spring (670). The warmest spring measurements range from 34.6° to 47.1°C (94.3° to 116.8°F).

Mase et al. (1979) calculate geothermal heat flow from wells in Saline Valley ranges from 1.24 to 2.08 hfu (heat flow units) with a mean of 1.6 hfu. The geothermal gradient in five boreholes in Saline Valley ranges from 3.0°C/100 meters to 4.9°C/100 meters (5.4°F/328 ft to 8.8°F/328 ft; Mase et al. 1979). The authors conclude that the heat discharge at Saline Valley can be accounted for by heat transfer to groundwater circulating to a depth of 1,000 meters (3,281 ft). The most recent igneous activity at Saline Valley is dated as Pliocene; therefore, it is too old to be the heat sources for the modern springs (Mase et al. 1979).

Furnace Creek Springs Complex

The hydrogeologic system providing the flow of springs at Furnace Creek has been recently described and analyzed by Bredehoeft, Fridrich, Jansen, and King (Inyo County Yucca Mountain Repository Assessment Office 2005) and Fridrich, Blakely, and Thompson (2003a and 2003b). These studies propose groundwater flow through the Paleozoic and Mesozoic carbonate rocks (PMc) of the southern Funeral Mountains supplying the spring flow at Texas (931), Travertine (880–885 and 936–940), Nevares (872–876, 934, and 935), and Salt and Cow Creek springs (414 and 416–423). Flow from the Amargosa Desert southwest through the southern Funeral Mountains is supported by detailed geologic mapping and regional groundwater potential (Fridrich et al. 2003a and 2003b). From the southern Funeral Mountains, groundwater flows northwest through the carbonate rocks parallel and northeast of the Death Valley–Furnace Creek fault toward the regional springs in the Furnace Creek area. At least part of the fault zone is inferred to be permeable and possibly acting as a medium of conveyance allowing groundwater to flow across or from the fault zone to Travertine and Texas springs.

Interbasin flow of groundwater through carbonate rocks in the southern Funeral Mountains is supported by the chemical, radioisotope, and rare earth signatures of the water (Winograd and Thordarson 1975, Thomas et al. 1996, Johannesson et al. 1997, and Steikampf and Werrell 2001). Travertine and Texas springs, which emerge near Furnace Creek Ranch, are stratigraphically controlled by the contact of the water-bearing Tertiary gravel of the Funeral Formation with the underlying clay of the Furnace Creek Formation (fig. 13). The springs discharge at the eroded southwest limb end of a southeast plunging syncline in the basin fill deposits of Tertiary age. Nevares Spring discharges groundwater that traverses further westward in carbonate rocks of the northeast plate of the Death Valley–Furnace Creek fault. The spring emerges from the Bonanza King Formation, a unit of the carbonate rock sequence, unit PMc of figure 5, near the juxtaposition of the formation with Cenozoic rocks on the southwest block of the Death Valley–Furnace Creek fault. The Bonanza King Formation appears to be terminated to the west of the spring by Cenozoic rocks on the downthrown block of a normal fault (Troxel and Wright 1989).

Grapevine, Staininger, Surprise Springs Complex

Grapevine Springs (131–133, 533–563, 614, and 615) emerge well above the floor of Death Valley on the up-hydraulic-gradient side of the Death Valley–Furnace Creek fault. The groundwater upgradient of the fault is possibly held at a high level by low permeability fault gouge and/or low permeability Cenozoic deposits downgradient of the fault. Staininger Spring (457) and Surprise Spring (458 and 520–527) issue from Paleozoic carbonate rocks (unit PMc, fig. 5). Surprise Spring issues above an outcrop of low permeability older basin fill (unit Cvb, fig. 5) and Staininger Spring rises from carbonate rocks underlying the channel of creek in Grapevine Canyon. Groundwater at Staininger Spring is collected for use at the Scotty's Castle Visitor Center. Groundwater at Surprise Spring is collected for use at the park's Grapevine housing area and ranger station.

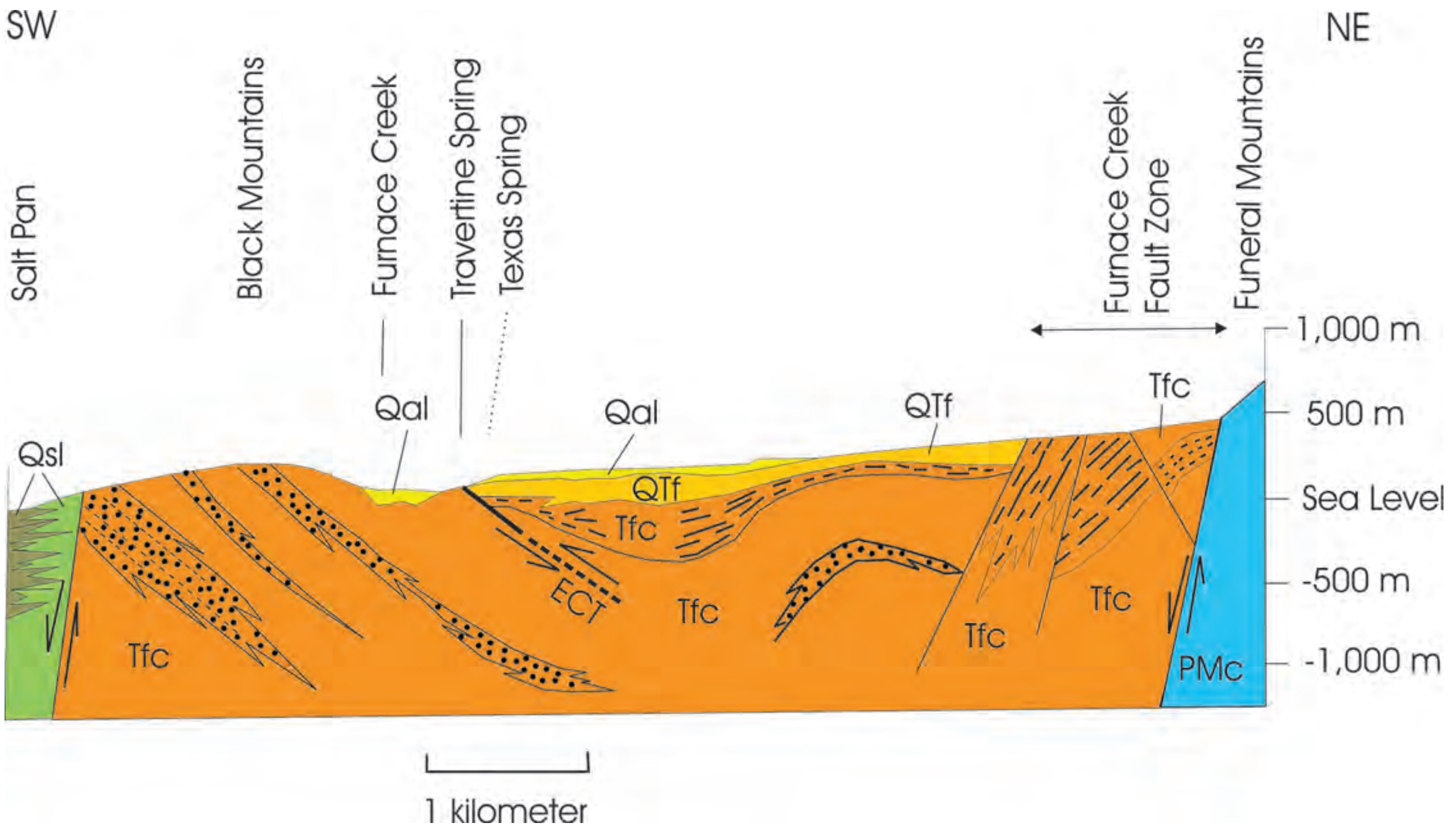


Figure 13. Schematic cross section of Furnace Creek basin from Funeral Mountains to Death Valley salt pan showing hydrogeologic setting of Travertine and Texas springs. Texas Spring is located about 1.2 miles (1.9 km) NW of this section. Texas and Travertine springs emerge on the trace of the Echo Canyon Thrust (ECT) where groundwater flow is impeded by thinning of gravel beds in alluvium and Funeral Formation and by low permeability beds of the Furnace Creek Formation. Flows to the springs is from interbasin flow through Paleozoic carbonate rocks in the southern Funeral Range. Part of the interbasin flow enters the Funeral Formation and overlying alluvium giving rise to Travertine and Texas springs and part continues to flow northwest to Nevares Spring (not shown, located about 4.5 miles [7.2 km] NW of this section) where the carbonate rocks are terminated by faulting. ECT, Echo Canyon Thrust; Qsl, saline lake beds of Death Valley; Qal, alluvium; Tfc, Furnace Creek Formation; QTf, Funeral Formation; PMc, Paleozoic carbonate rocks. After Hunt and Mabey 1966, McAllister 1970, Machette et al. 2000, Inyo County Yucca Mountain Repository Assessment Office 2005, and Fridrich et al. 2003b.

Photograph 17. Ibex Spring. Ibex Spring is a small spring in the Ibex Hills north of Saratoga Spring. The elevation of the spring in relation to the regional potentiometric surface indicates its source is regional flow.

Mesquite Springs Complex

Mesquite Springs (605-508) rises in a marshy area of the Death Valley Wash about 60 kilometers (37 mi) upstream from Cottonball Basin (fig. 16). One of the springs is dug out and boxed to collect water for a nearby camping area. The springs are a few kilometers south of the latitude of Surprise Spring. The source of the spring may be regional inflow from Nevada with a component of recharge from within the Death Valley hydrologic basin. Miller (1977) reports the flow of the spring to be 34 liters per minute (9 gal/min).

Sand and Little Sand Springs

Sand (508–515) and Little Sand springs (516 and 517) are located on the Furnace Creek–Death Valley Fault. The springs are above the floor of Death Valley Wash on the upgradient side of the fault indicating the fault is a barrier to groundwater flow in this location. The springs are of small flow, and the source of the springs may be in part local recharge to alluvial deposits from which the springs discharge.

Ibex and Superior Mine Tank B Springs

The Superior Mine Tank B Spring (585) and Ibex Springs (586 and 587) are near and northeast of Saratoga Spring. Saratoga Spring, a regional spring, is discussed under the heading of valley floor springs. The springs are in the structural zone of Saratoga Spring in the Pahrump Series rocks. The location and elevation of the springs in relation to the regional groundwater head (plate 1) suggest the springs may be of regional flow origin. The potential local catchment area of the springs, being less than 1,500 m (4,922 ft) above sea level, indicates low precipitation and recharge in the nearby area. There are no temperature and chemical data to evaluate the source of the springs.

Devils Hole and Ash Meadows Complex

Devils Hole is adjacent to Ash Meadows National Wildlife Refuge in southwestern Nevada (fig. 14). In 1952 a 40-acre (16.2-ha) tract of land containing Devils Hole was incorporated into the Death Valley National Monument as a detached management area. The area is currently a part of Death Valley National Park. Ash Meadows National Wildlife Refuge, a reservation of the U. S. Fish and Wildlife Service, encompasses 2,300 acres (931 ha) of spring-fed wetlands providing habitat for about 25 endemic species. Devils Hole is an active extensional fault opening, enlarged by collapse near the surface, in the limestone hills above Ash Meadows. Devils Hole is a pool about 15 meters (49.2 ft) below the surface, connected at great depth to the underlying regional carbonate aquifer. The pool is home to the endangered endemic species

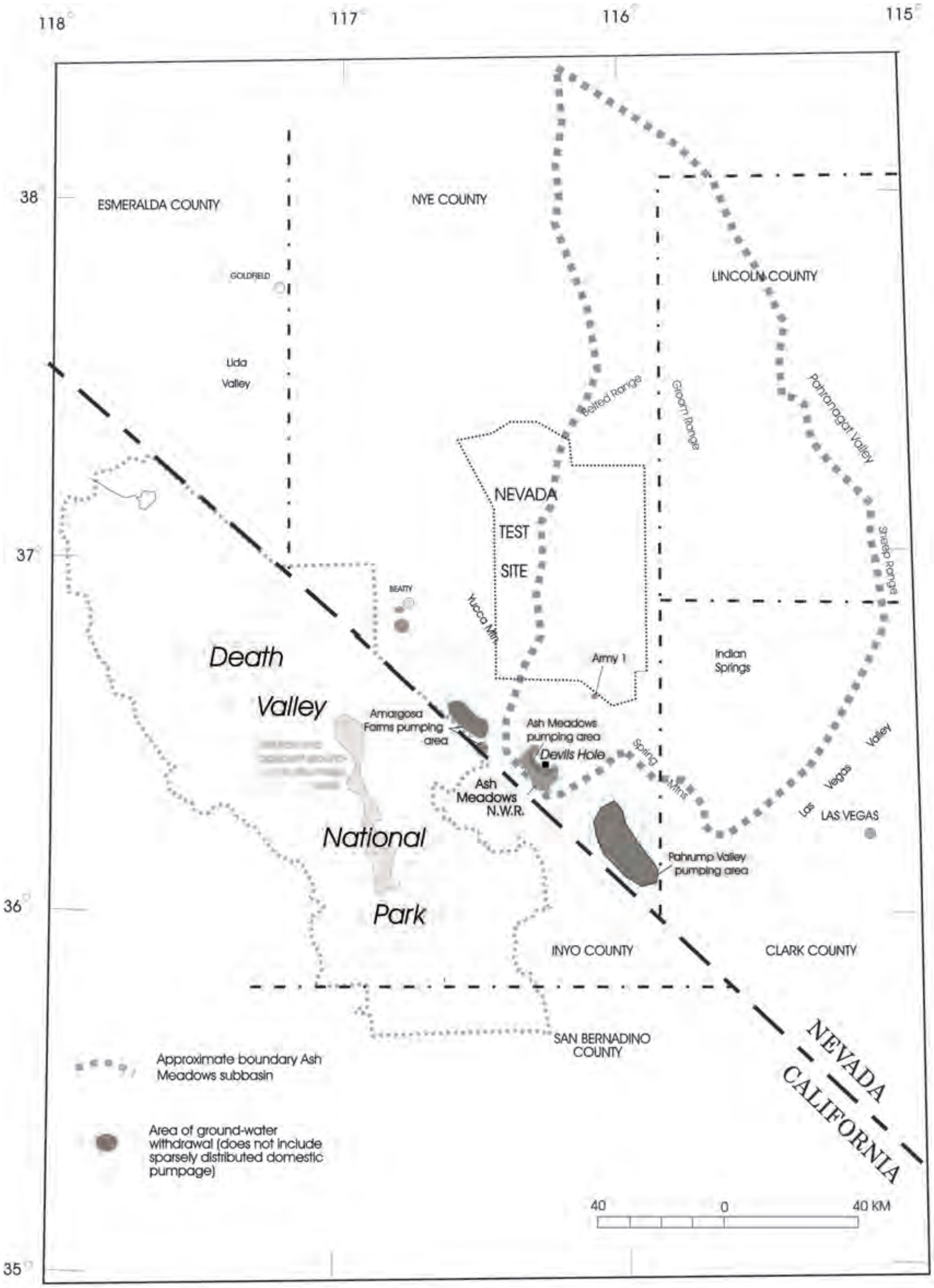


Figure 14. Map showing location of Devils Hole, Ash Meadows ground-water subbasin, and pumping centers of southwest Nevada.

Photograph 18 (above). Crystal Spring. Crystal Spring is one of several large springs that discharge from carbonate rocks of the Death Valley groundwater flow system in Ash Meadows. Ash Meadows is an intermediate discharge area of the Death Valley flow system. Photograph by A. Van Luik.

of desert pupfish *Cyprinodon diabolis*. The population feeds and reproduces on a slightly submerged rock ledge. Devils Hole is a window to the Death Valley groundwater flow system; the aquifer is the source of the nearby large springs of Ash Meadows.

The water level in Devils Hole, the natural environment of the endangered Devils Hole pupfish, and the spring flow and wetland habitat of Ash Meadows are subject to depletion by withdrawal of groundwater in the region (Bedinger and Harrill 2006).

Ash Meadows is the major area of natural discharge of groundwater in the Ash Meadows groundwater subbasin (fig. 15). The water moves southward and westward through faults and solution channels in the Paleozoic carbonate rocks of the groundwater subbasin to Ash Meadows where it


Thomas M. Baugh

Photograph 19 (right). Devils Hole pupfish *(Cyprinodon diabolis).* Devils Hole, a collapse depression in limestone hills adjacent to Ash Meadow National Wildlife Refuge, contains a warm-water pool that is the home of a unique species of endangered pupfish, *Cyprinodon diabolis.* The population feeds and reproduces on a slightly submerged rock ledge. In 1952 a 40-acre (16.2-ha) tract of land containing Devils Hole was incorporated into the Death Valley National Monument as a detached management area. The area is currently a part of Death Valley National Park.

flows across bounding faults into the basin-fill sediments. In Ash Meadows groundwater discharge is by springs and evapotranspiration of shallow groundwater from an area about 3.2 by 16 kilometers (2 by 10 mi) long, bordering the limestone upland. The westward extent of the spring discharge area has been called the "spring line" by Dudley and Larson (1976). The springs are inferred to be controlled by faulting. West of the spring line, the alluvial materials in the upper basin-fill deposits are fine grained, generally lack travertine and continental limestone deposits, and are generally not productive for high capacity wells (Dudley and Larson 1976). Here also, the water table is near the land surface and the fluctuations of the water table are largely controlled by evapotranspiration and local recharge. Probably a large portion of the Ash Meadows subbasin flow discharges at Ash Meadows. The groundwater in the basin fill at Ash Meadows is tributary to the alluvium of the Amargosa Desert.

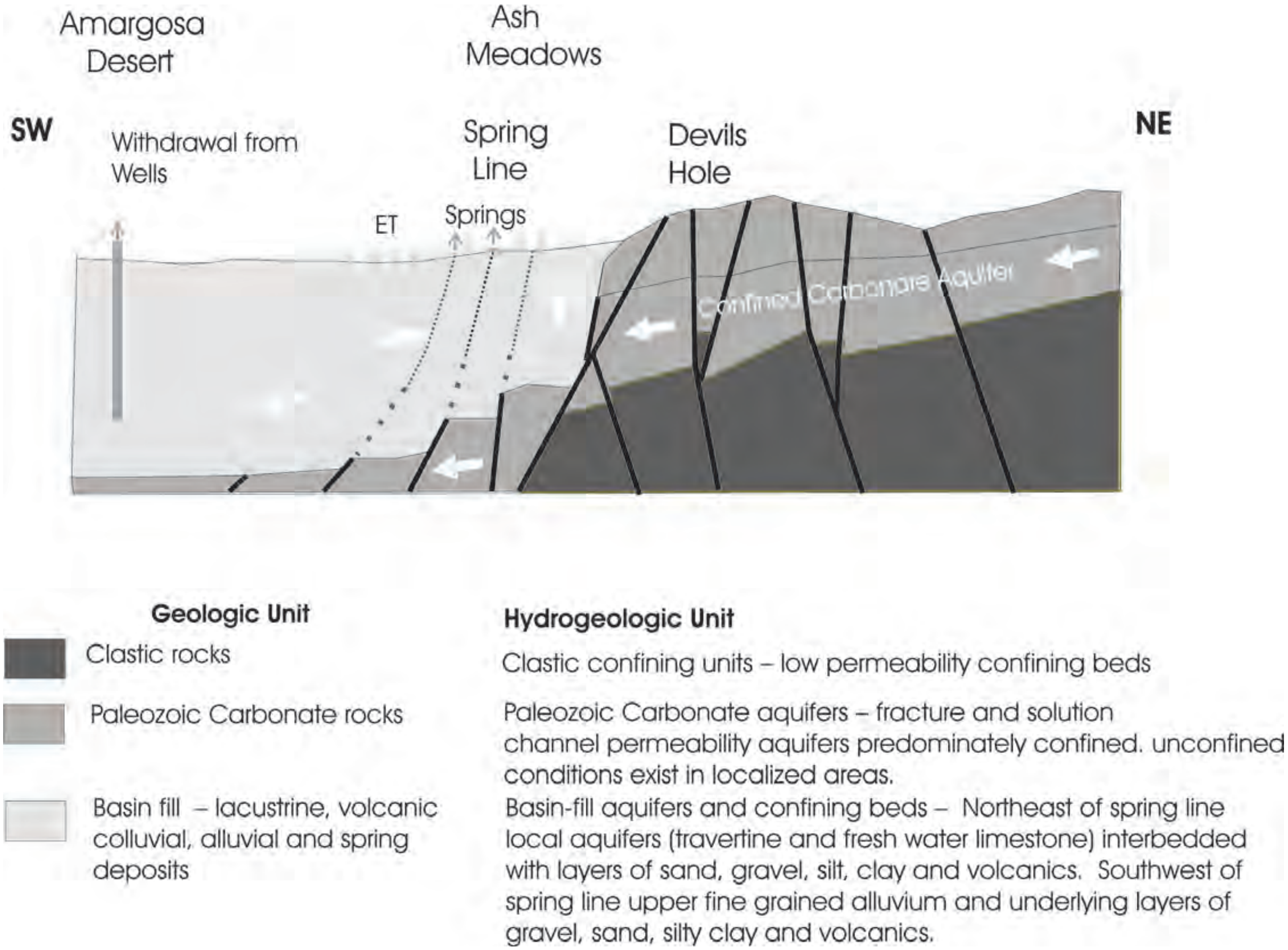


Figure 15. Cross section showing hydrogeologic setting of Devils Hole and Ash Meadows springs. After Bedinger and Harrill 2006b, Dudley and Larson 1976, Winograd and Thordarson 1975, and Carr 1991.

	Geologic Unit	Hydrogeologic Unit
■	Clastic rocks	Clastic confining units – low permeability confining beds
▨	Paleozoic Carbonate rocks	Paleozoic Carbonate aquifers – fracture and solution channel permeability aquifers predominately confined. unconfined conditions exist in localized areas.
□	Basin fill – lacustrine, volcanic colluvial, alluvial and spring deposits	Basin-fill aquifers and confining beds – Northeast of spring line local aquifers (travertine and fresh water limestone) interbedded with layers of sand, gravel, silt, clay and volcanics. Southwest of spring line upper fine grained alluvium and underlying layers of gravel, sand, silty clay and volcanics.

Valley Floor Springs

Valley floor springs are shown in figure 16.

Cottonball Basin

Hunt and Robinson (1960) reveal that the chemistries of the east and west side spring waters are quite different and provide a basis for ascribing their sources. The spring water chemistry on the west side is of sodium sulfate type similar to the water at Mesquite Flat. The water chemistry of the east side springs is calcium bicarbonate type similar to the groundwater of Nevares, Texas, and Travertine springs.

Salt Spring and Sulfur Spring

The springs of Cottonball Marsh on the west side of Cottonball Basin are Salt Spring (915) and Sulfur Spring (916). Threloff (written communication, 6 November 1993) records the temperature of Salt Spring as 33.5°C (92.3°F). Hunt et al. (1966) describes the springs as aligned along faults oriented in the direction of Mesquite Flat

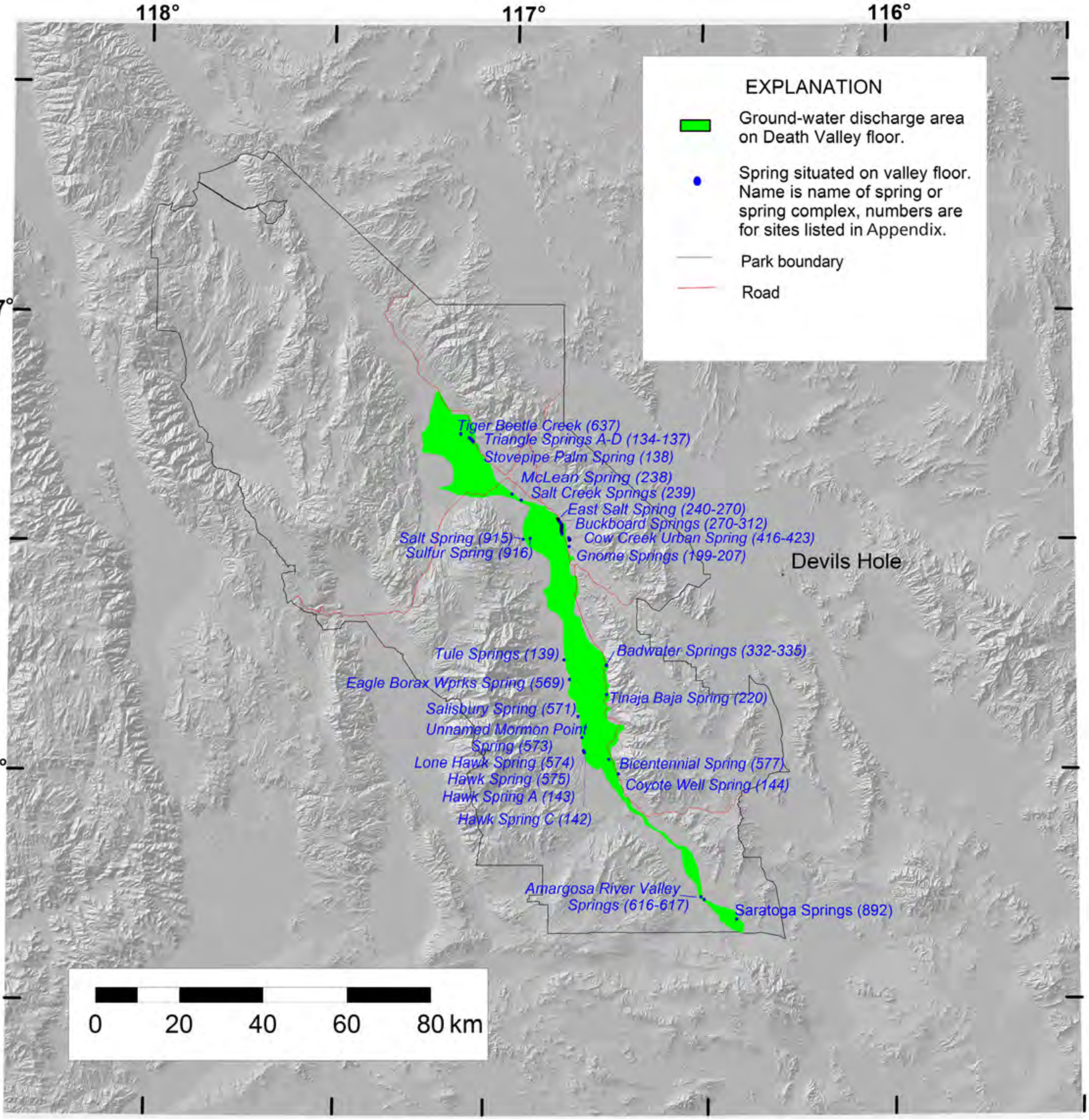


Figure 16. Map showing location of springs on the floor of Death Valley.

to the north of the marsh. Hunt et al. (1966) estimate the flow of Cottonball Marsh to be 42.5 liters per second (11.2 gal/s).

Thermal properties of the Cottonball Marsh springs, the thermal wells at Stovepipe Wells, and the related geochemical properties of the waters suggest that the groundwater in the west portion of Cottonball Basin is regional flow from either Saline Valley or Panamint Valley, both of which contribute regional flow to Death Valley and are up-regional-gradient from Cottonball Marsh (Bedinger and Harrill 2006a). The perennial pools of the springs on the west side of Cottonball Basin contain a population of desert pupfish (*Cyprinodon salinus*), the same species that lives in Salt Creek, 16 kilometers (10 mi) to the north.

East Salt Spring and Buckboard Spring

About 73 springs are aligned along the east margin of Cottonball Basin (East Salt Springs, 240–270, and Buckboard Springs, 271-312). These springs on the east margin of the basin appear to be regional inflow. A local source for the springs is considered to be limited because of the low potential for recharge in the Tertiary deposits in the area adjoining Funeral Mountains. Hunt et al. (1966, B29) describe the groundwater source of the springs as being confined by fine-grained sediments—silts and clays—that make up the confining bed. The surface expressions of these conduits are tube-like openings ranging in size from the diameter of a pencil to about five centimeters (2 in). Hunt et al. (1966) describe the confined response of these springs to barometric pressure and the flow, 3.8 to 7.6 liters per hour (1 to 2 gal/hr).

Salt Creek Springs

McLean Spring (238) and Salt Creek Spring (239) (fig. 16) issue from the channel of Salt Creek in the Salt Creek Hills, an uplift of the low permeability Furnace Creek Formation (Hunt et al. 1966, B19). The discharge of Salt Creek Springs is believed derived from groundwater from Mesquite Flat. The regional groundwater flow to Mesquite Flat, as indicated by the regional potential contours (plate 1), would be from adjacent basins—Saline and Eureka valleys to the west, and Lida Valley and Sarcobatus Flat to the east. Daily discharge measurements of Salt Creek are given in Lamb and Downing (1979) during water years 1974 to 1977. Flow of Salt Creek is continuously sustained by the discharge of Salt Creek Springs. Monthly mean flows vary seasonally with flows in winter months being as much as 1,715 m^3/d (60,557 ft^3d), about four times greater than the low monthly mean flows of the summer. The flow is virtually all base flow, groundwater discharge, with an occasional runoff peak from a local storm. The reduced summer flow represents the loss of groundwater by the greater seasonal evapotranspiration from the alluvial groundwater basin upstream of the gauging station and riparian vegetation along the channel.

Saratoga Spring

Steinkampf and Werrell (2001) considered Saratoga Spring (892) to be derived from regional flow on the basis of water chemistry. Steinkampf and Werrell (2001) ascribe the source of Saratoga Spring to the southern Spring Mountains on the basis of geochemistry of the water. The chemistry and setting of Saratoga Spring and Keane Wonder Spring, also a regional spring discussed earlier in this report, are similar in that they emerge from the Pahrump Series of Proterozoic age and the water chemistry indicates flow through hydrothermally altered terrane which contributes complex water chemistry (Steinkampf and Werrell 2001).

Groundwater is conveyed to Saratoga Spring from the recharge area in the Spring Mountains to Death Valley principally in the Paleozoic and Mesozoic carbonate rocks. The carbonate rock unit (PMcc) extends south of the Nopah Range where it is terminated by upbending of the strata. From the Nopah Range regional flow occurs through the stratigraphically underlying Proterozoic and Lower Paleozoic clastic and carbonate rocks (ZPcc) containing the Pahrump Series. Flow of the spring is reported to be 288 m^3/d (10,169 ft^3/d) by Jacobs (2005), 817 m3/d (28,848 ft^3/d) by King (1999), and 700 m^3/d (24,717 ft^3/d) by D'Agnese et al. (1997).

Amargosa River Valley Springs

Amargosa River Valley Springs (616 and 617) issue from the channel of the Amargosa River about eight km northwest of Saratoga Springs. Hunt et al. (1966) ascribe the springs as a rising of groundwater from the alluvium of the Amargosa River over a structural barrier. The barrier is fine-grained lacustrine deposits of Tertiary age, probably correlative with the barrier at Salt Springs on Salt Creek above the Cottonball Basin. The springs are assumed to be derived largely from regional groundwater flow and recharge along the Amargosa River upstream from the springs. Regional flow to the springs is believed to be from the lower clastic and carbonate rocks (ZPcc) that supply flow to Saratoga Spring. The springs are not situated (plate 1) at a propitious location to be supplied by regional flow from the southwest. The other avenue of regional inflow is the groundwater that has entered the Amargosa River alluvium upstream from the park boundary. Perennial flow is maintained in segments of the Amargosa River upstream from the park by groundwater base flow, primarily in the Amargosa Narrows. Flow has been observed by the authors in the Amargosa River at Highway 127 near the park boundary. Miller (1977) reports the flow March 21, 1967, at this crossing to be 17 liters per second (4.5 gal/s). Downstream from this crossing the streamflow infiltrates into the alluvium.

Photograph 20. Saratoga Spring. The Saratoga Springs pupfish lives only in Saratoga Spring ponds. Five rare invertebrate species also occur at Saratoga Spring and include the Amargosa tryonia snail, the Amargosa spring snail, the Saratoga Springs belostoma bug, the Amargosa naucorid bug, and the Death Valley June beetle. The first four species are strictly aquatic in nature and live only in Saratoga Spring. The June beetle lives on land, but its distribution is limited to saltgrass habitats where shallow groundwater is present. The June beetle and both snail species have distributions which are entirely confined to the Amargosa River drainage. Five notable bird species are known to occur at Saratoga Spring: the yellow warbler, the Cooper's hawk, the western snowy plover, the long-billed curlew, and the long-eared owl. All of these species have been placed on state or federal sensitive species lists because of habitat loss or population declines across their geographic ranges. Saratoga Spring is also unique in that it is one of the few locations in the park where red-spotted toads and Pacific tree frogs occur in the same area (Threloff 1988). Photograph by NPS.

Photograph 21. Amargosa River Valley Springs. Valley Springs are located along the Amargosa River channel five miles (8 km) northwest of Saratoga Springs. The springs are responsible for the presence of permanent water along a two-mile (3.2-km) reach of the river. Valley Springs are not known to have a unique invertebrate fauna, but do possess habitat that is occupied by the Amargosa River pupfish. This pupfish subspecies only exists at two locations along the length of the Amargosa River. One site is inside the park at Valley Springs, and the other is outside the park in Tecopa Canyon. Valley Springs also have been documented as having Amargosa Canyon speckled dace, another species of fish, following flash flood events. The vegetation at Valley Springs consists primarily of common reed, bulrush, saltgrass, and salt cedar (Threloff 1988).

Springs and Wells at Foot of Panamint Range

A line of springs at the base of alluvial fans discharge groundwater from recharge in the Panamint Range. The springs discharge from alluvial fan material overlying older clastic and carbonate rocks (ZPcc). The springs rise above the fresh-saltwater interface in alluvial deposits in a zone at the toe of the alluvial fan bordering discharge area of the Death Valley playa (fig. 16). Along this linear boundary area are also shallow relatively freshwater wells. The springs include Eagle Borax Spring (569) and Tule Spring; the wells include Bennetts well, Shortys well (567), Gravel Well (141), and Salt Well (921).

One spring in this area has a recorded temperature significantly above the average ambient air temperature. The groundwater temperatures of two wells reported by Miller (1977) are also above ambient air temperature. The groundwater temperature of one well, 50 feet (15.2 m) in depth, at Eagle Borax Spring was measured to be 28.5°C (83.3°F); in the other well near Bennetts well, 32 feet (9.8 m) in depth, the groundwater temperature was measured at 29.5°C (85.1°F). The temperature of these wells approaches the range considered indicative of regional flow (Bedinger and Harrill 2006a).

Springs and Wells at Foot of Black Mountains

Small springs and wells, including Badwater Springs (232 and 332–345), Tinaja Baja Spring (220), Bicentennial Spring (577), and Coyote Well Spring (144), issue along the fault zone and from the toes of small fans at the base of the Black Mountains. The small flows would indicate that the groundwater is derived from recharge to the metamorphic and igneous rocks in the Black Mountains. Two wells, Ashford Well (582) and Confidence Mill Well (583), are located along the Black Mountain front. No springs issue at the margin of the Black Mountains from the Furnace Creek fan to Badwater, an area in which the rocks are largely the Artist Drive Formation of the older basin-fill (Cvb) unit.

Upland Springs

Upland springs can be visualized as the discharge of groundwater from the circulation of groundwater cells above the regional flow. The flow of an upland spring is derived from infiltration of precipitation in an area above the spring. The occurrence of upland springs is neither uniform nor random. Upland springs tend to occur in clusters that are related to similarities of the structural setting, hydrologic characteristics of the rock terrane, and source area elevation. Likewise, areas devoid of springs can similarly be related to structural, lithologic, and climatic characteristics of the geologic and topographic setting. The occurrence of upland springs is discussed in the following paragraphs with respect to groupings based on the geologic settings (fig. 17).

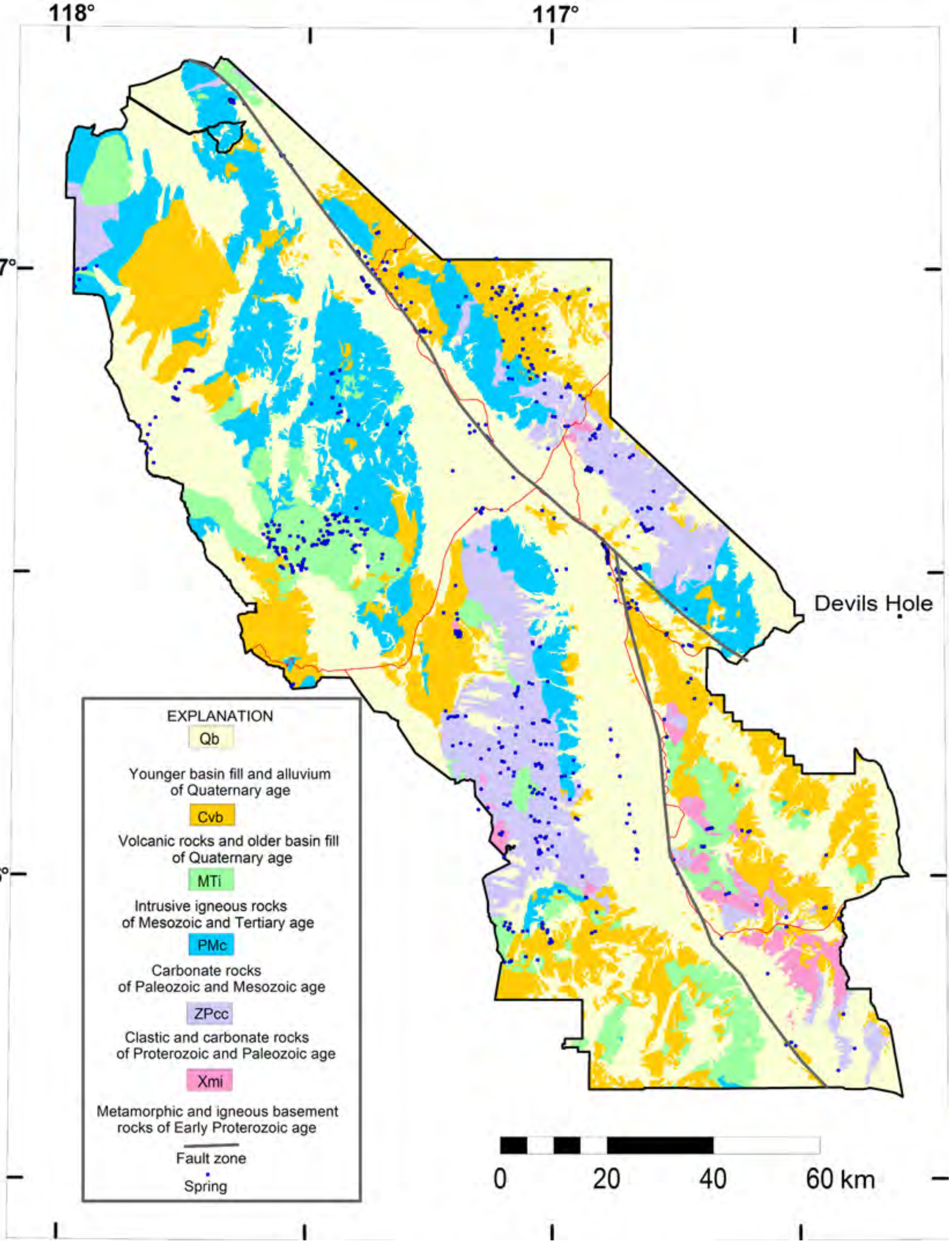


Figure 17. Map showing distribution of springs of Death Valley National Park. Springs are listed in the Appendix. Upland springs occur in bedrock areas and are derived from recharge to local mountain areas. Valley floor springs issue from Quarternary basin fill and alluvium and are derived from recharge in nearby mountains and regional flow. Regional springs issue at the valley floor (fig. 16) and above the valley floor (fig. 11) and originate from interbasin flow from outside Death Valley National Park.

Upland springs vary widely in discharge, though most upland springs are small and discharge a fraction to a few liters per minute (<one gal/min; fig. 18). The temperature of upland springs discharge is related to the temperature of the recharge water, the local geothermal gradient, and the depth of groundwater circulation to the spring. The temperature of local springs is commonly near the mean annual ambient air temperature at the spring orifice. But some springs have elevated temperatures indicating deeper circulation of the groundwater in transit to the springs. Springs having discharge temperatures 5°C (9°F) or greater above the mean annual temperature are shown in figure 19.

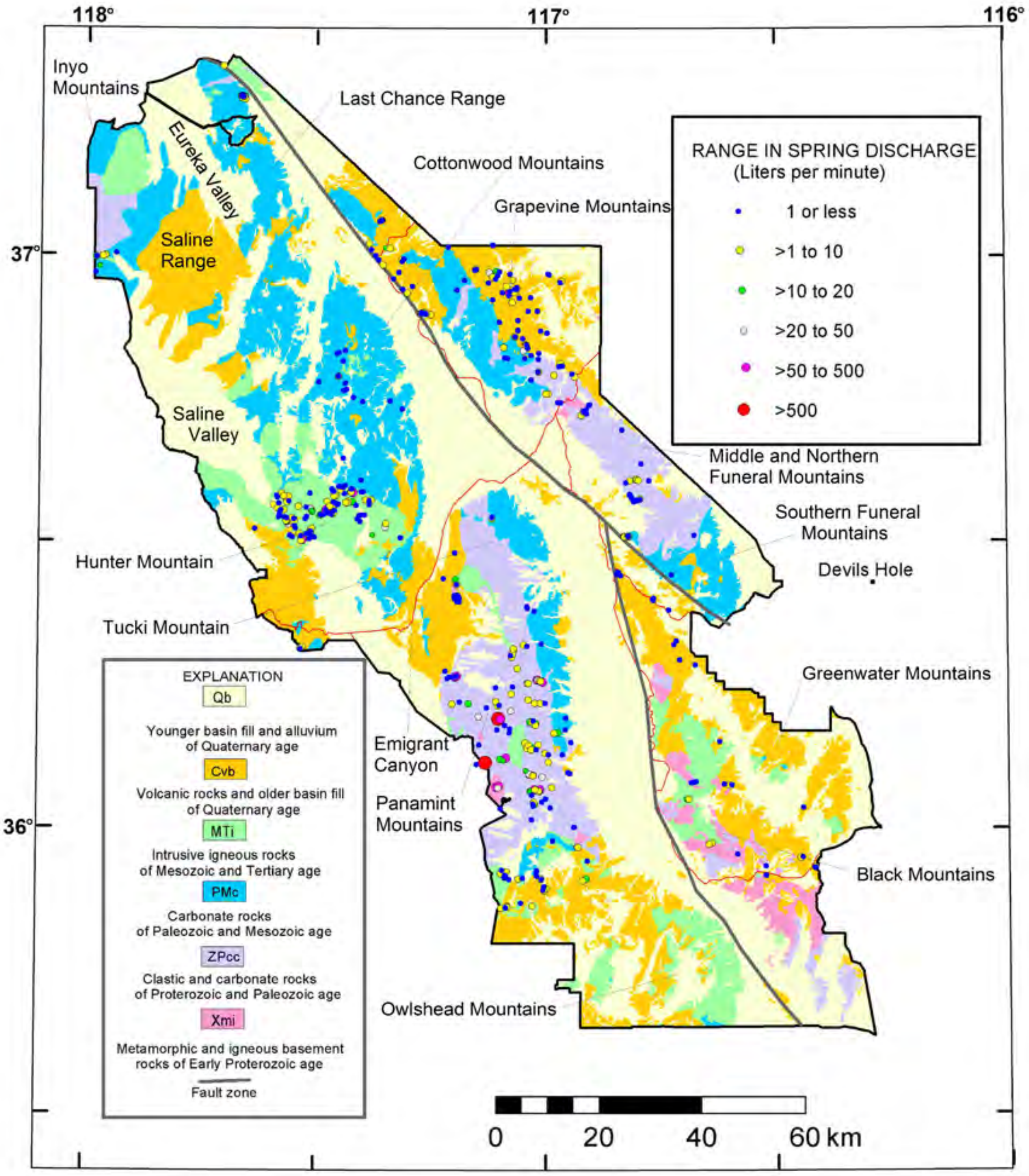
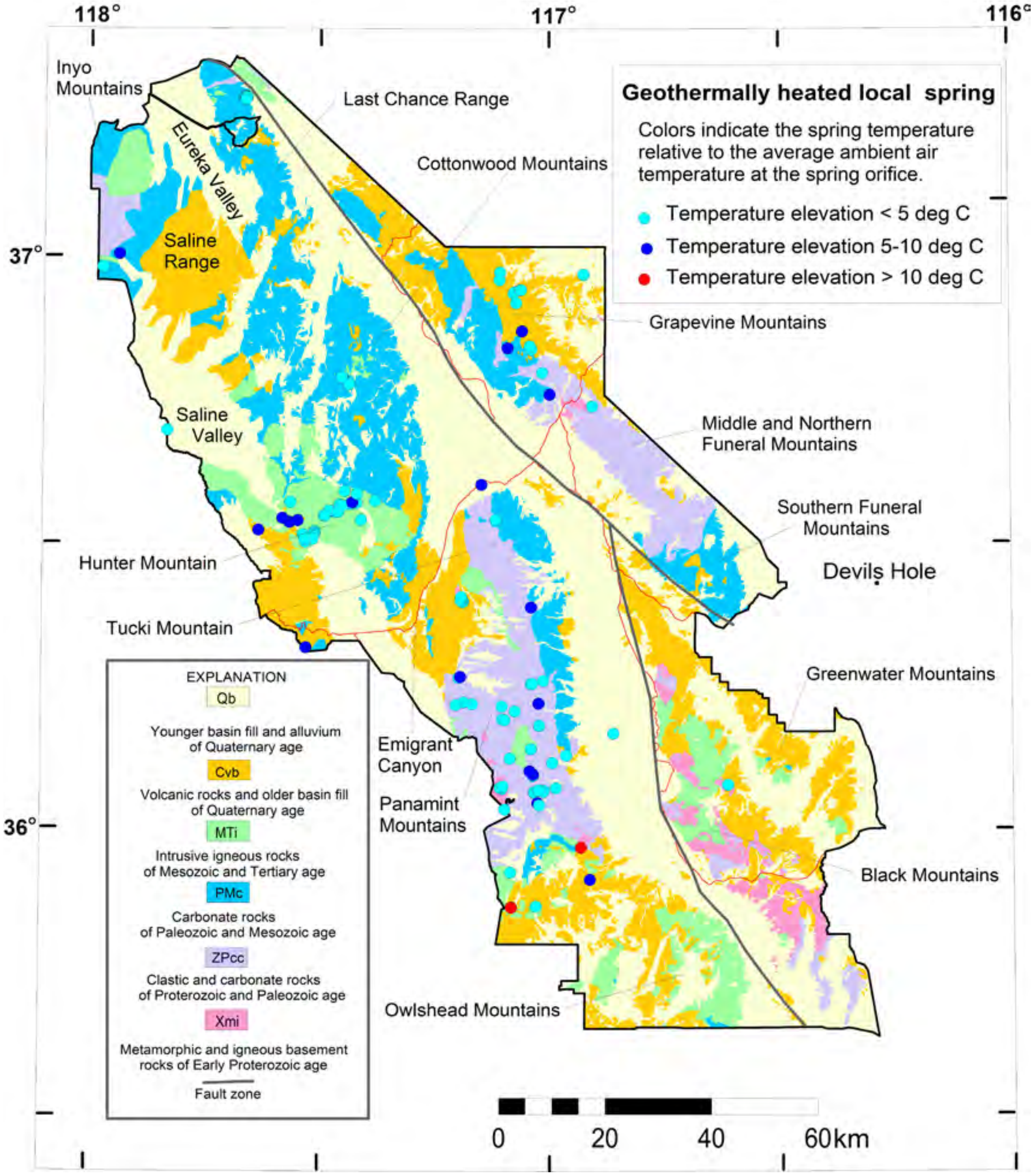


Figure 18. Map showing ranges of discharge in upland springs of Death Valley National Park. Springs are listed in the Appendix.

Figure 19. Map showing geothermally heated local springs of Death Valley National Park. Springs are listed in the Appendix.



Panamint Range

Carbonate Rock (PMc) Terrane: A huge slice of the carbonate rock unit (PMc) rests on clastic and carbonate rocks (ZPcc) in the lower plate of the Tucki Mountain detachment fault (fig. 4) on the eastern slope of the Panamint Range. This terrane lies at elevations at or below 1,000 meters (3,281 ft) and probably does not receive significant recharge. The principal source of the approximately 10 springs in this terrane is at higher elevation in terrane underlain by the older clastic and carbonate rock unit (ZPcc). The following quote from Hunt et al. (1966) refers to the structural setting of springs in the upper detachment block of the Panamint Range: “The structural geology is also important in controlling the occurrence of water in the mountain blocks. In the Panamint Range the formations dip east 25°–60°, and they are broken by a series of faults of the Amargosa thrust system (see Hunt et al. 1966), most of which dip west 10°–45°. The crushed rocks along the faults act as conduits, and practically every spring along the east slope of the Panamint Range is along one of these faults.” The Amargosa thrust system referred to above is now recognized as a system of detachment faults formed during Tertiary extension of the region (Troxel and Wright 1987).

Warm Springs, a group of three springs, discharge water geothermally heated to 16°C (29°F) above the ambient average air temperature. Warm Springs was ascribed to be discharge of regional flow (Faunt, D’Agnese, and O’Brien 2010, fig. D-7), but because the setting of the spring, at 750 meters (2,461 ft) in elevation, is well above the regional potential (plate 1), the spring is now known to be discharge of nearby recharge in the Panamint Range. Warm Springs issue from the carbonate rock unit (PMc) in the lower plate of the Butte Valley thrust fault (Steinkampf and Werrell 2001 and Anderson 1999). The source of the springs is recharge to the ZPcc rock unit at higher altitude in the Panamint Mountains.

Clastic and Carbonate Rocks (ZPcc) Terrane: The detachment fault plane becomes lower stratigraphically with distance south of Tucki Mountain; upper plate rocks become predominantly clastic and carbonate (ZPcc). Springs on the crest and high slopes of the Panamint Range reflect the large precipitation and highly fractured and faulted nature of the clastic and carbonate rocks (ZPcc) of the upper detachment plate. The flow of the numerous springs ranges from less than 1 liter per minute (.26 gal/min) to greater than 500 liters per minute (132 gal/min; fig. 18). Many springs arise along saturated permeable fault zones exposed in deep linear ravines draining the range. Discharge temperatures (fig. 19) of many springs indicate moderate depths of circulation. Hunt et al. (1966, B22) state, “Most of the springs, and all the big ones, issue from the noncarbonate rocks. The spring waters are high in sulfates and comparatively low in chlorides and carbonate.”

Metamorphic (Xmi), Granitic (Mti), and Volcanic Rock (Cvb) Terrane: Few springs issue from basement (Xmi) and granitic rocks (Mti). The locations of some springs appear to be controlled by flow barriers created by these intrusive rock masses.

Tucki Mountain: Three springs, West Twin Spring (472), Tucki Spring (473), and Gypsum Spring (477), emerge at elevations from 1,000 to 1,240 meters (3,281 to 4,068 ft) in Mosaic Canyon north of Tucki Peak, elevation 2,000 meters (6,732 ft), in the contorted Proterozoic metamorphic and clastic rocks of the Tucki Mountain Detachment zone.

Emigrant Canyon Area: A dozen or more springs emerge from Tertiary basaltic and sedimentary rocks (Cvb) along the west side of Emigrant Canyon in the northern Panamint Range south of Tucki Mountain.

Photograph 22. Upper Warm Spring. Warm Springs, one of the larger springs in the Panamint Mountains, discharges water geothermally heated to 16°C (29°F) above the average ambient temperature by deep circulation. The source of the spring is nearby recharge in the clastic and carbonate rock unit (ZPcc) at high altitudes of the Panamint Mountains and issues from the carbonate rock unit (ZPcc) in the lower plate below the Butte Valley thrust. The spring issues near the contact with igneous intrusive rocks.

Cottonwood Mountains and Last Chance Range

The Cottonwood Mountains separate Saline Valley from Death Valley; the Last Chance Range separates Eureka Valley from Death Valley. The elevation of the Cottonwood Range is high enough to receive precipitation for groundwater recharge. The higher parts of each of these ranges attain elevations of more than 2,500 meters (8,200 ft), and a large part of the ranges are above 2,000 meters (6,562 ft) elevation. The ridges in the Cottonwood Mountains are separated by three high playas at elevations from 1,200 to 1,500 meters (3,937 to 4,922 ft). These playas are dry, with no springs or phreatophytes, and the water level is at great depth beneath the playas.

Granitic (MTi) terrane of Hunter Mountain: The granitic rocks (MTi) of Hunter Mountain area in the southern part of the Cottonwood Range are the upper plate of a detachment. Springs emerge along fracture and fault zones created by regional extension. The area is conducive to recharge from the greater precipitation in the higher altitudes. Closure of the joints and fractures with depth limits deep circulation of groundwater. A few springs issue at temperatures of 5° to 10°C (9° to 18°F) above the ambient air temperature.

Carbonate (PMc) terrane of Cottonwood Mountains and Last Chance Range: The outcropping carbonate terrane of the Cottonwood and Last Chance Range is the upper plate of a detachment overlying lower-plate clastic and carbonate rocks (ZPcc)

(Sweetkind et al. 2001). The carbonate-rock-dominated terrane is punctuated by small outcrops of igneous intrusions. The carbonate terrane is virtually devoid of springs, even though elevations are great enough that the area receives ample precipitation for recharge. The lack of springs and the presence of dry playas are products of the permeable well-fractured and faulted carbonate rocks that allow groundwater to percolate to great depths and recharge to the zone of regional flow. Discharge of the regional flow is to Mesquite Flat.

Granitic intrusions (MTi) in carbonate terrane of northern Cottonwood Mountains and Last Chance Range: Fingers of a deep seated igneous intrusion reach the surface in the carbonate rock terrane in the vicinity of White Top Mountain in the Cottonwood Mountains and at Last Chance Springs in the Last Chance Range. Springs commonly arise in these settings, where deep percolation of groundwater is impeded by the igneous rocks. Willow Spring (849) issues from igneous granitic rock from the Death Valley–Furnace Creek Fault zone near the Death Valley National Park boundary.

Black Mountains and Greenwater Valley

The Black Mountains border the floor of Death Valley on the east from the Furnace Creek Ranch area to Saratoga Spring. The Greenwater Valley separates the Black Mountains from the Greenwater Range to the east (fig. 4). The Greenwater Range runs parallel to the Black Mountains and lies to the east of the Funeral Mountains. Proterozoic crystalline basement and sedimentary rocks underlie the Black Mountains and are locally overlain by Tertiary volcanic rock and Tertiary sedimentary basin filling rocks (fig. 7). Proterozoic and Cambrian clastic and carbonate rocks crop out in the southern part of the Black Mountains. The highest points in the Black Mountains are near 1,800 meters (5,900 ft). The Greenwater Range is lower, with the highest peaks about 1,500 meters (4,900 ft). The general low altitudes provide scant opportunity for much moisture in excess of potential evapotranspiration. Few small, widely scattered springs emerge in the ranges. The type area of Amargosa chaos (Noble 1941 and Troxel and Wright 1987), an area of intensely and complex faulted upper-plate detachment, occurs in the southeast part of the Black Mountains. A few small springs occur in the chaos area even though the precipitation is less than 170 millimeters per year (6.7 in/yr).

Photograph 23. Long-eared owl in tamarisk at Warm Spring. Warm Spring in the Panamint Mountains is one of hundreds of springs in the mountains of Death Valley National Park that provides water for plants and animals. Plant foliage in turn provides food and shelter for birds and other animals. At Warm Spring are found exotic plants, oleander and tamarisk, among the native plants.

Funeral Mountains

Carbonate rock (PMc) terrane of southern Funeral Mountains: Elevations of two peaks in the southern part of the Funeral Mountains reach near 2,000 meters (6,600 ft) elevation. The virtual absence of springs is the result of deep infiltration of recharge into the permeable carbonate rocks. Recharge on the west front of the Funeral Mountains may augment the flow of Navel Springs and the regional springs that discharge at Furnace Creek.

Lower Clastic and Carbonate rock (ZPcc) terrane of the middle and northern Funeral Mountains: Lower Clastic and Carbonate rocks (ZPcc) are the lower plate of a detachment underlies the middle segment of the Funeral Range. The elevation of mountain peaks in this part of the ranges from 1,000 to 1,800 meters (3,300 to 5,900 ft). The minor recharge in the middle portion of this segment, lower in elevation than the portions to the southeast and northwest, supports a dozen or so small springs discharging about one liter per minute (.26 gal/min). The springs in the very northern part of this segment have discharge temperatures several degrees above ambient air temperature. The springs are located in deeply incised canyons opening to Death Valley. On the western flank of the Funeral Mountains, Keane Wonder Spring, a regional spring discussed previously, issues from the Proterozoic Pahrump Series.

Grapevine Mountains

Carbonate (PMc) and volcanic rock (Cvb) terranes: A body of largely carbonate rock with clastic rocks, broken by transverse and sub parallel thrust faults and normal faults, underlies the western portion of the Grapevine Mountains and is bounded on the west by the Death Valley–Furnace Creek fault zone. The eastern portion of this segment of the Grapevine Mountains is underlain by lava flows, breccias, and tuffs. Many springs in the southeastern part of the area occur in deeply incised canyons in carbonate and clastic rocks. The temperature of several of these springs is elevated above the average ambient air temperature. Few springs occur in the carbonate rock terrane in the northwest part of the Grapevine Mountains. Several springs issue from Miocene and Pliocene deposits overlying the lower slopes of the western part of the Grapevine Mountains. The higher volcanic terrane of the eastern part of the southeastern Grapevine Mountains supports about 30 springs (533–563, Appendix) of which six have spring outlet temperatures greater than average air temperature.

Klare Spring (356, Appendix) issues from the Titus Canyon thrust fault. The lower plate is rock of the Wood Canyon formation (Reynolds 1974). The upper plate is the Carrara Formation. Both formations are part of the Proterozoic and Cambrian Lower Clastic and Carbonate rock unit (ZPcc). The Carrara Formation is overlain by the Bonanza King Formation.

Owlshead Mountains

The curved ridges of granitic (Mti) and volcanic rocks (Cvb) of the Owlshead Mountains are underlain by granitic (Mti) and volcanic rocks (Cvb) appearing to form a large circular highland. Few of the higher ridges reach elevations greater than 1,200 meters (4,000 ft). The sparse precipitation and significant potential evapotranspiration provides scant excess moisture for recharge. The virtual lack of springs in the range and the two large dry playas (the eyes of the owl) signal that recharge is minimal and groundwater is well beneath the surface. One spring, Owl Hole Spring, south of the Owl Mountains, beyond the national park boundary, was a rest stop for the 20-Mule-Team borax wagons on their trek from Death Valley to the rail junction at Mojave, California.

Saline Range and Inyo Mountains

The Saline Range, between Saline Valley and Eureka Valley, is underlain by volcanic flows (Cvb). West of the Saline Range, the adjoining Inyo Mountains are underlain by carbonate, clastic, and large igneous batholiths (ZPcc, PMc, and Mti). There are no springs in the volcanic rocks. The carbonate rocks of the Inyo Mountains gives rise to a group of springs near but outside the park boundary discharging about 80 liters per minute (21 gal/min).

Photograph 24. Remains of an Arrastre mill at Telephone Spring. Arrastre mills were primitive stone structures used to break up ore, commonly gold or silver ore. Telephone Spring in the Panamint Range at an elevation of 833 meters (2,733 ft) was named from the 1906 telephone line from Rhyolite to Skidoo that passed through the canyon. The NPS spring records contain a note by A. E. Borell, dated 1935, stating, "A small flow of good water. Has been dug out and boarded over. Small birds and mammals can get water but not large birds or sheep. There is an arrastre mill and several tent houses nearby, area is strewn with debris." The spring was reported to be dry in 1959 and subsequent reports.

Vulnerability of Death Valley Groundwater to Natural and Human-Induced Stresses

Local Springs

Local springs include upland springs and springs at the valley floor derived from nearby recharge. Recharge is primarily a function of climatic and geologic factors and is thus beyond the control of park management. Environmental conditions at and near the spring outlet can control the riparian vegetation, endemic wildlife, and utility of the spring for watering wildlife. Biological and physical conditions at the spring outlet are a function of natural factors, largely climate, geology, and extra-environmental factors (i.e., human-induced detrimental changes or by invasion of exotic plants or animals that may degrade the natural environmental conditions). Extra-environmental factors that influence conditions at the spring outlet are subject to control by park management.

Stresses Outside the Park

The greater part of the water resources of the park, probably on the order of 60%, originates outside the park boundaries. Regional flow is the major component of groundwater that maintains the regional springs, the few perennial stream reaches, the areas of riparian vegetation at springs, phreatophytes at areas of shallow groundwater, perennial lakes, and marshes. The regional inflow is a function of both natural factors and human-induced stresses such as groundwater withdrawals.

Regional flow to Death Valley originates within the Death Valley flow system whose boundaries are shown in plate 1. Stresses on the flow system outside the park that affect the quantity or quality of groundwater may have an effect on the groundwater in the park. Consideration is given here of human-made stresses on the flow system that may affect groundwater at the park, with major reference to ongoing, planned, or proposed developments and the physical properties of the flow system that control the magnitude and time response of resultant groundwater-related changes in the park.

Land Management Practices

Management practices that affect natural plant cover and natural conditions of the soil and subsoil—as by excavation, agriculture, mining, forestry, plant removal, introduction of exotic plants and animals, range management practices, construction, urbanization, surface water diversions, groundwater withdrawal, or impoundment of reservoirs—have the potential for affecting the aquifer system.

Water Resource Developments

Groundwater withdrawal reduces the system flow and potentially reduces the water resources of Death Valley. Groundwater withdrawals outside the park are the most common and widespread causes of potential impact on groundwater resources of the park. The magnitude of the effect of groundwater withdrawal may vary from a direct proportion to a lesser percentage depending on the hydrogeologic setting of the point of withdrawal. Withdrawal of groundwater that would have been partially consumed by evapotranspiration in an intermediate discharge area would have a diminished effect on flow to Death Valley. The larger groundwater withdrawal areas near the park are listed in table 8.

The location of Devils Hole and pumping centers in southwest Nevada are shown in figure 14. Based on analysis of the hydrogeologic setting, the history of water-level fluctuations, and hydrologic properties of the groundwater system, groundwater withdrawals from three pumping centers have significant effect on the stage at Devils Hole and the flow of springs at Ash Meadows (Bedinger and Harrill 2006b). Large withdrawals of groundwater for irrigation were made from Ash Meadows from 1969 to 1977. Ash Meadows is adjacent to Devils Hole, and a cause–effect relationship between pumping and water level decline in Devils Hole has been established (Dudley and Larsen 1976 and Rojstaczer 1987). Pumping in the Amargosa Desert, west of Devils Hole, is currently the nearest large-scale pumping to Devils Hole. The distance to the Amargosa Desert pumping from Devils Hole ranges from about 13 to 34 kilometers (8 to 21 mi). Army Well 1, about 29 kilometers (18 mi) upgradient from Devils Hole, is the closest pumping well completed in the carbonate rock aquifer that supplies groundwater to Devils Hole and Ash Meadows. Analytical calculations indicated that the magnitude of pumpage from this well may be capable of causing changes in the water level in Devils Hole (Bedinger and Harrill 2006b).

Pahrump Valley, southeast of Devils Hole, contains a large pumping center (fig. 14) but is believed to be separated from Devils Hole by clastic rocks that restrict water level declines from propagating from Pahrump Valley to Devils Hole (Winograd and Thordarson 1975). Eventually pumping effects could propagate to Devils Hole by expanding south of the confining unit barrier or the effects could be transmitted slowly through the confining units. Water level records in wells south of Ash

Meadows show no indication of pumping effects. The main effect of pumping in Pahrump Valley will be a potential reduction in groundwater flow to southern Death Valley and the lower Amargosa River.

Withdrawal of groundwater from Army Well 1 reduces the flow to Ash Meadows and lowers the level of Devils Hole (Bedinger and Harrill 2006b). These pumping centers in Nevada draw water directly from the Death Valley flow system on permeable flow paths that lead to Death Valley. Regional water level declines in Amargosa Desert are documented by measurements from observation well networks (Harrill and Bedinger 2005). Water level declines in Death Valley National Park have been recorded at Travertine Point Well and at Travertine Well (Texas Spring Syncline-1) near Furnace Creek (Harrill and Bedinger 2005). These declines are possibly due to the large withdrawals from the Amargosa Desert.

In California large groundwater withdrawals are concentrated in a few alluvial basins: the Mojave River Valley, Indian Wells Valley, and Searles Lake Valley (Bedinger and Harrill 2006a). Withdrawals from the Mojave River Valley have reduced the flow of the river to Soda Lake Valley (Stamos, Martin et al. 2001). Surface inflow into Soda Lake Valley is usually lost there by evaporation, but on rare occasions an unusually heavy rainfall has caused runoff to Soda Lake Valley to overflow to Death Valley through Silver Lake. There are large surface water diversions from the Owens River. Historically flow of the Owens River was largely lost by evaporation from Owens Lake. Diversions of surface water may have lowered the groundwater levels in the Owens River Valley. The head decline would have minor effect on groundwater flow to Death Valley. Groundwater withdrawals at Indian Wells Valley and Searles Lake Valley probably salvage groundwater that under natural conditions would have been lost to evapotranspiration. These basins are in Precambrian igneous and metamorphic rocks which have low capacity to transmit regionally significant quantities of groundwater.

Potential Contaminant Sources

The Nevada Test Site has been the location of nuclear device testing above and below the water table, disposal of low-level radioactive and other wastes, and storage and disposal of other potential contaminants by well injection, drainage ponds, leach fields, sumps, tailings, and tanks (fig. 20). Disposal of high-level radioactive waste is proposed for an underground repository in the unsaturated zone at Yucca Mountain near the west boundary of the Nevada Test Site. A decommissioned low-level radioactive waste site exists near Beatty where waste is stored in the unsaturated zone above the water table (Bedinger 1989). Gold mining at Rhyolite, near Beatty, in the 1990s used a cyanide leaching process to recover gold from ore. Groundwater flow is the primary mechanism by which radioactive and other contaminants from these sites could be transported from the disposal sites to the accessible environment. Groundwater flow from these potential sites of contamination is tributary to Death Valley National Park. The following paragraphs do not discuss specific contaminants or their properties, do not predict mobilization of contaminants in groundwater, nor predict time of travel from potential contaminant sites to the accessible environment. The discussion is a broad overview of probable routes of groundwater flow in the upper part of the saturated zone and the underlying principal zone of flow, groundwater flow directions, discharge areas, and the most probable Death Valley entry points of groundwater from the potential contaminant sites. The ultimate discharge points of groundwater from areas of potential contamination are the Death Valley floor discharge areas and regional springs of Death Valley that issue above the valley floor. Intermediate natural groundwater discharge occurs at intermediate areas in the flow system before it reaches Death Valley. Intermediate discharge areas include areas along the Amargosa River, Franklin Playa, Ash Meadows, and Oasis Valley (Laczniak 1996; plate 1).

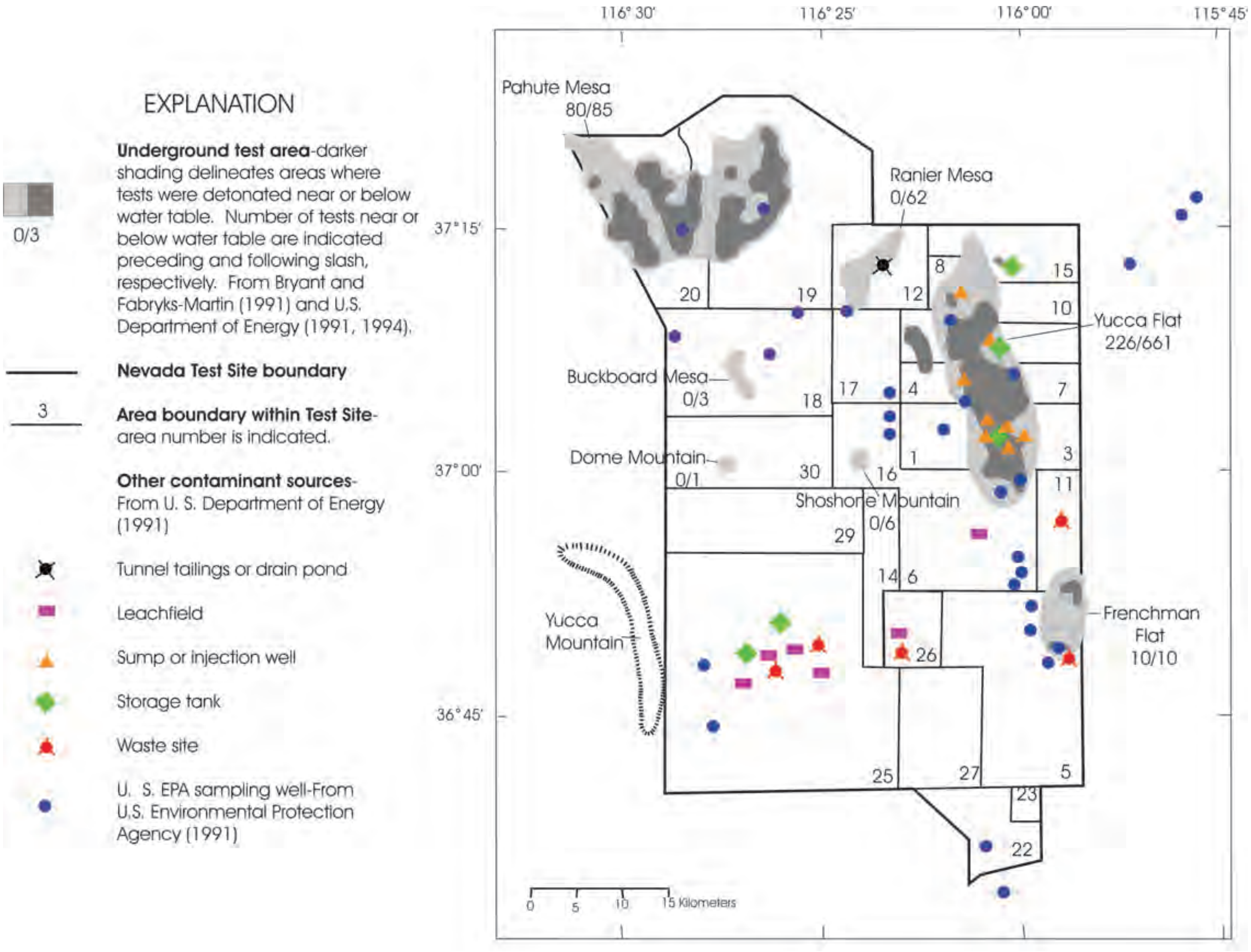


Figure 20. Map showing general areas of underground testing and other potential sources of subsurface contamination at Nevada Test Site. From Laczniak et al. 1996.

The general directions of flow from contaminant sites to Death Valley are shown in figure 21. Many of the potential sites of contamination are above the zone of saturation or are at relatively shallow depths beneath the water table. Initial transport of the contaminants from these sites would be in the upper part of the flow system. In some areas this zone may be the principal zone of lateral groundwater flow.

Although confining units are commonly present above the carbonate rocks, in the eastern part of the Nevada Test Site, basin-fill deposits of Yucca and Frenchman Flats overlie carbonate rock without an intervening confining layer (Laczniak et al. 1996). Groundwater flow from this part of the Nevada Test Site is in both alluvium and carbonate rocks. This groundwater flow, a part of the Ash Meadows groundwater subbasin of Winograd and Thordarson (1975), flows southward to about the southern boundary of the Nevada Test Site, thence southwestward to Devils Hole and Ash Meadows, a large intermediate discharge area from the carbonate aquifer. It is conjectural whether all the groundwater of the Ash Meadows subbasin is discharged at Ash Meadows and the carbonate aquifer is terminated or the carbonate aquifer continues southward or southwestward from Ash Meadows. It is customary for hydrochemists to compare the solute and isotope chemistry of the groundwater at the Furnace Creek springs in Death Valley (this includes Travertine Springs, Texas Springs, Salt Springs, and Nevares Springs) to the groundwater of the springs discharging from carbonate rocks at Ash Meadows and ascribe the source as the Ash Meadows subbasin. However, the chemical signatures do not provide a unique match between the two waters. The Furnace Creek springs could be derived,

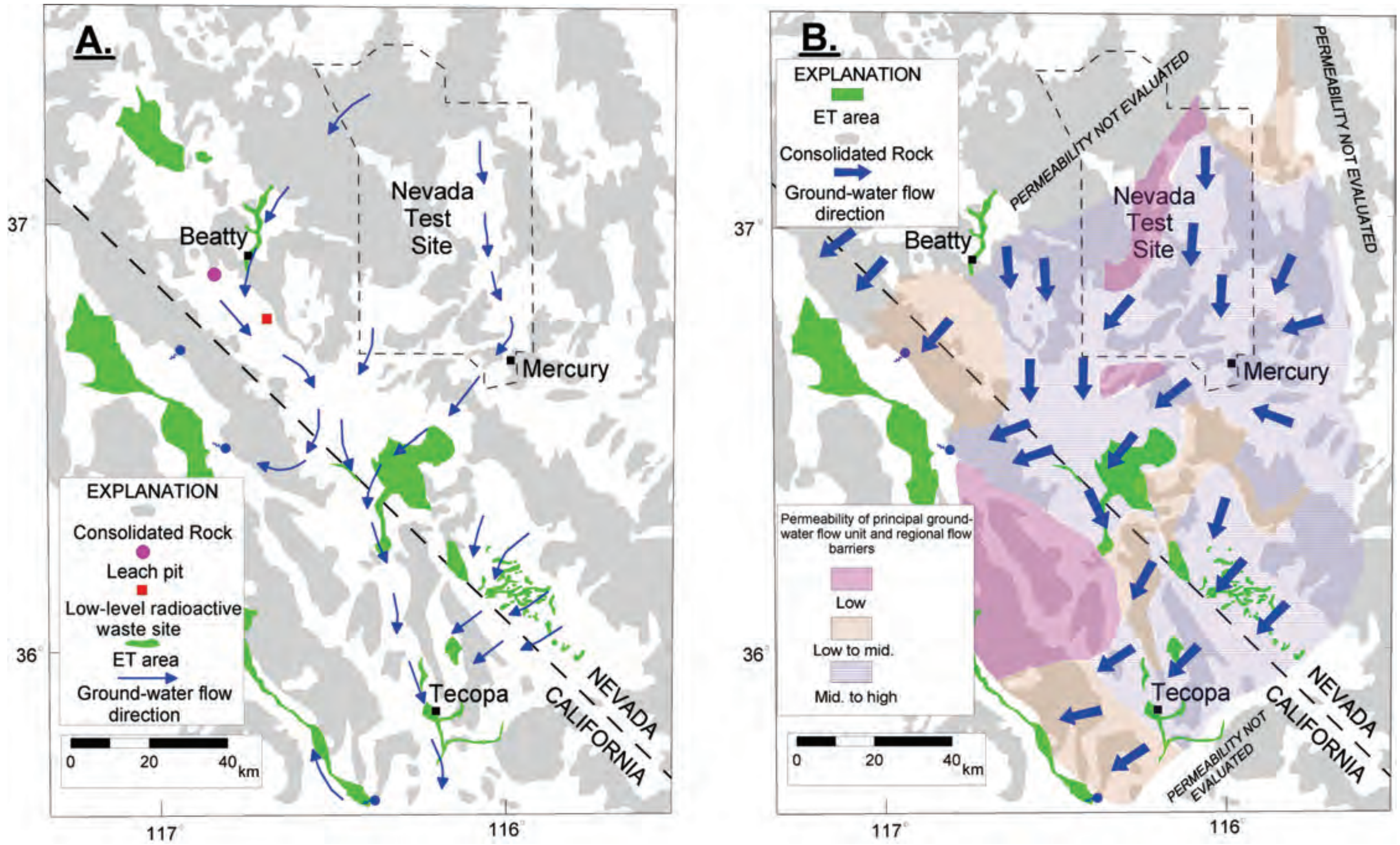


Figure 21. Maps showing general direction of groundwater flow from the Nevada Test Site to areas in Death Valley National Park.
A. Direction of flow of groundwater in the upper part of the zone of saturation, potential contamination sites, and intermediate and final discharge areas are also shown.
B. Schematic showing relative permeability of principal groundwater flow unit, direction of groundwater flow, and ultimate discharge area.
From Laczniak et al. 1996; Winograd and Thordarson 1975; Sweetkind et al. 2004; Waddell et al. 1984; Faunt, D'Agnese, and O'Brien 2010; and Dettinger et al. 1995.

all or in part, from groundwater flow in carbonate rocks from west of the Ash Meadows subbasin, a concept proposed by Bredehoeft et al. (2005).

Groundwater flow from volcanic calderas in the northwest part of the Nevada Test Site is southward toward the Beatty area. Beyond the volcanic rocks of the calderas, groundwater flows in alluvium and flow in the underlying carbonate rocks. Intermediate discharge at Oasis Valley is derived in part from flow from the caldera area of Nevada Test Site. Shallow flow continues from Oasis Valley to the Amargosa Desert. Deep groundwater flows southward beneath the Amargosa Desert.

The Beatty low-level waste site, the cyanide pits near Rhyolite, and the proposed repository in Yucca Mountain are in the unsaturated zone and overlie groundwater in alluvial and basin-fill deposits. The groundwater in the basin fill beneath these sites flows southeastward to the central Amargosa Desert.

Bredehoeft et al. (2005) present the hypothesis that groundwater in the carbonate aquifer beneath Yucca Mountain flows southward beneath the basin fill of the Amargosa Desert to the southern Funeral Mountains where it flows through the exposed carbonate rocks and discharges at the Furnace Creek springs. This flow regime is discussed further under the section on regional springs. The hydrogeologic system should be examined to determine if basin-fill groundwater of the Amargosa Desert also flows into carbonate rocks of the southern Funeral Mountains and to the Furnace Creek springs. Furnace Creek springs area is one of the principal areas of discharge of groundwater originating in the potential contamination sites (fig. 21).

Another Death Valley entry area for groundwater from the contaminant areas is the southern Death Valley floor from groundwater flow along the course of the Amargosa River. Flow in bedrock aquifers would involve flow though segments of low- to mid-range permeability rocks (fig. 21b), rock unit ZPcc of this report. This flow would discharge in the southern Death Valley floor.

Table 8. Areas of groundwater withdrawal in the Death Valley flow system

		Pumpage			
Number	Hydrologic Area Name	m^3/day	m^3/day x1000	Year	Source
117	Fish Lake Valley	4,145	4	1970	Rush and Katzer (1973)
144	Lida Valley	2	<1	1998	San Juan et al. (2004)
146	Sarcobatus Flat	69	<1	1998	San Jaun et al. (2004)
147	Gold Flat	118	<1	1998	San Juan et al. (2004)
148	Cactus Flat	155	<1	1998	San Juan et al. (2004)
158A	Emigrant Valley	946	1	1998	San Juan et al. (2004)
159	Yucca Flat	250	<1	1998	San Juan et al. (2004)
160	Frenchman Flat	1,462	2	1998	San Juan et al. (2004)
161	Indian Springs Valley	2,162	2	1998	San Juan et al. (2004)
162	Pahrump Valley	120,069	120	1998	San Juan et al. (2004)
163	MesquiteValley	85	<1	1998	San Juan et al. (2004)
164B	Southern Ivanpah Valley		<1	1975	Bedinger et al. (1963)
170	Penoyer Valley	42,902	43	1998	San Juan et al. (2004)
173A	S Railroad Valley	13	<1	1998	San Juan et al. (2004)
211	Three Lakes Valley (southern)	1,125	1	1998	San Juan et al. (2004)
225	Mercury Valley	10	<1	1998	San Juan et al. (2004)
226	Rock Valley	1	<1	1998	San Juan et al. (2004)
227A	Jackass Flat	506	<1	1998	San Juan et al. (2004)
227B	Buckboard Mesa	321	<1	1998	San Juan et al. (2004)
228	Oasis Valley	848	<1	1998	San Juan et al. (2004)
229	Crater Flat	469	<1	1998	San Juan et al. (2004)
230	Amargosa Desert	84,133	84	1998	San Juan et al. (2004)
240	Chicago Valley		<1	2004	Field obs by authors
241	California Valley		<1	2004	Field obs by authors
242	Lower Amargosa Desert	91	<1	1998	San Juan et al. (2004)
243	Death Valley	111	<1	1998	San Juan et al. (2004)
244	Valjean Valley	info NA			Calif. DWR (2004 update)
245	Shadow Mountain Valley	info NA			Calif. DWR (2004 update)
247	Adobe Lake Valley	info NA			
248	Long Valley	345	<1	1997	Calif. DWR (2004 update)
249	Owens Valley	174,523	175	^{w}1999	Calif. DWR (2004 update)
250	Deep Springs Valley		<1	2004	Field obs by authors
251	Eureka Valley		<1	2004	Field obs by authors
252	Saline Valley		<1	2004	Field obs by authors
253	Racetrack Valley Area		<1	2004	Field obs by authors
254	Darwin Plateau B.		<1	2004	Field obs by authors
255	Panamint Valley		<1	2004	Field obs by authors
256	Searles Valley	info NA			Calif. DWR (2004 update)
257	E. Pilot Knob & Brown Mt. V.		<1	2004	Field obs by authors
258	Lost Lake-Owl Lake V.		<1	2004	Field obs by authors
259	Leach Valley	info NA			
260	Red Pass Valley	info NA			
261	Riggs Valley	info NA			Calif. DWR (2004 update)
262	Soda Lake Valley		<1	2004	Field obs by authors
263	Kelso Valley	info NA			Calif. DWR (2004 update)
264	Cronise Valley	info NA			Calif. DWR (2004 update)
265	Bicycle Valley		<1	2004	Field obs by authors

Table 8 continued

Number	Hydrologic Area Name	Pumpage m³/day	 m³/day x1000	Year	Source
266	Goldstone Valley	info NA			
267	Superior Valley	info NA			
268	Coyote Lake Valley	5,721	6	1995	Calif. DWR (2004 update)
269	Lower Mojave River Valley	130,662	131	w1998	Calif. DWR (2004 update)
270	Lucerne Valley	33,850	34	1976	Calif. DWR (2004 update)
271	Upper Mojave River Valley	264,633	265	w1998	Calif. DWR (2004 update)
272	Middle Mojave River Valley	90,719	91	w1998	Calif. DWR (2004 update)
273	Harper Valley	90,719	91	w1998	Calif. DWR (2004 update)
274	Antelope Valley	53,298	53	1970	Durbin (1970)
275	Fremont Valley	108,321	108	1960	Calif. DWR (2004 update)
276	Cuddleback Valley	info NA			Calif. DWR (2004 update)
277	Indian Wells Valley	6,810	7	1985	Bettenbrock and Martin (1989)
278	Rose Valley	info NA			Calif. DWR (2004 update)

w1998 indicates water year ending in 1998

Flow Systems Adjoining Death Valley Flow System

The natural boundaries of the Death Valley regional flow system are hydraulic barriers, groundwater divides, or groundwater flow lines. The boundaries are subject to being shifted by natural or human-made stresses that disturb the balance of hydraulic head and groundwater flow and cause groundwater to flow across the original boundary location. The potential for hydraulic boundaries to be changed or moved depends upon the hydraulic properties of the flow system at the boundary. The hydraulic properties of the flow system control the rate of movement of groundwater and the probability that nearby groundwater withdrawal would affect the flow system boundary. Segments of the Death Valley regional flow system boundary are shown in figure 22. The potential for these segments to shift in response to natural and pumping stresses are discussed in the following paragraphs.

<u>White River boundary segment:</u> The White River boundary segment (A to B, fig. 22) is highly subject to change because of the relatively low height of the divide, the relatively high transmissivity of the flow system, and past and probable continuing efforts to develop groundwater supplies nearby to the east and north in the adjacent White River flow system.

<u>Spring Mountains to Clark Mountain segment:</u> The segment (B to C, fig. 22) follows groundwater divide from the crest of the Spring Mountains to the Clark Mountain Range. The bedrock is largely Paleozoic siliceous and carbonate rocks. Recharge in the boundary area is a source of groundwater flow in the flow system to Death Valley. There is heavy pumping east of the boundary in Las Vegas Valley and west of the boundary in Pahrump Valley. Stresses from either or both of these areas could eventually cause a shift in location of the boundary.

<u>Mojave segment:</u> The Mojave segment (C to D, fig. 22) follows the relatively low groundwater divide separating the Death Valley flow system from the lower Colorado River flow system. Bedrock is largely metamorphic, igneous, and volcanic rocks of low permeability. Large groundwater flux is restricted to relatively small areas. Precipitation is low, potential evapotranspiration is large, and recharge is low. Very limited flow originates in this area for contribution to Death Valley. The bedrock along this segment generally acts as a relative barrier to groundwater flow, and significant shifts in location of the boundary are not anticipated.

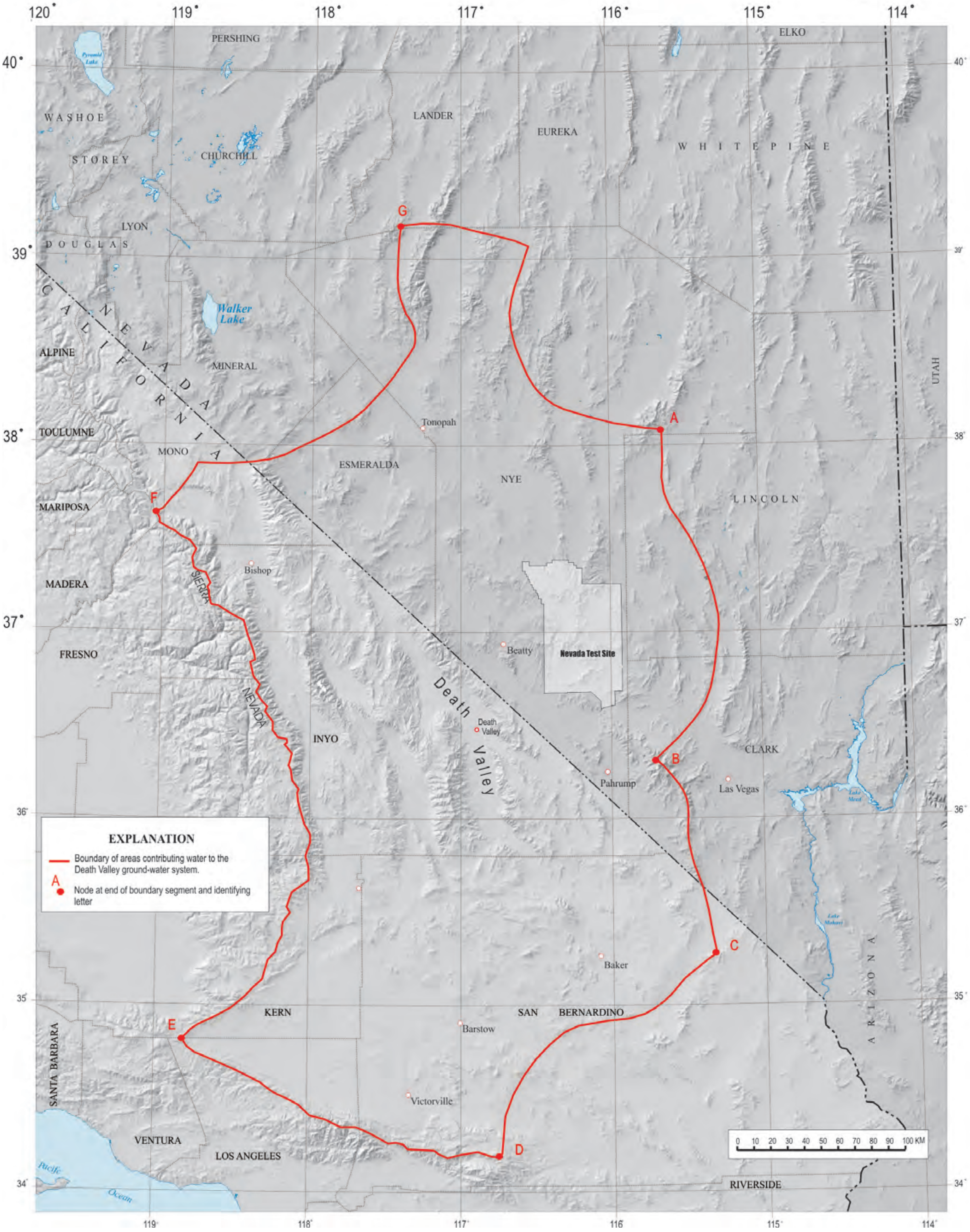


Figure 22. Map showing segments of the Death Valley regional flow-system boundaries.

San Bernardino–San Gabriel Mountain segment: This segment (D to E, fig. 22) follows the crest of the San Bernardino and San Gabriel Mountains. The bedrock is largely igneous intrusives. The flow system boundary, a groundwater divide, generally follows the crest of the ranges. The divide is generally high and maintained by groundwater recharge to the bedrock of low to moderate permeability. The bedrock is a relative barrier to groundwater flow; consequently, significant shifts in the location of the boundary are not anticipated.

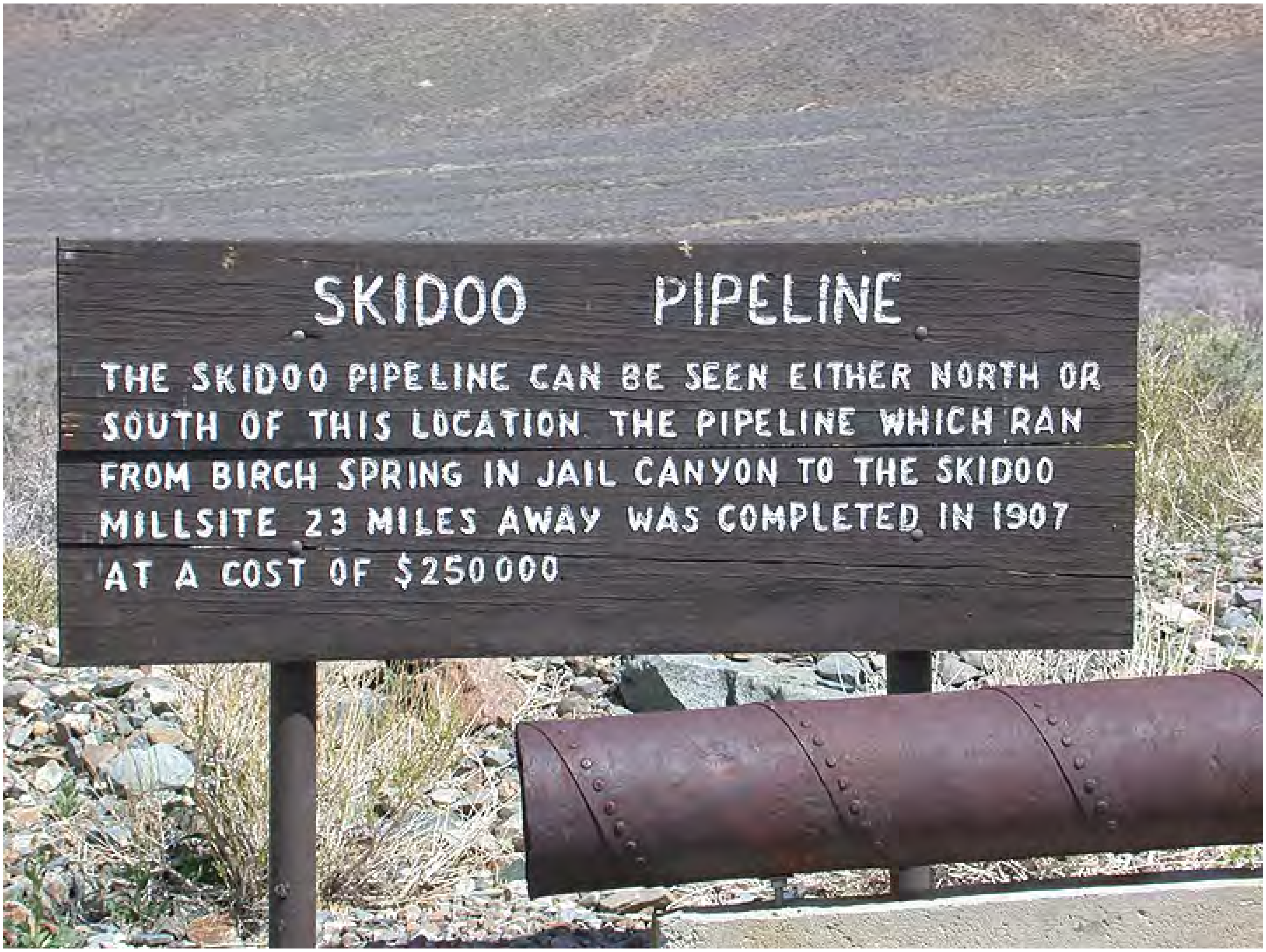
Sierra Nevada segment: The Sierra Nevada segment (E to F, fig. 22) follows the crest of the Sierra Nevada from San Gabriel Mountains to the Long Valley geothermal field. The Sierra Nevada is underlain by a huge batholith of igneous rock. Recharge in the range is limited by the moderate to low permeability of the igneous rocks. Locally, zones of large permeability are believed to exist in the high temperature geothermal systems at Coso and Long valley. Modest recharge that occurs in the Sierra Nevada is tributary to the basin valleys of the Death Valley flow system that border the range. Most of the recharge and surface runoff to the Owens River has been diverted to the U. S. west coast for water supply since the 1930s resulting in large reductions of evapotranspiration in Owens Valley (including the drying up of Owens Lake) and some reduction of natural groundwater flow toward Death Valley. A significant shift on location of the boundary in this segment is not anticipated.

Northwest segment: The Northwest segment (F to G, fig 22) is generally a low groundwater divide separating the Death Valley regional flow system from the Humboldt–Truckee groundwater flow system. The boundary extending from the Sierra Range to the Shoshone Mountains in central Nevada does not cross high ranges that would afford significant recharge. The boundary area is subject to shifting as a result of groundwater withdrawals in the adjacent flow system. This could result in diversion of water from the Death Valley flow system.

Northern segment: The Northern segment (G to A, fig 22) extends from the Shoshone Range eastward across the Toiyabe Range and Big Smoky Valley to Monitor Valley, thence the boundary turns southward and extends in an arc concave to the northeast to the beginning point of the White River segment. This segment traverses the highest points on the boundary of the Death Valley flow system. The area traversed by this boundary receives significant recharge to the Death Valley flow system. Flow in the Death Valley flow system is subject to depletion in response to withdrawal from groundwater in the boundary area, particularly the basin fill areas in Reese River Valley, Big Smoky Valley, and Monitor Valley.

Historic Impacts on Groundwater in the Park

Prospecting, mining claims, mine development, mining scams, mine company promotions, and mining were the principal endeavors in Death Valley until the early 1930s when Death Valley became a national monument as a part of the National Park System. Mining endeavors and promotions focused on a broad gamut of natural resources from precious metals, gold and silver, to talc, salts of borax and sulfate, lead, filter clay, and even mud, with fraudulent schemes involving oil and copper (Lingenfelter 1986). Gold, the perennial favorite of the prospectors' quest, was found at many places in Death Valley. In addition to many small gold mining operations, two large gold mines came into production, the Skidoo Mine in the Panamint Range and the Keane Wonder Mine in the Funeral Mountains. Each of these mines produced gold valued at one million dollars or more, but not enough to return a profit to the investors after the costs of mining, machinery, transportation of ore, and diverting water to the mines that was needed for the mining and milling. The most remunerative mining ventures were those involved in recovering borate, talc, and filter clay. Mining of borax and the famous 20-Mule-Team wagons are well known. Borate was found and mined in the playa of Death Valley and in the older Tertiary deposits in the Furnace Creek



Photograph 25. Skidoo Pipeline. The Skidoo pipeline brought water to the gold mine at Skidoo for generating steam power to operate the mill. Prospecting and mining was the principal endeavor in Death Valley until the early 1930s when Death Valley was made a national monument as a part of the National Park System. Water, required for the sustenance of the miners, their burros and other livestock in prospecting, and for mining and milling operations and mining towns, was the critical and often the limiting factor of a successful venture. Elaborate and extensive engineering projects were constructed to convey water from springs to the stamping mills and steam generators where ore was processed. Gold, the perennial favorite of the prospectors' quest, was found at many places in Death Valley. In addition to many small gold mining operations, two large gold mines came in to production, the Skidoo Mine in the Panamint Mountains and the Keane Wonder Mine in the Funeral Mountains.

basin, where mining rights still exist to this day and active mining continued until recently (NPS, M. Essington, oral communication).

Water, the most essential commodity, was probably the most valuable when all is said and done. Water, required for the sustenance of the miners, their burros and other livestock in prospecting, and for mining and milling operations and mining towns, was the critical and often the limiting factor of a successful venture. Elaborate and extensive engineering projects were constructed to convey water from springs to the stamping mills and steam generators where ore was processed. A 34-kilometer (21-mi) pipeline was constructed from Birch Spring near Telescope Peak to bring water to the mine at Skidoo for steam power and to run a fifty-stamp mill (Lingenfelter 1986, 289). Wells provided water for some camps; Stovepipe Well, Shortys Well, Bennetts Well, and many others were dug but did not find water. Subsurface exploration of the copper prospect at Greenwater was continued to a depth of 427 meters (1,400 ft). Apparently groundwater was not encountered. Because water for the prospectors and miners was scarce—the local spring hardly provided enough water for a burro—water was hauled in from Furnace Creek, about 28 kilometers (17.4 mi) away (Lingenfelter 1986). Springs, being the primary source of water, were often the site of camps established by prospectors. The outlet of many springs were altered and modified by excavations, tunnels, pits, piping, and other means to aid in collecting and directing the flow of springs. The remnants of these activities are evident today at many springs. Many a prospector's or miner's burro, mule, or horse strayed or was left behind when no longer needed.

Photograph 26. Burros of Death Valley National Park. Abandoned by prospectors who brought them to Death Valley, these animals stayed and thrived so well that Death Valley has been faced with a population explosion. This is not very good grazing land, but the burros have thoroughly adapted to it. Burros have been accused of fouling water holes and driving bighorn sheep off some of the range. However, in the burros' defense, the evidence and observations show that the burros occupy land that has been little used by sheep during the past 2,000 years, and the two animals have never seriously competed for range in Death valley, according to Ralph and Florence Wells who made the first complete survey of wildlife water resources in the park in the 1950s and C. B. Hunt who mapped the geology, vegetation, and archeology of Death Valley in the 1960s. Photograph from C. B. Hunt, USGS files, circa 1960; caption information from C. B. Hunt 1975.

There is a population of burros to this day that survives in the park. Burros have been and are detrimental to the conditions of many springs and, as a result, to the native fauna, particularly mountain sheep, that depend on springs for their water supply. An NPS document from the 1970s includes notes on the conditions and rehabilitation needed at springs, some degraded by burros. The original inventory of springs (1976) and the recent inventory of springs (2006) provide information on the use of springs by burros and native species and the detrimental effect of burros on spring conditions. However, the contention that burros compete with bighorn sheep for forage is obviated by the evidence and observations that show that the burros occupy land that has been little used by sheep during the past 2,000 years, and the two animals have never seriously competed for range in Death Valley. This conclusion is made by C. B. Hunt (1975) who mapped the geology, vegetation, and archaeology of Death Valley in the 1960s and who states that the conclusion is in accord with the findings of Ralph and Florence Wells who made the first complete survey of wildlife water resources in the park in the 1950s.

Appendix: Springs of Death Valley

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (ºC)	Amb Air[2] Temperature (ºC)	Spring–Amb Air[3] Temperature (ºC)
1	Hole in Rock Spring (New)	502941	4066452	14 S	44 E	15 NW	851	0.5	14.5	17.2	-2.7
2	Burro Spring B	459770	4071666	13 S	42 E	21 NW	2194	2	18.9	7.8	11.1
3	Burro Spring A	459705	4071705	13 S	42 E	21 NW	2209	1	9.5	7.7	1.8
4	Burro Spring C	459835	4071657	13 S	42 E	21 NW	2186	<1		7.8	
5	Ranger Spring	468398	4093281	11 S	42 E	24 SW	645	7	17.4	18.6	-1.2
6	Quartz Spring	455956	4070547	13 S	41 E	26 SW	1543	1	10.3	12.3	-2.0
7	Horsetail Spring	458483	4049739	15 S	41 E	36 NE	1653			11.5	
8	Thicket Spring	458785	4049288	15 S	41 E	36 SW	1764			10.8	
9	Goldbelt Grade Spring	458649	4049402	15 S	41 E	36 SW	1751			10.9	
10	Goldbelt Spring	459775	4050256	15 S	42 E	30 SE	1478			12.8	
11	Covered Spring	483175	4028208	17 S	44 E	35 SW	1544	<1		12.3	
12	Wee Spring	483176	4028376	17 S	44 E	35 SW	1577			12.1	
13	Ed Spring	483195	4028661	17 S	44 E	35 NW	1540			12.3	
14	Burns Spring (Lower)	483209	4028058	18 S	44 E	2 NW	1545	2	14.5	12.3	2.2
15	Burns Spring (Upper)	483135	4027966	18 S	44 E	2 NW	1564	1	14.4	12.2	2.2
16	Emigrant Willow Spring	482729	4027930	18 S	44 E	3 NE	1582			12.0	
17	Chukar Spring	482794	4028254	17 S	44 E	34 SE	1507	3	16.9	12.6	4.3
18	Centennial Spring	482793	4028258	17 S	44 E	34 SE	1506	10	15.1	12.6	2.5
19	Canyon Spring A	482830	4028915	17 S	44 E	34 NE	1416	>1	11.2	13.2	-2.0
20	Canyon Spring B (Main)	482837	4028935	17 S	44 E	34 NE	1414	20	17	13.2	3.8
21	Emigrant Burro Spring	482950	4028963	18 S	44 E	35 NW	1421	1		13.2	
22	Tree Spring	482673	4031108	17 S	44 E	27 SE	1213			14.6	
23	Emigrant Spring (Upper)	482650	4031170	17 S	44 E	27 SE	1200	8	14.1	14.7	-0.6
24	Emigrant Spring (Lower)	482512	4032153	17 S	44 E	27 NE	1132	15	7.6	15.2	-7.6
25	Jayhawker Spring	480103	4032309	17 S	44 E	21 SW	1243	<1	9.2	14.4	-5.2
26	Bullfrog Spring	503283	4073565	13 S	45 E	unclear	1413			13.2	
27	Daylight Willow Spring	502927	4074076	13 S	45 E	15 NW	1423	4	12.1	13.2	-1.1
28	Hole in the Rock Spring (Old)	502315	4066455	14 S	46 E	16 NE	861			17.1	
29	Fire Spring	500529	4068158	14 S	46 E	8 SE	1110	2	13.6	15.3	-1.7
30	Corkscrew Spring	500010	4068201	14 S	46 E	8 SE	1245	2	23.2	14.4	8.8
31	Baccharis Bunch (Daylight Pass)	505093	4072032	13 S	45 E	23 SW	1335			13.8	
32	Bindle Spring	502553	4073523	13 S	45 SE	16 SW	1481			12.7	
33	Buck Spring #1	503101	4090073	11 S	45 E	29 NE	1622	3	10.4	11.8	-1.4
34	Cordwood	491581	4087885	11 S	44 E	31 NW	2156			8.0	-8.0
35	Brier Spring A	493028	4087889	11 S	44 E	31 NE	1940	75	11.2	9.5	1.7
36	Brier Spring B	493118	4088139	11 S	44 E	31 NE	1918			9.7	-9.7

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (°C)	Amb Air[2] Temperature (°C)	Spring–Amb Air[3] Temperature (°C)
37	Brier Spring C	493252	4088127	11 S	44 E	32 NW	1933	40	12.5	9.6	2.9
38	Brier Spring D	493318	4088228	11 S	44 E	32 NW	1932	5	7.6	9.6	-2.0
39	Cave Rock #1	499091	4080405	12 S	44 E	25 NE	1539	0	9.7	12.3	-2.6
40	Cave Rock #2	500282	4079999	12 S	44 E	25 NE	1479			12.8	
41	McDonald #1	496628	4084252	12 S	44 E	10 NE	1896			9.8	
42	McDonald #2	498439	4084279	12 S	44 E	11 SW	1666	0.5	10.7	11.5	-0.8
43	Wood Camp Potholes	500726	4091297	11 S	44 E	24 SE	1462	<1	8.2	12.9	-4.7
44	Buck Spring #2	502846	4089815	11 S	45 E	28 NE	1607	1	6.8	11.9	-5.1
45	Woodcamp Spring	500486	4091459	11 S	44 E	24 SE	1459	1	8.2	12.9	-4.7
46	Currie Wells	506602	4091506	11 S	45 E	22 NE	1365	7	15.2	13.6	1.6
47	Goldbar Well	507049	4088584	11 S	45 E	34 NE	1410			13.2	
48	Bebbia Potholes	499264	4062317	14 S	46 E	30 SE	537	0	20.6	19.4	1.2
49	Prospect Well	509058	4058140	29 N	1 E	32 SW	507			19.6	
50	Keane Wonder Spring Main	507094	4058698	15 S	46 E	1 SE	402	200	33.2	20.3	12.9
51	Keane Wonder Spring A	506555	4058949	15 S	46 E	1 SW	380	5	7.5	20.5	-13.0
52	Keane Wonder Spring b	506661	4058785	15 S	46 E	1 SW	338	<1		20.7	-20.7
53	Keane Wonder Spring c	506664	4058777	15 S	46 E	1 SE	334	1	17.9	20.8	-2.9
54	Keane Wonder Spring d	506658	4058766	15 S	46 E	1 SE	332	5	17	20.8	-3.8
55	Keane Wonder Spring E	506672	4058776	15 S	46 E	1 SE	336			20.8	
56	Keane Wonder Spring F	506678	4058770	15 S	46 E	1 SE	337			20.8	
57	Keane Wonder Spring G	506661	4058647	15 S	46 E	1 SE	315	<1	18.4	20.9	-2.5
58	Keane Wonder Spring H	506979	4058606	15 S	46 E	1 SE	347	6	25.9	20.7	5.2
59	Keane Wonder Spring I	507008	4058612	15 S	46 E	1 SE	353	3	20.1	20.6	-0.5
60	Keane Wonder Spring J	507192	4058393	15 S	46 E	1 SE	332	2	21.8	20.8	1.0
61	Keane Wonder Spring K	506960	4058184	15 S	46 E	1 SE	299	3	19.4	21.0	-1.6
62	Keane Wonder Spring L	506951	4058177	15 S	46 E	1 SE	298	2	21.5	21.0	0.5
63	Keane Wonder Spring M	506947	4058217	15 S	46 E	1 SE	299	1	21.2	21.0	0.2
64	Keane Wonder Spring N	506878	4058223	15 S	46 E	1 SE	289	1	18.8	21.1	-2.3
65	Keane Wonder Spring O	506874	4058237	15 S	46 E	1 SE	292	1	19.7	21.1	-1.4
66	Keane Wonder Seep A	506568	4058890	15 S	46 E	1 SW	372	<1	22.3	20.5	1.8
67	Keane Wonder Seep B	506654	4058817	15 S	46 E	1 SE	339	<1		20.7	
68	Keane Wonder Seep C	506693	4058809	15 S	46 E	1 SE	344	<1		20.7	
69	Keane Wonder Seep D	506707	4058790	15 S	46 E	1 SE	344	<1		20.7	
70	Keane Wonder Seep E	506745	4058762	15 S	46 E	1 SE	350	<1		20.7	
71	Keane Wonder Seep F	506693	4058737	15 S	46 E	1 SE	336	<1		20.8	
72	Keane Wonder Seep G	506764	4058562	15 S	46 E	1 SE	312	1		20.9	
73	Keane Wonder Seep H	507206	4058461	15 S	46 E	1 SE	344	1		20.7	

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.

[2] Ambient air temperature at spring outlet.

[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (°C)	Amb Air[2] Temperature (°C)	Spring–Amb Air[3] Temperature (°C)
74	Keane Wonder Seep I	506794	4058343	15 S	46 E	1 SE	289	<1		21.1	
75	Keane Wonder Seep J	506694	4058419	15 S	46 E	1 SE	314	<1		20.9	
76	Keane Wonder Seep K	506643	4058454	15 S	46 E	1 SE	320	1		20.9	
77	Keane Wonder Seep L	506593	4058445	15 S	46 E	1 SE	309	1	23.3	21.0	2.3
78	Keane Wonder Seep M	506558	4058417	15 S	46 E	1 SE	303	1		21.0	
79	Keane Wonder Seep N	506524	4058440	15 S	46 E	1 SE		1	20.1	23.1	-3.0
80	Keane Wonder Seep O	506493	4058459	15 S	46 E	1 SE	304	<1		21.0	
81	Keane Wonder Seep P	506472	4058464	15 S	46 E	1 SE	300	<1		21.0	
82	Keane Wonder Seep Q	506273	4058556	15 S	46 E	1 SE	285	<1		21.1	
83	Keane Wonder Seep R	506166	4058420	15 S	46 E	1 SE	274	<1		21.2	
84	Keane Wonder Well A	506563	4058887	15 S	46 E	1 SW	369	0.5	18.3	20.5	-2.2
85	Keane Wonder Well B	506616	4058828	15 S	46 E	1 SW	366		25.2	20.6	4.6
86	Keane Wonder Well C	506719	4058724	15 S	46 E	1 SE	338	<1	19.5	20.7	-1.2
87	Keane Wonder Well D	506956	4058579	15 S	46 E	1 SE	343		18.1	20.7	-2.6
88	Keane Wonder Well E	506968	4058603	15 S	46 E	1 SE	345		20.1	20.7	-0.6
89	Keane Wonder Well F	507005	4058599	15 S	46 E	1 SE	349		24.6	20.7	3.9
90	Keane Wonder Well G	507212	4058443	15 S	46 E	1 SE	342		24.6	20.7	3.9
91	Keane Seep	508882	4058028	29 N	1 E	32 SW	465	<1		19.9	
92	Keane Spring	508730	4066605	30 N	1 E	8 NW	1172	2	15.9	14.9	1.0
93	Hopeful Spring #1	508522	4066084	30 N	1 E	8 SW	1139	<1	7.9	15.1	-7.2
94	Hopeful Spring #2	508575	4066036	30 N	1 E	8 SW	1148			15.1	
95	Pump House Well	508299	4065921	30 N	1 E	7 SE	1116	<1	18.3	15.3	3.0
96	Jingle Seep	507806	4065080	30 N	1 E	18 NE	1086			15.5	
97	Rice's Pothole Spring	514781	4061150	30 N	1 E	26 SE	1361	<1	6.7	13.6	-6.9
98	Rice's Well	514704	4061132	30 N	1 E	26 SE	1378			13.5	
99	East of Chloride City Well B	511582	4061072	30 N	1 E	28 SE	1394			13.4	
100	Sedge Seep A	520965	4028563	26 N	2 E	9 NE	371			20.5	
101	Sedge Seep B	520956	4028541	26 N	2 E	9 NE	369			20.5	
102	Sedge Seep C	520912	4028428	26 N	2 E	9 NE	368			20.5	
103	Sedge Seep D	520834	4028368	26 N	2 E	9 NE	363			20.6	
104	Sedge Seep E	520865	4028220	26 N	2 E	9 NE	364	<1		20.6	
105	Navel Spring Again	525505	4026230	26 N	2 E	12 SW	595	3	9.6	18.9	-9.3
106	Warm Spring C	506111	3980246	22 S	47 E	5 NW	747	25	34.4	17.9	16.5
107	Warm Spring B	506110	3980234	22 S	47 E	5 NW	750	30	33.7	17.9	15.8
108	Warm Spring A	506303	3980186	22 S	47 E	5 NW	719	6	20.6	18.1	2.5
109	Anvil Spring	492350	3975425	21 S	45 E	23 NE	1258	5	17.7	14.3	3.4
110	Quail Spring	491220	3975050	21 S	45 E	12 SW	1501	>2	7.5	12.6	-5.1

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[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (°C)	Amb Air[2] Temperature (°C)	Spring–Amb Air[3] Temperature (°C)
111	Hatchet Spring	491476	3975694	21 S	45 E	14 SW	1386			13.4	
112	Greater View D	492131	3974612	21 S	45 E	23 SE	1307		9.8	14.0	-4.2
113	Greater View C	492094	3974573	21 S	45 E	23 SE	1316			13.9	
114	Greater View B	492091	3974561	21 S	45 E	23 SW	1314			13.9	
115	Greater View A	492087	3974532	21 S	45 E	23 SW	1312			13.9	
116	Russel Camp B	491986	3974370	21 S	45 E	23 SW	1325	4	14.9	13.8	1.1
117	Russel Camp A	491946	3974334	21 S	45 E	23 SW	1322	<1	9.4	13.9	-4.5
118	Greater View E	492214	3974654	21 S	45 E	23 SW	1292	1	13.8	14.1	-0.3
119	Jubilee	492835	3973913	21 S	45 E	26 NE	1218			14.6	
120	Mill Spring A	492020	3974727	21 S	45 E	23 SW	1333			13.8	
121	Mill Spring B	492111	3974676	21 S	45 E	23 SW	1313			13.9	
122	Grubstake	501322	3981363	22 S	46 E	35 SW	1043			15.8	
123	Anvil Willow	494646	3974020	21 S	46 E	30 NW	1061	3	6.6	15.7	-9.1
124	Unnamed Manly Peak Spring A	495439	3974134	21 S	46 E	29 SE	1059			15.7	
125	Five Mile Spring A	498202	3975354	21 S	46 E	29 NW	996			16.1	
126	Five Mile Spring b	498157	3975443	21 S	46 E	29 NW	984		10.2	16.2	-6.0
127	Five Mile Spring C	498192	3975523	21 S	46 E	27 NW	929	1	9.5	16.6	-7.1
128	Five Mile Spring D	498210	3975654	21 S	47 E	27 NW	911			16.7	
129	Little Spring	498285	3974542	21 S	46 E	27 SW	975	1	11.9	16.3	-4.4
130	Across from Little Spring	498125	3974783	21 S	46 E	27 SW	984			16.2	
131	Grapevine Ranch 001	464641	4097652	11 S	42 E	3 NW	643	6	19.9	18.6	1.3
132	Grapevine Ranch 002	464582	4097698	11 S	42 E	3 NW	644	12	16.6	18.6	-2.0
133	Grapevine Ranch 005	464591	4097941	11 S	42 E	3 NW	672	4	14.8	18.4	-3.6
134	Triangle Spring C	488089	4064399	14 S	45 E	19 NW	-15	0	17	23.2	-6.2
135	Triangle Spring A	487851	4064658	14 S	45 E	19 NW	-18			23.2	
136	Triangle Spring B	487887	4064631	14 S	45 E	19 NW	-18	0		23.2	
137	Triangle Spring D	488409	4064067	14 S	45 E	19 NW	-8	<1	13.2	23.2	-10.0
138	Stovepipe Palm	488794	4063665	14 S	45 E	19 SE	-8	1	12.3	23.2	-10.9
139	Tule Springs	510651	4010963	25 N	1 E	28 NW	-109	<1	24.7	23.9	0.8
140	Bennett's Well	512407	4002399	24 N	1 E	22 SW	-109		26.1	23.9	2.2
141	Gravel Well	513647	3993797	23 N	1 E	22 NE	-100			23.8	
142	Hawk Spring C	515519	3988634	22 N	1 E	1 NW	-109		16.6	23.9	-7.3
143	Hawk Spring A	515540	3988691	22 N	1 E	1 NW	-111	0	12.4	23.9	-11.5
144	Coyote Well	522991	3984600	22 N	2 E	15 SE	-107	>1	14	23.9	-9.9
145	Table Spring B	516325	4048625	28 N	1 E	1 NE	351	<1	12.3	20.7	-8.4
146	Table Spring A	516348	4048650	28 N	1 E	1 NE	355	<1	13.6	20.6	-7.0

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (ºC)	Amb Air[2] Temperature (ºC)	Spring–Amb Air[3] Temperature (ºC)
147	Table Spring C	516286	4048553	28 N	1 E	1 NE	334	<1	11.4	20.8	-9.4
148	Scraper Spring A	516709	4048051	28 N	2 E	6 SW	361			20.6	
149	Scraper Spring B	516813	4047812	28 N	2 E	6 SW	368	<1	12	20.5	-8.5
150	Scraper Spring C	516983	4047648	28 N	2 E	7 NW	354			20.6	
151	Scraper Spring D	517248	4047500	28 N	2 E	7 NW	378			20.5	
152	USGS Spring A	518335	4047804	28 N	2 E	6 SE	491	2	21	19.7	1.3
153	USGS Spring B	518301	4047711	28 N	2 E	6 SE	476			19.8	
154	Scraper (Upper)	517737	4047511	28 N	2 E	7 NW	430			20.1	
155	Scraper Spring I	517549	4047389	28 N	2 E	7 NW	397	<1	13.5	20.3	-6.8
156	Scraper Spring H	517519	4047401	28 N	2 E	7 NW	396			20.3	
157	Scraper Spring G	517510	4047409	28 N	2 E	7 NW	395	<1		20.3	
158	Scraper Spring F	517492	4047419	28 N	2 E	7 NW	396	<1		20.3	
159	Scraper Spring E	517449	4047449	28 N	2 E	7 NW	393			20.4	
160	Scraper (Lower)	517110	4047199	28 N	2 E	7 NW	353			20.6	
161	Lantern Seep A	465105	4093663	11 S	42 E	22 NW	563			19.2	
162	Lantern Spring A	465129	4093635	11 S	42 E	22 NW	562	0	14.2	19.2	-5.0
163	Lantern seeps B-I	465152	4093599	11 S	42 E	22 NW	560	<1		19.2	
164	Lantern Spring B	465214	4093524	11 S	42 E	22 NW	557	<1	14.5	19.2	-4.7
165	Virgin Spring A	537342	3978882	21 N	4 E	6 NE	704			18.2	
166	Virgin Spring B	537395	3978883	21 N	4 E	6 NE	696	1	12	18.2	-6.2
167	Rhodes Spring	542848	3976621	21 N	4 E	10 SE	554	1	17.4	19.2	-1.8
168	Rhodes well	542849	3976593	21 N	4 E	10 SE	552	1	19.6	19.3	0.4
169	Bradbury A	542890	3974833	21 N	4 E	15 SE	512			19.5	
170	Bradbury B	542856	3974841	21 N	4 E	15 SE	510			19.5	
171	Bradbury C	542823	3974846	21 N	4 E	15 SE	511			19.5	
172	Salsberry A	552496	3976479	21 N	5 E	10 SE	981	2	12.7	16.2	-3.5
173	Salsberry B	552500	3976389	21 N	5 E	10 SE	1003	1	8.9	16.1	7.2
174	Salsberry C	552463	3976387	21 N	5 E	10 SE	998	<1		16.1	
175	Salsberry D	552438	3976362	21 N	5 E	10 SE	1008	1	8.4	16.1	-7.7
176	Timpapah Spring	532371	3981021	22 N	3 E	27 SW	714	10	9.9	18.1	-8.2
177	Scotty's Spring	531789	3980799	22 N	3 E	34 NW	578	10	14.6	19.1	-4.5
178	Navel Seeps (Upper)	525505	4026230	26 N	2 E	13 SW	565	3	9.6	19.2	-9.6
179	Dune Salt Well	490700	4051100	15 S	45 E	32 NW	-38			23.4	
180	Bradbury well	542809	3974822	21 N	4 E	15 SE	513			19.5	
181	Owl Spring	501634	4071794	13 S	46 E	28 SW	1365	3	6.2	13.6	-7.4
182	Spider Spring B	513829	4033141	27 N	1 E	27 NE	15	<1	20.6	23.0	-2.4
183	Spider Spring C	513824	4033124	27 N	1 E	27 NE	17	<1	12.9	23.0	-10.1

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (ºC)	Amb Air[2] Temperature (ºC)	Spring–Amb Air[3] Temperature (ºC)
184	Spider Spring D	513804	4033114	27 N	1 E	27 NE	11	<1		23.0	
185	Spider Spring A	513784	4033160	27 N	1 E	27 NE	7	<1	17.9	23.1	-5.2
186	Gnome Spring 4A	512684	4038397	27 N	1 E	3 SE	-20	<1	12.6	23.3	-10.7
187	Gnome Spring 4B	512653	4038390	27 N	1 E	3 SE	-21	<1	11.9	23.3	-11.4
188	Gnome Spring 4C	512634	4038384	27 N	1 E	3 SE	-25	<1	12	23.3	-11.3
189	Gnome Spring 1	512370	4038459	27 N	1 E	3 SW	-40	<1	16.4	23.4	-7.0
190	Gnome Spring 2A	512406	4038416	27 N	1 E	3 SW	-43	<1	12.9	23.4	-10.5
191	Gnome Spring 2B	512397	4038422	27 N	1 E	3 SW	-45	<1	11.6	23.4	-11.8
192	Gnome Spring 3	512529	4038416	27 N	1 E	3 SE	-40	<1		23.4	
193	Gnome Spring 4D	512564	4038395	27 N	1 E	3 SE	-35	<1	12.1	23.4	-11.3
194	Gnome Spring 4E	512542	4038377	27 N	1 E	3 SE	-29	<1	13.1	23.3	-10.2
195	Gnome Spring 4F	512531	4038374	27 N	1 E	3 SE	-30	<1	22.2	23.3	-1.1
196	Gnome Spring 5B	512567	4038363	27 N	1 E	3 SE	-21	<1	16.4	23.3	-6.9
197	Gnome Spring 5A	512599	4038355	27 N	1 E	3 SE	-21	<1	16.6	23.3	-6.7
198	Gnome Spring 6	512547	4038330	27 N	1 E	3 SE	-21	<1	21.3	23.3	-2.0
199	Gnome Spring G	512482	4038361	27 N	1 E	3 SW	-38	<1	19.3	23.4	-4.1
200	Gnome Spring H	512432	4038362	27 N	1 E	3 SW	-39	<1	20.7	23.4	-2.7
201	Gnome Spring I	512360	4038360	27 N	1 E	3 SW	-49	1	20.8	23.5	-2.7
202	Gnome Spring J	512358	4038371	27 N	1 E	2 SW	-41	1	16.8	23.4	-6.6
203	Gnome Spring K	512337	4038399	27 N	1 E	1 SW	-43	1	17.5	23.4	-5.9
204	Gnome Spring L	512347	4038466	27 N	1 E	3 SE	-44	1	28.9	23.4	5.5
205	Gnome Spring M	512175	4038387	27 N	1 E	3 SW	-56	2	13.7	23.5	-9.8
206	Gnome Spring N	512089	4038375	27 N	1 E	3 SW	-55	1	17.5	23.5	-6.0
207	Gnome Spring O	511973	4038376	27 N	1 E	3 S	-59	<1	18.2	23.5	-5.3
208	Miller Spring	550140	3987986	22 N	3 E	11 NW	1010	<1	1.8	16.0	-14.2
209	Gnome North #1	512280	4038552	27 N	1 E	3 SW	-46	<1	17	23.4	-6.4
210	Gnome North #2	512283	4038517	27 N	1 E	3 SW	-46	1	15.4	23.4	-8.0
211	Lost Creek C	475793	4083773	43 E	12 S	23 NW	468	1	13.1	19.8	-6.7
212	Lost Creek B	475829	4083832	43 E	12 S	23 NW	478	2	16.9	19.8	-2.9
213	QA Spring	476451	4084154	43 E	12 S	23 NE	601	12	19.9	18.9	1.0
214	Forgotten Creek A	476530	4083882	43 E	12 S	23 NE	530	1	15.4	19.4	-4.0
215	Sheep Spring E	528297	3992733	22.5 N	3 E	20 NW	633	<1	18.3	18.7	-0.4
216	Sheep Spring A	529264	3992940	23 N	3 E	32 SE	749	<1	13.4	17.9	-4.5
217	Sheep Spring B	529233	3992922	23 N	3 E	32 SE	749			17.9	
218	Sheep Spring C	529024	3992870	23 N	3 E	32 SE	725			18.0	
219	Sheep Spring D	528691	3992844	23 N	3 E	32 SE	687			18.3	
220	Tinaja Baja	521223	4003349	24 N	2 E	21 NE	-114	<1	16.5	23.9	-7.4

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (ºC)	Amb Air[2] Temperature (ºC)	Spring–Amb Air[3] Temperature (ºC)
221	China Garden A	452249	4018901	19 S	41 E	4 NE	921	3	18	16.7	1.3
222	China Garden B	452242	4018874	19 S	41 E	4 NE	929	<1	17.4	16.6	0.8
223	China Garden Well	452229	4018872	19 S	41 E	4 NE	920	0	8.7	16.7	-8.0
224	Unnamed Darwin Hills	452631	4019237	19 S	41 E	3 NW	893	10	21.9	16.9	5.0
225	Telephone Spring	482313	4037312	17 S	44 E	3 SE	833			17.3	
226	Willow Spring B (Gold Valley)	527447	3989474	22.5 N	3 E	31 SE	717	12	15.1	18.1	-3.0
227	Willow Spring C (Gold Valley)	527331	3989568	22.5 N	3 E	31 SW	699	12	13.7	18.2	-4.5
228	Willow Spring A (Gold Valley)	527828	3989572	22.5 N	3 E	31 SE	747	2	11.8	17.9	-6.1
229	Brown Spring	534690	3992497	22.5 N	3 E	23 E	1589	1	15.6	12.0	3.6
230	Hidden Spring	535841	3992250	22.5 N	3 E	24 E	1423	4	11.2	13.2	-2.0
231	Pool Spring	536183	3992378	22.5 N	3 E	24 E	1403	<1	13.8	13.3	0.5
232	Badwater Potholes	520514	4012830	25 N	2 E	21 NW	-53			23.5	
233	Ram Spring	507219	3973711	21 N	1 E	19 NW	695	8	12.3	18.2	-5.9
234	Lost Spring	507841	3974023	21 N	1 E	19 NW	649	20	27	18.6	8.4
235	Anvil Mesquite Spring	508118	3977561	21 N	1 E	7 NW	468	<1	16.1	19.8	-3.7
236	Upper Talc Mine Spring	505443	3984053	22 S	46 E	24 NE	875	<1	10.1	17.0	-6.9
237	Lower Talc Mine Spring	505515	3984110	22 S	46 E	24 NE	849	1	14.1	17.2	-3.1
238	McLean Spring	498160	4051036	16 S	46 E	10 NE	-65	1	16.2	23.6	-7.4
239	Salt Creek	500306	4049594	16 S	46 E	10 NE	-85	12	10	23.7	-13.7
240	East Salt Spring A	509172	4044984	28 N	1 E	18 NE	-113	<1	21	23.9	-2.9
241	East Salt Spring B	509190	4044952	28 N	1 E	18 NE	-114	<1	24	23.9	0.1
242	East Salt Spring C	509205	4044950	28 N	1 E	18 NE	-110	<1		23.9	
243	East Salt Spring D	509197	4044928	28 N	1 E	18 NE	-108	1		23.9	
244	East Salt Spring E	509238	4044936	28 N	1 E	18 NE	-109	<1		23.9	
245	East Salt Spring F	509290	4044908	28 N	1 E	18 NE	-108	<1	20.6	23.9	-3.3
246	East Salt Spring G	509283	4044898	28 N	1 E	18 NE	-111	<1		23.9	
247	East Salt Spring H	509282	4044886	28 N	1 E	18 NE	-111	1	23.1	23.9	-0.8
248	East Salt Spring I	509283	4044873	28 N	1 E	18 NE	-107	<1	9.4	23.9	-14.5
249	East Salt Spring J	509315	4044863	28 N	1 E	18 NE	-107	<1		23.9	
250	East Salt Spring K	509343	4044850	28 N	1 E	18 NE	-106	<1		23.9	
251	East Salt Spring L	509351	4044836	28 N	1 E	18 NE	-107	<1		23.9	
252	East Salt Spring M	509352	4044817	28 N	1 E	18 NE	-106	<1		23.9	
253	East Salt Spring N	509380	4044807	28 N	1 E	18 NE	-106	<1	12.3	23.9	-11.6
254	East Salt Spring O	509378	4044778	28 N	1 E	18 NE	-107	<1		23.9	
255	East Salt Spring P	509394	4044776	28 N	1 E	18 NE	-108	<1	12.6	23.9	-11.3
256	East Salt Spring Q	509395	4044752	28 N	1 E	18 NE	-106	<1	13.9	23.9	-10.0
257	East Salt Spring R	509405	4044729	28 N	1 E	18 NE	-107	<1		23.9	

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[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (°C)	Amb Air[2] Temperature (°C)	Spring–Amb Air[3] Temperature (°C)
258	East Salt Spring S	509420	4044697	28 N	1 E	18 NE	-107	<1	13.4	23.9	-10.5
259	East Salt Spring T	509419	4044668	28 N	1 E	18 NE	-107	<1		23.9	
260	East Salt Spring U	509431	4044641	28 N	1 E	18 NE	-107	1	15	23.9	-8.9
261	East Salt Spring V	509468	4044622	28 N	1 E	18 NE	-108	<1		23.9	
262	East Salt Spring W	509451	4044568	28 N	1 E	18 SE	-106	<1	13.8	23.9	-10.1
263	East Salt Spring X	509468	4044551	28 N	1 E	18 SE	-107	<1		23.9	
264	East Salt Spring Y	509484	4044515	28 N	1 E	18 SE	-108	<1		23.9	
265	East Salt Spring Z	509479	4044483	28 N	1 E	18 SE	-108	<1		23.9	
266	East Salt Spring AA	509499	4044462	28 N	1 E	18 SE	-108	<1		23.9	
267	East Salt Spring BB	509515	4044416	28 N	1 E	18 SE	-107	<1	17	23.9	-6.9
268	East Salt Spring CC	509542	4044375	28 N	1 E	18 SE	-107	<1		23.9	
269	East Salt Spring DD	509584	4044337	28 N	1 E	18 SE	-107	<1		23.9	
270	East Salt Spring EE	509632	4044327	28 N	1 E	18 SE	-107	<1	19.8	23.9	-4.1
271	Buckboard Spring B	509949	4043765	28 N	1 E	21 SW	-108	<1	22.9	23.9	-1.0
272	Buckboard Spring C	510015	4043720	28 N	1 E	21 SW	-109	<1		23.9	
273	Buckboard Spring D	510036	4043704	28 N	1 E	21 SW	-109	0	21.9	23.9	-2.0
274	Buckboard Spring E	510063	4043700	28 N	1 E	21 SW	-109	<1	22.9	23.9	-1.0
275	Buckboard Spring F	510074	4043617	28 N	1 E	21 SW	-109	<1		23.9	
276	Buckboard Spring G	510081	4043558	28 N	1 E	21 SW	-110	<1		23.9	
277	Buckboard Spring H	510105	4043543	28 N	1 E	21 SW	-109	<1	19.7	23.9	-4.2
278	Buckboard Spring I	510082	4043513	28 N	1 E	21 SW	-109	<1		23.9	
279	Buckboard Spring J	510085	4043459	28 N	1 E	21 SW	-110	1		23.9	
280	Buckboard Spring K	510074	4043411	28 N	1 E	21 SW	-110	<1	22.2	23.9	-1.7
281	Buckboard Spring L	510099	4043367	28 N	1 E	21 SW	-109	1		23.9	
282	Buckboard Spring M	510102	4043332	28 N	1 E	21 SW	-108	<1		23.9	
283	Buckboard Spring N	510110	4043285	28 N	1 E	21 SW	-110	<1	19	23.9	-4.9
284	Buckboard Spring O	510129	4043248	28 N	1 E	21 SW	-110	<1		23.9	
285	Buckboard Spring P	510167	4043274	28 N	1 E	21 SW	-110	<1	18.2	23.9	-5.7
286	Buckboard Spring Q	510205	4043194	28 N	1 E	21 SW	-108	<1	12	23.9	-11.9
287	Buckboard Spring A	509876	4043886	28 N	1 E	21 SW	-108	<1	20.2	23.9	-3.7
288	Buckboard Spring R	510217	4043175	28 N	1 E	21 SW	-107	<1		23.9	
289	Buckboard Spring S	510246	4043150	28 N	1 E	21 SW	-107	<1	12.5	23.9	-11.4
290	Buckboard Spring T	510196	4043121	28 N	1 E	21 SW	-109	1	10.9	23.9	-13.0
291	Buckboard Spring U	510177	4043048	28 N	1 E	21 SW	-109	<1	12.5	23.9	-11.4
292	Buckboard Spring V	510163	4043009	28 N	1 E	21 SW	-109	<1		23.9	
293	Buckboard Spring W	510049	4042816	28 N	1 E	21 SW	-108	<1		23.9	
294	Buckboard Spring X	510085	4042834	28 N	1 E	21 SW	-109	1		23.9	

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (ºC)	Amb Air[2] Temperature (ºC)	Spring–Amb Air[3] Temperature (ºC)
295	Buckboard Spring Y	510120	4042787	28 N	1 E	21 SW	-108	<1	12.6	23.9	-11.3
296	Buckboard Spring Z	510053	4042676	28 N	1 E	21 SW	-109	<1		23.9	
297	Buckboard Spring AA	510114	4042583	28 N	1 E	21 SW	-107	1	13.4	23.9	-10.5
298	Buckboard Spring BB	510036	4042559	28 N	1 E	21 SW	-108	0	14.6	23.9	-9.3
299	Buckboard Spring CC	509986	4042536	28 N	1 E	21 SW	-109	<1		23.9	
300	Buckboard Spring DD	510051	4042499	28 N	1 E	21 SW	-108	<1		23.9	
301	Buckboard Spring EE	510066	4042424	28 N	1 E	21 SW	-108	<1		23.9	
302	Buckboard Spring FF	510049	4042350	28 N	1 E	21 SW	-108	1	13.9	23.9	-10.0
303	Buckboard Spring GG	510024	4042277	28 N	1 E	21 SW	-107	<1	17.6	23.9	-6.3
304	Buckboard Spring HH	509988	4042175	28 N	1 E	21 SW	-108	3	7.7	23.9	-16.2
305	Buckboard Spring II	510045	4042134	28 N	1 E	21 SW	-108	3	7.7	23.9	-16.2
306	Buckboard Spring JJ	510052	4042104	28 N	1 E	21 SW	-108	2	7.7	23.9	-16.2
307	Buckboard Spring KK	510094	4041983	28 N	1 E	21 SW	-108	3	9.8	23.9	-14.1
308	Buckboard Spring LL	510131	4041913	28 N	1 E	21 SW	-109	1		23.9	
309	Buckboard Spring MM	510150	4041841	28 N	1 E	21 SW	-106	3	10.4	23.9	-13.5
310	Buckboard Spring NN	510153	4041680	28 N	1 E	21 SW	-106	1	14.1	23.9	-9.8
311	Buckboard Spring OO	510154	4041579	28 N	1 E	21 SW	-107	3	14	23.9	-9.9
312	Buckboard Spring PP	510164	4041367	28 N	1 E	21 SW	-108	4	14	23.9	-9.9
313	White Tank Potholes	504716	3994482	21 S	47 E	37 N	567	0	9.6	19.1	-9.5
314	White Tanks	504297	3994776	21 S	47 E	18 SW	581	<1	13.9	19.0	-5.1
315	Benny Spring	503915	4005298	20 S	46 E	26 NE	495	<1	18.5	19.6	-1.1
316	Shootemup Spring	515253	4040451	28 N	1 E	36 SW	189	10	22.4	21.8	0.6
317	Bangbang Spring	515284	4040391	28 N	1 E	36 SW	192	3	19.7	21.8	-2.1
318	Annie Oakley Spring	515378	4040372	28 N	1 E	36 SW	202	10	30	21.7	8.3
319	Ratatatat Spring	515381	4040319	28 N	1 E	36 SW	198	12	23.7	21.7	2.0
320	Bighorn Seep A	516041	4040567	28 N	1 E	36 NW	247	<1		21.4	
321	Bighorn Seep B	516057	4040551	28 N	1 E	36 NW	247	2	16.5	21.4	-4.9
322	Bighorn Seep C	516102	4040505	28 N	1 E	36 NW	250	5	19.8	21.4	-1.6
323	Bighorn Seep D	516120	4040452	28 N	1 E	36 NW	250	2	17.9	21.4	-3.5
324	Bighorn Seep E	516108	4040409	28 N	1 E	36 NW	248	2	18.6	21.4	-2.8
325	Bighorn Seep F	516136	4040359	28 N	1 E	36 NW	254	1	15.9	21.3	-5.4
326	Surveyor's Well	486426	4066764	14 S	45 E	13 NW	-13	<1	18.1	23.2	-5.1
327	Stovepipe Airstrip Well	486026	4051301	15 S	44 E	36 SW	-31			23.3	
328	Stovepipe Well #1	486806	4050721	15 S	44 E	36 SE	0	20	29.9	23.1	6.8
329	Stovepipe Ranger Well #1	487256	4051512	15 S	44 E	36 NE	-36			23.4	
330	Stovepipe Ranger Well #2	487257	4051430	15 S	44 E	36 NE	-35			23.4	
331	Stovepipe Ranger Well #3	487307	4051355	15 S	44 E	36 SE	-35			23.4	

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (°C)	Amb Air[2] Temperature (°C)	Spring–Amb Air[3] Temperature (°C)
332	Badwater Spring #1	520973	4009658	25 N	2 E	33 NW	-113	<1	19.7	23.9	-4.2
333	Badwater Spring #3	520934	4009557	25 N	2 E	33 NW	-110	<1	17.4	23.9	-6.5
334	Badwater Spring #4	520931	4009550	25 N	2 E	33 NW	-112	<1	19	23.9	-4.9
335	Badwater Spring #5 (Main)	520927	4009536	25 N	2 E	33 NW	-112	1	18.1	23.9	-5.8
336	Main Hanaupah Spring #1	496997	4004324	20 S	46 E	19 NE	1238	25	11.4	14.4	-3.0
337	Main Hanaupah Spring #2	496930	4004586	20 S	46 E	19 NE	1248	15	15.8	14.4	1.4
338	Main Hanaupah Spring #4	497606	4004700	20 S	46 E	19 NE	1146			15.1	
339	South Hanaupah Spring #1	498020	4003901	20 S	46 E	20 SW	1213	4	16.6	14.6	2.0
340	South Hanaupah Spring #2 (Middle)	498022	4003976	20 S	46 E	20 NW	1180	12	16.4	14.9	1.5
341	South Hanaupah Spring #3 (Lower)	498073	4004284	20 S	46 E	20 NW	1129	15	13.4	15.2	-1.8
342	Overlook Seep	498641	4076078	13 S	46 E	8 NW	1458	<1	3.9	12.9	-9.0
343	Lostman Spring	497168	4070899	13 S	45.5 E	NONE	910	<1	14.2	16.7	-2.5
344	Fern (Upper)	498660	4072444	13 S	46 E	30 SW	1157	4	15.1	15.0	0.1
345	Badwater Spring #2	520953	4009572	25 N	2 E	33 NW	-113	<1	16.4	23.9	-7.5
346	Indian Map Well	481774	4058306	15 S	44 E	9 NW	-111			23.9	
347	Main Hanaupah Spring #3 (Middle)	497333	4004593	20 S	46 E	19 NE	1190	8	15.8	14.8	1.0
348	Fern (Lower)	498591	4072436	13 S	46 E	30 SW	1143	<1	18.8	15.1	3.7
349	Potlicker Seep	498548	4074915	13 S	46 E	8 SW	1301	1	14.7	14.0	0.7
350	Two Barrel Spring	497206	4075623	13 S	45.5 E	NONE	1543			12.3	
351	Leadfield Spring	495552	4078927	12.5 S	45 E	2 NW	1304	<1		14.0	
352	Upper Leadfield Spring	496489	4077005	13 S	45 E	NONE	1430	<1	15.7	13.1	2.6
353	Trigger	492674	4075080	13 S	45.5 E	NONE	1065	<1	13.6	15.7	-2.1
354	Poacher	492043	4075155	13 S	45.5 E	NONE	1008			16.1	
355	Unnamed Well A (Craig Canyon)	425835	4061534	14 S	38 E	27 NW	298	30	23.7	21.0	2.7
356	Klare Spring	491882	4077242	12.5 S	45 E	2 SW	911	10	22.8	16.7	6.1
357	Salt Well (Craig Canyon)	427046	4059776	14 S	38 E	35 NW	317	0		20.9	
358	Gervais Well	425687	4063263	14 S	38 E	22 NW	309	0		21.0	
359	Flowing Well	425992	4064960	14 S	38 E	15 NE	299	5	22.5	21.0	1.5
360	Artesian Well 4066600	426378	4066797	14 S	38 E	10 NE	301	5	21.3	21.0	0.3
361	Fat Tuesday (Unnamed Well)	427424	4068086	14 S	38 E	2 NE	309			21.0	
362	Unnamed Well C (Craig Canyon)	424171	4066478	14 S	38 E	9 NW	314		16.4	20.9	-4.5

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[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (ºC)	Amb Air[2] Temperature (ºC)	Spring–Amb Air[3] Temperature (ºC)
363	Unnamed Well D (Craig Canyon)	424362	4066577	14 S	38 E	9 NE	315			20.9	
364	Lower Warm Springs South Shelf Spring D	430896	4071509	13 S	39 E	30 NW	355	<1	11.9	20.6	-8.7
365	Lower Warm Springs South Shelf Spring I	431570	4071393	13 S	39 E	30 NE	352	<1	15.3	20.7	-5.4
366	Lower Warm Springs South Shelf Spring H	431433	4071238	13 S	39 E	30 NE	345	<1	18.1	20.7	-2.6
367	Lower Warm Springs South Shelf Spring G	431296	4071328	13 S	39 E	30 NE	349	<1	17.7	20.7	-3.0
368	Lower Warm Springs South Shelf Spring F	431072	4071383	13 S	39 E	30 NE	345	<1	17.9	20.7	-2.8
369	Lower Warm Springs South Shelf Spring E	431003	4071409	13 S	39 E	30 NE	351	<1	18.6	20.7	-2.1
370	Lower Warm Springs South Shelf C	430759	4071610	13 S	39 E	30 NW	354	<1	16	20.6	-4.6
371	Lower Warm Springs South Shelf B	430708	4071693	13 S	39 E	30 NW	355	<1	16.4	20.6	-4.2
372	Lower Warm Springs South Shelf Spring A	430622	4071703	13 S	39 E	30 NW	354	<1	19.4	20.6	-1.2
373	Greenleaf Spring A	498896	3991342	21 S	46 E	33 NE	1263	100	16	14.3	1.7
374	Greenleaf Spring B	498724	3991087	21 S	46 E	33 NE	1311	20	17	13.9	3.1
375	Greenleaf Spring C	498643	3991116	21 S	46 E	33 NE	1338	10	13.5	13.7	-0.2
376	Cloud Spring	497280	3990346	21 S	46 E	33 NW	1693	<1	12.7	11.3	1.4
377	High Dog Spring B	496970	3990987	21 S	46 E	32 SE	1635	12	14.5	11.7	2.8
378	High Dog Spring A	497002	3991023	21 S	46 E	32 SE	1629	20	15.1	11.7	3.4
379	Dog Spring	497725	3991398	21 S	46 E	32 NE	1456	200	16.6	12.9	3.7
380	Low Dog Spring	497929	3991405	21 S	46 E	33 NW	1428	8	15	13.1	1.9
381	Jack 17	449993	4042927	16 S	40 E	19 NW	1705	25	10.7	11.2	-0.5
382	Jack 20	449712	4043391	16 S	40 E	18 SW	1660	10	10.1	11.5	-1.4
383	Jack 19	449622	4043507	16 S	40 E	18 SW	1628	10	8.2	11.7	-3.5
384	Jack 18	449631	4043509	16 S	40 E	18 NE	1625	5	7.4	11.7	-4.3
385	Jack A	449512	4043570	16 S	40 E	18 NW	1605	3	17.2	11.9	5.3
386	Jack 29	449182	4044307	16 S	40 E	18 NW	1513		12.5		
387	Jack 42	448128	4047039	16 S	40 E	1 SW	1310	1	12.5	13.9	-1.4
388	Jack 46	450093	4047476	16 S	40 E	6 SW	1434		13.1		
389	Jack 45	449690	4047430	16 S	40 E	1 SW	1404	2.5	15.6	13.3	2.3

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[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (°C)	Amb Air[2] Temperature (°C)	Spring–Amb Air[3] Temperature (°C)
390	Jack 43	447150	4046696	16 S	40 E	14 NW	1196	3	15.6	14.7	0.9
391	Jack 32	447924	4046065	16 S	40 E	2 NE	1299	1.5	11.2	14.0	-2.8
392	Jack 33	447913	4046030	16 S	40 E	1 NW	1299	1.5	13.5	14.0	-0.5
393	Jack 35	449107	4045708	16 S	40 E	11 NW	1452	7	12.8	13.0	-0.2
394	Arrow Spring	471752	4040235	16 S	43 E	28 SE	1070	<1		15.6	
395	Scout Spring (West)	496106	4077685	13 S	45.5 E	NE	1445	5	12.7	13.0	-0.3
396	Scout Spring (Upper East)	496297	4077664	13 S	45.5 E	NE	1611			11.8	
397	Scout Spring (Lower East)	496179	4077592	13 S	45.5 E	NE	1507	2	17.3	12.6	4.7
398	Butterfly Spring	495711	4076518	13 S	45.5 E	NE	1422	40	13	13.2	-0.2
399	Shotgun Spring A	498318	4012650	19 S	46 E	29 NW	1196	100	16	14.7	1.3
400	Shotgun Spring B	498409	4012707	19 S	46 E	29 NW	1132	25		15.2	
401	Uppermost Spring	496412	4012068	19 S	46 E	30 SW	1718	50	13.6	11.1	2.5
402	Pistol Spring	496607	4012059	19 S	46 E	30 SW	1548	6	14.4	12.3	2.1
403	Mossy Spring	498780	4012639	19 S	46 E	29 NE	1068	7	19	15.6	3.4
404	Second Spring	499051	4012438	19 S	46 E	29 NE	1023	2	16.9	16.0	0.9
405	Machette Spring	499409	4012274	19 S	46 E	28 NW	950	75	15.6	16.5	-0.9
406	Tule George Spring A	494334	4088497	11 S	44 E	32 NE	1869	<1	9.3	10.0	-0.7
407	Tule George Spring B	494410	4088525	11 S	44 E	32 NE	1868	1	13.2	10.0	3.2
408	Bonnie Claire Seep	481143	4096743	10 S	43 E	36 SW	1669	1	8.8	11.4	-2.6
409	Tule George Spring C	494466	4088518	11 S	44 E	32 NE	1852	8	12.5	10.2	2.4
410	Larkspur Spring	493901	4087891	11 S	44 E	32 NE	1979	2	8.5	9.3	-0.8
411	Little Willow	493987	4088547	11 S	44 E	32 NE	1946			9.5	
412	Knoll Spring	494372	4088815	11 S	44 E	29 SE	1885			9.9	
413	Black Spot Spring	492439	4089115	11 S	44 E	30 SE	2007	4	9.7	9.1	0.6
414	Cow Creek Urban Spring A	511960	4039770	28 N	1 E	34 SW	-53			23.5	
415	Koramatsu Spring	512612	4039935	28 N	1 E	34 SE	11	1	18.2	23.0	-4.8
416	Cow Creek Urban Spring B	512128	4039875	28 N	1 E	34 SW	-35	1		23.4	
417	Cow Creek Urban Spring C	512063	4039899	28 N	1 E	34 SW	-26	15	24.5	23.3	1.2
418	Cow Creek Urban Spring D	511958	4039946	28 N	1 E	34 SW	-38	<1		23.4	
419	Cow Creek Urban Spring E	511933	4040045	28 N	1 E	34 SW	-42	<1		23.4	
420	Cow Creek Urban Spring F	511988	4040149	28 N	1 E	34 SW	-36	2	23.6	23.4	0.2
421	Cow Creek Urban Spring G	511847	4040290	28 N	1 E	34 SW	-37	1	23.4	23.4	0.0
422	Cow Creek Urban Spring H	511850	4040328	28 N	1 E	34 SW	-39	<1	21.1	23.4	-2.3
423	Cow Creek Urban Spring I	511830	4040443	28 N	1 E	34 SW	-37	<1	19.1	23.4	-4.3
424	Winter Spring	501216	3991796	21 S	46 E	25 SW	1132	2	18.9	15.2	3.7
425	Saline Valley Marsh	426533	4062309	14 S	38 E	22 SE	294		15.3	21.1	-5.8
426	Jack 41	449730	4047169	16 S	40 E	12 NW	1403	2	12.4	13.3	-0.9

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (°C)	Amb Air[2] Temperature (°C)	Spring–Amb Air[3] Temperature (°C)
427	East Chloride City Well A	514150	4060725	30 N	1 E	26 SW	1540			12.3	
428	Jack 02	452506	4039708	16 S	41 E	32 NE	1291	2	15.6	14.1	1.5
429	Mill Canyon Spring	452644	4039911	16 S	41 E	33 NW	1287	200	12	14.1	-2.1
430	Jack 06	453488	4041023	16 S	41 E	28 NE	1458	1	9.2	12.9	-3.7
431	Jack 05	453831	4040911	16 S	41 E	28 SE	1435	2	15.9	13.1	2.8
432	Jack 14	454581	4042120	16 S	41 E	26 SW	1640	8	10.8	11.6	-0.8
433	Keir Spring	454417	4041761	16 S	41 E	27 SE	1546	15	15.2	12.3	2.9
434	Jack 12	454300	4041516	16 S	41 E	27 SE	1501	1	16.1	12.6	3.5
435	Jack 13	454341	4041286	16 S	41 E	27 SW	1473	35	17.2	12.8	4.4
436	Mill Cottonwood	454115	4040908	16 S	41 E	27 SW	1375	30	18	13.5	4.5
437	Jack 04	454325	4040664	16 S	41 E	34 NW	1380	<1	10.1	13.5	-3.4
438	Shannon Spring	454019	4040276	16 S	41 E	34 NW	1286	18	18.5	14.1	4.4
439	Jack 03	455004	4040383	16 S	41 E	34 NW	1377	<1	14.6	13.5	1.1
440	Heinz Spring	454073	4040086	16 S	41 E	34 NW	1257	<1	14.5	14.3	0.2
441	Mendoza Spring	452126	4041125	16 S	41 E	29 SE	1435	3	14.8	13.1	1.7
442	Jack 07	452395	4040680	16 S	41 E	29 SE	1384	<1	11.6	13.4	-1.8
443	Jack 08	452468	4040190	16 S	41 E	32 NE	1321	12	15.9	13.9	2.0
444	Jack 09	450783	4040466	16 S	41 E	29 SW	1509	<1	13.5	12.6	0.9
445	Jack 10	450685	4040589	16 S	41 E	30 SE	1530	<1	13.6	12.4	1.2
446	Jack 11	450264	4040814	16 S	41 E	30 SE	1660	<1	12	11.5	0.5
447	Jaybird Spring	489050	4091789	11 S	43 E	15 NW	2020	40	7.7	9.0	-1.3
448	Pine Spring	489754	4090893	11 S	43 E	15 SE	2068	2	7.9	8.6	-0.7
449	Log Spring	490423	4091934	11 S	43 E	13 SW	1924	18	12	9.6	2.4
450	C-B Spring	491020	4091846	11 S	43 E	14 NE	2000			9.1	
451	Wildhorse Spring	490255	4011248	19 S	45 E	26 SE	1875			10.0	
452	Malapi Spring a	482310	4028483	18 S	44 E	3 NE	1520			12.5	
453	Malapi Spring b	482441	4028572	18 S	44 E	3 NE	1494	2	9.6	12.7	-3.1
454	Malapi Spring c	482493	4028670	18 S	44 E	3 NE	1477	4	13.2	12.8	0.4
455	Malapi Spring d	482527	4028735	18 S	44 E	3 NE	1441	15	10.1	13.0	-2.9
456	Daylight Pass Spring	505619	4071470	13 S	45 E	35 NE	1329	2	12.6	13.8	-1.2
457	Staininger Spring	471230	4098555	11 S	43 E	5 SE	968	>1000	19.7	16.3	3.4
458	Surprise Spring NPS	469461	4095004	11 S	43 E	18 SE	836	>150	25.7	17.3	8.4
459	Red Rock Spring	461118	4070316	13 S	42 E	29 SW	1932	<1	12.2	9.6	2.6
460	Wagon Spring	461383	4069082	13 S	42 E	32 NE	1831			10.3	
461	Rye Grass Spring	460770	4068846	13 S	42 E	32 NW	1920			9.7	
462	Wildrose (Station) Spring	480884	4013002	19 S	44 E	21 SE	1071			15.6	
463	Mud Spring	480459	4014374	19 S	44 E	16 SW	1202	<1	16.1	14.7	1.4

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (°C)	Amb Air[2] Temperature (°C)	Spring–Amb Air[3] Temperature (°C)
464	Roadside Spring	482317	4013265	19 S	44 E	20 SE	1168	100	18.9	14.9	4.0
465	Poplar Spring (b)	482634	4013400	19 S	44 E	20 SE	1198	1	16.7	14.7	2.0
466	Poplar Spring (a)	482639	4013422	19 S	44 E	20 SE	1224	60	20.2	14.5	5.7
467	Thorndike Spring	493295	4009948	19 S	45 E	35 SW	2305	4	6.5	7.0	-0.5
468	Greenwater Spring	533820	4000814	23 N	3 E	12 NE	1516			12.5	
469	Young Spring	529035	4015659	25 N	3 E	20 SW	902			16.8	
470	Navel Spring	525463	4026217	26 N	2 E	13 SW	582	>1	17.6	19.0	-1.4
471	Salty Navel Spring	524956	4026424	26 N	2 E	13 SW	544	1	17	19.3	-2.3
472	Fossil Spring	523905	4026259	26 N	2 E	13 SW	466	<1	16.7	19.9	-3.2
473	West Twin Spring	489565	4043931	16 S	45 E	30 NE	1240	2	16	14.4	1.6
474	Tucki Spring	489581	4044113	16 S	45 E	30 NE	1138			15.1	
475	Gypsum	489593	4044250	16 S	45 E	30 NE	1077	<1	12.8	15.6	-2.8
476	Monarch Spring	506929	4064024	14 S	46 E	24 SE	871	5	14.9	17.0	-2.1
477	Bed Spring b	507378	4064669	14 S	46 E	24 SE	952	>5	17.4	16.5	0.9
478	Unnamed East Tin Spring	472260	4088494	12 S	43 E	5 NE	540			19.3	
479	Shrike Spring	473186	4087811	12 S	43 E	4 SE	540	5	19.6	19.3	0.3
480	Whisker Spring	x	x	11 S	43 E	16 SW	857			17.1	
481	Bee Seep	472208	4093915	11 S	43 E	20 NW	849			17.2	
482	Mortar Spring	472076	4094186	11 S	43 E	17 SE	877	4	15.1	17.0	-1.9
483	Bushy Seep (Upper)	471489	4091802	11 S	43 E	31 NE	695			18.2	
484	Bushy Seep (Lower)	470461	4090575	11 S	43 E	31 NE	615			18.8	
485	Unnamed LCM 005	443668	4125438	8 S	40 S	18 NW	1336	<1	10.2	13.8	-3.6
486	Last Chance Springs A	440921	4126114	8 S	39 E	2 SE	1743	10	13.4	10.9	2.5
487	Last Chance Springs B	441002	4126165	8 S	39 E	2 SE	1748			10.9	-10.9
488	Last Chance Springs C	411052	4126186	8 S	39 E	2 SE	1767			10.7	-10.7
489	Last Chance Springs F	441059	4126221	8 S	39 E	2 SE	1747	2	0.8	10.9	-10.1
490	Last Chance Springs E	441056	4126208	8 S	39 E	2 SE	1746	<1		10.9	
491	Last Chance Springs D	441059	4126199	8 S	39 E	2 SE	1746	2	11	10.9	0.1
492	Last Chance Springs G	441080	4126211	8 S	39 E	2 SE	1739	<1	12.5	10.9	1.6
493	Last Chance Springs H	441143	4126202	8 S	39 E	2 SE	1719	2	13.6	11.1	2.5
494	Last Chance Springs I	441170	4126169	8 S	39 E	2 SE	1706	2	15.3	11.2	4.1
495	Last Chance Springs J	441180	4126192	8 S	39 E	2 SE	1717	<1	14.1	11.1	3.0
496	Last Chance Springs K	441205	4126190	8 S	39 E	2 SE	1714			11.1	
497	Last Chance Springs L	441265	4126224	8 S	39 E	2 SE	1716		8.4	11.1	-2.7
498	Last Chance Springs M	441226	4126108	8 S	39 E	2 SE	1680	2	13.5	11.4	2.1
499	Last Chance Springs T	441668	4126025	8 S	39 E	2 SE	1617	10	10.9	11.8	-0.9
500	Last Chance Springs S	441481	4126057	8 S	39 E	2 SE	1654	5	11	11.5	-0.5

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.

[2] Ambient air temperature at spring outlet.

[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (ºC)	Amb Air[2] Temperature (ºC)	Spring–Amb Air[3] Temperature (ºC)
501	Last Chance Springs R	441449	4126023	8 S	39 E	2 SE	1645	1		11.6	
502	Last Chance Springs Q	441426	4126061	8 S	39 E	2 SE	1663	1	12.4	11.5	0.9
503	Last Chance Springs P	441404	4126048	8 S	39 E	2 SE	1663	20	15.4	11.5	3.9
504	Last Chance Springs O	441390	4126055	8 S	39 E	2 SE	1666	20	14.5	11.5	3.0
505	Last Chance Springs N	441358	4126065	8 S	39 E	2 SE	1668	10		11.4	
506	Unnamed LCM 003	441224	4125695	8 S	39 E	2 SW	1713	7	15.9	11.1	4.8
507	Unnamed LCM 004	441748	4125560	8 S	39 E	2 SW	1586	6	11.9	12.0	-0.1
508	Unnamed Sand Seep b	450394	4116201	9 S	41 E	7 SE	931		10	16.6	-6.6
509	Unnamed Sand Seep a	450324	4116283	9 S	41 E	7 SW	932			16.6	
510	Unnamed Sand Seep c	450495	4116024	9 S	41 E	7 SE	922			16.7	
511	Unnamed Sand Seep d	450459	4115962	9 S	41 E	7 SE	917			16.7	
512	Unnamed Sand Seep e	450587	4115892	9 S	41 E	7 SE	917			16.7	
513	Sand Spring a	450802	4115930	9 S	41 E	7 SE	929	3	16.5	16.6	-0.1
514	Sand Spring b	450854	4115935	9 S	41 E	7 SE	926	2	15.2	16.6	-1.4
515	Sand Spring c	450919	4115885	9 S	41 E	7 SE	926	40	9.7	16.6	-6.9
516	Little Sand Spring a	452108	4114205	9 S	41 E	17 SE	890	3	16.7	16.9	-0.2
517	Little Sand Spring b	452215	4114117	9 S	41 E	17 SE	887	1	15.3	16.9	-1.6
518	Scotty's Cottonwood	468986	4096542	11 S	42 E	12 SW	800	12	26	17.5	8.5
519	Gargoyle Spring	469790	4096445	11 S	43 E	7 SE	898	2	10.9	16.8	-5.9
520	Surprise Springs a	469325	4095153	11 S	43 E	18 NW	829			17.3	
521	Surprise Springs b	469314	4095138	11 S	43 E	18 NW	826	3.5	18.9	17.3	1.6
522	Surprise Springs c	469305	4095137	11 S	43 E	18 NW	823			17.4	
523	Surprise Springs d	469313	4095124	11 S	43 E	18 NW	825	1	12	17.3	-5.3
524	Surprise Springs e	469316	4095098	11 S	43 E	18 NW	820			17.4	
525	Surprise Springs f	469316	4095087	11 S	43 E	18 NW	820	<1	7.8	17.4	-9.6
526	Surprise Springs g	469313	4095072	11 S	43 E	18 NW	817			17.4	
527	Surprise Springs h	469298	4095035	11 S	43 E	18 NW	805	2	17.9	17.5	0.4
528	Traderat	467602	4094285	11 S	42 E	24 NW	648	<1	11.9	18.6	-6.7
529	Unnamed Harris Hill Spring	460681	4055745	15 S	42 E	6 SW	1317			13.9	
530	Single Tree Spring	461127	4050399	15 S	42 E	29 SW	1373			13.5	
531	Fry Pan Spring	460679	4050057	15 S	42 E	29 SW	1420			13.2	
532	Burro Slide Spring	460196	4050215	15 S	42 E	29 SE	1483	1	7.5	12.7	-5.2
533	Grapevine Ranch Spring o	464644	4097647	11 S	42 E	3 NW	638	10	20	18.6	1.4
534	Grapevine Ranch Spring n	464590	4097702	11 S	42 E	3 NW	636	<100	16.2	18.7	-2.5
535	Grapevine Ranch Spring m	464581	4097698	11 S	42 E	3 NW	636	100	16.9	18.7	-1.8
536	Grapevine Ranch Spring l	464603	4097793	11 S	42 E	3 NW	640	100	17.6	18.6	-1.0
537	Grapevine Ranch Spring j	464591	4097950	11 S	42 E	3 NW	567	5	16.6	19.1	-2.5

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (ºC)	Amb Air[2] Temperature (ºC)	Spring–Amb Air[3] Temperature (ºC)
538	Grapevine Ranch Spring k	464608	4097957	11 S	42 E	3 NW	668	60	16.6	18.4	-1.8
539	Grapevine Ranch Spring i	464574	4097988	11 S	42 E	3 NW	661	60	17.3	18.5	-1.2
540	Grapevine Ranch Spring g	464507	4097901	11 S	42 E	3 NW	654	60	7.2	18.5	-11.3
541	Grapevine Ranch Seep o	464557	4098090	11 S	42 E	3 NW	664	<1		18.5	
542	Grapevine Ranch Seep m	464551	4098096	11 S	42 E	3 NW	665	<1		18.5	
543	Grapevine Ranch Spring h	464542	4098103	11 S	42 E	3 NW	664	2	14.4	18.5	-4.1
544	Grapevine Ranch Seep l	464535	4098109	11 S	42 E	3 NW	661	<1		18.5	
545	Grapevine Ranch Seep i	464531	4098110	11 S	42 E	3 NW	664	1		18.5	
546	Grapevine Ranch Seep k	464547	4098121	11 S	42 E	3 NW	674	<1		18.4	
547	Grapevine Ranch Seep n	464569	4098109	11 S	42 E	3 NW	674	<1		18.4	
548	Grapevine Ranch Seep p	x	x	11 S	42 E	3 NW	674	<1		18.4	
549	Grapevine Ranch Seep j	464568	4098134	11 S	42 E	3 NW	680	<1		18.4	
550	Grapevine Ranch Spring f	464542	4098142	11 S	42 E	3 NW	678	<1	13.6	18.4	-4.8
551	Grapevine Ranch Spring e	464533	4098170	11 S	42 E	3 NW	679	1	14.9	18.4	-3.5
552	Grapevine Ranch Seep h	464505	4098179	11 S	42 E	3 NW	678	<1		18.4	
553	Grapevine Ranch Spring d	464468	4098175	11 S	42 E	3 NW	671	>10	20	18.4	1.6
554	Grapevine Ranch Seep f	464440	4098190	11 S	42 E	3 NW	674			18.4	
555	Grapevine Ranch Spring C	464457	4098194	11 S	42 E	3 NW	679	2	16.3	18.4	-2.1
556	Grapevine Ranch Seep g	464444	4098208	11 S	42 E	3 NW	682	<1		18.3	
557	Grapevine Ranch Seep e	464434	4098216	11 S	42 E	3 NW	683	<1		18.3	
558	Grapevine Ranch Seep D	464419	4098224	11 S	42 E	3 NW	683	<1		18.3	
559	Grapevine Ranch Seep C	464405	4098240	11 S	42 E	3 NW	681	<1		18.3	
560	Grapevine Ranch Seep B	464382	4098273	11 S	42 E	3 NW	681	<1		18.3	
561	Grapevine Ranch Spring A	464364	4098346	11 S	42 E	3 NW	683	1.5	9.6	18.3	-8.7
562	Grapevine Ranch Spring b	464391	4098439	11 S	42 E	3 NW	699			18.2	
563	Grapevine Ranch Seep A	464446	4098388	11 S	42 E	3 NW	702			18.2	
564	Triangle Spring B	488101	4064404	14 S	45 E	19 NW	-16	<1		23.2	
565	Triangle Seep	487887	4064631	14 S	45 E	19 NW	-19	<1		23.2	
566	Triangle Spring A	487856	4064650	14 S	45 E	19 NW	-18			23.2	
567	Shorty's Well	510747	4009089	25 N	1 E	33 SW	-106			23.9	
568	Eagle Borax Works Well	511957	4006225	20 S	1 E	9 NE	-112	<1	20.2	23.9	-3.7
569	Eagle Borax Works Spring	511988	4006211	20 S	1 E	9 NE	-111		22.2	23.9	-1.7
570	Sowbelly Well	511939	4006098	25 N	1 E	9 SE	-112			23.9	
571	Salisbury Spring	514060	3997227	23 N	1 E	2 SW	-107			23.9	
572	Mesquite Well a	514161	3995457	23 N	1 E	14 NW	-106			23.9	
573	Unnamed Mormon Point Spring	515036	3992195	23 N	1 E	23 NE	-108	1	12.9	23.9	-11.0

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[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (ºC)	Amb Air[2] Temperature (ºC)	Spring–Amb Air[3] Temperature (ºC)
574	Lone Hawk Spring	515368	3989035	22 N	1 E	1 NW	-109	1	13.9	23.9	-10.0
575	Hawk Spring b	515634	3988587	22 N	1 E	1 NE	-110	1	12.8	23.9	-11.1
576	Salt Well (Mormon Point)	515411	3987288	22 N	1 E	12 NW	-113			23.9	
577	Bicentennial Spring	522240	3987145	22 N	2 E	3 SW	-111	1	14.5	23.9	-9.4
578	Wheelbarrow Spring	465402	4093218	11 S	42 E	16 NE	528	1	21.6	19.4	2.2
579	Wheelbarrow Seep	465431	4093154	11 S	42 E	16 NE	550			19.3	
580	Horsefly Spring (a)	465467	4093079	11 S	42 E	16 NE	549	1	17.3	19.3	-2.0
581	Horsefly Spring (b)	465478	4093066	11 S	42 E	16 NE	554	1	14.9	19.2	-4.3
582	Ashford Well	530986	3972772	21 N	3 E	28 NE	-21			23.3	
583	Confidence Mill Well	539415	3966265	20 N	4 E	9 NW	-29			23.3	
584	Blister Well	542795	3953225	19 N	4 E	21 SW	13			23.0	
585	Superior Mine Tank B	555336	3952592	19 N	5 E	25 NW	116	1		22.3	
586	Ibex Spring #1	553298	3958899	19 N	5 E	2 NE	317	<1		20.9	
587	Ibex Spring #2	553269	3958866	19 N	5 E	2 NE	315			20.9	
588	BlackJack Spring (a)	465979	4092270	11 S	42 E	15 SW	560	<1		19.2	
589	BlackJack Spring (b)	465991	4092255	11 S	42 E	15 SW	553	<1		19.2	
590	BlackJack Spring (c)	466019	4092212	11 S	42 E	15 SW	561	<1		19.2	
591	BlackJack Spring (d)	466021	4092194	11 S	42 E	15 SW	560			19.2	
592	BlackJack Spring (e)	466026	4092186	11 S	42 E	15 SW	557			19.2	
593	BlackJack Spring (f)	466028	4092181	11 S	42 E	15 SW	561			19.2	
594	BlackJack Spring (g)	466031	4092166	11 S	42 E	15 SW	554			19.2	
595	BlackJack Spring (h)	466026	4092146	11 S	42 E	15 SW	554	<1		19.2	
596	BlackJack Spring (i)	466032	4092132	11 S	42 E	15 SW	556			19.2	
597	BlackJack Spring (j)	466047	4092119	11 S	42 E	15 SW	556			19.2	
598	BlackJack Spring (k)	466060	4092106	11 S	42 E	15 SW	554			19.2	
599	BlackJack Spring (l)	466061	4092099	11 S	42 E	15 SW	552			19.3	
600	BlackJack Spring (m)	466066	4092085	11 S	42 E	15 SW	553			19.2	
601	BlackJack Spring (n) Main BJ	466081	4092058	11 S	42 E	1 SW	552	5	21	19.3	1.8
602	BlackJack Spring (o)	466084	4092017	11 S	42 E	15 SW	555			19.2	
603	BlackJack Spring (p)	466134	4091908	11 S	42 E	15 SW	548			19.3	
604	Hobo Spring (a)	466620	4091298	11 S	42 E	22 SW	518			19.5	
605	Mesquite Campground spring (a)	466926	4090906	11 S	42 E	26 SE	516			19.5	
606	Mesquite Campground spring (b)	467091	4090843	11 S	42 E	26 SE	541			19.3	
607	Mesquite Campground spring (d)	467332	4090894	11 S	42 E	26 SE	519			19.5	

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (°C)	Amb Air[2] Temperature (°C)	Spring–Amb Air[3] Temperature (°C)
608	Mesquite Campground spring (c)	467233	4090954	11 S	42 E	26 SE	519		22.6	19.5	3.1
609	Blackjack Annex a	466431	4092208	11 S	42 E	26 NE	560			19.2	
610	Blackjack Annex b	466384	4092174	11 S	42 E	26 NE	562			19.2	
611	Blackjack Annex c	466326	4092140	11 S	42 E	26 NE	562			19.2	
612	Blackjack Annex d	466257	4092103	11 S	42 E	26 NE	562			19.2	
613	Blackjack Annex e	466237	4092060	11 S	42 E	26 NE	556	1		19.2	
614	Grapevine Palm	467037	4095112	11 S	42 E	11 SE	650			18.6	
615	Grapevine Niblet	466204	4096224	11 S	42 E	11 NW	656			18.5	
616	Valley Spring	544525	3953058	19 N	4 E	24 SE	1			23.1	
617	Amargosa River	543746	3953712	19 N	4 E	24 NW	-6	>1000	8.6	23.2	-14.6
618	Montgomery Spring	549691	3978274	21 N	5 E	4 SW	1035	2	12	15.9	-3.9
619	Unnamed Salsberry Peak	550099	3978406	21 N	5 E	4 SW	983	<1		16.2	
620	Bed Spring a	507374	4064765	30 N	45 E	18 NW	942			16.5	
621	Salty Navel	525028	4026372	26 N	2 E	14 SW	552			19.3	
622	Triangle Spring c	488405	4064069	14 S	45 E	19 NW	-11	1	15.3	23.2	-7.9
623	Hobo Spring (b)	466698	4091200	11 S	42 E	22 SW	517			19.5	
624	Lost Creek B	475829	4083833	43 E	12 S	23 NW	484	5	15.9	19.7	-3.8
625	Lost Creek A	475857	4083898	43 E	12 S	23 NW	482	1	10.7	19.7	-9.0
626	Lost Creek C	475795	4083773	43 E	12 S	23 NW	488	2	14.5	19.7	-5.2
627	Trickling Spring A	476694	4083745	43 E	12 S	23 NE	579	1	17.3	19.1	-1.8
628	Trickling Spring B	476759	4083748	43 E	12 S	23 NE	558	1		19.2	
629	Trickling Spring C	476860	4083827	43 E	12 S	23 NE	570	2	13	19.1	-6.1
630	Forgotten Creek B	476417	4083748	43 E	12 S	23 NE	511	1	9.6	19.5	-9.9
631	Cow Springs	513324	4039554	27 N	1 E	3 NW	29	10	19.3	22.9	-3.6
632	Calf Spring b	512863	4039581	27 N	1 E	3 NW	29			22.9	
633	Calf Spring a	512960	4039530	27 N	1 E	3 NW	14	2	12.8	23.0	-10.2
634	Jacknife Spring	477670	4083629	12 S	43 E	24 SW	603	4	15.9	18.9	-3.0
635	Midway Well	487827	4066716	14 S	45 E	18 NW	-9	1	19	23.2	-4.2
636	Stovepipe Well 2	492884	4057052	15 S	46 E	15 NW	-44			23.4	
637	Tiger Beetle Creek	485785	4065512	14 S	45 E	14 SE	-20		11.6	23.3	-11.7
638	Ruiz Well	484906	4065238	14 S	45 E	14 SW	-15			23.2	
639	Unnamed Mesquite Flat Well	484845	4066604	14 S	45 E	14 NW	-14			23.2	
640	Moth Spring	515550	4050883	29 N	1 E	36 NW	346			20.7	
641	Maidenhair Spring	516364	4051323	29 N	1 E	25 SE	429	5	21.5	20.1	1.4
642	Poison Spring	517527	4051604	29 N	2 E	30 SE	553	5	12.9	19.2	-6.3
643	Point Spring	517717	4051452	29 N	2 E	30 SE	577	2	15.2	19.1	-3.9

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (°C)	Amb Air[2] Temperature (°C)	Spring–Amb Air[3] Temperature (°C)
644	Indian Pass Potholes Spring	518009	4051349	25 N	2 E	30 SE	603	2	14	18.9	-4.9
645	Petroglyph Spring	520060	4051323	29 N	2 E	29 SW	796			17.5	
646	Copperbell Spring	518531	4054542	29 N	46 E	17 SW	955			16.4	
647	Shanche Spring d	468216	4101933	10 S	42 E	25 NW	1110	3	9.7	15.3	-5.6
648	Shanche Spring c	468201	4101943	10 S	42 E	25 NW	1110	<1		15.3	
649	Shanche Spring b	468160	4101947	10 S	42 E	25 NW	1107	2	26.8	15.4	11.4
650	Shanche Spring a	467833	4101737	10 S	42 E	25 NW	1071	<1	15.8	15.6	0.2
651	Whisper Spring	504880	4000576	20 S	46 E	19 NE	420	<1	12.7	20.2	-7.5
652	Arsenic Spring	503861	4002979	20 S	46 E	35 SE	518	0		19.5	
653	Panamint Burro Spring	502329	4002461	20 S	46 E	28 NE	684	11	15.6	18.3	-2.7
654	Panamint Mule Spring	501639	4002327	20 S	46 E	28 NW	784	6	14.5	17.6	-3.1
655	Dry Trail Spring	493129	4017469	19 S	45 E	11 NW	1583			12.0	
656	Apron Spring	493581	4017809	19 S	45 E	2 SE	1523	4	6.3	12.5	-6.2
657	Tarantula Spring	493750	4018362	19 S	45 E	2 NW	1397	5	9.6	13.3	-3.7
658	High Noon Spring	493756	4018743	19 S	45 E	2 NW	1355	4	12.2	13.6	-1.4
659	Blue Cliff B	493377	4017083	19 S	45 E	11 NW	1718	15	1	11.1	-10.1
660	Blue Cliff A	493372	4017143	19 S	45 E	11 NW	1704	5	0.6	11.2	-10.6
661	Flicker Spring	496640	4008852	20 S	46 E	6 NW	1498	4	13.9	12.6	1.3
662	Noggin Spring	498868	4008219	20 S	46 E	5 SW	1273	10	15.3	14.2	1.1
663	Tin Can Spring	494601	4082442	12 S	44 E	27 NE	1556			12.2	
664	Epipactus Spring a	494650	4080510	12 S	44 E	34 SE	1378	1	19.8	13.5	6.3
665	Epipactus Spring b	494677	4080533	12 S	44 E	34 SE	1389	<1	18.4	13.4	5.0
666	Hohum Spring a	494095	4079267	12.5 S	44 E	3 NW	1173	2	13.7	14.9	-1.2
667	Hohum Spring b	494106	4079265	12.5 S	44 E	3 NW	1174	1	14.4	14.9	-0.5
668	Upper Warm Spring a	434242	4076549	13 S	39 E	9 NW	532	1	16.2	19.4	-3.2
669	Upper Warm Spring b	434201	4076532	13 S	39 E	9 NW	532	>2	42.1	19.4	22.7
670	Upper Warm Mesquite Spring	434025	4076647	13 S	39 E	4 SW	528	1	15.7	19.4	-3.7
671	Travertine Seep	433812	4076680	18 S	39 E	5 SE	531			19.4	
672	Unnamed West of Teakettle Junction	433484	4076750	18 S	39 E	5 SE	531	1	16.2	19.4	-3.2
673	Stone Spring	432965	4076809	18 S	39 E	5 SE	531	3	18.3	19.4	-1.1
674	Dry Stone Seep	432924	4076732	13 S	39 E	5 SE	520			19.5	
675	Doggie Spring	432758	4076597	18 S	39 E	5 SE	517	2	16.9	19.5	-2.6
676	Palm Spring	431692	4074419	18 S	13 E	18 NE	423	30	47.1	20.2	26.9
677	Lower Warm Springs D	431155	4073392	13 S	39 E	18 SE	394	2	34.6	20.4	14.2
678	Lower Warm Springs C	431124	4073474	13 S	39 E	18 SE	393	<1		20.4	
679	Lower Warm Springs A	431093	4073614	13 S	39 E	18 SE	396	4	18.3	20.3	-2.0

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[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (ºC)	Amb Air[2] Temperature (ºC)	Spring–Amb Air[3] Temperature (ºC)
680	Lower Warm Springs B	431038	4073601	13 S	39E	18 SE	395	30	42.6	20.3	22.3
681	Lemonade Spring	526036	4016585	25 N	2 E	1 SE	1141			15.1	
682	Ward Spring	524875	4019535	25.5 N	25 E	35 NE	1015	1	8.3	16.0	-7.7
683	Monument Canyon Spring	525348	4020288	25.5 N	2 E	26 SE	860	1	11.4	17.1	-5.7
684	Jack 35	448553	4045732	16 S	40 E	12 SE	1373			13.5	
685	SOSP 04 (Myers Ranch)	492509	3968651	20 N	45 E	11 NE	995	8	24.2	16.1	8.1
686	SOSP 03 (Meyers Ranch)	492515	3968604	20 N	45 E	11 NE	992	5	25.6	16.2	9.4
687	SOSP 02	492169	3968415	20 N	45 E	11 NE	970	1	7.6	16.3	-8.7
688	Sourdough Spring	491287	3968370	20 N	45 E	11 SW	919	2	16.9	16.7	0.2
689	Jacobs Spring	500025	3972128	21 N	46 E	34 NW	1033	5	14.9	15.9	-1.0
690	Nopah Spring	499638	3971825	21 N	46 E	34 NW	1105	4	12.6	15.4	-2.8
691	Nopah Falls Spring	499463	3971863	21 N	46 E	34 NW	1172	1	11.7	14.9	-3.2
692	Needle Spring	499701	3972360	21 N	46 E	34 NW	1059	12	12.5	15.7	-3.2
693	Strummer Spring	499657	3972563	21 N	46 E	27 SW	1044			15.8	-15.8
694	Squaw Spring D	499107	3973768	21 N	46 E	28 NE	993	12	13.9	16.2	-2.3
695	Squaw Spring C	499152	3973974	21 N	46 E	28 NE	982	1	16.5	16.2	0.3
696	Squaw Spring B	499035	3974067	21 N	46 E	28 NE	976	3	14.8	16.3	-1.5
697	Squaw Spring A	499145	3974258	21 N	46 E	28 NE	919	12	14.2	16.7	-2.5
698	Arrastre Spring	497288	3985524	22 N	46 E	17 SE	1690	1		11.3	-11.3
699	Wilson Spring	499325	3993863	23 N	46 E	22 SW	1157	>40	13.4	15.0	-1.6
700	Fang Spring	497496	3994100	21 S	46 E	20 SW	1387	4	14.4	13.4	1.0
701	Hungry Bill Spring B	496802	3994206	21 S	46 E	20 SW	1491	50	17.1	12.7	4.4
702	Hungry Bills Spring A	496802	3994441	21 S	46 E	20 SW	1489	>50	17.6	12.7	4.9
703	Towhee Spring	496131	3995100	21 S	46 E	20 NW	1639	12	18	11.6	6.4
704	Mint Spring	497629	3994134	23 N	46 E	21 SW	1365	30	13.9	13.6	0.3
705	Jack 22	450693	4043534	13 S	34 E	18 SW	1738	7	7.9	10.9	-3.0
706	Jack 23	451104	4043969	13 S	34 E	17 SE	1800	<1	13.6	10.5	3.1
707	Lee Pump	451115	4043869	13 S	34 E	17 SE	1772	8	15.9 1	10.7	5.2
708	Jack 25	451225	4043524	13 S	34 E	17 SW	1794	5	10.9 1	10.6	0.3
709	Jack 28	450690	4044196	13 S	34 E	18 NE	1743	6	9.2	10.9	-1.7
710	Jack 21	449690	4044196	13 S	34 E	18 NW	1622	>1	11.5	11.8	-0.3
711	Jack 44	447913	4048187	13 S	35 E	1 NW	1103			15.4	
712	Jack 51	447714	4048473	13 S	35 E	1 NE	1045	1	12.2	15.8	-3.6
713	Jack 48	450078	4048335	13 S	34 E	6 NW	1337	2	11.7	13.8	-2.1
714	Little Dodd Spring	449115	4048413	13 S	35 E	1 NE	1229	2	14.5	14.5	0.0
715	Big Dodd Spring	448687	4049016	13 S	34 E	36 SE	1153	10	15.9	15.0	0.9
716	Jack 31	448166	4044365	13 S	35 E	13 NW	1541	1	20.4	12.3	8.1

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (ºC)	Amb Air[2] Temperature (ºC)	Spring–Amb Air[3] Temperature (ºC)
717	Jack 30	448267	4044848	13 S	35 E	13 NW	1447			13.0	
718	Jack 34	448386	4045493	13 S	35 E	12 NW	1358	1	13.7	13.6	0.1
719	Widow Spring	499863	3998404	21 S	46 E	3 NW	978	3	16.5	16.3	0.2
720	Lower Snake Spring	497521	3999404	21 S	46 E	5 SE	1266	>20	12.2	14.3	-2.1
721	Upper Snake Spring	498581	4000061	21 S	46 E	5 SE	1399	3	13.9	13.3	0.6
722	Phantom Spring	495927	4000478	21 S	46 E	31 NW	1557	>3	11.5	12.2	-0.7
723	Middle Snake Spring	496703	3999999	21 S	46 E	5 SE	1404	>3	14.3	13.3	1.0
724	Primrose Spring	496374	3999408	21 S	46 E	5 NW	1424	8	15.1	13.1	2.0
725	Road Runner Spring	497202	3999149	21 S	46 E	5 NE	1297	3	11.3	14.0	-2.7
726	Flores Ranch Spring	500522	3996699	21 S	46 E	15 NE	957	2	21	16.4	4.6
727	Quartzite Spring	503235	3998144	21 S	46 E	1 SE	754	<1	21.1	17.8	3.3
728	Mexican Camp Spring	497094	4086836	12 S	45 E	3 NE	1748			10.9	
729	Alkali Spring	493528	4086003	12 S	45 E	5 SE	2015	2	13.3	9.0	4.3
730	Wombat Spring	492848	4087277	12 S	43 E	31 SE	1982			9.2	
731	Ghost Spring	500521	3998184	21 S	46 E	10 NE	1056			15.7	
732	Windy Spring	498181	3999145	21 S	46 E	4 NW	1199	0	0	14.7	-14.7
733	Unnamed Monarch Canyon	507936	4064340	30 N	1 E	18 SW	1096	1	12.7	15.4	-2.7
734	SOSP 06	497305	3968782	20 N	46 E	8 NE	1146	2	20	15.1	4.9
735	SOSP 05	495158	3969356	20 N	46 E	6 SW	1143			15.1	-15.1
736	Birch Spring	490804	4005149	20 S	45 E	16 SE	2248	600	9.6	7.4	2.2
737	Mexican Spring	494878	4086780	12 S	45 E	3 NE	1907			9.8	
738	Drum Spring	500857	3987813	22 S	46 E	10 NE	1291			14.1	
739	Six Spring Canyon	499990	3989560	22 S	46 E	3 NW	1274			14.2	
740	Sidehill Spring	497656	3988913	22 S	46 E	4 SW	1609	>6	17.1	11.9	5.2
741	Jigger Spring	497526	3988624	22 S	46 E	5 SE	1682			11.3	-11.3
742	Lizard Spring	497603	3988149	22 S	46 E	9 NW	1651	<1		11.6	-11.6
743	Liar Spring	497966	3988477	22 S	46 E	9 NW	1544	15	14.3	12.3	2.0
744	Edge Spring	499240	3989025	22 S	46 E	3 NW	1469			12.8	
745	Blackrock Well	443490	4042081	13 S	35 E	21 SW	1774	0	16.4	10.7	5.7
746	Blackwater Spring B	496402	4026922	18 S	47 E	7 NW	936	<1	24.5	16.6	7.9
747	Blackwater Spring A	496389	4026931	18 S	47 E	7 NW	936	1	15	16.6	-1.6
748	Wetfork Spring	x	x	18 S	47 E	7 NW	917			16.7	
749	Cliff Spring	493084	4091427	11 S	44 E	19 NE	1844	<1	10.6	10.2	0.4
750	Delfs Spring #1	490314	4090486	11 S	44 E	22 SW	2058	<1	12	8.7	3.3
751	Delfs Spring #2	490735	4091185	11 S	44 E	22 SE	2087			8.5	
752	Rabbit Brush Spring	493548	4090327	11 S	44 E	20 SW	1824	>2	10.7	10.3	0.4
753	Jack 40 (Unnamed)	452019	4046366	16 S	41 E	8 NE	1832	6	10.9	10.3	0.6

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (ºC)	Amb Air[2] Temperature (ºC)	Spring–Amb Air[3] Temperature (ºC)
754	Zawada Spring	458300	4045425	16 S	41 E	13 NE	1872	>200	14.1	10.0	4.1
755	Hunter Spring Creek	457330	4045694	16 S	41 E	11 SE	1990	200	16	9.2	6.8
756	Niebyl Spring	457241	4045734	16 S	41 E	11 SE	1996	1	12.6	9.1	3.5
757	Claussen Spring	457618	4047340	16 S	41 E	2 SW	1954	12	9	9.4	-0.4
758	Dirty Fingers	458807	4047225	16 S	41 E	1 SE	2003			9.1	
759	Early Bird	459232	4046928	16 S	42 E	6 SW	1891	1	14.4	9.9	4.5
760	Muska Spring	461206	4047101	16 S	42 E	5 SW	1606	2	15	11.9	3.1
761	Badman Spring	461500	4047068	16 S	42 E	5 E	1592	3	13.6	12.0	1.6
762	Flycatcher	462522	4047189	16 S	42 E	4 SW	1499	20	14.6	12.6	2.0
763	Longhorn Spring	466153	4047630	16 S	42 E	11 NW	1012	5	19.5	16.0	3.5
764	Deadhorse	465695	4047433	16 S	42 E	2 NE	1108			15.4	
765	Horseshoe	465033	4047640	16 S	42 E	3 NE	1141	10	14.2	15.1	-0.9
766	Lightning	465659	4046677	16 S	42 E	11 NW	1234			14.5	
767	Jail Spring	491216	4005038	20 S	45 E	15 SW	2374	180	10	6.5	3.5
768	Yellowjacket Spring	486959	4005580	20 S	45 E	13 NW	1594	30	13.4	12.0	1.4
769	Wildrose Ranger Station Well	484166	4013385	19 S	44 E	23 SE	1288			14.1	
770	Antimony Spring	481247	4013302	19 S	44 E	21 SW	1114			15.3	
771	Roadside Spring	481872	4013298	19 S	44 E	22 SW	1147			15.1	
772	Furnace Creek Inn Well	513873	4034107	27 N	1 E	23 NW	-2			23.1	
773	Echo Waterholes	528792	4040719	28 N	3 E	32 NE	1360			13.6	
774	Naghipah Spring	497868	4008219	20 S	45 E	13 NW	1981	2.5	14.8	9.2	5.6
775	WACA 01	412652	4092026	11 S	37 E	30 NW	2229			7.5	
776	WACA 02	413447	4093277	11 S	37 E	19 NE	2097	12	10.6	8.4	2.2
777	Panamint A	490694	3991689	21 S	45 E	34 NE	1696	50	16	11.2	4.8
778	Lightfoot Spring	490374	3991865	21 S	45 E	34 NE	1659	100	15.9	11.5	4.4
779	Panamint B	490868	3992126	21 S	45 E	27 SE	1774	>100	14.2	10.7	3.5
780	Stone Corral	491223	3987673	22 S	45 E	10 SE	1764	0.5	14.6	10.8	3.8
781	South Fork Spring	497724	4026068	46 E	18 S	8 NE	842			17.2	
782	Waucoba 3B	412780	4095038	11 S	37 E	7 SE	2010			9.0	
783	Waucoba 3A	412770	4095061	11 S	37 E	7 SE	2005	20	10.5	9.1	1.4
784	Waucoba 04	413208	4095276	11 S	37 E	7 SE	1991	50	8.3	9.2	-0.9
785	Jack 39	453507	4046257	16 S	41 E	9 NE	1964			9.4	
786	Spanish Spring (Well)	454260	4048944	15 S	41 E	33 SE	1846			10.2	
787	Hunter Cabin	456265	4044781	16 S	41 E	11 SW	2055			8.7	
788	Hunter Spring	456265	4044781	16 S	41 E	11 SW	2084	20	11.9	8.5	3.4
789	Hunter Corral	456365	4044762	16 S	41 E	11 SE	2053	12	10.5	8.7	1.8
790	Panic Pete's Spring	456052	4044548	16 S	41 E	14 NE	2071	12	7.6	8.6	-1.0

[1] Universal Transverse Mercator projection, Zone 11, NAD27; in meters.
[2] Ambient air temperature at spring outlet.
[3] Spring temperature minus ambient air temperature at spring outlet.

Appendix continued

Spring Number	Spring Name	UTM Easting[1]	UTM Northing[1]	Township	Range	Quarter Section	Elevation (meters)	Discharge (liters/minute)	Spring Temperature (°C)	Amb Air[2] Temperature (°C)	Spring–Amb Air[3] Temperature (°C)
791	Jack 38	454623	4045417	16 S	41 E	10 SE	2060	20	9.6	8.7	0.9
792	Quail Spring	454581	4045594	16 S	41 E	10 NW	2044	12	9.5	8.8	0.7
793	Jack 36	454381	4045908	16 S	41 E	10 NW	2028	30	8.9	8.9	0.0
794	Jackass Spring	453523	4044378	16 S	41 E	16 NW	2102			8.4	
795	Jack 26	453322	4044015	16 S	41 E	16 SW	2028	1	4.7	8.9	-4.2
796	Johnnie Shoshone	493533	4011415	19 S	45 E	35 SW	2148	1	4.7	8.1	-3.4
797	Green Spring	482260	4028972	18 S	44 E	3 NW	1514			12.5	
798	Newfound Spring	456928	4044787	16 S	41 E	14 NE	2070	0.3	9.3	8.6	0.7
799	Amos Spring	457782	4045048	16 S	41 E	8 SE	2024	0.5	6.5	8.9	-2.4
800	Walrus Spring	458980	4045546	16 S	41 E	12 SE	1811		14.4	10.4	4.0
801	Bottle Spring	458081	4046379	16 S	42 E	7 NE	1934	1.25	10.9	9.6	1.3
802	Colin Spring	459081	4046666	16 S	41 E	1 SW	1870	1.5	10.8	10.0	0.8
803	Jolley Spring	459467	4046734	16 S	42 E	7 NW	1810	0.5	11.7	10.4	1.3
804	Duke Spring	459750	4046762	16 S	42 E	7 SE	1787	0.3	14.6	10.6	4.0
805	Open Spring	464795	4044696	16 S	42 E	10 SE	1346			13.7	
806	Panther Spring	463125	4046549	16 S	42 E	9 NE	1489	0.1	14	12.7	1.3
807	Heather Spring	463740	4044532	16 S	42 E	16 NE	1375	0.1		13.5	
808	Poorman Spring	463402	4043949	16 S	42 E	16 SE	1459	0.2	15	12.9	2.1
809	Rising Sun	x	x	16 S	42 E	15 NW	1346			13.7	
810	Tiny Tank	463920	4043390	16 S	42 E	15 SW	1299			14.0	
811	Tuber Spring	490695	4007683	20 S	45 E	9 NE	2379	5	9.7	6.5	3.2
812	Upper Tuber Spring	490911	4007795	20 S	45 E	9 NE	2480			5.8	
813	Hummingbird Spring	490273	4008536	20 S	45 E	4 SW	2184	2	7.3	7.8	-0.5
814	Cottonwood Spring	466264	4040786	42 E	16 S	26 SW	1074	15	16.6	15.6	1.0
815	Sidewinder Spring	468815	4042279	16 S	43 E	19 SW	935	25	14.1	16.6	-2.5
816	Lower Cottonwood	468961	4043028	16 S	43 E	19 NW	896	2.5	15.4	16.8	-1.4
817	Sister D	458395	4044863	16 S	41 E	13 NE	1986	1	9.1	9.2	-0.1
818	Sister A	458301	4045021	16 S	41 E	12 SW	1947	0.4	10.4	9.5	0.9
819	Sister E	458597	4044932	16 S	41 E	13 NE	1943	3	8	9.5	-1.5
820	Sister C	458583	4044937	16 S	41 E	13 NE	1932	4	10.3	9.6	0.7
821	Sister B	458527	4045033	16 S	41 E	12 SE	1910	4	10.7	9.7	1.0
822	Sister F	458809	4045074	16 S	41 E	12 SE	1837	1.3	11.6	10.3	1.3
823	Obsidian Seeps (a, b, c)	474151	4089087	12 S	43 E	3 NW	730			18.0	-18.0
824	Mahogany Spring A	493257	4006728	20 S	45 E	11 SE	2220	30	12	7.6	4.4
825	Noggin Spring	499868	4008219	20 S	46 E	5 SW	1273			14.2	
826	Late Spring	490520	4002995	20 S	45 E	25 SW				23.1	
827	Upper Hall Canyon Pipe	487020	4000045	21 S	46 E	5 NW	2214			7.6	

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Appendix continued

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828	Upper Hall Canyon Spring	x	x	20 S	45 E	36 NW		10	19	23.1	-4.1
829	Middle Tuber Canyon Spring	484974	4008123	20 S	45 E	1 SW	1490	>20	16.7	12.7	4.0
830	Ideal Spring	483270	4008445	20 S	45 E	2 SW	1235	>1	17.8	14.5	3.3
831	Lower Tuber Spring	481787	4007981	20 S	45 E	3 SW	1050	>6	17.5	15.8	1.7
832	Jack 16	451188	4042574	16 S	41 E	20 NW	1718	>1	10.8	11.1	-0.3
833	Jack 15	451240	4042428	16 S	41 E	20 SW	1672	>1	12.3	11.4	0.9
834	Jack 15b	451316	4042241	16 S	41 E	20 SW	1630	>1	9.8	11.7	-1.9
835	Lamb Spring	458883	4048367	16 S	41 E	1 NE	1739	4	12	10.9	1.1
836	Bighorn Spring 1	461126	4076660	13 S	42 E	5 NW	1799	<1	9.4	10.5	-1.1
837	Bighorn Spring 2	461113	4076638	13 S	42 E	5 NW	1804	<1	11.1	10.5	0.6
838	Bighorn Spring 3	x	x	13 S	42 E	5 NW	1808	<1	9.6	10.5	-0.9
839	Sheep Spring	459905	4076199	13 S	42 E	6 SE	2029	0		8.9	
840	Yashiro Spring	459561	4076047	13 S	42 E	6 SW	2083	<1	5.5	8.5	-3.0
841	Sheepwater Spring	495950	4075100	13 S	42 E	7 NW	2238			7.4	
842	Pinyon Spring	460700	4074600	13 S	42 E	7 NE	2253			7.3	
843	Paintbrush Spring	459245	4048454	13 S	41 E	31 SW	1630	>10	12.6	11.7	0.9
844	Upper Lamb	457618	4047323	16 S	41 E	1 SW	1950	5	10.2	9.5	0.7
845	Morning Glory Spring	494473	4014937	11 S	43 E	13 SW	1951	3	5.9	9.5	-3.6
846	Dose Spring	461719	4047324	16 S	42 E	5 NE	1562	6	17.2	12.2	5.0
847	Dripping Spring	495737	4019523	19 S	47 E	12 NW	1257	2	14.6	14.3	0.3
848	Wheel Spring	499175	4019726	19 S	47 E	33 SW	744	1	17.6	17.9	-0.3
849	LCM Willow Spring	437539	4132038	39 E	7 SE	21 NE	1731	7	7.1	11.0	-3.9
850	Mound Spring	465820	4097486	11 S	42 E	2 SW	776	5	33.8	17.7	16.1
851	White Crown Spring	460222	4049528	15 S	42 E	31 NE	1490	1.5	15.2	12.7	2.5
852	Bull Spring	460975	4048852	15 S	42 E	32 NW	1546			12.3	
853	Wahguyhe Spring	489741	4086486	12 S	45 E	7 E	1798			10.5	
854	Doe Spring	488877	4089751	11 S	45 E	1 NW	2189			7.8	
855	Bechtold Spring	461913	4049098	15 S	42 E	32 NE	1330	15	12.4	13.8	-1.4
856	Coyote Hole	458840	4049347	15 S	42 E	31 NW	1713			11.1	
857	Kroll Spring	462250	4049125	15 S	42 E	33 NW	1292	6	15.1	14.1	1.0
858	Highison Spring	462287	4049751	15 S	42 E	33 NW	1272	<1	14.4	14.2	0.2
859	Marble Potholes	x	x	15 S	42 E	21 NW	1322			13.9	
860	Pate Spring	462443	4049719	15 S	42 E	33 NE	1249	<1	12.1	14.4	-2.3
861	Tjonakwie Spring	462622	4049015	15 S	42 E	33 NW	1255	100	16.1	14.3	1.8
862	Pussywillow Spring	464573	4049140	15 S	42 E	34 NE	1096	1		15.4	
863	Schwab Spring	x	x	15 S	42 E	34 NW	1125	<1	14.4	15.2	-0.8
864	Grapevine Willow Spring	489769	4097065	10 S	43 E	35 SE	1902	<1	8	9.8	-1.8

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Appendix continued

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865	Grapevine Willow 2	489736	4097142	10 S	43 E	35 SE	1895	1	8.8	9.8	-1.0
866	Grapevine Willow Tank	489826	4097114	10 S	43 E	35 SE	1870			10.0	
867	Nelson Spring	486482	4092394	11 S	43 E	16 SE	2052	<1	8.7	8.8	-0.1
868	Nelson B Spring	486461	4092411	11 S	43 E	9 SW	2045	3	8.6	8.8	-0.2
869	Funston Spring	486315	4092231	11 S	43 E	16 SE	2040	<1	4.6	8.8	-4.2
870	Ramhorn Spring	482791	4088387	12 S	44 E	4 SE	1298			14.0	
871	Willow Spring (LCM)	437539	4132038	7 S	39 E	21 NE	1731	20	7.1	11.0	-3.9
872	Nevares A	516023	4040823	28 N	1 E	36 NE	260	1.5	36.2	21.3	14.9
873	Nevares B	516020	4040823	28 N	1 E	36 NE	260	0.5	37.8	21.3	16.5
874	Nevares E	516042	4040784	28 N	1 E	36 NE	260	1	38.5	21.3	17.2
875	Nevares D	516039	4040791	28 N	1 E	36 NE	264	<1	37.7	21.3	16.4
876	Nevares C	516028	4040797	28 N	1 E	36 NE	261	<1	33.8	21.3	12.5
877	Waucoba Spring	416673	4095777	11 S	37 E	8 SE	1834	<1	15.7	10.3	5.4
878	Waucoba 06	414628	4095381	11 S	37 E	8 SW	1903	6	10.4	9.8	0.6
879	Waucoba 05	x	x	11 S	37 E	8 SW	1914	3	9.5	9.7	-0.2
880	Travertine F	515432	4033091	27 N	1 E	25 NW	92	1000	35.4	22.5	12.9
881	Travertine G	515453	4033090	27 N	1 E	25 NW	92	5	35.6	22.5	13.1
882	Travertine H	515466	4033068	27 N	1 E	25 NW	91			22.5	-22.5
883	Travertine I	515476	4033096	27 N	1 E	25 NW	94			22.5	-22.5
884	Travertine J	515553	4032874	27 N	1 E	25 NW	88	<1	23.1	22.5	0.6
885	Travertine K	515506	4033113	27 N	1 E	25 NW	99	<1	32.4	22.4	10.0
886	Leaning Rock Tanks	x	x	13 S	42 E	4 NW	1676			11.4	
887	Brewery Spring	488216	3996651	21 S	45 E	16 NW	1448	700		13.0	
888	Sourdough Spring	491132	3997298	21 S	45 E	16 NW	1999	19		9.1	
889	Unnamed Panamint C	486485	3996280	21 S	4 SE	17 NW	1204			14.7	
890	Jody Spring	491780	3997070	21 S	45 E	11 SW	1999	12		9.1	
891	Water Canyon/ Thompson Spring	492293	3997547	21 S	45 E	11 NW	2060		13.6	8.7	4.9
892	Saratoga Springs	552341	3948596	18 N	5 E	2 NW	70	200	28.5	22.6	5.9
893	Falcon Seep	x	x				1313			13.9	
894	Unnamed Dry Bone Tanks	x	x	14 S	43 E	6 NE	714			18.1	
895	Unnamed* (East Salt Flat)	x	x	14 S	43 E	9 NW	343			20.7	
896	Palmer Seep	x	x	12 S	44 E	29 NW	1658			11.5	
897	Spur Spring	x	x	20 S	46 E	34	1000			16.1	
898	Eagle Spring	x	x	20 S	45 E	22 NE	2885			2.9	
899	Telescope Spring	x	x	20 S	45 E	23 SW	2704			4.2	
900	Dixon Spring	x	x	20 S	45 E	29 NW	2918			2.7	

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901	Superior Mine Tanks A	x	x	19 N	3 E	26 NW	804			17.5	
902	Sump in Furnace Creek Wash	x	x	27 N	1 E	26 NE	79			22.6	
903	Furnace Creek Inn Tunnel	x	x	27 N	1 E	23 SW	56			22.7	
904	NPS Trench	x	x	27 N	1 E	23 SW	45			22.8	
905	NPS Well #1	x	x	27 N	1 E	24 NW	153			22.0	
906	Sewer Lagoon	x	x	28 N	1 E	33 SW	-8			23.2	
907	Furnace Creek Ranch Ponds	x	x	27 N	1 E	19 NE	51			22.8	
908	Lower Nevares (12)	x	x	28 N	1 E	33-36	144			22.1	
909	Saltbush (sewer)	x	x	27 N	1 E	4 NW	72			22.6	
910	Wired Rock Spring	x	x	13 S	45 E	NE1/4 NE1/4	1493			12.7	
911	White Pass Gate Seep	x	x	13 S	46 E	SE1/4 NE1/4	1524			12.4	
912	Shell Spring	x	x	11 S	44 E	34 NW	2347			6.7	
913	Stovepipe Wells (Hotel)	x	x	16 S	44 E	1 NE	37			22.9	
914	NPS RO Well	x	x	15 S	44 E	36 SE	6			23.1	
915	Salt Spring	x	x	16.5 S	46 E	28 NE	-75			23.6	
916	Sulfur Spring	502550	4040300	16.5 S	46 E	27 NE	-78			23.7	
917	Furnace Creek Wash Monitoring Site	x	x							23.1	
918	Confidence	x	x							23.1	
919	Pry Well	x	x	23 N	1 E	2				23.1	
920	Mesquite Well B	x	x							23.1	
921	Salt Well	x	x							23.1	
922	Charlie's Well	x	x	28 N	1 E	SE1/4 NW1/4	-76			23.6	
923	Prospector	x	x	20 S	46 E	26 NE1/4 NE1/4				23.1	
924	Wildrose Stock Tank	x	x	19 S	44 E	23 NW1/4 SE1/4	1325			13.8	
925	Pioneer Spring	x	x	17 S	44 E	22 SW1/4 SE1/4	1146			15.1	
926	Unnamed Wildrose Peak	x	x							23.1	
927	Buried Tile FC Wash	x	x	27 N	2 E	26 NE	1036			15.9	
928	Feather Spring	x	x	21 S	46 E	33 NE1/4 NE1/4		25		23.1	
929	Highgrade Spring	496350	4019250	18 S	46 E	31 SW	1200			14.7	
930	Texas Springs (9)	x	x	27 N	1 E	23 NE`	127	210		22.2	
931	27 Undeveloped springs in Furnace Creek area	x	x							23.1	
932	Black Spring #4495	x	x							23.1	
933	Trail Spring	x	x							23.1	
934	Nevares Spring (5)	516114	4040543	28 N	1 E	36 NE	195	150	40	21.7	18.3
935	Nevares Spring Cave	515989	4040469	28 N	1 E	36 NE	185	20	33	21.8	11.2

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Appendix continued

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936	Travertine A	x	x	27 N	1 E	25 NW				23.1	
937	Travertine B	x	x	27 N	1 E	25 NW				23.1	
938	Travertine C	x	x	27 N	1 E	25 NW				23.1	
939	Travertine D	x	x	27 N	1 E	25 NW				23.1	
940	Travertine E	x	x	27 N	1 E	25 NW				23.1	
941	Grapevine Ranch	x	x							23.1	
942	Redtail Spring	488450	4007300	20 S	45 E	8 NW	1250			14.4	

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Bibliography

Andrew, J. E. 1999. Preliminary results of detailed structural investigation and large-scale mapping in the southern Panamint Range, California. U. S. Geological Survey Open-File Report 99-153: 31–32.

Aarno, S. F. 1984. Timberline: Mountain and arctic forest frontiers. Seattle: The Mountaineers.

Avon, L., and T. J. Durbin. 1994. Evaluation of the Maxey–Eakin method for estimating recharge to groundwater basins in Nevada. American Water Resources Association Water Resources Bulletin 30, no. 1:99–111.

Beatley, J. C. 1976. Vascular plants of the Nevada Test Site and central-southern Nevada: Ecologic and geographic distributions. Technical Report TID-26881. Technical Information Center, Office of Technical Information, Energy Research and Development Administration.

Bedinger, M. S. 1989. Geohydrologic aspects for siting and design of low-level radioactive waste disposal. U. S. Geological Survey Circular 1034.

Bedinger, M. S., and J. R. Harrill. 2006a. The Death Valley regional groundwater flow system in southeastern California. National Park Service, Fort Collins, Colorado.

———. 2006b. Analytical regression stage analysis for Devils Hole, Death Valley National Park, Nevada. Journal of the American Water Resources Association 42, no. 4:0827–0839.

———. 2010. Regional potential for interbasin flow, Appendix I. In Death Valley regional groundwater flow system, Nevada and California—Hydrogeologic framework and transient groundwater flow model, ed. W. R. Belcher, and D. S. Sweetkind. U.S. Geological Survey Scientific Investigations Professional Paper 1711, 345–364. (Originally released in U. S. Geological Survey Scientific Investigations Report 2004-5205.)

Bedinger, M. S., J. R. Harrill, and J. M. Thomas. 1984. Maps showing groundwater units and withdrawal, Basin and Range province, Nevada. U.S. Geological Survey Water Resources Investigations Report 83-4119A.

Bedinger, M.S., W. H. Langer, W. R. Moyle. 1984. Maps showing groundwater units and withdrawal, Basin and Range province, Southern California. U.S. Geological Survey Water Resources Investigations Report 83-4116-A.

Bedinger, M. S., W. H. Langer, and J. E. Reed. 1989a. Groundwater hydrology. In Studies of geology and hydrology in the Basin and Range province, southwestern United States, for isolation of high-level radioactive waste—Characterization of the Death Valley region, Nevada and California. ed. M. S. Bedinger, K. A. Sargent, and W. H. Langer, 28–35. U.S. Geological Survey Professional Paper 1370-F.

———. 1989b. Hydraulic properties of rocks in the Basin and Range province. In Studies of geology and hydrology in the Basin and Range province, southwestern United State,s for isolation of high-level radioactive waste —Basis of characterization and evaluation, ed. M. S. Bedinger, K. A. Sargent, W. H. Langer, F. B. Sherman, J. E. Reed, and B. T. Brady, 16–18. U. S. Geological Survey Professional Paper 1370-A.

Belcher, W. R., F. A. D'Agnese, and G. M. O'Brien. 2010. Chapter A, Introduction. In Death Valley regional groundwater flow system, Nevada and California—Hydrogeologic framework and transient groundwater flow model, ed. W. R. Belcher and D. S. Sweetkind, 3–18. U.S. Geological Survey Professional Paper 1711. (Originally released in U. S. Geological Survey Scientific Investigations Report 2004-5205.)

Belcher, W. R., and D. S. Sweetkind, eds. 2010. Death Valley regional groundwater flow system, Nevada and California—Hydrogeologic framework and transient groundwater flow model. U.S. Geological Survey Professional Paper 1711. (Originally released in U.S. Geological Survey Scientific Investigations Report 2004-5205.)

Blakely, R. J., and D. S. Ponce. 2001. Map showing depth to Pre-Cenozoic basement in the Death Valley model area, Nevada and California. U. S. Geological Survey Miscellaneous Field Studies Map MF 2381-E, version 1.0.

Bryant, E. A., and M. Fabryka. 1991. Survey of hazardous materials used in nuclear testing. Los Alamos National Laboratory Report LA-12014-MS.

Bredehoeft, J., C. Fridrich, and M. King. 2005. The lower carbonate aquifer as a barrier to radionuclide transport. Waste Management Conference ’05, WM-5482. Tucson, AZ.

California Department of Water Resources. 2004. California’s groundwater. California Department of Water Resources Bulletin 118 (with basin descriptions available online).

Carr, W. J. 1991 Geology of the Devils Hole Area, Nevada. U. S. Geological Survey Open-File Report 87-560.

Cemen, I., L. A. Wright, R. E. Drake, and F. C. Johnson. 1985. Cenozoic sedimentation and sequence of deformational events at the southeastern end of the Furnace Creek strike-slip fault zone, Death Valley region, California. In Strike-slip deformation and basin formation. ed. K. T. Biddle and N. Christie-Blick, 127–141. Society of Economic Paleontologists and Mineralogists Special Publication 37.

D’Agnese, F. A., C. C. Faunt, K. A. Turner, and M. C. Hill. 1997. Hydrogeologic evaluation and numerical simulation of the Death Valley regional groundwater flow system, Nevada and California. U.S. Geological Survey Water Resources Investigations Report 96-4300.

Dettinger, M. D., J. R. Harrill, D. L. Schmidt, and J. W. Hess. 1995. Distribution of carbonate-rock aquifers and the potential for their development, southern Nevada and parts of Arizona, California, and Utah. U.S. Geological Survey Water Resources Investigations Report 91-4146.

DeMeo, G. A., R. J. Laczniak, R. A. Boyd, J. L. Smith, and W. E. Nylund. 2003. Estimated groundwater discharge by evapotranspiration from Death Valley, California, 1997–2001. U.S. Geological Survey Water Resources Investigations Report 03-4254.

Dudley, W. W., Jr., and J. D Larson. 1976. Effect of irrigation pumping on desert pupfish habitats in Ash Meadows, Nye County, Nevada. U.S. Geological Survey Professional Paper 927.

Durbin, T. J. 1978. Calibration of a mathematical model of the Antelope Valley groundwater basin, California. U.S. Geological Survey Water Supply Paper 2046.

Eakin, T. E. 1966. A regional interbasin groundwater system in the White River area, southeastern Nevada. Water Resources Research 2, no. 2:251-271.

Eakin, T. E. and D. O. Moore. 1964. Uniformity of discharge of Muddy River Springs, southeastern Nevada and relation to interbasin movement of groundwater. In Geological Survey Research 1964, 171–176. U.S. Geological Survey Professional Paper 501-D.

Eakin, T. E., D. Price, and J. R. Harrill. 1976. Summary appraisals of the nation’s groundwater resources-Great Basin region. U.S. Geological Survey Professional Paper 813-G.

Eakin, T. E. and I. J. Winograd. 1965. Interbasin movement of groundwater in South-Central Nevada—some implications. In Abstracts for 1964: Geological Society of America Special Paper 82:52.

Faunt, C. C., J. B. Blainey, M. C. Hill, F. A. D’Agnese, and G. M. O’Brien. 2010. Chapter F, Transient Numerical Model. In Death Valley regional groundwater flow system, Nevada and California—Hydrogeologic framework and transient groundwater flow model, ed. W. R. Belcher and D. S. Sweetkind, 251–344. U.S. Geological Survey Professional Paper 1711. (Originally released in U. S. Geological Survey Scientific Investigations Report 2004-5205.)

Faunt, C. C., F. A. D’Agnese, and G. M. O’Brien. 2010. Chapter D, Hydrology. In Death Valley regional groundwater flow system, Nevada and California—Hydrogeologic framework and transient groundwater flow model, ed. W. R. Belcher and D. S. Sweetkind, 133–160. U.S. Geological Survey Professional Paper 1711. (Originally released in U. S. Geological Survey Scientific Investigations Report 2004-5205.)

Faunt, C. C., D. S. Sweetkind, and W. R. Belcher. 2010. Chapter E, Three-dimensional hydrogeologic framework model. In Death Valley regional groundwater flow system, Nevada and California—Hydrogeologic framework and transient groundwater flow model, ed. W. R. Belcher and D. S. Sweetkind, 161–250. U.S. Geological Survey Professional Paper 1711. (Originally released in U. S. Geological Survey Scientific Investigations Report 2004-5205.)

Flint, A. L., L. E. Flint, J. A. Hevesi, and J. B. Blainey. 2004. Fundamental concepts of recharge in the desert southwest, a regional modeling perspective. In Groundwater recharge in a desert environment, the Southwestern United States, ed. J. F. Hogan, F. M. Phillips, and B. R. Scanlon, 115–128. American Geophysical Union, Geophysical Monograph 122.

Forester, R. M. 2000. An Ostracode record of Holocene climate change from Owens Lake, California. In Impacts of climate change on landscapes of the eastern Sierra Nevada and western Great Basin, 7–8. U.S. Geological Survey Open-File Report 01-202.

Fridrich, C., R. Blakely, and R. Thompson. 2003a. Hydrogeologic investigations of the southern Funeral Mountains, Part I Studies in FY 2002. U. S. Geological Survey Administrative Report to Inyo County, California, August 5, 2003:1–7

———. 2003b, Hydrogeologic investigations of the southern Funeral Mountains, Part I Studies in 2003. U.S. Geological Survey Administrative Report to Inyo County, California, August 5, 2003:8–24

Gale, H. S. 1914. Salt, borax, and potash in Saline Valley, Inyo County, California. In Contributions to Economic Geology 1912, Part I.—Metals and Nonmetals except fuels, 416–421. U.S. Geological Survey Bulletin 540.

Greene, R. C. 1997. Geology of the northern Black Mountains, Death Valley, California. U.S. Geological Survey Open-File Report 97-79.

Grose, T. L., and G. I. Smith. 1989. Geology. In Studies of geology and hydrogeology in the Basin and Range Province, southwestern United States, for isolation of high-level radioactive waste, ed. M. S. Bedinger, K. A. Sargent, and W. H. Langer, 5–19. U.S. Geological Survey Professional Paper 1370-F.

Hale, G. S. and C. L. Westenberg. 1995. Selected groundwater data for Yucca Mountain region, southern Nevada and eastern California, calendar year 1993. U.S. Geological Survey Open-File Report 95-158.

Hamilton, W. B. 1988. Detachment faulting in the Death Valley region, California and Nevada. In Geologic and hydrologic investigations of a potential nuclear waste disposal site at Yucca Mountain, southern Nevada, ed. M. D. Carrand J. C. Yount, 51–85. U. S. Geological Survey Bulletin 1790.

Harrill, J. R. 1986. Groundwater storage depletion in Pahrump Valley, Nevada–California, 1962-75. U.S. Geological Survey Water Supply Paper 2279.

———. 1995a. Evaluation of scientific literature pertaining to the conceptualization of the groundwater flow system, Nevada and California. Private Consultant, Pal Consultants Inc., 14380 Story Road, San Jose, California.

———. 1995b. A conceptual model of the Death Valley groundwater flow system Nevada and California. Private Consultant, Pal Consultants Inc., 14380 Story Road, San Jose, California.

Harrill, J. R. and M. S. Bedinger. 2005 (Originally released in 2000). Groundwater level fluctuations in Devils Hole, 1962-1999, regional stresses and water-level changes in the Death Valley Region, Nevada and California. Technical Report NPS/NRWRD/NRTR-2005/339, U.S. Department of the Interior, National Park Service.

———. 2010. Estimated model boundary flows, Appendix 2, Plate 1. In Death Valley regional groundwater flow system, Nevada and California—Hydrogeologic framework and transient groundwater flow model, ed. W. R. Belcher and D. S. Sweetkind, 345–364. U.S. Geological Survey Professional Paper 1711. (Originally released in U. S. Geological Survey Scientific Investigations Report 2004-5205.)

Harrill, J. R., J. S. Gates, and J. M. Thomas. 1988. Major groundwater flow systems in the Great Basin Region of Nevada, Utah, and adjacent States. 2 sheets, map scale 1:1,000,000, with errata sheet. U.S. Geological Survey Hydrologic Investigations Atlas HA-694-C.

Hevesi, J. A., A. L. Flint, and L. E. Flint. 2002. Preliminary estimates of spatially distributed net infiltration and recharge for the Death Valley region, Nevada–California. USGS Water Resources Investigation Report 02-4010.

———. 2003. Simulation of net infiltration and potential recharge using a distributed-parameter watershed model of the Death Valley region, Nevada and California. U.S. Geological Survey Water Resources Investigation Report 2003-4090.

Hollett, K. J., W. R. Danskin, W. F. McCaffrey, and C. L. Walti. 1991. Geology and water resources on Owens Valley, California. U.S. Geological Survey Water Supply Paper 2370-B.

Hunt, C. B. 1967. Natural regions of the United States and Canada. W. H. Freeman and Company, San Francisco, California.

———. 1975. Death Valley, geology, ecology, archaeology. University of California Press, Berkeley, California.

Hunt, C. B. and L. W. Durrell. 1966. Distribution of fungi and algae. In Plant ecology of Death Valley, California, ed. C. B. Hunt. U.S. Geological Survey Professional Paper 509.

Hunt, C. B., and D. R. Mabey. 1966. Stratigraphy and structure Death Valley, California. U.S. Geological Survey Professional Paper 494-B.

Hunt, C. B., and T. W. Robinson. 1960. Possible interbasin circulation of groundwater in the southern part of the Great Basin. U.S. Geological Survey Professional Paper 400-B: B273–B274.

Hunt, C. B., T. W. Robinson, W. A. Bowles, and A. L. Washburn. 1966. Hydrologic basin Death Valley, California. U.S. Geological Survey Professional Paper 494-B: B1–B147.

Inyo County Yucca Mountain Repository Assessment Office. 2005. Death Valley lower carbonate aquifer monitoring program—wells downgradient of the proposed Yucca Mountain nuclear waste repository. Final Project Report. U. S. Department of Energy Cooperative Agreement DE-FC08-02RW12162.

Jacobs, C. 2005. Death Valley National Park spring inventory. Great Basin Institute. University of Nevada, Reno, Nevada.

James, J. W. 1993. Climate of the Death Valley Region, Nevada, California. State of Nevada, Office of the State Climatologist. University of Nevada, Reno, Nevada.

Johannesson, K. H., K. J. Stetzenbach, and V. Hodge. 1997. Rare earth elements as geochemical tracers of regional groundwater mixing. Geochemica et Cosmochimica Acta, 61:3605–3618.

King, M. J., and J. D. Bredehoeft. 1999. Death Valley springs geochemical investigation, Yucca Mountain Nuclear Repository, Inyo County Oversight–1998. The Hydrodynamics Group, Edmonds, Washington.

La Camera, R. J. and G. L. Locke. 1997. Selected groundwater data for Yucca Mountain region, southern Nevada and Eastern California, through December 1996. U.S. Geological Survey Open-File Report 97-821.

La Camera, R. J., and C. L. Westenberg. 1994. Selected groundwater data for Yucca Mountain region, southern Nevada and Eastern California, through December 1992. U.S. Geological Survey Open File Report 94-54.

La Camera, R. J., C. L. Westenburg, and G. L. Locke. 1996. Selected groundwater data for Yucca Mountain region, southern Nevada and eastern California, through December 1995. U.S. Geological Survey Open-file Report 96-553.

Laczniak, R. J., J. C. Cole, D. A. Sawyer, and D. A. Trudeau. 1996. Summary of hydrogeologic controls on groundwater flow at the Nevada Test Site, Nye County, Nevada. U.S. Geological Survey Water Resources Investigations Report 96-4109.

Laczniak, R. J., L. J. Smith, and G. A. DeMeo. 2006. Annual groundwater discharge by evapotranspiration from areas of spring-fed riparian vegetation along the eastern margin of Death Valley, 2000-02. U.S. Geological Survey Scientific Investigations Report 2006-5145.

Laczniak, R. J., L. J. Smith, P. E. Elliot, G. A. DeMeo, M. A. Chatigny, and G. J. Roemer. 2001. Groundwater discharge determined from estimates of evapotranspiration, Death Valley regional flow system, Nevada and California. U.S. Geological Survey Water-Resources Investigations Report 01-4195.

Lamb, C. E., and D. J. Downing. 1979. Hydrologic data, 1974-77, Stovepipe Wells Hotel area, Death Valley National Monument, Inyo County, California. U.S. Geological Survey Open-file Report 79-203.

Lingenfelter, R. E. 1986. Death Valley & the Amargosa—A land of illusion. University of California Press, Berkeley, California.

Machette, M. N., W. J. Stephenson, R. A. Williams, J. K. Odum, D. M. Worley, and R. L. Dart. 2000. Seismic-reflection investigations of the Texas Springs Syncline for groundwater development, Death Valley National Park. U.S. Geological Survey Open-File Report 2000-106.

Malmberg, G. T. 1967. Hydrology of the valley-fill and carbonate-rock reservoirs, Pahrump Valley, Nevada–California. U.S. Geological Survey Water Supply Paper 1832.

Mase, C. W., S. P. Galanis, Jr., and R. J. Munroe. 1979. Near-surface heat flow in Saline Valley, California. U.S. Geological Survey Open-File Report 79-1136.

Maxey, G. B. and T. E. Eakin. 1949. Groundwater in White River Valley, White Pine, Nye, and Lincoln Counties, Nevada. Nevada State Engineer, Water Resources Bulletin 8.

McAllister, J. F. 1970. Geology of the Furnace Creek borate area, Death Valley, Inyo County, California. California Department of Conservation, Division of Mines and Geology Map Sheet 14.

Mifflin, M. D. 1968. Delineation of groundwater flow systems in Nevada. University of Nevada, Las Vegas, Desert Research Institute Technical Report Series H-W, Publication 4.

Mifflin, M. D., and J. W. Hess. 1979. Regional carbonate flow systems in Nevada. In Hydrogeology—The George Burke Maxey Memorial Volume, ed. W. Back and D. A. Stephenson. Contemporary Journal of Hydrology 43:217–235.

Miller, G. A. 1977. Appraisal of the water resources of Death Valley, California–Nevada. U.S. Geological Survey Open-File Report 77-728.

Moreo, M. T., K. J. Halford, R. J. La Camera, and R. J. Laczniak. 2003. Estimated groundwater withdrawals from the Death Valley regional flow system, Nevada and California, 1913–1998. U.S. Geological Survey Water-Resources Investigations Report 03-4245.

Noble, L. F. 1934. Rock formations of Death Valley, California Science 80, no. 2069:173–180.

Noble, L. F. 1941. Structural features of the Virgin Spring area, Death Valley, California. Geological Society of America Bulletin 52:942–1000.

Pistrang, M. A. and F. Kunkel. 1964. A brief geologic and hydrologic reconnaissance of the Furnace Creek Wash area, Death Valley National Monument, California. U.S. Geological Survey Water Supply Paper 1779-Y.

Potter, C. J., D. S. Sweetkind, R. P. Dickerson, and M. L. Kilgore. 2002. Hydrostructural maps of the Death Valley regional flow system, Nevada and California. U.S. Geological Survey Miscellaneous Field Studies Map MF-2372.

Prudic, D. E., J. R. Harrill, and T. J. Burbey. 1995. Conceptual evaluation of regional groundwater flow in the carbonate rock province of the Great Basin, Nevada, Utah, and adjacent states. U.S. Geological Survey Professional Paper 1409-D.

Reynolds, M. W. 1974. Geology of the Grapevine Mountains, Death Valley, California—A summary. In Guidebook—Death Valley Region, California and Nevada, 92–99. Geological Society of America Field Trip Number 1, Cordilleran Section, 70th annual meeting. The Death Valley Publishing Company, Shoshone, California.

Rice, W. A. 1984. Preliminary two-dimensional regional hydrologic model of the Nevada Test Site and vicinity. Pacific Northwest Laboratory, Richland, Washington, under Sandia Contract No. 37-3171.

Riggs, A. C. and J. E. Deacon. 2002. Connectivity in desert aquatic ecosystems: The Devils Hole story. In Conference Proceedings, Spring-fed Wetlands: Important Scientific and Cultural Resources of the Intermountain Region, May 7–9, 2002, Las Vegas, Nevada, ed. D. W. Sada and S. E. Sharpe. DHS Publication No. 41210.

Rojstaczer, S. 1987. The local effects of groundwater pumpage within a fault-influenced groundwater basin, Ash Meadows, Nye County, Nevada, USA. Journal of Hydrology 91:319–337.

Rowlands, P. G. 1993. Vegetation and climate of Death Valley National Monument and the adjacent Mojave and Great Basin Deserts, California and Nevada. In Proceedings of the Fourth Conference on research in California's National Parks, National Park Service. National Park Service Transactions and Proceedings Series 9:66-82.

Rush, F. E. 1968. Water Resources appraisal of Clayton Valley-Stonewall Flat area, Nevada and California. Nevada Department of Conservation and Natural Resources, Water Resources-Reconnaissance Report 45.

Sada, D. W., and K. F. Pohlmann. 2003. National Park Service Mojave inventory and monitoring network spring survey protocols, Level I, Draft Unpublished.

———. 2006. Environmental and biological characteristics of springs in Death Valley National Park, California. Draft Report to Death Valley National Park, National Park Service.

San Juan, C. A., W. R. Belcher, R. J. Laczniak, and H. M. Putnam. 2010. Chapter C, Hydrologic components for model development. In Death Valley regional groundwater flow system, Nevada and California—Hydrogeologic framework and transient groundwater flow model, ed. W. R. Belcher and D. S. Sweetkind, 95–132. U.S. Geological Survey Professional Paper 1711. (Originally released in U. S. Geological Survey Scientific Investigations Report 2004-5205.)

Sargent, K. A. 1989.Quaternary tectonism. In Studies of Geology and Hydrology in the Basin and Range Province, Southwestern United State, for isolation of high-level radioactive waste – Characterization of the Death Valley Region, Nevada and California, ed. M. S. Bedinger, K. A. Sargent, and W. M. Langer, 24–27. U.S. Geological Survey Professional Paper 1370-F.

Sibson, R. H. 1986. Brecciation processes in fault zones—inferences from earthquake rupturing. PAGEOPH 124: 159–175.

Snow, J. K. 1989. Day 7: Neogene dextral translation of the Cottonwood Mountain Area, California. In Extension Tectonics in the Basin and Range Province between the southern Sierra Nevada and the Colorado Plateau, ed. J. Wernicke, J. K. Snow, G. J. Axen, B. C. Burchfiel, K. V. Hodges, J. D. Walker, and P. L. Guth, 56–67. American Geophysical Union, IGC Field Trip T138.

Stamos, C. L., T. Nishikawa, and P. Martin. 2001. Water supply in the Mojave River Groundwater Basin 1931-99, and the benefits of artificial recharge. U.S. Geological Survey Water Fact Sheet 122-0.

Stamos, C. L., P. Martin, T. Nishikawa, and B. Cox. 2001. Simulation of groundwater flow in the Mojave River basin, California. U.S. Geological Survey Water Resources Investigations Report 01-4002 Version 1-2.

Steinkampf, W. C., and W. L. Werrell. 2001. Groundwater flow to Death Valley, as inferred from the chemistry and geohydrology of selected springs in Death Valley National Park, California and Nevada. U.S. Geological Survey Water-Resources Investigations Report 98-4114.

Stewart, J. H. 1967. Possible large right-lateral displacement along fault and shear zones in Death Valley–Las Vegas area, California and Nevada. Geological Society of America Bulletin 78, no. 2:131–142.

———. 1970. Upper Precambrian and Lower Cambrian strata in the southern Great Basin, California and Nevada. U.S. Geological Survey Professional Paper 620.

Sweetkind, D. S., R. P. Dickerson, R. J. Blakely, and P. D. Dunning. 2001. Interpretive geologic cross sections for the Death Valley regional flow system and surrounding areas, Nevada and California. U.S. Geological Survey Miscellaneous Filed Studies Map MF-2370.

Sweetkind, D. S., W. R. Belcher, C. C. Faunt, and C. J. Potter. 2010. Chapter B., Geology and Hydrogeology. In Death Valley regional groundwater flow system, Nevada and California—Hydrogeologic framework and transient groundwater flow model, ed. W. R. Belcher and D. S. Sweetkind, 19–94. U.S. Geological Survey Professional Paper 1711. (Originally released in U. S. Geological Survey Scientific Investigations Report 2004-5205.)

Thomas, J. M., A. H. Welch, and M. D. Dettinger. 1996. Geochemistry and isotope hydrology of representative aquifers in the Great Basin region of Nevada, Utah, and adjacent states. U.S. Geological Survey Professional Paper 1409-C.

Thornthwaite, C. W. 1948. An approach toward a rational classification of climates. Geographical Review 38, no. 1:54–94.

Troxel, B. W., and L. A. Wright. 1976. Geologic features Death Valley, California. California Division of Mines and Geology Special Report 106.

———. 1987. Tertiary extensional features, Death Valley region, eastern California. In Decade of North America Geology, Centennial Field Guide: v. 1, ed. M. L. Hill, 121–132.

———. 1989. Geologic map of the central and northern Funeral Mountains and adjacent areas, Death Valley region, southern California. U.S. Geological Survey Open-File Report 89-348.

U.S. Department of Agriculture. 1988. Database for CONUS, Alaska, and Hawaii in BASINS Publication Information. U.S. Environmental Protection Agency. http://www.epa.gov/OST/BASINS

U.S. Department of Energy. 1991. Environmental restoration and waste management—Five year plan for fiscal years 1992-1996. U.S. Department of Energy, Nevada Operations Office, unnumbered report.

———. 1994. United States nuclear tests: July 1945 through September 1992. U.S. Department of Energy, Nevada Operations Office, DOE/NV-209 (rev. 14).

U.S. Environmental Protection Agency. 1991. Offsite environmental monitoring report—Radiation monitoring around United States nuclear test areas calendar year 1990. U.S. Environmental Protection Agency Report, EPA 600/4-91/030 (DOE/DP 00539-063).

Waddell, R. K., Jr. 1982. Two dimensional, steady state model of groundwater flow, Nevada Test Site and vicinity, Nevada–California. U.S. Geological Survey Water Resources Investigations Report 82 4085.

Waddell, R. K., J. H. Robison, and R. K. Blankenagel. 1984. Hydrology of Yucca Mountain and vicinity, Nevada–California—Investigative results through mid-1983. U.S. Geological Survey Water-Resources Investigations Report 84-4267.

Walker, G. E. and T. E. Eakin. 1963. Geology and groundwater of Amargosa Desert, Nevada–California. Nevada Department of Conservation and Natural Resources, Groundwater Resources–Reconnaissance Report 14.

Wernicke, J., J. K. Snow, G. J. Axen, B. C. Burchfiel, K. V. Hodges, J. D. Walker, and P. L. Gurht. 1989. Extension tectonics in the Basin and Range Province between the southern Sierra Nevada and the Colorado Plateau. American Geophysical Union, IGC Field Trip T138.

Westenberg, C. L. and R. La Camera. 1996. Selected groundwater data for Yucca Mountain region, southern Nevada and Eastern California, through December 1994. U.S. Geological Survey Open-File Report 96-205.

Williams, T. R. and M. S. Bedinger. 1984. Selected geologic and hydrologic characteristics of the Basin and Range Province, Western United States, Pleistocene Lakes and Marshes. U.S. Geological Survey Miscellaneous Investigations Series Map 1523-D.

Winograd, I. J., and W. Thordarson. 1975. Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada–California, with special reference to the Nevada Test Site. U.S. Geological Survey Professional Paper 712-C.

Workman, J. B., C. M. Menges, W. R. Page, E. Taylor, E. B. Ekren, P. D. Rowley, G. L. Dixon, R. A. Thompson, and L. A. Wright. 2002a. Geologic map of the Death Valley groundwater model area, Nevada and California. U.S. Geological Survey Miscellaneous Field Studies Map MF-2381-A.

Workman, J. B., C. M. Menges, W. R. Page, E. B. Ekren, P. D. Rowley, G. L. Dixon, R. A. Thompson, and L. A. Wright. 2002b. Tectonic map of the Death Valley groundwater model area, Nevada and California. U.S. Geological Survey Miscellaneous Field Studies Map MF-2381-B.

Wright, L.A., and B. W. Troxel. 1993. Geologic map of the central and northern Funeral Mountains and adjacent areas, Death Valley region, southern California. U.S. Geological Survey Miscellaneous Investigations Series Map I-2305.

Wright, L.A., R. C. Green, I. Cemen, F. C. Johnson, and A. R. Prave. 1999. Tectonostratigraphic development of the Miocene–Pliocene Furnace Creek Basin and related features, Death Valley region, California. In Cenozoic basins of the Death Valley region, ed. L. A. Wright and B. W. Troxel, 87–114. Geological Society of America Special Paper No. 333.

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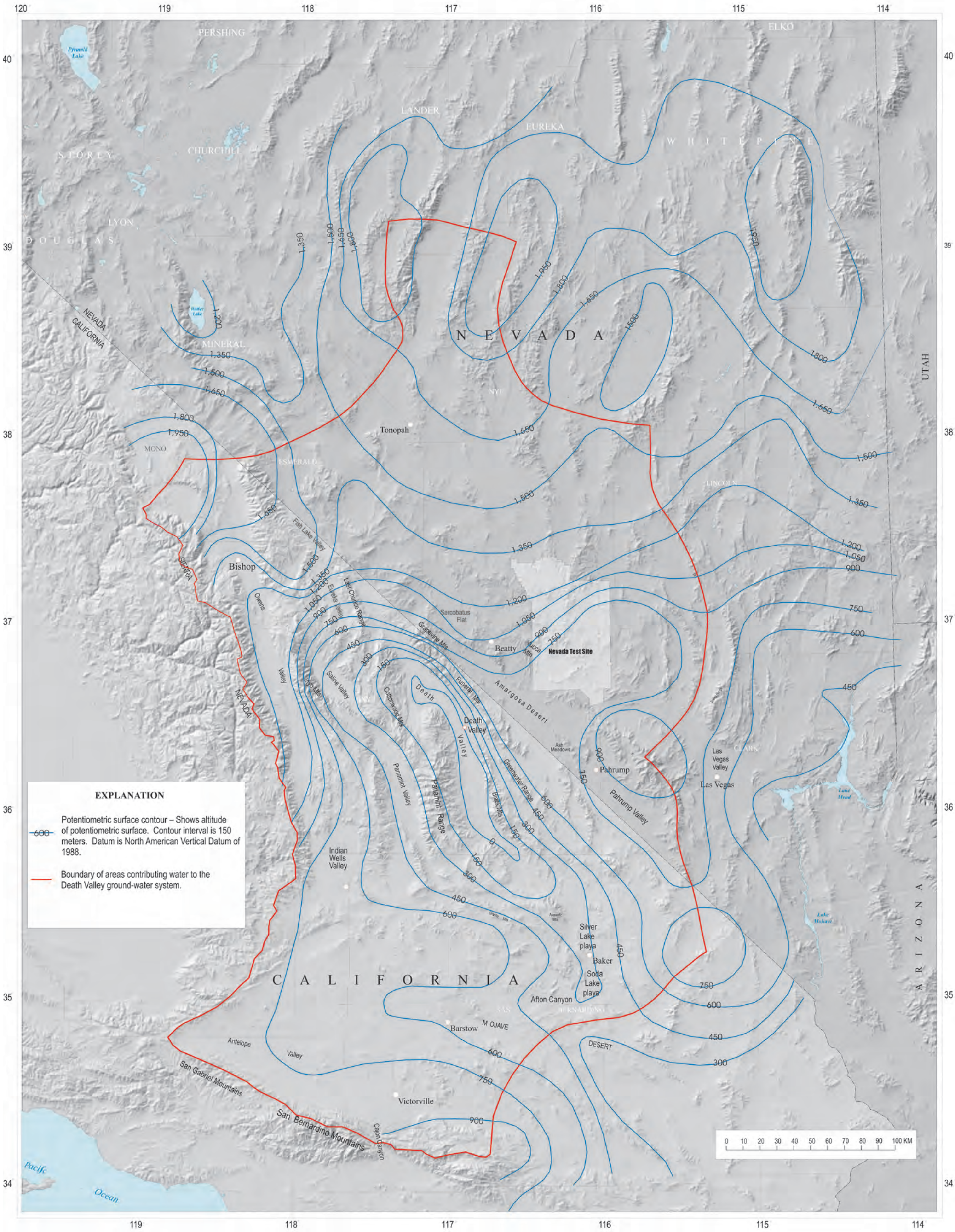

Plate 1. Regional potential for flow of groundwater in the Death Valley regional groundwater flow system, Nevada and California. After Bedinger and Harrill 2010.

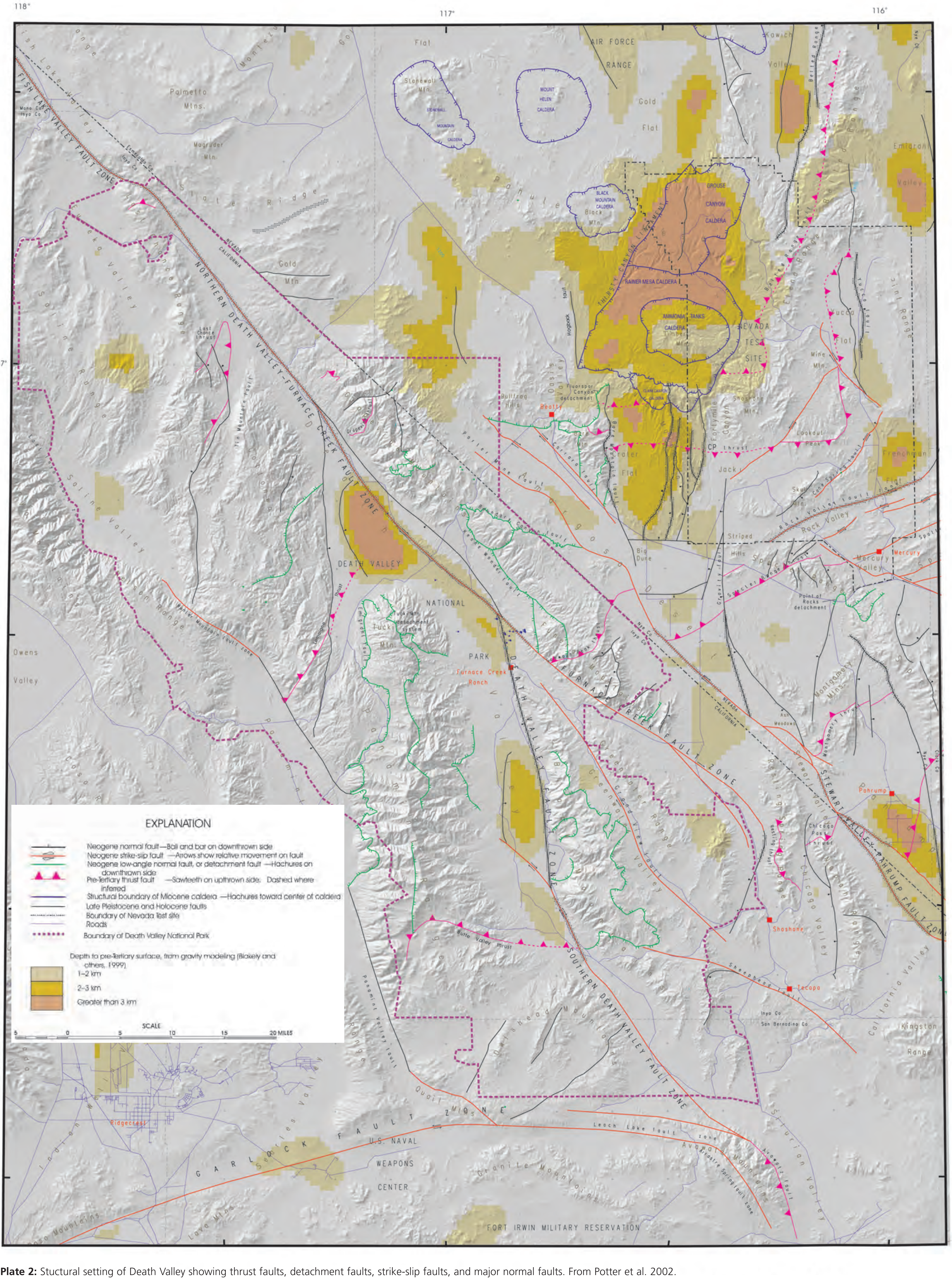

Plate 2: Stuctural setting of Death Valley showing thrust faults, detachment faults, strike-slip faults, and major normal faults. From Potter et al. 2002.