Chapter 3

Water and Water Use in Southern Nevada

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Introduction

Water and water use in southern Nevada is an important issue. The scarcity of water resources for both human and biologic communities often leads to intense competition for both surface and groundwaters. Anthropogenic and climate change impacts on scarce water resources need to be understood to assess human and ecosystem health for the study area.

This chapter outlines the state of the science for hydrology in southern Nevada—groundwater, surface water, and water quality. A brief summary of the knowledge of hydrology of southern Nevada is presented and recommendations for filling gaps in knowledge of the hydrology are proposed. This chapter serves as a synthesis of information to aid in meeting Sub-Goal 1.3 of the SNAP Science and Research Strategy, which is to restore and sustain proper function of Southern Nevada's watersheds and landscapes (table 1.3; Turner and others 2009).

Habitats greatly influenced by groundwater in the Mojave Desert include streams, riparian areas, and wetlands. These habitats are a relatively small fraction of the landscape, but are extremely important by any biologic measure (Miller and others 2007). These "wet" habitats contain a great deal of biodiversity, possess a relatively high vegetative density, are relied on by terrestrial mammals, and support diverse aquatic species. The conceptual model of these habitats in the Mojave Desert is that they are largely supported by groundwater (Miller and others 2007).

Study Area

The Southern Nevada Agency Partnership (SNAP) study area lies within the southern part of the Basin and Range physiographic province (Planert and Williams 1995) with most of the study area being within the internally drained Great Basin subprovince (Fenneman 1931). The very eastern edge is in the Colorado River drainage formed by the Virgin, Muddy, and Colorado Rivers (fig.1.1). The SNAP study area includes several large valleys, including the Amargosa Desert, Pahrump Valley, Las Vegas Valley, and Pahranagat Valley. The region also includes several major mountain ranges including the Spring Mountains, the Sheep and Pahranagat Ranges. Late Cenozoic tectonic activity accounts for much of the observed topographic relief across the study area (Grose and Smith 1989).

The relief between valleys and adjoining mountains locally exceeds 1,500 m (Bedinger and others 1989). Principal mountain ranges in the southern one-half of the study area trend northwest-southeast. Throughout the study area the trends of intermediate-scale topographic features are quite variable (fig.1.1).

Land Use

Most of the land in southern Nevada is owned by the U.S. Government and is administered by numerous Federal agencies, such as the Bureau of Land Management, the U.S. Fish and Wildlife Service, the National Park Service, the U.S. Forest Service, the Department of Energy, and the Department of Defense. Privately owned land is scattered throughout the region, but most private ownership is concentrated near the urban areas of Las Vegas Valley and agricultural centers of Amargosa Desert and Pahrump Valley. The major land-use activities in the region are recreation, mining and agriculture along the river corridors.

From January 1951 through September 1992, 828 underground nuclear tests were conducted at the Nevada National Security Site (NNSS; formerly the Nevada Test Site). Depths of these tests ranged from 30 to 1,500 meters below the ground surface with approximately one-third of these tests being at or below the groundwater table. This resulted in some radioactive contamination of the groundwater at the NNSA. The Department of Energy's (DOE) National Nuclear Security Administration (NNSA) has funded the Underground Test Area (UGTA) program to assess the nature, extent, and future migration of contaminants at the NNSS. Since there is no feasible method to remediate deep groundwater contamination at the NNSS, the UGTA program has a long-term strategy consisting of developing computer models to simulate groundwater flow and contaminant migration, developing a groundwater monitoring system, and establishing institutional control to limit access to contaminated groundwater in and around the NNSS.

Water Use

Water in southern Nevada is used mostly for domestic, commercial, and to a lesser extent agricultural, wildlife groundwater, military, and mining purposes. Water resources in the SNAP area include water resources for biological resources with adjudicated water rights for their protection. A significant example is the endangered Devils Hole pupfish (*Cyprinidon diabolis*) whose continued existence depends on naturally occurring spring discharges and stable pool levels in Devils Hole within Death Valley National Park. Water resources also include a number of local and regional spring sources that add greatly to the biodiversity of the area.

The study area is subdivided into hydrographic areas that generally consist of valleys separated by surface-water drainage divides (Rush 1968). The USGS and the NDWR systematically delineated hydrographic areas in Nevada for scientific and administrative purposes (Cardinalli and others1968; Rush 1968) for both surface water and groundwater. Official hydrographic-area names, numbers, and geographic boundaries continue to be used in USGS and other agency's scientific reports and NDWR administrative activities pertaining to Nevada.

Ground-water rights in Nevada are assigned according to these hydrographic areas. Where perennial yield is less than the water use, certain hydrographic areas have been "designated," meaning that certain administrative strategies have been applied to these "over allocated" (pumping is greater than the perennial yield) basins. Table 3.1 presents the hydrographic areas in the SNAP area with The Nevada State Engineer's estimated perennial yield, water use, and designation status for ground water.

Table 3.1. Water Use for Southern Nevada Agency Partnership Study Area by Hydrographic Area.

Hydrographic Area No.	Hydrographic Area Name	Designated?	Annual perennial yield (acre ft)	Annual perennial yield use (m^3)	Annual water use (acre ft)	Annual water use (m^3)
141	RALSTON VALLEY	Y (all)	6,000	7,401,715	4,306	5,311,409
145	STONEWALL FLAT	N	100	123,362	12	14,532
146	SARCOBATUS FLAT	Y (all)	3,000	3,700,858	3,535	4,361,362
147	GOLD FLAT	N	1,900	2,343,876	414	510,792
148	CACTUS FLAT	N	300	370,086	248	306,160
149	STONE CABIN VALLEY	Y (all)	2,000	2,467,238	11,532	14,226,528
157	KAWICH VALLEY	N	2,200	2,713,962	0	0
158A	EMIGRANT VALLEY-GROOM LAKE VALLEY	N	2,800	3,454,134	12	15,198
158B	EMIGRANT VALLEY-PAPOOSE LAKE VALLEY	N	10	12,336	0	0
159	YUCCA FLAT	N	350	431,767	0	0
160	FRENCHMAN FLAT	N	100	123,362	0	0
161	INDIAN SPRINGS VALLEY	Y (portion)	500	616,810	1,392	1,717,124
162	PAHRUMP VALLEY	Y (all)	12,000	14,803,430	62,597	77,220,713
163	MESQUITE VALLEY (SANDY VALLEY)	Y (all)	1,500	1,850,429	386	476,004
164A	IVANPAH VALLEY-NORTHERN PART	Y (all)	700	863,533	1,913	2,359,988
164B	IVANPAH VALLEY-SOUTHERN PART	Y (all)	250	308,405	781	963,148
165	JEAN LAKE VALLEY	Y (all)	50	61,681	340	419,875
166	HIDDEN VALLEY (SOUTH)	Y (all)	NA	NA	67	82,541
167	ELDORADO VALLEY	Y (all)	500	616,810	2,256	2,783,094
168	THREE LAKES VALLEY (NORTHERN PART)	N	3,700	4,564,391	3,700	4,564,391
169A	TIKAPOO VALLEY-NORTHERN PART	N	2,600	3,207,410	2,594	3,199,626
169B	TIKAPOO VALLEY-SOUTHERN PART	N	1,700	2,097,153	1,700	2,097,153
170	PENOYER VALLEY (SAND SPRING VALLEY)	Y (all)	4,000	4,934,477	15,083	18,606,247
171	COAL VALLEY	N	6,000	7,401,715	32	38,958
172	GARDEN VALLEY	N	6,000	7,401,715	558	688,804
173A	RAILROAD VALLEY-SOUTHERN PART	N	2,800	3,454,134	3,931	4,849,382
181	DRY LAKE VALLEY	N	12,700	15,666,964	1,066	1,314,495
182	DELAMAR VALLEY	N	2,550	3,145,729	7	8,931
197	ESCALANTE DESERT	N	1,000	1,233,619	71	87,698
203	PANACA VALLEY	Y (all)	25,000	30,840,480	29,201	36,022,729
204	CLOVER VALLEY	N	25,000	30,840,480	2,768	3,414,843
205	LOWER MEADOW VALLEY WASH	Y (all)	25,000	30,840,480	21,483	26,501,261
206	KANE SPRINGS VALLEY	N	1,000	1,233,619	1,000	1,233,619
208	PAHROC VALLEY	N	21,000	25,906,003	39	48,037
209	PAHRANAGAT VALLEY	NA	25,000	30,840,480	12,800	15,790,498
210	COYOTE SPRING VALLEY	Y (all)	1,900 to 1,8000	2,343,877 to 22,205,146	16,200	19,984,631
211	THREE LAKES VALLEY (SOUTHERN PART)	Y (portion)	4,500	5,551,286	4,500	5,551,619
212	LAS VEGAS VALLEY	Y (all)	25,000	30,840,480	95,631	117,971,794
213	COLORADO VALLEY	Y (all)	200	246,724	4,557	5,621,023
214	PIUTE VALLEY	Y (all)	300	370,086	5,039	6,216,331
215	BLACK MOUNTAINS AREA	Y (all)	1,300	1,603,705	6,048	7,460,509
216	GARNET VALLEY	Y (all)	400	493,448	3,366	4,151,795
217	HIDDEN VALLEY (NORTH)	Y (all)	200	246,724	2,275	2,805,953
218	CALIFORNIA WASH	Y (all)	2,200	2,713,962	10,568	13,036,283
219	MUDDY RIVER SPRINGS AREA (UPPER)	Y (all)	100 to 3,6000	123,362 to 44,410,291	14,557	17,958,399
220	LOWER MOAPA VALLEY	Y (all)	50	61,681	5,721	7,057,930
221	TULE DESERT	N	2,100	2,590,600	5,004	6,172,562
222	VIRGIN RIVER VALLEY	Y (all)	3,600	4,441,029	12,343	15,226,056
223	GOLD BUTTE AREA	N	500	616,810	1	1,382
224	GREASEWOOD BASIN	N	300	370,086	4	4,996
225	MERCURY VALLEY	N	24,000	29,606,861	0	0
226	ROCK VALLEY	N	24,000	29,606,861	0	0
227A	FORTYMILE CANYON-JACKASS FLATS	N	24,000	29,606,861	58	71,969
227B	FORTYMILE CANYON-BUCKBOARD MESA	N	24,000	29,606,861	0	0
228	OASIS VALLEY	Y	24,000	29,606,861	1,296	1,598,869
229	CRATER FLAT	N	24,000	29,606,861	681	840,539
230	AMARGOSA DESERT	Y (portion)	24,000	29,606,861	25,479	31,431,211

Groundwater

The current understanding of regional groundwater flow in the Great Basin came from the basin studies done under the U.S. Geological Survey and the State of Nevada cooperative groundwater program. Maxey and Eakin (1949) compared recharge and discharge estimates of individual basins and realized that many basins were not closed to groundwater transfer to or from adjacent basins. Eakin (1966) identified a system of interconnected basins of the White River and Muddy River springs area. The water budget imbalances within and between basins was useful in discerning interbasin flow and defining the basins of the White River flow system (part of the Colorado River flow system).

In southern Nevada, groundwater flow is strongly influenced by the physical framework of the system, which is characterized by aquifers, confining units, and flow barriers. Groundwater flows through a diverse assemblage of rocks and sediments in the region, and geologic structures exert significant control on groundwater movement as well (Faunt and others 2010).

The groundwater hydrology of southern Nevada, as in all flow systems, is influenced by geology and climate and varies with time. In general, groundwater moves through permeable zones under the influence of hydraulic gradients from areas of recharge to areas of discharge in the regional system. The topography produces numerous local subsystems within the major flow system (Freeze and Cherry 1979). Water that enters the flow system in a recharge area may be discharged in the nearest topographic low, or it may be transmitted to a regional discharge area (Faunt and others 2010).

Aquifers

An aquifer is "a geologic unit that can store and transmit water at rates fast enough to supply reasonable amounts to wells" (Fetter 2001: 95). The Basin and Range aquifers are located in an area that comprises most of Nevada. The water-yielding materials in this area are in valleys and basins, and consist primarily of unconsolidated alluvial-fan deposits, although locally flood plain and lacustrine (lake) beach deposits may yield water to wells. Also, the consolidated volcanic and carbonate rocks that underlie the unconsolidated alluvium are a source of water if the consolidated rocks are sufficiently fractured or have solution openings. Many of these valleys and basins are internally drained; that is, water from precipitation that falls within the basin recharges the aquifer and ultimately discharges to the land surface and evaporates within the basin. Groundwater is generally unconfined at the margins of the basins, but as the unconsolidated deposits become finer grained toward the centers of the basins, the water becomes confined. The current conceptual model of interbasin flow suggests that basins are hydraulically connected in the subsurface by fractures or solution openings in the underlying bedrock. These multiple-basin systems end in a terminal discharge area, or sink, from which water leaves the flow system by evapotranspiration. Also, several basins or valleys may develop surface-water drainage that hydraulically connects the basins, and groundwater flows between the basins, mostly through the unconsolidated alluvial stream/floodplain sediments (Planert and Williams 1995).

Three principal aquifer types exist within southern Nevada: volcanic-rock aquifers, which are primarily tuff, rhyolite, or basalt of Tertiary age; carbonate-rock aquifers, which are primarily limestones and dolomites of Mesozoic and Paleozoic age; and basin-fill aquifers, which are primarily unconsolidated sand and gravel of Quaternary and Tertiary age. Any or all three aquifer types may be in, or underlie, a particular basin and constitute three separate sources of water; however, the aquifers may be hydraulically connected to form a single source. Other rock types within the region have low permeability and act as boundaries to the flow of fresh groundwater (Planert and Williams 1995).

Regional Groundwater Flow Systems

The ground-water flow systems of southern Nevada are in individual basins and/or more hydraulically connected basins through which groundwater flows to a terminal discharge point or sink. Except for relatively small areas that drain to the Colorado River, water is not discharged to major surface-water bodies but is lost primarily through evapotranspiration. Each basin has essentially the same characteristics: the impermeable rocks of the mountain ranges serve as boundaries to the flow system, and the majority of the groundwater flows through basin-fill deposits and permeable rock formations of the mountain ranges. In the area where carbonate rocks underlie the basins, substantial quantities of water can flow between basins through the carbonate rocks and into the basin-fill deposits, but this water also is ultimately discharged by evapotranspiration. Most recharge to the basin-fill deposits originates in the mountains as snowmelt, and, where the mountain streams emerge from bedrock channels, the water infiltrates into the alluvial fans and replenishes the basin-fill aquifer. Intense thunderstorms may provide some direct recharge to the basin-fill deposits, but, in most cases, any rainfall that infiltrates the soil is either immediately evaporated or taken up as soil moisture. Thus, little water percolates downward through the unsaturated zone to reach the water table in the valleys. In mountain areas underlain by permeable carbonate rocks, most of the recharge may enter the carbonate rocks and little water remains to supply runoff (Planert and Williams 1995).

Groundwater flow in southern Nevada is dominated by interbasin flow with several relatively shallow and local flow systems that are superimposed on deeper intermediate and regional flow systems (fig. 3.1). The regional groundwater flow patterns do not coincide with local topographic basins. Regional groundwater flow generally follows the regional topographic gradient as water moves toward the lowest point in the region at Death Valley, California, for groundwater flow systems in the Great Basin (Faunt and others 2010) or toward the Colorado River for those groundwater flow systems in the Colorado River drainage (Harrill and others 1988).

Interbasin flow has been established by scientific studies over the past century. Interbasin flow, although it is not uniform between all basins, is common and is a function of the hydraulic gradient between basins and hydraulic conductivity of the intervening rocks. Several decades of geologic and hydrologic work in the Great Basin province led to the conclusion that groundwater flow results from an interconnected, complex groundwater flow system (Carpenter 1915; Eakin 1966; Eakin and Moore 1964; Eakin and Winograd 1965; Harrill and others 1988; Hunt and others 1966; Mendenhall 1909; Mifflin 1968; Mifflin and Hess 1969; Winograd and Thordarson 1975). Knowledge of interbasin groundwater flow through bedrock and basin-fill deposits of the region is the basis for regional groundwater management and water-resource planning in the Great Basin province. The concept and development of interbasin flow is summarized in Belcher and others (2009).

In the prevailing conceptual model of interbasin flow, water enters the system as interbasin underflow and as recharge from precipitation in upland areas. Because of present-day arid conditions, present-day recharge is restricted to higher altitudes; virtually no recharge occurs and no perennial surface water flows in the lowlands and valley floors (Winograd and others 2005). Groundwater flow paths within the system diverge from the highlands and are superimposed on deeper regional flow paths that are controlled largely by flow in the regional carbonate-rock aquifer. The SNAP area

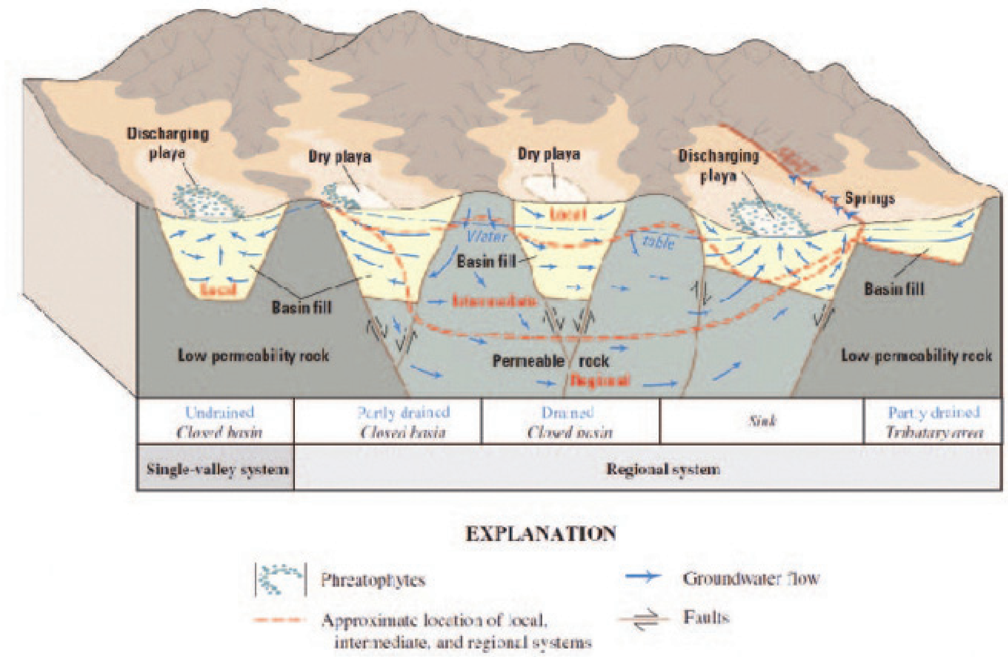

Figure 3.1—Schematic block diagram illustrating the structural relations between mountain blocks, valleys, and groundwater (interbasin) flow (Faunt and others 2010; modified from Eakin and others 1976).

is contained within two regional groundwater flow systems: the Death Valley flow system and the Colorado flow system (Harrill and others 1998; fig. 3.2). The Death Valley flow system is located in the southern part of the Great Basin province and is approximately 100,000 km^2 in area; it consists of recharge areas in the mountains of central and southern Nevada and discharge areas of wet playas and springs south and west of the Nevada National Security Site and in Death Valley, California. The Colorado flow system is located in the Colorado River drainage system just east of the southern part of the Great Basin and is approximately 42,000 km^2 in area. Recharge areas are in some mountainous areas within the flow system, but recharge to the system is also from groundwater flow from adjacent flow systems. The Virgin and Colorado Rivers are the major discharge areas of the system.

Water Budgets

A basic way to evaluate the occurrence and movement of groundwater in an aquifer system is to develop a water budget accounting for the aquifer system's inflows (recharge) and outflows (discharge) (Laczniak and others 2007). A water budget is developed to evaluate the balance between the flow into and flow out of a groundwater flow system. The primary components of a regional water budget are natural discharge (evapotranspiration and spring flow), pumpage, recharge, and lateral flow into and out of an area (estimated by using Darcy calculations or existing water budgets). The introduction of pumping as a discharge from the flow system initially decreases hydraulic heads and ultimately affects one or more flow components by decreasing natural discharge or by increasing recharge, as well as by removing groundwater from aquifer storage (San Juan and others 2010).

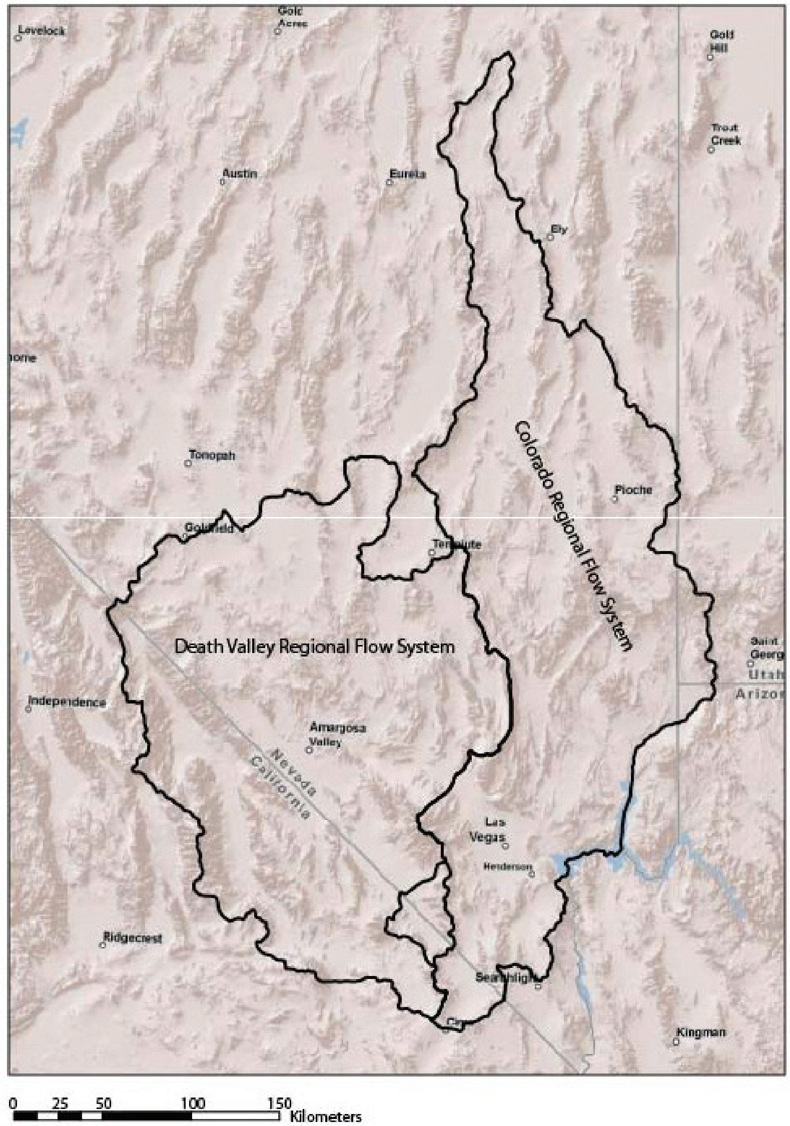

Figure 3.2—The Death Valley and Colorado regional groundwater flow systems (Harrill and others 1998).

The relation between precipitation and evapotranspiration is a major factor in water availability. Generally, if annual precipitation exceeds annual potential evapotranspiration, then there is a net surplus of water and streamflow is perennial. However, annual potential evapotranspiration can exceed annual precipitation, which causes a net deficit of water. A net annual moisture deficit occurs almost everywhere in Nevada. Water is available to recharge aquifers only at times when precipitation or snowmelt is greater than actual evapotranspiration (Planert and Williams 1995).

Current sources of groundwater flow in the region are (1) recharge from precipitation in the mountains (usually winter storms) within the model domain, and (2) lateral flow into the study area, predominantly through the carbonate-rock aquifer via interbasin flow. Most groundwater recharge results from infiltration of precipitation and runoff on the mountain ranges (Bedinger and others 1989). Water may infiltrate from melting snowpack in the mountains primarily on volcanic or carbonate rocks or adjacent to the mountains from streams flowing over alluvium (fans and channels) (Harrill and Prudic 1998).

Groundwater discharge in the region is from:

1. seeps and spring flow from the regional carbonate-rock aquifer and local systems;
2. evapotranspiration (ET);
3. pumpage for irrigation, mining, public supply, commercial, and domestic uses; and
4. subsurface flow in or out of the groundwater basins of the study area (Harrill and others 1988).

Most natural groundwater discharge today originates as spring or seep flow caused by variations in permeability created by geologic structures and varying lithologies (Winograd and Thordarson 1975). In particular, many of the regional (larger volume and higher temperature) springs occur along major faults. For example, at Ash Meadows, a high concentration of springs exists. More than 30 springs and seeps are aligned in an approximate linear pattern spanning about 10 miles. Spring discharge varies substantially across the area with a maximum measured discharge of nearly 3,000 gal/min at Crystal Pool. The combined measured discharge has been estimated at about 10,500 gal/min. More than 80 percent of the measured springflow discharges from nine of the springs (Laczniak and others 1999). Groundwater flow is impeded by the presence of one or more buried faults (Gravity fault) that down drop the carbonate bedrock block beneath and west of Ash Meadows. The contrast in hydraulic properties between the more permeable faulted and fractured carbonate rock and the juxtaposed, less permeable basin-fill deposits hinders southwestwardly flowing groundwater forcing it upward to the surface, producing the springs at Ash Meadows (Winograd and Thordarson 1975). Pohlmann and others (1998) concluded that springs in Black Canyon south of Hoover Dam included components from local, sub-regional, and Lake Mead sources. These local springs are unrelated to large, regional groundwater flow systems like those in the carbonate-rock aquifer. Justet and others (in preparation) reach similar conclusions with these springs being from locally derived groundwater most likely driven by the hydrostatic pressure of Lake Mead.

Most regional spring discharge is ultimately consumed by evapotranspiration. Major discharge areas primarily occur in the lower part of intermontane valleys where the potentiometric surface is near or above land surface.

In addition to direct spring flow measurement, natural groundwater discharge in the SNAP area is estimated by calculating ET. The underlying assumption of this approach is that most of the groundwater issuing from springs and seeps within a discharge area ultimately is evaporated or transpired locally and therefore is accounted for in estimates of ET. Evapotranspiration (ET) refers to water evaporated or transpired from the regional groundwater flow system, not water evapotranspired from precipitation infiltrating into the shallow flow system. ET estimates in the SNAP area includes work presented in reports by Laczniak and others (1999, 2001) and DeMeo and others (2003, 2006) for Ash Meadows and the Death Valley flow system and DeMeo and others (2008) for the Colorado River flow system. These investigations were similar in that continuous micrometeorological data were collected to estimate local ET rates, and remotely sensed multispectral data were used to distribute measured ET rates over the area evaluated.

Discharge also occurs as pumping for irrigation, mining, public supply, commercial, and domestic uses (Bedinger and others 1989; Moreo and Justet 2008; Moreo and others 2003). Since 1959, pumpage inventories have been conducted almost annually by the NDWR in Pahrump Valley, and since 1983, almost annually in all valleys with irrigation (NDWR 2011, http://water.nv.gov/data/pumpage/, last accessed May 26, 2011). Moreo and Justet (2008) compiled pumpage estimates for the Death Valley regional flow system, which comprises a large part of the SNAP study area.

Lateral flow from one basin to another (interbasin flow) has been compiled by Harrill and others (1988) based on the series of reconnaissance reports done under the U.S. Geological Survey and the State of Nevada cooperative groundwater program.

Surface Water

In the study area, perennial streamflow is sparse, with the exception of the Colorado River drainage. Most surface water in the region is either runoff or spring flow discharge. Precipitation falling on the slopes of the mountains forms small, intermittent streams that quickly disappear and infiltrate as groundwater recharge. In addition, several streams originate from snowmelt in the high altitudes of the Spring Mountains. Both of these types of streams have highly variable base flows and in dry years have almost imperceptible discharges. Springs maintain perennial flow for short distances in some of the drainages.

Fluvial Systems

In most of Nevada, nearly all the streams that originate in the mountains are ephemeral and lose flow to alluvial aquifers as the streams emerge onto the valley floors. In southern Nevada, there are three main fluvial systems: The Colorado River (Lakes Mead and Mohave), the Virgin and Muddy Rivers, and the Las Vegas Wash (fig. 3.3). The Colorado River is supplied primarily by runoff from the Rocky Mountains. The Virgin and Muddy Rivers and the Las Vegas Wash are all tributaries to the Colorado River. The Muddy River begins as a series of regional springs in Moapa Valley and drains into the northern arm of Lake Mead (Colorado River). The Virgin River originates in Navajo Reservoir in southwestern Utah and enters Lake Mead from the north (forming the northern arm of the lake). Prior to the construction of the Hoover Dam, the Muddy River joined the Virgin River. The Las Vegas Wash drains Las Vegas Valley and largely contains urban runoff, shallow groundwater, reclaimed water, and storm water runoff. The Las Vegas Wash supports a large wetland. USGS measures discharge on all four of these rivers.

Flow in the Colorado River and its tributaries (Muddy and Virgin Rivers) is monitored by entitlement holders, the Bureau of Reclamation, and the USGS. The flow is monitored to assess the amount of Colorado River that is diverted, returned, and consumptively used to determine whether individual users have exceeded their entitlement of water (Matuska 2011). The Southern Nevada Water Authority and the USGS have measured water quality on the Muddy River at various times as part of tributary inflow to Lake Mead. The USGS has monitored water quality (temperature, specific conductance, sediment concentration, and chemical analyses) on the Virgin River since 1948 to assess salt-loading problems by establishing baseline loading conditions over a variety of hydrologic conditions.

The Colorado River drainage is the main source of water for southern Nevada. Approximately 90 percent of southern Nevada's water resources are obtained from the Colorado River and its tributaries (Southern Nevada Water Authority 2011, http://www.snwa.com/html/wr_index.html, last accessed May 26, 2011). The state of Nevada is permitted, by the Colorado River Compact of 1922 and the Boulder Canyon Project Act of 1928, an allotment of 300,000 acre-feet per year from the Colorado River and its tributaries.

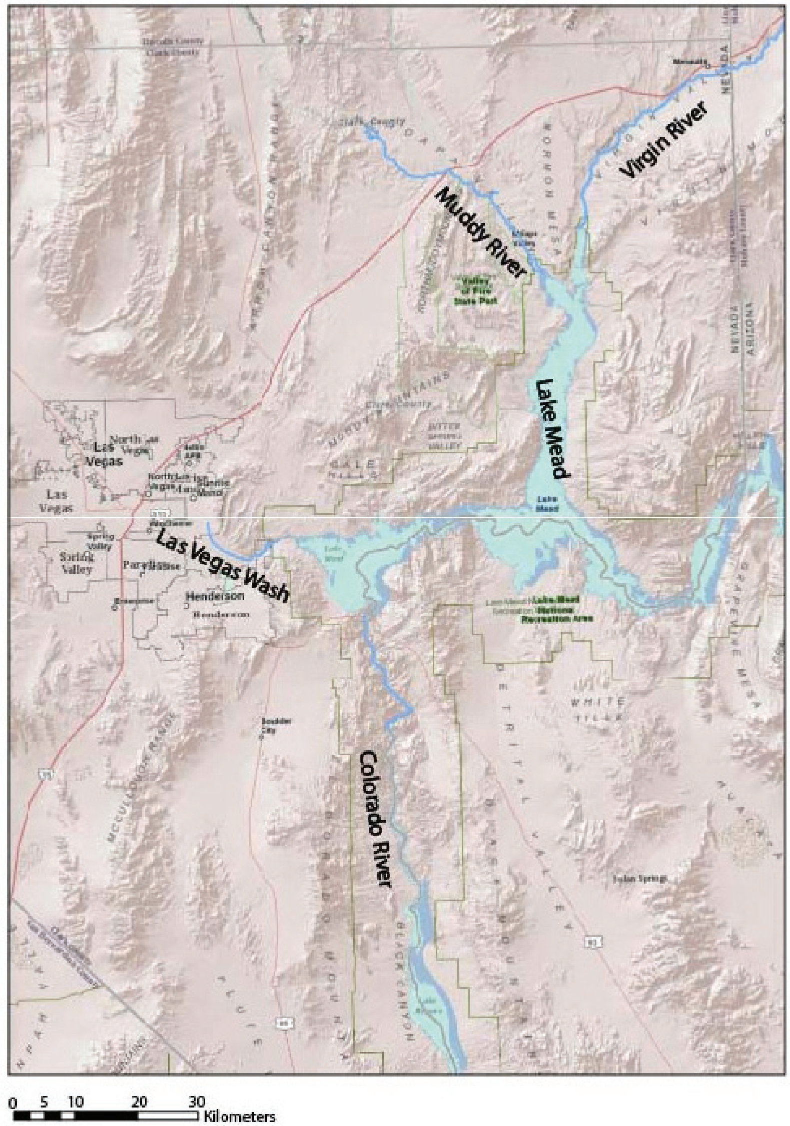

Figure 3.3—Perennial fluvial system in southern Nevada.

Springs

A spring is where groundwater flows to the land surface. Spring discharge can form pools or creeks and can provide water to plants and animals. Most of the groundwater discharged naturally in southern Nevada flows from springs and seeps. Springs also are an important and complex component of the groundwater budget. Spring discharge can originate from a local or regional source, or a mixture of more than one source. Geography, geology, and precipitation control spring discharge. Discharge from springs can flow along the land surface, infiltrate back into the groundwater system, evaporate, be transpired, or undergo a combination of these processes. Measurable properties of spring discharge reflect these sources, controls, and processes, and therefore can be used to estimate local or regional components of the study area groundwater budget.

In southern Nevada, springs are an important water resource. Historically, Native Americans, early pioneers, miners and settlers, and modern residents (including farmers and ranchers) have used spring water for drinking, bathing, agriculture, mining, and recreational purposes. Many of the settlements and towns in the study area are located near larger springs that have been a source of water for humans since Native Americans began utilizing them thousands of years ago. Springs in southern Nevada support a large amount of the aquatic and riparian species in arid regions (Fisher and others 1972; Gubanich and Panik 1986; Myers and Resh 1999; Williams and Koenig 1980).

Because springs are sourced ultimately in groundwater, increased groundwater pumping from existing wells and new points of diversion, could impact nearby water-dependent ecosystems by reducing the amount of groundwater discharge and decreasing shallow water tables. Increased pumping could result from increasing water supplies for population growth and from the development of solar power plants. Springs emanating from perched aquifer systems in the higher mountain ranges in the study area are threatened by climate change.

Springs help sustain unique aquatic, riparian, and phreatophytic ecosystems, some of which support threatened or endangered species endemic to the region. Some of the more recognizable threatened or endangered species include the Devils Hole pupfish (*Cyprinodon diabolis*), the Ash Meadows Amargosa pupfish (*Cyprinodon nevadensis mionectes*), and the Moapa dace (*Moapa coriacea*) (http://www.fws.gov/endangered/, last accessed Sept. 1, 2011).

Groundwater discharges at the Ash Meadows National Wildlife Refuge, Pahranagat National Wildlife Refuge, the Moapa Valley, at numerous springs and seeps in the mountainous areas, and along parts of the Amargosa River. Additionally, groundwater is intersected at Devils Hole, a fissure in the regional carbonate-rock aquifer in the Ash Meadows area. Several hundred springs are scattered throughout Clark County and basic environmental and biological characteristics of the larger discharge springs have been inventoried (Sada 2000; Sada and Nachlinger 1996, 1998). The MSHCP reported 506 springs in Clark County, although most of these springs dry frequently and fewer than 200 springs occur persistently in Clark County (Sada, 2000; Sada and Nachlinger 1996, 1998). Most springs can be classified as local (low discharge and cool temperatures) or regional (high discharge and warmer temperatures).

Local Springs—Local springs are generally low volume, low temperature springs that mostly discharge from areas within the mountain ranges of southern Nevada. These local springs are believed to be derived from local recharge from precipitation. Local springs occur both at higher altitudes in mountainous areas and at lower altitudes adjacent to mountain fronts. The higher altitude springs are less susceptible to impacts from pumping than their lower altitude counterparts. Because these local springs are dependent on local recharge from precipitation, changes in precipitation patterns as a result of climate change could impact their discharge. In most cases, only the locations of the springs (derived from the USGS National Hydrologic Dataset) are available. Discharge and water quality information is not routinely collected for most local springs by the USGS or any other Federal, state, or local agency. The Nevada Natural Heritage Program classifies one wetland in the extreme southern part of the study area as a "priority wetland" for conservation: Mojave riparian wetlands along the Colorado River below Davis Dam (Skudlarek 2008).

In the Spring Mountains, water moving laterally from bedrock and alluvial aquifers to the surface form the over 100 surveyed springs (Hershey 1989; Purser 2002; Sada and Nachlinger 1998). Spring discharge varies from year to year with some springs drying up annually, some drying only after extended droughts, and others flowing continuously

(Sada and others 2005). A few perennial streams (such as Carpenter Canyon, Clark Canyon, Cold Creek, Deer, McFarland, Santa Cruz, Sawmill, and Willow) are associated with large springs and/or spring complexes (Hughes 1966; Maxey and Jameson 1948; Nachlinger and Reese 1996).

Regional Springs—Regional high-volume springs having flows greater than 1,500 cubic meters per day (m^3/d) discharge in Ash Meadows (60,000 m^3/d), Manse Spring in Pahrump Valley (5000 m^3/d), Pahranagat Valley (60,000 m^3/d from Hiko, Ash, and Crystal Springs), the Muddy River springs area in Moapa Valley (10,500 m^3/d), and Rogers and Blue Point Springs along Lake Mead in the Muddy Mountains (4,200 m^3/d and 1,400 m^3/d, respectively) (fig. 3.4). Typically, these regional springs discharge water with temperatures greater than 30 degrees Celsius (°C) directly from the rocks that make up the regional carbonate-rock aquifer (Harrill and Prudic 1998; San Juan and others 2010). Discharge from these large springs is typically taken up by evapotranspiration. The exception to this is Muddy Springs in Moapa Valley, which discharge into the Muddy River (Harrill and Prudic 1998). Discharge from these regional springs is measured by the USGS and cooperating agencies and entered into NWIS.

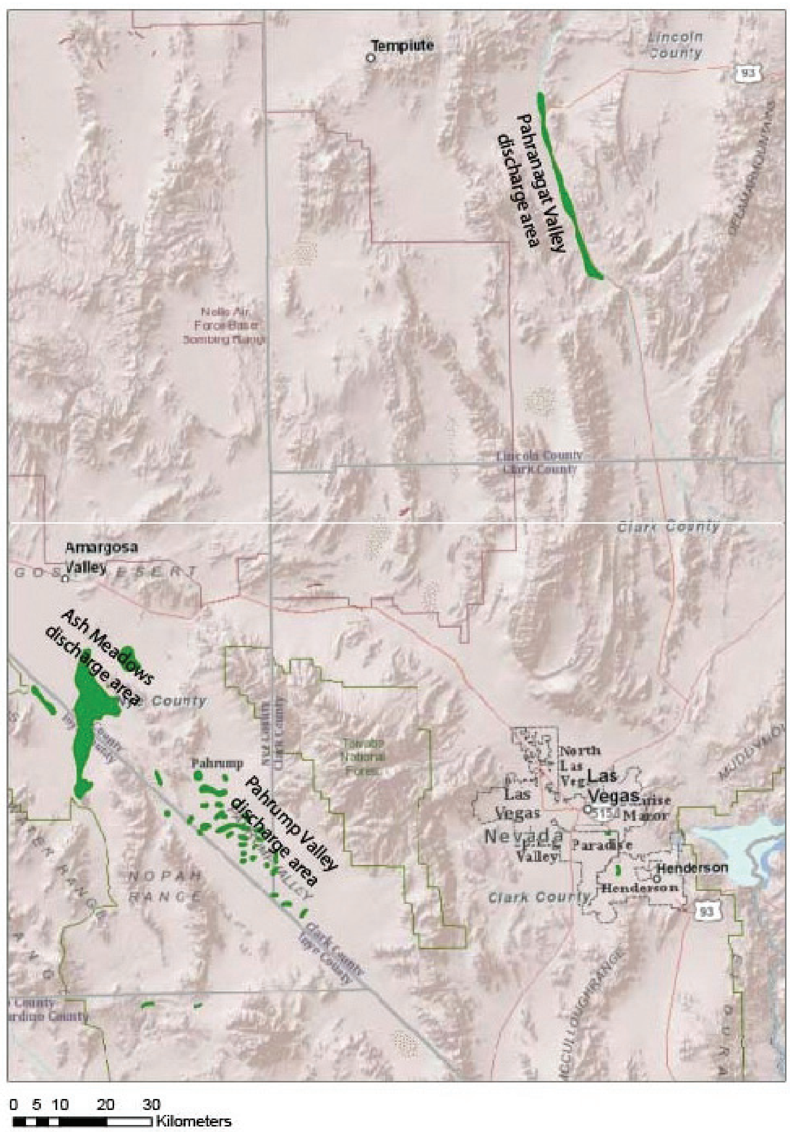

Figure 3.4—Regional spring discharge areas in southern Nevada (Harrill and others 1988).

In some areas in southern Nevada (Ash Meadows in the Death Valley regional system and the Virgin River in the Colorado River system), diffuse discharge has been estimated by using micrometerological stations and remote sensing to estimate the amount of regional evapotranspiration from some major discharge areas in southern Nevada (DeMeo and others 2008; Laczniak and others 2001).

Water Chemistry

Water chemistry issues within the Lake Mead National Recreation Area (LAME) probably have the greatest visibility in Southern Nevada. Lake Mead is the largest and one of the most intensely used reservoirs in the western United States. Many human activities can affect the chemistry of water in Lake Mead such as boating and fishing, runoff from agricultural lands, inflows of treated wastewater, and urban runoff. Many of the water chemistry issues that affect LAKE have been summarized in a U.S. Geological Survey (USGS) Circular titled Lake Mead National Recreation Area Aquatic Ecosystem (Rosen and others 2012).

Perchlorate and mercury are two contaminants that have been found in LAME that have anthropogenic sources (Shimshack and others 2007; USEPA 2001). Studies suggest that perchlorate and mercury may have health effects on fish populations in LAME (Cizdziel and others 2003; Crouch 2003; Kramer 2009; Snyder and others 2002). Concentrations of organic contaminants have been high enough in Lake Mead to cause toxicity or endocrine disruption to aquatic organisms (Advanced Concepts and Technologies International 2010). Better understanding of the sources, transport, and fate of contaminants is important to understanding their effects on aquatic organisms and the overall aquatic ecosystem of LAME.

Water chemistry has been studied in several rivers in the southern Nevada, most notably the Muddy and Virgin Rivers. The USGS has analyzed a variety of chemical constituents in samples from these rivers including major ions, nutrients, and pesticides. Although these data have not been analyzed, the results suggest that anthropogenic activities influence the chemistry of water in these rivers. In desert landscapes common in Southern Nevada, springs provide the only reliable source of water and support unique ecosystems. The chemistry of water from springs is critical to the abundance and diversity of species found at springs (Sada and others 2005). For example, spring snails are restricted to portions of springs that provide suitable physical and chemical conditions (Sada 2008). In general, human disturbances of the natural ecosystems at springs have been limited to livestock trampling and recreation and have not resulted in significant changes in the water chemistry of springs.

The USGS has conducted several intensive studies of the water chemistry of springs in several areas of Southern Nevada region. Samples from 28 springs throughout Clark County were collected from July 2008 to September 2010 and analyzed for a variety of chemical constituents. Results indicate that the groundwater from these springs is derived from various aquifers in the region. In Black Canyon south of Hoover Dam, springs support unique riparian ecosystems. Using geologic and geochemical methods, it was determined that the source of water to springs in Black Canyon is locally derived groundwater most likely driven by the hydrostatic pressure of Lake Mead (Justet and others, in preparation).

Hydrologic and Water Quality Data Collection

The USGS investigates the occurrence, quantity, quality, distribution, and movement of surface and groundwater and disseminates the data to the public: Tribal, state, and local governments; public and private utilities; and other Federal agencies involved with managing Nevada's water resources. In 1889, the U.S. Geological Survey established its first gaging station in Nevada that provides data to the public about Nevada's water resources.

The USGS has a distributed water database that is locally managed within the Nevada Water Science Center. Surface water, groundwater, and water quality data are compiled from these local, distributed databases into a national information system. Data collected on behalf of or by cooperating agencies is compiled, quality-assured, and entered into the database. Information from these sites is served on the Internet through NWISWeb, the National Water Information System Web Interface. NWISWeb provides all USGS water data that are approved for public release.

The USGS also collects and analyzes chemical, physical, and biological properties of water, sediment, and tissue samples. The NWISWeb discrete sample database is a compilation of over 4.4 million historical water quality analyses in the USGS district databases through September 2005. The discrete sample data is a large and complex set of data that has been collected by a variety of projects ranging from national programs to studies in small watersheds. At selected surface-water and groundwater sites, the USGS maintains instruments that continuously record physical and chemical characteristics of the water including pH, specific conductance, temperature, dissolved oxygen, and percent dissolved-oxygen saturation. Supporting data such as air temperature and barometric pressure are also available at some sites. Published and provisional hydrologic and water quality data collected or compiled by the USGS are available online: http://waterdata.usgs.gov/nv/nwis/nwis.

The USGS and various DOE contractors routinely collect groundwater levels at the NNSS to aid in the development of the groundwater models. USGS collected data is entered into NWIS, but much of the information collected by DOE contractors is not. Data from the USGS NNSS programs, in addition to being available in NWIS, are available at: http://nevada.usgs.gov/doe_nv/. While budget constraints at the DOE for monitoring has resulted in a reduced monitoring network, many Federal agencies still see value in continuing to collect this information. Many wells from the old Yucca Mountain monitoring network have been picked up for continued water-level data collection by Interior agencies (USGS, BLM, and FWS) and Nye County.

To assist with these efforts to better understand the dynamics of Lake Mead, the USGS, in cooperation with the National Park Service, Southern Nevada Water Authority, and Clark County Water Reclamation, collects water-quality, water-velocity, and meteorological data as part of its Lake Mead Monitoring Network. Studies are currently underway to determine temporal changes and spatial distributions of natural and anthropogenic chemical compounds in Lake Mead. The USGS currently maintains one monitoring station on the lake in Boulder Basin south of Sentinel Island. The Sentinel Island station records depth-dependent measurements of water temperature and specific conductance and hourly averaged meteorological data (air temperature, relative humidity, solar and net radiation, and wind speed and direction). The Black Canyon station records depth-dependent measurements of water temperature, specific conductance, dissolved oxygen, pH, and turbidity. The water-quality data are collected every 6 hours beginning each day just after midnight. Both stations are equipped to record hourly water-velocity data.

The Southern Nevada Water Authority (SNWA) collects water-quality data from source water as well as finished drinking water as part of providing a safe drinking water supply to the Las Vegas metropolitan area. This includes collecting water-quality data from Lake Mead, the largest source of drinking water for Las Vegas. The USGS cooperates with SNWA to collect water-quality data from Lake Mead as well as other areas of southern Nevada including the Virgin River and Colorado River below Hoover Dam. Other Federal, state, and local agencies collect water-quality data in southern Nevada including the U.S. Bureau of Reclamation (BOR), the U.S. Environmental Protection Agency (EPA), the Clark County Water Reclamation District (CCWRD), the City of Las Vegas, and the City of Henderson. The BOR collects water-quality data from Lake Mead while the EPA collects water-quality data below Hoover Dam. The CCWRD, City of Las Vegas, and City of Henderson cooperate to collect water-quality data at a number of sites in the Las Vegas Wash and from Lake Mead.

Knowledge Gaps and Management Implications

As climate change and increasing populations potentially reduce available water supplies for both human and biologic communities, the collection and interpretation of information to define and assess local and regional hydrologic conditions becomes vital. Assessing the information that is regularly collected by Federal agencies in southern Nevada has indicated that there are several gaps in data collection. Since there tends to be a project by project approach to data collection, at times there is no long term program(s) to collect data. Data are collected for the goals of a certain project and once the project is completed, data collection ends. There is very little long-term continuity or planning on basic data collection that could be used to assess the hydrologic and biologic health of the study area.

Base Conditions of Springs and Rivers

Base conditions of springs and rivers just prior to settlement of southern Nevada are largely unknown. A qualitative assessment of these conditions could be accomplished by examining historical records (such as early settler diaries and journals, military exploration reports, and 19th century scientific reports) and compiling observations of streamflow and springs conditions.

Water Levels

Water levels are currently collected by a variety of agencies over the SNAP area for a variety of purposes. This work is primarily project based. Collection of water-level data is concentrated in few areas (for example, Las Vegas Valley, Pahrump Valley, Amargosa Desert, and the Nevada National Security Site). For some hydrographic areas there is very little or no water-level data. The water level data is essential to establishing baseline conditions of and estimating amounts of regional groundwater flow. Work could be done to establish areas where a paucity of data exist and then canvass these areas for existing wells that could be used to collect water levels. In areas where no wells exist, it may be necessary to drill wells to be able to obtain water-level information.

Pumping Inventories

Currently, the pumping inventories in the study area are estimated by Nevada Division of Water Resources (NDWR) in irrigated valleys, along with some project specific work (such as the Death Valley regional flow system). A systematic method of estimating pumping using the existing inventories, along with remote sensing for the entire

SNAP study area on an annual basis would aid in estimating water budgets. Updating the water use data base would involve:

1. Acquisition and processing of Thematic Mapper imagery to estimate irrigated acreage;
2. Compiling State Pumpage Inventories;
3. Estimating, by user and location, annual groundwater pumpage; and
4. Entering annual pumpage estimates into a database.

Evapotranspiration Estimates

Estimates of evapotranspiration (ET) are performed by government and (or) scientific organizations on a project-by-project basis and rarely as a comprehensive program. Estimates of ET could be performed to assess the amount of water discharging from the regional groundwater system over the entire study area. These estimates could be repeated every few years to assess potential impacts of changing recharge due to climate change. High-resolution multi-spectral imagery will be used to delineate the extent, density, and diversity of riparian vegetation within groundwater discharge areas. Discharge area mapping techniques would be based on land-cover classification methods and defined vegetation index threshold values. The accuracy of these mapped discharge areas will be assessed with field-based ground-truth observations. Atmospheric and water-level data would be measured with micrometeorological stations consisting of eddy-covariance and energy-balance sensors. Each ET site will also be equipped with rain gages to measure precipitation, and a monitoring well equipped with a pressure transducer to monitor daily and seasonal groundwater-level fluctuations. Periodic collection of samples and additional field measurements will be needed to partition between phreatophytic consumptive use of groundwater, precipitation, and periodic surface water flow. At each ET site, precipitation, plant-stem water, soil water, groundwater, and surface water flow, if available, could be sampled quarterly and analyzed for stable hydrogen- and oxygen-isotope concentrations. The isotope data will be used as a tracer to evaluate the relative proportion of source waters (precipitation, groundwater, and possibly surface water) contributing to the measured ET. Soil-water content could be measured quarterly using a neutron-moisture probe to document seasonal changes in soil-water storage (upper 1 m) that occur in response to precipitation, surface water flow, and ET.

Recharge Estimates

Knowing the amount of recharge in the mountainous areas is an important component of a water budget. In the past, recharge amounts have been estimated using a variety of methods, with generally more sophisticated methods utilized as the processes involved in recharge became better known. Recently, more sophisticated methods of estimating the amount of recharge to the groundwater system have been developed. These newer methods should be used to get more accurate estimates of recharge for water budgets. Net infiltration has been used as a proxy for groundwater recharge from infiltration (San Juan and others 2010). Net infiltration for the DVRFS was estimated using a distributed-parameter method, INFILv3, described by Hevesi and others (2003). As an extension and improvement of this method, these existing estimates were refined and updated using the more recent Basin Characterization Model (BCM) that has been used in the Great Basin (Flint and others 2011). Direct measurement or improved estimates of precipitation could be helpful in refining these estimates of recharge. Additionally, both INFILv3 and BCM use streamflow estimates as calibration points; collection of more streamflow discharge could help to constrain the model.

Interbasin Flow

Knowing the amount of recharge from underflow from adjacent basins would help to refine water budgets and assess natural resource damage in a hydrographic basin from activities in adjacent basins. Currently there are rough estimates from the NDWR Reconnaissance Reports and from several regional groundwater models constructed for various uses in southern Nevada. A review of the existing hydrologic and geologic data and results from numerical models for both the Death Valley and Colorado flow systems could help to refine the amount of interbasin flow in the study area.

Spring Discharges

Establishing baseline conditions for spring discharge and water quality would be useful for restoration work, management guidelines and to better understand effects of climate change and other anthropogenic impacts to these ecosystems. Currently, several springs in the study area are monitored by various Federal agencies using full continuous stage/discharge streamgages or biennial or quarterly direct discharge measurements. These springs are mostly regional springs emanating from the carbonate-rock aquifer. While the regional springs play a significant role in evaluating overall water resource viability in the study area, more data are needed on important local springs in mountainous areas. These data would be useful for assessing water budgets and the potential for climate change associated with lessening recharge.

The collection of continuous stage/discharge data is required for calculating spring output and assessing seasonal and overall trends. For instance, a drop in stage and discharge at a given spring could indicate potential drawdown from pumping nearby. Not every local spring is large enough to support a full streamgage; field reconnaissance to assess target springs must be completed.

On those springs that support sensitive species of fish and other animals, water quality data are needed to establish baselines and direct conservation efforts. At the very least, simple water temperature probes can be installed for monitoring continuous water temperature data. For a more robust solution, continuous water quality probes that collect many different chemical parameters (i.e. temperature, conductance, pH, and turbidity) can also be considered. Historical baseline conditions of springs could be obtained by searching historical records from the 19th and early 20th centuries. Mendenhall (1909) has descriptions of springs in the Mojave Desert from the late 19th and early 20th centuries.

Streamgaging

Direct measurement of peak flows in natural streams presents a unique challenge in the desert environment. During summer monsoons, rain can be localized and peak flows on streams can last 30 minutes or less. A worker must essentially be on-site when the rain begins in order to measure summer peak flows. During winter rains, peak flows can last from several hours to several days but often contain very high sediment and debris loads, which make direct measurements extremely difficult and unsafe to attain. Acoustic Doppler profiling technology is favored for quickly measuring highly unstable elevated flows as measurements can be obtained in as little as 12 minutes. Recent advances in Doppler technology have made it more useful for measuring discharges with high sediment loads. Conventional current meter methods can also be used to measure discharge in those streams where Doppler would be impractical. Direct measurement of peak flows coupled with long term flow monitoring would greatly aid in assessing a more accurate total water budget for surface water. Although less preferable than long-term flow monitoring, short-term studies focusing on synoptic streamgaging (i.e. performing multiple discharge measurements on the same stream at the same time to provide a "snapshot" of conditions) would help improve understanding of where the streams lose or gain flow from the groundwater system.

Measurements of peak flows can be made either from a bridge or cableway or by wading. Wading is typically very unsafe in desert washes where the water can rise from a trickle flow to several feet deep in a short period of time. However, many streamgaging sites are located in areas where a bridge or cableway does not exist. In cases where a worker cannot enter the water to directly measure, an indirect measurement of discharge must be done after the water has receded. High water marks such as debris piles, mud lines, and cut marks are flagged and surveyed and an approximate discharge for the flood is computed. Indirect methods can be accurate to within 5 percent of true peak discharge, but often are only within 20 percent of the peak. More cableways must be funded and installed in areas where bridges do not exist.

While channel-mounted up-looking acoustic devices can work well for directly measuring discharge in unwadeable stable channels (for instance, concrete-lined irrigation ditches), they do not work well for most natural channels in southern Nevada due to scour and fill processes occurring in the channel during flow. Instrumentation installed in concrete-lined urban channels in the Las Vegas Valley have issues with vandalism, theft, and the potential for urban debris striking and damaging or destroying expensive equipment during periods of flow. Additionally, these urban channels undergo annual or semi-annual cleaning during which debris is scraped from the channel using heavy machinery. Any instrumentation placed in the channel has the potential to be damaged during these operations.

Should cableway installation be impractical and direct measurement of discharge impossible, a series of crest stage gages (CSGs) could be installed in selected indirect measurement reaches. A CSG is a piece of pipe with caps on the top and bottom vertically anchored next to a stream. There are a series of holes in the sides of the caps, a wooden stick inside the pipe, and powdered cork in a reservoir in the bottom cap. During high flows, water enters the bottom of the pipe through the holes in the cap and carries the powdered cork up as it rises inside the pipe. As the water recedes a cork line is left on the stick, which provides a very reliable high water mark from the flood. High water marks in CSGs are more accurate than those determined by debris piles, mud lines, or cut marks and help reduce the uncertainty in indirect discharge measurement computations. If several CSGs are installed in a given gaged reach, an accurate high water mark profile and slope can be determined. These, in turn, would be used to determine the amount of stream discharge that could be used to improve long-term monitoring efforts.

Water Chemistry and Quality

Numerous gaps in water-quality information exist in Southern Nevada and the data needed are dependent on the area of interest and the scientific question to be answered. An example of a data gap is the lack of information on stable isotopes of hydrogen and oxygen in precipitation water. Understanding the modern signature of stable isotopes in precipitation relative to groundwater is important in delineating modern from ancient recharge and enhances understanding of the sources and flow paths of groundwater and the sustainability of groundwater resources.

Data Repositories

While the USGS maintains a large database on hydrologic information (NWIS), there are hydrologic data collected by various governmental and scientific organizations that are not contained within these national databases and thus cannot be used for answering questions concerning management of the natural and cultural resources of the study area. Some effort needs to be put forth to capture these data and enter them into NWIS for use by scientists working in southern Nevada, as well as the general public.

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