5.0 OCCURRENCE AND MOVEMENT OF GROUNDWATER

In addition to the hydrogeologic framework, potentiometric data and locations of the major recharge and discharge areas are necessary to identify the occurrence and movement of groundwater within the flow systems of the study area. The compilation and analysis of potentiometric data are documented in Volume 4 of SNWA (2008a). The processes used to delineate the recharge and discharge areas and estimate the associated volumes are described in Sections 7.0 and 9.0, respectively. Relevant features are shown in Plate 1.

5.1 Groundwater Occurrence

Groundwater is known to occur within all the defined RMUs depending on their locations and volumes within the hydrogeologic framework model. However, only the saturated portions of the most expansive RMUs are considered to form major aquifers and to be relevant at the scale of this regional study. These RMUs include the UVF, LVF, UC, and LC. Groundwater occurring in both the UVF and LVF is termed the “basin-fill” aquifer, and groundwater occurring in the UC and LC is termed the “carbonate” or “regional” aquifer.

Although the basin-fill aquifer is discontinuous through the study area, it constitutes a major source of groundwater. This aquifer generally occurs within the valleys, between the mountain ranges, forming a series of aquifers. These basin-fill aquifers may be locally confined or semiconfined, but overall they are considered to form a major unconfined aquifer over most of the study area. Observed depth-to-water levels in the basin-fill aquifers are included in SNWA (2008a). Depth-to-water varies from above the ground surface in the discharge areas of some valleys to hundreds of feet beneath the floors of other valleys.

The carbonate aquifer is present everywhere in the study area, except where interrupted by calderas, and occurs under both confined and unconfined conditions. It is unconfined in areas where carbonate rocks crop out to the surface. The carbonate aquifer is confined in areas where a confining unit separates it from the basin-fill aquifer, as it is in the southern part of the study area where the Kps is present. In the northern part of the study area, the UC is separated from the LC by a confining unit, the UA. The LC is, therefore, under confined conditions in this area. Mean observed depth-to-water measurements in the carbonate aquifer are reported in SNWA (2008a).

5.2 Groundwater Movement

Although the general flow patterns in flow systems of the Great Basin region are understood, the flow patterns within the flow systems of the study area are subject to interpretation because of sparse data.

5.2.1 General Groundwater Flow Patterns

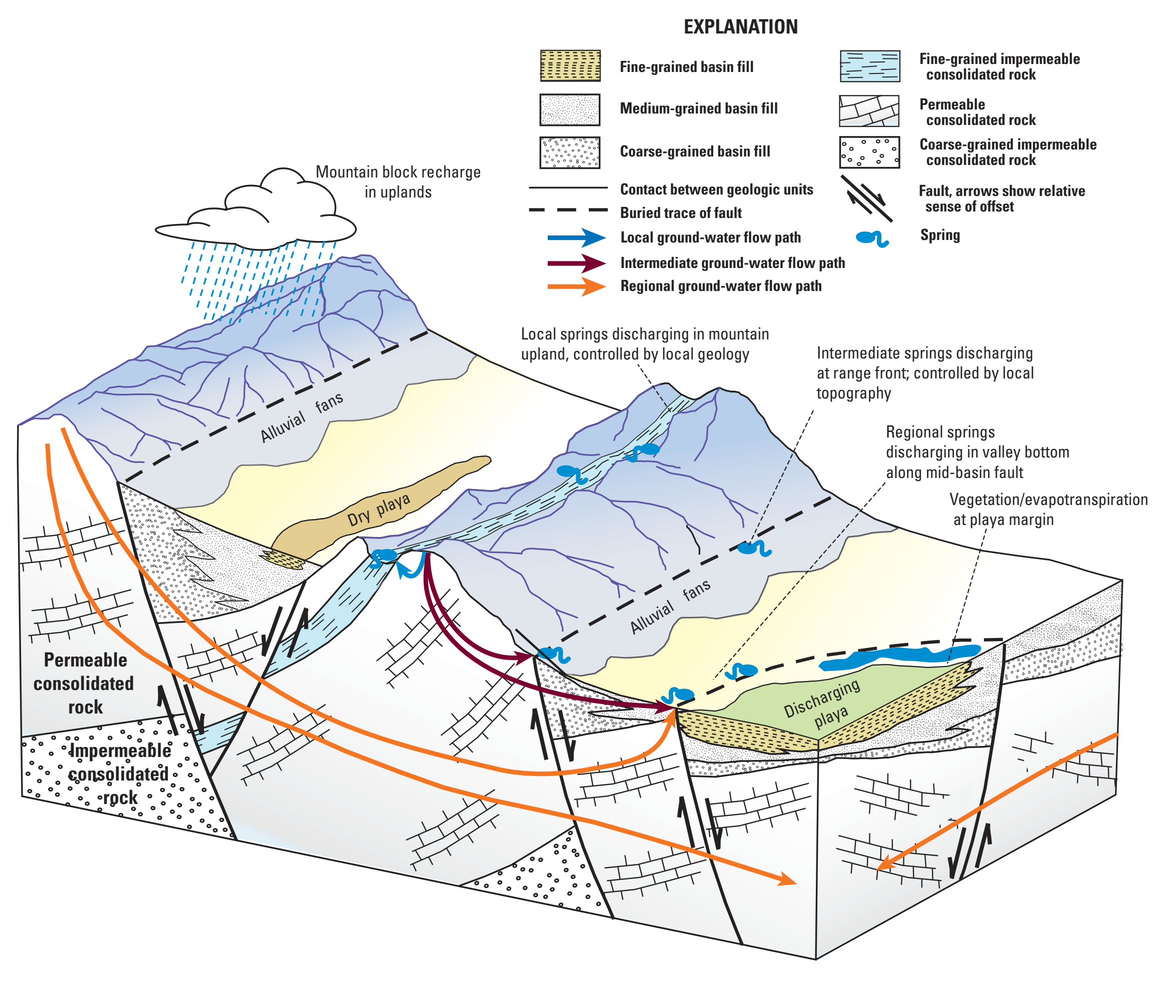
In general, a flow system can be subdivided into three subsystems as a function of their depth and the lengths of their flow paths. These are the so-called regional, intermediate, and local flow systems (Tóth, 1963; Freeze and Cherry, 1979) shown on Figure 5-1, as depicted by Welch et al. (2008). Welch et al. (2008, p. 38) describe the general flow patterns as follows:

> Local flow systems are characterized by relatively shallow and localized flow paths that terminate at upland springs. Local springs are low volume, tend to have temperatures similar to annual average ambient atmospheric conditions and have discharge that fluctuates according to the local precipitation. Intermediate flow systems include flow from upland recharge areas to discharge areas along the floor of the intermontane valley. Within intermediate-flow systems, springs typically discharge near the intersection of the alluvial fan and the valley floor near the range front. Intermediate-flow system springs often are of moderate volume and tend to have less-variable flow relative to local springs. Regional ground-water flow follows large-scale (tens to hundreds of miles) topographic gradients as water moves toward low altitudes in the region. Discharge from these regional flow systems manifests as large springs and, in some areas, extensive wetlands.

The maximum extent of a given regional flow system is defined by the longest flow paths between the most up-gradient recharge area and the most down-gradient discharge area. The flow system is usually named after this discharge area. The flow-system boundaries are usually selected to coincide with the hydrographic-area boundaries of the outer basins of the flow systems. The hydrographic-area boundaries coincide with the crests of the mountains, which provide most of the recharge to the flow system and typically form groundwater divides. A portion of the recharge from precipitation occurs in place on the mountain block. The remainder infiltrates through the beds of perennial and ephemeral streams located on the alluvial aprons from mountain-front runoff (Eakin, 1966; Frick, 1985). A portion of the recharge infiltrates in place within the mountain blocks, then moves through the subsurface to areas of lower groundwater potential located within the same basins (local and intermediate flow system) or other basins located down-gradient (regional flow systems). In some basins, this groundwater is forced to the surface by structural features in the form of large groundwater-discharge areas, which may include regional springs. Some of the recharge flows past the discharge areas and exits the basins via the subsurface. Water discharged from the regional springs exits the flow system through the process of ET in most basins. In some areas, however, spring discharge flows on the surface, and a portion of it exits the basins as stream discharge.

5.2.2 Groundwater Flow in Model Area

This section describes groundwater flow within the flow systems in the model area, including flow directions, flow system boundaries, and groundwater movement within each flow system.



Source: BARCASS Summary Report (Welch et al., 2008).

Figure 5-1
General Conceptual Model of Groundwater Flow

5.2.2.1 Regional Groundwater Flow Directions

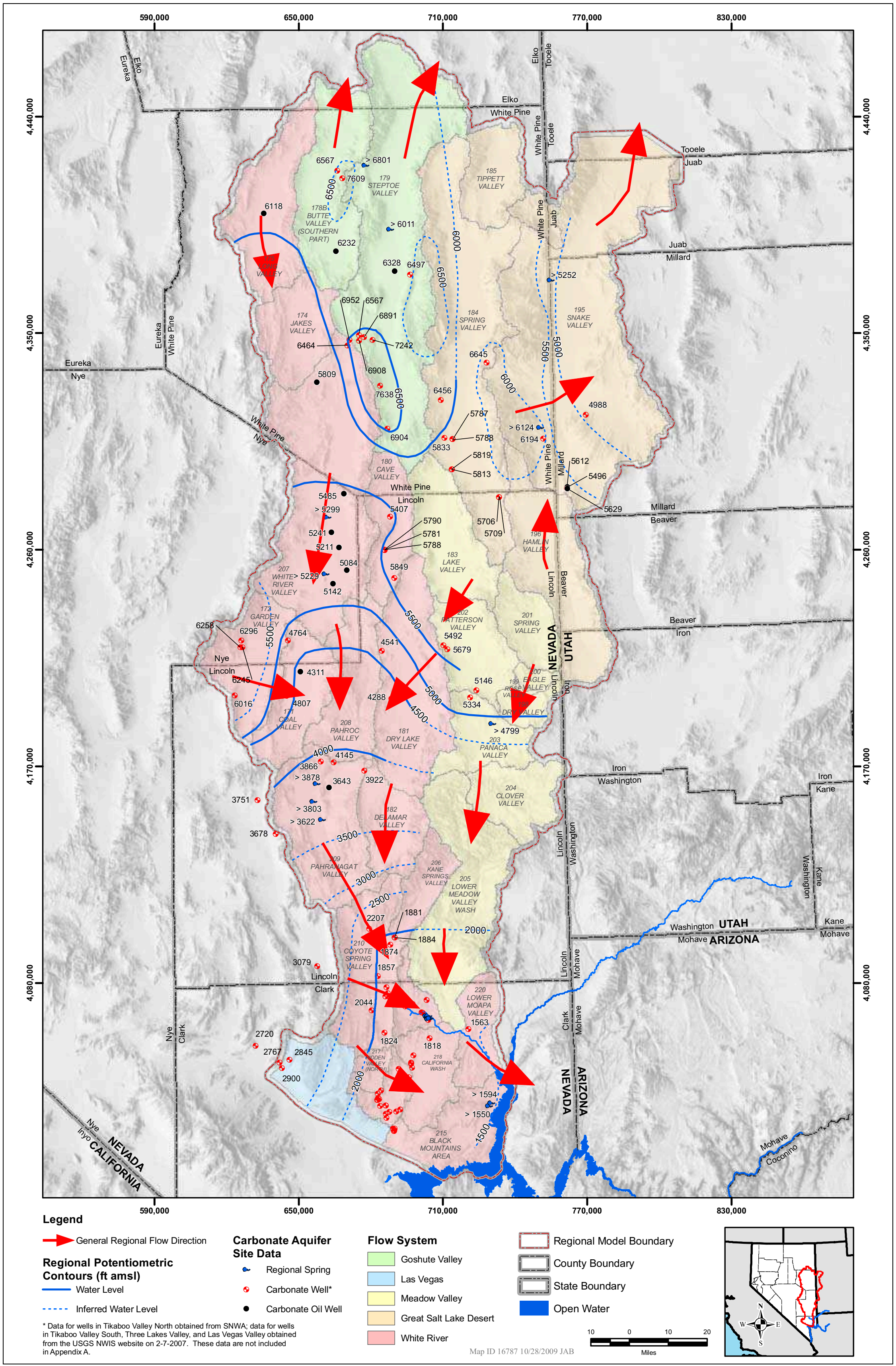
The northern part of the study area is higher in topography and precipitation than the southern area (Plate 1). Thus, wet valleys are found in the northern area, and dry valleys in the southern area. The study area is located in the central part of the Basin and Range Province where the extensional block faulting has produced the characteristic linear, northward-trending ranges and the intervening closed basins. The tectonic history has imprinted the rock mass with joints, faults, and fractures. Rock masses comprising such features are generally more permeable to groundwater than the rock matrix. The general direction of groundwater in the study area is from areas of both high precipitation and high topography to areas of low precipitation and topography.

Although data are available from a large number of wells in the study area, most wells are shallow and clustered in the central parts of the valleys where the water table is generally closest to the land surface. The current understanding of flow directions and quantities is constrained by the limited spatial distribution of the wells within the flow domain. The groundwater flow directions within the intermediate flow systems in the model area are interpreted to be from the mountains (zones of higher potential) to the bottoms of the valleys (zones of lower potential). Groundwater flow directions within the basin-fill aquifers were contoured from the water-level data available for wells completed in these aquifers. These maps may be found in Volume 4 of the Baseline Report (SNWA, 2008a). Groundwater flow directions within the deeper regional aquifer system are less obvious and subject to interpretation.

The available potentiometric data are insufficient to create detailed contour maps and identify definite regional flow directions. However, a simplified map of the potentiometric surface of the regional flow system was previously developed using a combination of the scarce available data, factors known to influence the potentiometric surface, and previous interpretations. This map was first presented in the Baseline Report (Figure E.1-1 in SNWA, 2008a). A modified version of that potentiometric map is presented in Figure 5-2. The available data used to develop this map (Figure 5-2) consisted of water-level elevations from 109 wells and 19 regional spring elevations. Factors influencing the potentiometric surface consist of geologic structures, topography, locations of recharge and discharge areas, and the extent of the carbonate-rock aquifer. Previous interpretations used to guide the construction of this map are those of Thomas et al. (1986), Prudic et al. (1995), Bedinger and Harrill (2004), and Wilson (2007). Due to the sparsity of the available point data, contour lines were hand-drawn at 500-ft intervals and were represented by dashed lines where uncertain or inferred. General regional flow directions have been depicted on this map by approximate arrows. Given the uncertainty associated with the regional potentiometric surface, the regional flow patterns cannot be identified with confidence in large portions of the model area (Figure 5-2). As a result, the boundaries of the flow systems are also uncertain and subject to interpretation.

5.2.2.2 Flow System Boundaries

The discussion of groundwater movement between and within the flow systems of the study area is supported by Plate 1, which depicts the five flow systems, their basins, and major groundwater features. Major features shown in Plate 1 consist of potential recharge areas (see Section 9.0), regional discharge areas including relevant springs and streams (see Section 7.0), and interbasin flow locations and directions (Section 8.0). Because of the sparsity of the available information, regional groundwater flow directions, and therefore, flow system boundaries, and interbasin flow are subject to interpretation. Thus, the initial configuration of interbasin flow used for this study (Section 8.0) was supplemented with previous interpretations. Major interpretations of interbasin flow locations and directions are shown on Plate 1 with arrows of different colors. These interpretations include those of Harrill et al. (1988) and Prudic et al. (1995) for the Great Basin; Belcher (2004) and San Juan et al. (2004) for the DVFS; SNWA (2007) for the WRFS; and Welch et al. (2008) for the BARCASS area (Plate 1). The interpretations contained in the Reconnaissance Series and those reported by Scott et al. (1971) are similar and have been incorporated and updated by Harrill et al. (1988) and were, therefore, not explicitly considered. More details about interpreted interbasin flow in the model area are provided in Section 5.2.2.2.2.



* Data for wells in Tikaboo Valley North obtained from SNWA; data for wells in Tikaboo Valley South, Three Lakes Valley, and Las Vegas Valley obtained from the USGS NWIS website on 2-7-2007. These data are not included in Appendix A.

Map ID 16787 10/28/2009 JAB

Note: Modified from Baseline Report (SNWA, 2008a).

Figure 5-2
Regional Potentiometric Map and General Regional Flow Directions

5.2.2.2.1 Interpretations of Flow System Extents

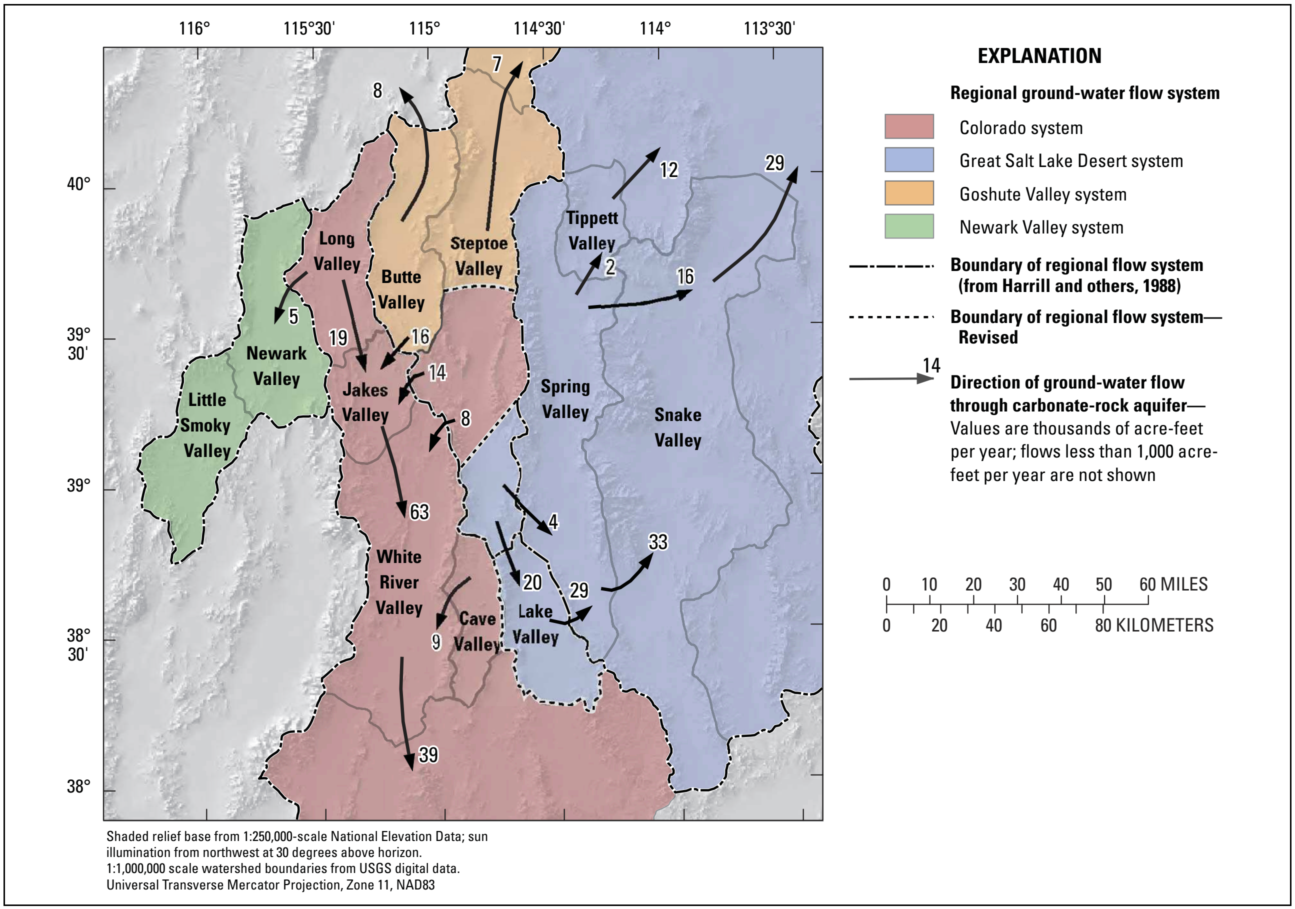
As stated in Section 2.5, several flow systems have been delineated within the study area and vicinity. The primary flow systems of interest to this Project are the Meadow Valley and White River flow systems and portions of the Goshute Valley, Great Salt Lake Desert, and Las Vegas flow systems as generally depicted by Harrill et al. (1988) (Figure 2-2). A few major interpretations exist for the entire study area or substantial portions of it (Harrill et al., 1988; Prudic et al., 1995; Welch et al., 2008). The available data do not prove or disprove any of these interpretations. Summaries of the three main interpretations are presented in this section.

Harrill et al. (1988) developed an atlas of the major groundwater flow systems of the Great Basin region as part of the RASA program. The purpose of their atlas was to synthesize the information available at that time into a map report to include a discussion of regional groundwater flow and the delineation and description of major flow systems. Harrill et al. (1988) used general concepts of groundwater flow at the regional scale and the available information as of 1984. Such information included reported hydraulic heads and estimates of water budgets and interbasin flow. Their interpretations, therefore, incorporate the findings and estimates reported in the Reconnaissance Series and summarized by Eakin (1966) for the WRFS and by Scott et al. (1971) for Nevada. They combined the WRFS and MVFS into a single flow system referred to as the Colorado System. Harrill et al. state that “the Colorado and Virgin rivers act as drains at terminus of system, but most discharge occurs upgradient at discharge points of major regional subsystems” (1988, Table 1, Sheet 1). The interbasin flow directions posted on their map are shown in Plate 1 of this report.

Prudic et al. (1995) developed a conceptualization of groundwater flow within the flow system of the Central Carbonate-Rock Province of the Great Basin region, using a numerical flow model based on the USGS code MODFLOW (McDonald and Harbaugh, 1988). The model is focused on Nevada and Utah and has two layers representing the deep regional aquifer and the shallow aquifers, using equivalent porous-media aquifer properties. Based on the potentiometric levels simulated by their numerical flow model, they identified the groundwater flow directions in the two model layers (Plate 1). They also subdivided the Central Carbonate-Rock Province into several regions, which were further subdivided into subregions. The subregions approximately correspond to flow systems as defined by previous investigators. Their boundaries do not correspond everywhere. For example, the White River subregion does not include Long and Jakes valleys, ends at the Muddy River Springs Area, and extends into the classic DVFS to the west and into the MVFS to the east. Prudic et al. (1995) stress that their interpretation is conceptual in nature. They state that “although a fairly detailed analysis of ground-water will be discussed, it does not intend to indicate that the study results presented here are adequate…”(Prudic et al., 1995, p. D-15). The concept of the WRFS has been a classic example of regional flow systems.

Another interpretation of the flow systems within the study area was the one put forth during BARCASS. The volume of recharge estimated for Steptoe Valley by Welch et al. (2008) as part of BARCASS was first estimated at 168,600 afy for the period of 1971 to 2004. It was then adjusted to 154,068 afy for the period of 1898 to 2006 to represent long-term mean conditions (Flint and Flint, 2007). This adjusted estimate was used in the groundwater-budget estimates. The difference between recharge and groundwater ET, about 53,000 afy, was routed to neighboring valleys through the subsurface (Figure 5-3). About 22,000 afy of groundwater was routed from Steptoe Valley to the

WRFS (Jakes and White River valleys). About 24,000 afy of groundwater was routed from Steptoe Valley to the GSLDFS (Lake and Spring valleys) (Figure 5-3). This led to a redefinition of the boundaries of the three flow systems by placing portions of Steptoe Valley in the WRFS and the GSLDFS. This interpretation was incorporated into the current analysis through the uncertainty analysis.



Shaded relief base from 1:250,000-scale National Elevation Data; sun illumination from northwest at 30 degrees above horizon.
1:1,000,000 scale watershed boundaries from USGS digital data.
Universal Transverse Mercator Projection, Zone 11, NAD83

Source: BARCASS Summary Report (Welch et al., 2008).

Figure 5-3
BARCASS Interpretation of Flow Routing and System Boundaries

The flow systems delineated in the model area are approximately consistent with the interpretations of Harrill et al. (1988) (Figure 2-2). This interpretation of the flow systems is used here for illustration purposes and in Section 9.0 for purposes of deriving an initial estimate of the recharge distribution. However, because of the uncertainties associated with the available information, other interpretations of regional flow patterns, and therefore flow-system boundaries, are possible and were not dismissed in this study. They constitute alternate interpretations that were considered during the calibration of the numerical model.

5.2.2.2.2 Groundwater Movement by Flow System

Each of the flow systems in the study area is described with an emphasis on the available interpretations of interbasin flow. The discussion is supported by four maps showing the reported ranges of interbasin flow (Figures 5-4 through 5-7) and a table summarizing and providing the sources of the flow ranges (Table 5-1). Arrows of opposite directions are shown on Plate 1 and in the four figures in cases where the interpretations conflict. The detailed list of reported interbasin flow annual volumes is provided in Appendix H. Findings of selected major studies are discussed in the subsections.

Goshute Valley Flow System

Most previous investigators, such as Harrill et al. (1988), define the GVFS to include Southern Butte, Goshute, and Steptoe valleys. A portion of this flow system, as defined by Harrill et al. (1988), consisting of Southern Butte and Steptoe valleys is included within the study area (Plate 1 and Figure 5-4). Even though SNWA does not have groundwater applications in the GVFS, baseline conditions have been established to evaluate potential future changes in the groundwater system.

To the northwest, the GVFS is bounded by the Butte Mountains along the western side of Southern Butte Valley. To the southwest, the GVFS is bounded by the Egan Range along the western side of Steptoe Valley. The Schell Creek Range forms most of the eastern boundary of the flow system along the eastern side of Steptoe Valley (Plate 1). A small portion of this boundary coincides with the Antelope Range and is shared with Antelope Valley located outside of the study area. The Egan and Schell Creek ranges meet at the southern end of Steptoe Valley and form the southern boundary of this flow system. To the north, Southern Butte Valley is open to Northern Butte Valley, and Steptoe Valley is open to Goshute Valley.

The Egan and Schell Creek ranges constitute important recharge areas and are interpreted to coincide with groundwater divides along their crests (Plate 1). The available water-level data (SNWA, 2008a, Volume 4) indicate the presence of groundwater at a high altitude on the Egan Range between Steptoe Valley and Jakes and White River valleys. The data may represent perched conditions but are indicative of recharge occurrence.

Groundwater discharge by the ET process occurs in the central part of Steptoe Valley (Plate 1). Groundwater ET in this area is primarily by phreatophytes. No surface-water outflow of groundwater origin occurs from this flow system. Groundwater discharge may also occur through the subsurface. Given that the largest mountain ranges are located in the southern part of this flow system, a large amount of recharge creates a groundwater divide separating the GVFS from the other flow systems.

Regional flow directions are generally depicted from south to north (Eakin et al., 1967; Frick, 1985; Harrill et al., 1988; and Nichols, 2000) (Figure 5-2). However, significant amounts of groundwater have also been interpreted to flow to the south (Welch et al., 2008) for example. The available potentiometric data are insufficient in this area to identify definite regional flow directions. Given the uncertainty associated with the potentiometric surface, the regional flow patterns cannot be identified with certainty, and the interbasin flow for this flow system is uncertain as well. Several interpretations exist (Plate 1) and are discussed in the following text.

In a report describing a numerical flow model of the valley-fill aquifer of Steptoe Valley, Frick (1985) identified the potential locations of groundwater flow out of Steptoe Valley. They are a narrow canyon north of Currie, Connors Pass, McGill, an area 7 mi north of Gallagher Gap, Smith Valley,

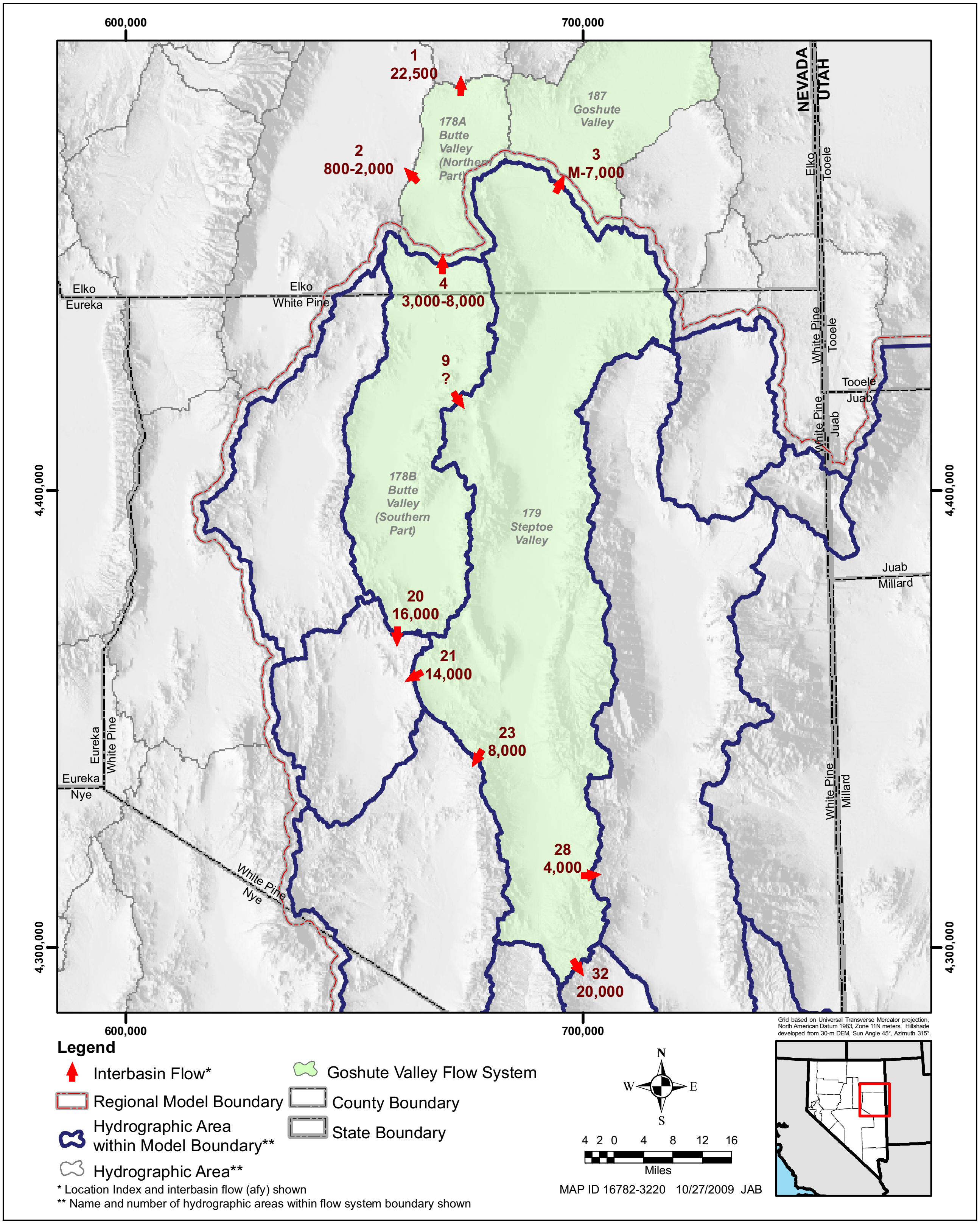
Table 5-1
Ranges of Reported Interbasin Flow Volumes
(Page 1 of 2)

Location Index[a]	Interbasin Flow (afy)[b]	Sources of Extreme Values
1	22,500	Nichols (2000)
2	800 to 2,000	Scott et al. (1971); Nichols (2000)
3	M to 7,000	Harrill et al. (1988); Welch et al. (2008)
4	3,000 to 8,000	Glancy (1968); Welch et al. (2008)
5	3,000	Harrill et al. (1988)
6	2,000 to 12,000	Harrill et al. (1988); Welch et al. (2008)
7	3,500 to 29,000	Carlton (1985); Welch et al. (2008)
8	1,000 to 8,500	Harrill et al. (1988); Carlton (1985)
9	?	Harrill et al. (1988)
10	? to 18,500	Harrill et al. (1988); Carlton (1985)
11	? to 12,700	Harrill et al. (1988); Prudic et al. (1995)
12	3,600	Nichols (2000)
13	3,000	Scott et al. (1971)
14	-2,000 to 2,000	Welch et al. (2008); Harrill (1971); Harrill et al. (1988)
15	6,000	Carlton (1985)
16	25,500 to 27,000	Carlton (1985); Harrill et al. (1988)
17	4,000 to 16,000	Nichols (2000); Welch et al. (2008)
18	?	Harrill et al. (1988)
19	8,000 to 19,000	Eakin (1961); Welch et al. (2008)
20	16,000	Welch et al. (2008)
21	14,000	Welch et al. (2008)
22	5,500 to 9,000	Carlton (1985); Harrill et al. (1988)
23	8,000	Welch et al. (2008)
24	? to 700	Harrill et al. (1988); Nichols (2000)
25	15,000 to 42,000	Hood and Rush (1965); Harrill et al. (1988)
26	16,527 to 63,000	Kirk and Campana (1990); Welch et al. (2008)
27	30,000	Scott et al. (1971)
28	4,000	Welch et al. (2008)
29	-4,250 to 4,000	Harrill et al. (1988); Carlton (1985)
30	4,250 to 26,500	Harrill et al. (1988); Carlton (1985)
31	-5,500 to 16,500	Harrill et al. (1988); Carlton (1985)
32	20,000	Welch et al. (2008)
33	5,500 to 30,000	Harrill et al. (1988); Carlton (1985)
34	4,000 to 11,180	Thomas and Mihevc (2007); Kirk and Campana (1990)
35	4,000 to 33,000	Rusk and Kazmi (1965); Welch et al. (2008)
36	29,000	Welch et al. (2008)
37	10,000	Scott et al. (1971)
38	14,000 to 15,000	Eakin (1966); LVVWD (2001)
39	3,000 to 17,000	Rusk and Eakin (1963); Thomas et al. (2001)
40	9,400 to 15,000	Thomas and Mihevc (2007); Thomas et al. (2001)
41	6,400 to 40,000	Thomas and Mihevc (2007); Scott et al. (1971)
42	1,500	Carlton (1985)
43	2,000	Thomas and Mihevc (2007)
44	M to 15,000	Scott et al. (1971); Thomas et al. (2001)

Table 5-1
Ranges of Reported Interbasin Flow Volumes
(Page 2 of 2)

Location Index[a]	Interbasin Flow (afy)[b]	Sources of Extreme Values
45	20,000 to 27,000	LVVWD (2001); Thomas and Mihevc (2007)
46	8,000 to 23,100	Eakin (1966); Thomas and Mihevc (2007)
47	0 to 16,000	Scott et al. (1971); Thomas et al. (2001)
48	9,000 to 28,000	Harrill et al. (1988); Thomas et al. (2001)
49	0 to 16,000	Scott et al. (1971); Thomas et al. (2001)
50	7,400 to 16,000	Thomas and Mihevc (2007); Thomas et al. (2001)
51	1,216 to 3,758	San Juan et al. (2004); Faunt et al. (2004)
52	10,000 to 20,000	Eakin (1963b); Thomas et al. (2001)
53	1,330 to 59,000	Kirk and Campana (1990); LVVWD (2001)
54	M to 36,000	Harrill et al. (1988); Thomas et al. (2001)
55	M to 9,000	Scott et al. (1971); Thomas et al. (2001)
56	5,000 to 17,700	Eakin (1966); Thomas and Mihevc (2007)
57	9,000 to 9,700	LVVWD (2001); Thomas and Mihevc (2007)
58	6,000	Eakin (1966)
59	811 to 11,307	San Juan et al. (2004); Faunt et al. (2004)
60	16,000 to 24,100	Thomas et al. (2001); Thomas and Mihevc (2007)
61	22,300 to 35,000	Thomas and Mihevc (2007); Eakin (1966)
62	S	Scott et al. (1971)
63	M to 6,000	Scott et al. (1971); Thomas et al. (2001)
64	? to 14,023	Harrill et al. (1988); Faunt et al. (2004)
65	2,400 to 13,000	Buqo (2002); Prudic et al. (1995)
66	28,000 to 37,700	Thomas et al. (1996); Eakin (1966); Thomas and Mihevc (2007)
67	32,000	LVVWD (2001); Thomas et al. (2001)
68	M to 41,804	Rush (1968b); Kirk and Campana (1990)
69	5,300 to 7,000	Thomas and Mihevc (2007); Rush (1968b)
70	M to 41,000	Rush (1968b); LVVWD (2001)
71, 73, 74	15,000 to 16,000	Thomas and Mihevc (2007); Thomas et al. (2001)
72	?	Harrill et al. (1988)
75	5,000	Harrill et al. (1988)
76	1,100 to 49,000[c]	Scott et al. (1971); LVVWD (2001)
77	?,M to 15,000	LVVWD (2001); Harrill et al. (1988); Thomas and Mihevc (2007)
78	? to 17,000	LVVWD (2001); Thomas et al. (2001)
79	M to 4,000	Scott et al. (1971); Thomas et al. (2001)
80	1,378	San Juan et al. (2004)
81	600 to 1,000	Thomas and Mihevc (2007); LVVWD (2001)
82	400 to 1,200	Rush (1968b); Harrill et al. (1988)
83	M to 2,000	Scott et al. (1971); Thomas et al. (2001)
84	4,000	Kirk and Campana (1990)

[a] Location of interbasin flow is shown on Figures 5-4 through 5-7 and Figure H-1.
[b] A positive value signifies flow in same direction as arrow, and a negative value signifies flow in the opposite direction.
[c] This value includes 1,000 afy outflow from Black Mountains Area to Lake Mead.
? = Flow volume not specified.
M = Minor quantity. An amount which is either less than 500 afy, or small in comparison to other quantities in the particular hydrologic area (Scott et al., 1971).
S = Some quantity. Sufficient information is not available to make an estimate (Scott et al., 1971).



Note: See Table 5-1 for sources of interbasin flow ranges.

Figure 5-4
Locations and Ranges of Interbasin Flow in Goshute Valley Flow System

and the southernmost boundary of Steptoe Valley. The canyon north of Currie is the only location on the boundary of Steptoe Valley where a topographic divide is not present (Plate 1). According to Spengler et al. (1979), plutons occur in the subsurface at this location. Spengler et al. (1979, p. 184) state that "the Currie pluton and Dolly Varden stock may be connected at depth despite observed contrasts of mineralogic and petrologic composition." This interpretation implies that groundwater outflow from Steptoe Valley through this location is probably restricted. Outflow simulated by the calibrated model through this location is 2,510 afy or 2.5 percent of the total simulated inflow to the valley-fill groundwater (Frick, 1985).

A positive hydraulic gradient to valleys adjacent to Steptoe Valley exists across the other potential locations of interbasin flow (Plate 1). However, the hydrogeological characteristics, especially the structural and stratigraphic orientations at these locations, are not favorable to interbasin flow (Frick, 1985). Specifically, dips of hydrostratigraphic units are in opposite directions to hydraulic gradients between Steptoe Valley and White River Valley, Connors Pass of Spring Valley, and the Duck Creek Valley area of Spring Valley (Frick, 1985). Frick (1985) explains this concept:

> Altitude of hydrostratigraphic units is important where the original stratigraphic units remain roughly parallel. If the hydrostratigraphic units dip in the same direction as the groundwater gradient, then the more transmissive layers, such as limestone and dolomite, may act as conduits for flow. However, if the hydrostratigraphic units dip in the opposite direction to the gradient, then the interbedded layers with low transmissivities are more likely to act as aquicludes or aquitards. Dips of hydrostratigraphic units are in opposite directions of groundwater gradients between Steptoe Valley and the following valleys: White River Valley, Connors Pass area of Spring Valley, Duck Creek Valley area of Spring Valley, and the northern part of Southern Butte Valley.

Thus, interbasin groundwater flow through these locations, if any, is probably insignificant. In addition, north-south-trending stratigraphic units and/or faults may impede or prevent interbasin flow between Steptoe Valley and White River, northern Spring, Northern Butte and the northern end of Southern Butte and Jakes valleys (Frick, 1985).

Prudic et al. (1995) included Steptoe Valley and Butte Valley South into their Spring-Steptoe subregion of the Bonneville Region and simulated 3,000 afy of outflow into the White River subregion of the Colorado River Region (Plate 1). In southern Steptoe Valley, simulated flow is westward from the Schell Creek Range and eastward from the Egan and Cherry Creek ranges (Plate 1) (Prudic et al., 1995). Simulated flow in Butte Valley is westward from the Egan and Cherry Creek ranges and eastward from Butte Mountains (Plate 1) (Prudic et al., 1995). Potential deeper groundwater flow from Butte Valley to Steptoe Valley was simulated beneath the Egan Range (Prudic et al., 1995). This potential interbasin flow is supported by limited geochemical evidence (Prudic et al., 1995).

Based on his independent estimates of groundwater recharge and ET, Nichols (2000) calculated an annual outflow volume of 4,000 afy from Steptoe Valley to Goshute Valley (Plate 1). He estimated a total of 24,500 afy of subsurface outflow from Butte Valley (Butte Valley North and South). This total outflow consists of 22,500 afy to Clover Valley and 2,000 afy to Ruby Valley (Plate 1).

In BARCASS, however, a significant amount of underflow is interpreted to flow from the GVFS to the WRFS and the GSLDFS (Welch et al., 2008). The three referenced flow systems are not as delineated by BARCASS; they are as delineated in Figure 2-2. Underflow to the WRFS is from Butte Valley South and the southern portion of Steptoe Valley to Jakes Valley and the northern portion of White River Valley (Plate 1). Underflow to the GSLDFS is from the southern portion of Steptoe Valley to Lake Valley to Spring Valley (Plate 1).

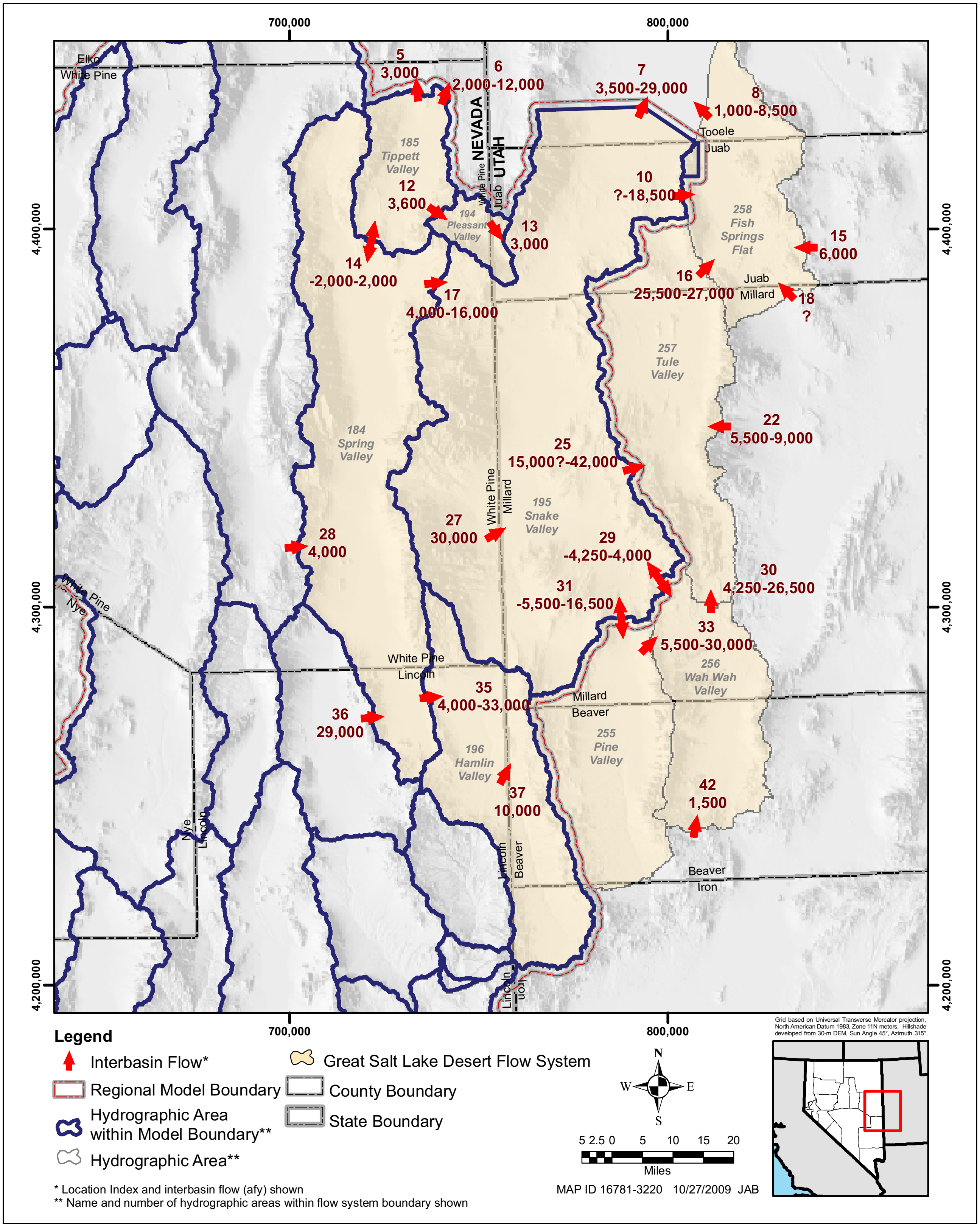
Great Salt Lake Desert Flow System

The part of the GSLDFS located in the study area includes Spring Valley, Tippett Valley, and Big Snake Valley (Pleasant, Snake, and Hamlin valleys), and a small portion of Fish Springs Flat comprising Fish Springs. Major features of the flow system, including interpretations of interbasin flow, are discussed (Plate 1 and Figure 5-5).

This part of the GSLDFS is bounded on the west by the Schell Creek and Fortification ranges; on the east by the Confusion Ranges, Middle Range, and Fish Springs Flat; and on the north by Deep Creek Range and a portion of the Antelope Range (Plate 1). Other major mountain ranges throughout the area are the Snake Range and Wilson Creek Range. No perennial streams connect any of the valleys, and the only interbasin ephemeral drainage is Hamlin Valley Wash that is tributary to Snake Valley. The small portion of Fish Springs Flat containing the springs is included in the study area. Fish Springs Flat encompasses about 590 mi^2 in Tooele, Juab, and Millard counties in Utah. The valley is bounded by the Fish Springs Range on the west, the Dugway and Thomas ranges and Drum Mountains on the east, the Little Drum Mountains on the southeast, and a low divide between Swasey Mountain and the Little Drum Mountains on the southern boundary. Fish Springs Flat opens to the Great Salt Lake Desert to the north (Bolke and Sumsion, 1978). Callao, Utah, is located approximately 25 mi to the west of Fish Springs, and Delta, Utah, is approximately 78 mi to the southeast. The Fish Springs NWR, which contains the springs of interest, was founded in 1959 and is located in the northwest corner of Fish Springs Flat (USFWS, 2004).

Groundwater recharge occurs in the mountains and discharges in two large ET areas primarily by phreatophytes on the valley floors in Spring and Snake valleys (Plate 1). No surface-water outflow of groundwater origin occurs from this flow system. Groundwater discharge may also occur through the subsurface primarily across the northern and the eastern boundary of the portion of the GSLDFS considered in this study. As will be discussed later in this section, groundwater discharge from Fish Springs is believed to originate from the portion of the GSLDFS east of the model area. Hamlin Valley is hydrologically connected to Snake Valley and is typically considered part of Snake Valley. A portion of this recharge flows through the subsurface to the east and northeast and exits the portion of the GSLDFS in the study area, most likely through the northern boundary of Snake Valley. A portion of the recharge to this flow system may exit the system from the eastern boundary of Snake Valley (Plate 1) towards Fish Springs Flat.

General regional flow directions are south to north (Figure 5-2). However, because of sparse information, the detailed configuration of groundwater flow and therefore interbasin flow within the flow system is not well understood and is subject to interpretation. Various interpretations exist and are summarized in the following text.



Grid based on Universal Transverse Mercator projection, North American Datum 1983, Zone 11N meters. Hillshade developed from 30-m DEM, Sun Angle 45°, Azimuth 315°.

* Location Index and interbasin flow (afy) shown

** Name and number of hydrographic areas within flow system boundary shown

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Note: See Table 5-1 for sources of interbasin flow ranges. Opposing arrows indicate conflicting interpretations.

Figure 5-5
Locations and Ranges of Interbasin Flow in Great Salt Lake Desert Flow System

Rush and Kazmi (1965) estimated that 4,000 afy of subsurface outflow occurs from Spring Valley to Hamlin Valley through the Snake Range. Scott et al. (1971) estimated that 2,000 afy of inflow to Spring Valley originates in Tippett Valley. This inflow was accepted and used by Scott et al. (1971) and by Harrill et al. (1988). This interpretation of flow routing was also used by SNWA in the Spring Valley water-rights hearing (SNWA, 2006).

In the RASA model, Prudic et al. (1995) included the GSLDFS, as delineated in this study, in the Bonneville region. Prudic et al. (1995) state that simulated flow in the basins of this flow system is primarily in the upper layer, from recharge areas in the mountains to discharge areas on the adjacent valley floors. About 78 percent of the total inflow is simulated through the upper layer (Prudic et al., 1995). Simulated flow in northern Spring Valley is eastward from the Schell Creek Range and westward from the Snake Range to the valley floor. In southern Spring Valley, groundwater is simulated to flow into Hamlin Valley through the Limestone Hills. In Snake Valley, most of the simulated flow is toward the Great Salt Lake Desert.

Nichols (2000) estimated recharge in excess of groundwater ET in Tippett and Spring valleys. He routed the excess water (9,600 afy) in Tippett Valley as outflow toward the north (Plate 1). Recharge from precipitation in Spring Valley was estimated to be about 104,000 afy, whereas groundwater ET was estimated at 90,000 afy. The difference of 14,000 afy may be the result of an underestimation of groundwater ET, an overestimation of recharge, or a combination of both. However, much of the excess recharge is believed to leave the valley as interbasin flow to the east. Nichols (2000) routed 4,000 afy through the southern end of Spring Valley to Hamlin Valley and the remaining 10,000 afy to Snake Valley through a topographic low between the northern end of the Snake Range and the Kern Mountains.

As part of BARCASS, Welch et al. (2008) derived a new flow-routing configuration for the GSLDFS (Plate 1 and Figure 5-3). They routed groundwater from Steptoe Valley and Lake Valley to Spring Valley. The total volume of this interbasin flow is 33,000 afy, which accounts for more than one-third of the recharge of Spring Valley. All outflow from Snake Valley was routed through the northern boundary of Snake Valley, even though a high-potential interbasin flow segment was placed on their geological map along the eastern boundary of the valley (Figure 5-3). Welch et al. (2008) also estimated 2,000 afy of groundwater to flow from Spring Valley to Tippett Valley. This interbasin flow volume is the same as the volume estimated by Scott et al. (1971). However, the flow direction is reversed (i.e., flow is from Tippett Valley to Spring Valley).

As part of BARCASS, Hershey et al. (2007) evaluated data on dissolved gases, stable isotopes, and tritium from 15 wells and springs located in the BARCASS area. Using these data, they derived estimates of recharge ages, recharge altitudes, and flowpath directions. Hershey et al. (2007) also identified the major flow paths using water-rock reaction models. The paths they identified are as follows: (1) from north to south in White River Valley; (2) from south to north in Steptoe Valley; (3) from the central part of Spring Valley northward and then to northern Snake Valley; (4) from the central part of the valley southward and then to southern Snake Valley; and (5) from south to north in Snake Valley. Groundwater ages were calculated using dissolved organic ^{14}C and dissolved inorganic ^{14}C for groundwater flowing across the following basin boundaries: between Lake and Spring valleys, between Steptoe and Spring valleys, and between Spring and Snake valleys. The calculated groundwater ages ranged from less than 1,000 years to 16,000 years.

Lundmark (2007) developed a steady-state, mass-balance groundwater-accounting model, using the discrete-state compartment code and the Monte Carlo method, to evaluate basin and regional water budgets for the BARCASS area. The model was used to calculate annual interbasin flow volumes based on the fluxes of a conservative tracer (deuterium), using the independent estimates of recharge and groundwater ET reported by Welch et al. (2008). The model results consist of deterministic estimates and a limited analysis (Monte Carlo) of the uncertainty in the predicted interbasin flow volumes resulting from the uncertainty in recharge characteristics.

Gillespie (2008) conducted an analysis of flow paths in the GSLDFS using water chemistry, stable isotopes, measurable tritium, ^{14}C activities, and geochemical models. He concluded that (1) interbasin flow from southern Spring Valley to southern Snake Valley cannot be confirmed or rejected and (2) interbasin flow from northern Spring Valley to northern Snake Valley is unlikely.

The Utah Geological Survey (UGS) (2008) published a provisional project map on its website (http://geology.utah.gov/esp/snake_valley_project/pdf/projectmap.pdf). In that map, the UGS posted the volume of interbasin flow reported by Welch et al. (2008). The location of that interbasin flow is, however, different from that used in BARCASS. The UGS used a location of interbasin flow similar to that depicted by Harrill et al. (1988).

Of particular interest in this portion of the GSLDFS are the springs located in Fish Springs Flat (Plate 1). Although the total discharge from Fish Springs is known (described above), the source of the spring flow is much larger than the estimated recharge within Fish Springs Flat. Most groundwater in Fish Springs Flat is in the eastern parts of the north-flowing GSLDFS. Some groundwater is derived from the Sevier Desert area (Wilberg, 1991), moving northward along basin-range fault zones into Fish Springs Flat (Bolke and Sumsion, 1978; Harrill et al., 1988) (Figure 5-5). Most groundwater discharging from Fish Springs is probably derived from Tule Valley. Some of the Tule Valley groundwater is probably derived from local precipitation, but most of the groundwater in Tule Valley is probably derived from the ranges to the south and passes northward along basin-range faults through Wah Wah Valley, Pine Valley, and the southeastern Snake Valley (Figure 5-5) (Harrill et al., 1988). A portion of this northward-moving groundwater may be deflected eastward (Stephens, 1977; Bolke and Sumsion, 1978; Gates and Kruer, 1981; Harrill et al., 1988), from Tule Valley to Fish Springs Flat. Findings of the major existing interpretations are summarized in the following text.

Bolke and Sumsion (1978) estimated a recharge from precipitation of 4,000 afy, a discharge by ET of 8,000 afy, a total spring discharge of 27,000 afy, and subsurface inflow to Fish Springs Flat of about 31,000 afy. Groundwater discharge by subsurface outflow is negligible. Bolke and Sumsion (1978) argued that the high local relief of the eastern Fish Springs Range may contribute some recharge from surface water to the area around Fish Springs, but most of the spring discharge is groundwater. They state that this groundwater is from subsurface inflow from other basins, such as Tule Valley, and imply that the other contributing basins may be Snake, Wah Wah, and Pine valleys located to the south and west of Fish Springs Flat. However, no allocated volumes of underflow were provided in their report.

Gates and Kruer (1981) presented a theory to explain the source of spring flow to Fish Springs. They used the various types of data available at the time to conclude that:

> Although available evidence indicates that interbasin flows occurs to and within west-central Utah and that it likely occurs through solution-enhanced fracture openings in carbonate rocks of Paleozoic age, the exact source area of all this water is not known. Water budgets of Fish Springs Flat, Tule Valley, and the southern Great Salt Lake Desert require that large quantities of water move to these basins by subsurface flow; and water levels in west-central Utah (pl. 2) show that ground water potentially could move eastward from Snake Valley and northward from Pine and Wah Wah Valleys to Tule Valley and Fish Springs Flat. (p. 34)

Carlton (1985) developed a numerical groundwater flow model for the flow system comprising Fish Springs Flat. The flow system comprises Fish Springs Flat, Pine, Tule, Snake, and Wah Wah valleys. He constructed the model using the data available at the time. The model simulated subsurface inflow from external sources as follows: 25,500 afy from Tule Valley; 6,000 afy from the Sevier Desert; and 18,500 afy from Snake Valley. Simulated subsurface outflow was 8,500 afy to the southern Great Salt Lake Desert. The simulated discharge from Fish Springs was 28,000 afy. As indicated by Carlton (1985), about 50 percent of the water discharged by Fish Springs originates in Snake Valley. These modeling results are uncertain as the model was based on limited data and reconnaissance studies.

In Sheet 2 of 2 of HA-694-C, Harrill et al. (1988) presented estimates of recharge by precipitation and underflow to Fish Springs Flat as follows: (1) recharge from precipitation of 4,000 afy; (2) subsurface outflow of less than 1,000 afy; (3) 27,000 afy of subsurface inflow from Tule Valley; and (4) unknown amounts from Snake Valley (through the Fish Springs Range) and Wah Wah Valley. An unknown portion of the underflow from Tule Valley originates from Snake Valley by underflow through the Confusion Range. The uncertainty in the flow routing within these basins is most probably the reason why Harrill et al. (1988) reported three potential values for the subsurface outflow from Snake Valley to Tule Valley through the Confusion Range: 22,000, 33,000, and 42,000 afy.

Bedinger et al. (1990) pointed out that hydraulic gradients in the carbonate rocks are very low, creating relatively long groundwater travel times from potential host rocks to natural discharge points, such as springs. They estimated these travel times to be on the order of 10,000 to 100,000 years, not including movement in the unsaturated zone of the host rock (Bedinger et al., 1990). The age reported for water from Fish Springs ranges between 9,000 to 21,000 years (Gates and Kruer, 1981; Carlton, 1985).

Based on the results of the RASA model, Prudic et al. (1995, p. D-84) state that "at least half of the simulated flow to Fish Springs Flat from Tule Valley originates in the Snake Valley drainage basin. Of the 23,000 afy simulated as entering Tule Valley in the lower Interbasin Flow layer, 14,000 is underflow from Snake Valley through the Confusion Range and 9,000 is from Wah Wah Valley."

In summary, although Harrill et al. (1988) queried possible eastward movement of groundwater through the northern Fish Springs Range, presumably along the east-striking faults or basal parts of the lower carbonate aquifer (Plates 2 and 4), no evidence exists to support such flow. The hills and ranges, including the Confusion Range, that form the western side of Tule Valley are, like the Fish Springs Range, underlain by the basement-confining zone, so it appears unlikely that substantial groundwater is derived from west of Tule Valley. Furthermore, through-going easterly trending faults do not cut the Confusion Range (Plates 2 and 3). Thus, the source of groundwater flow to the springs must be from neighboring basins through the carbonate aquifer.

Meadow Valley Flow System

The MVFS is roughly parallel to the WRFS, starting in Lake Valley and ending as the Lower Meadow Valley Wash joins the Muddy River in Upper Moapa Valley. The MVFS (Plate 1 and Figure 5-6) is hydraulically connected to the WRFS in the south and is part of the Colorado River Region. A portion of the Muddy Springs discharge is believed to originate from the MVFS along Meadow Valley Wash.

The MVFS is bounded by the Schell Creek Range to the north; by the Fairview, Bristol, Highland, Chief, Burnt Spring ranges, and the Delamar and Meadow Valley mountains to the west; and by the Fortification and Wilson Creek ranges and the Clover and Mormon mountains to the east (Plate 1).

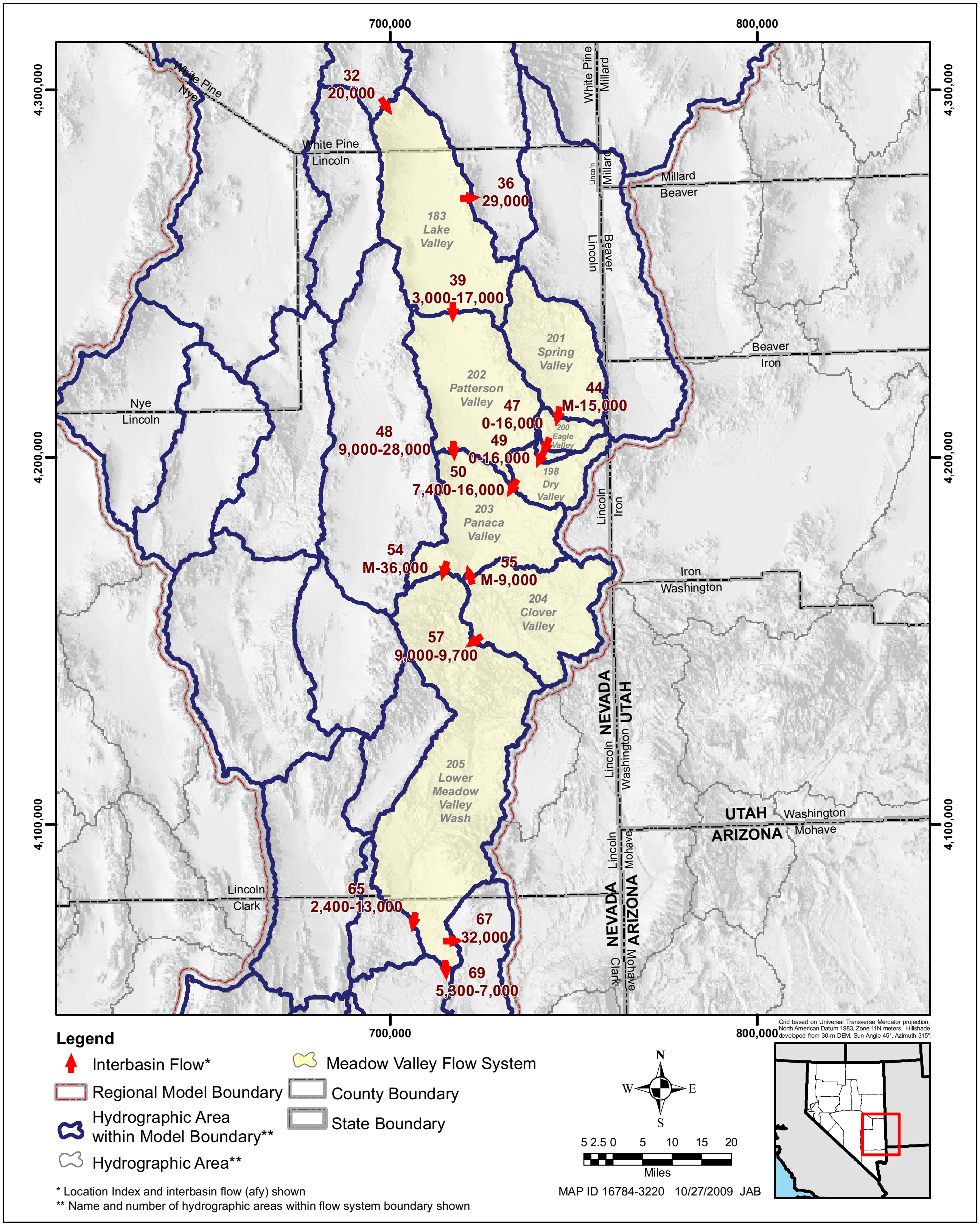
Recharge from precipitation occurs mostly on the mountains located in the northern and northwestern parts of this flow system (Plate 1). Groundwater discharges by the process of ET along the banks of Meadow Valley Wash, which has its headwaters in the Wilson Creek Range. The Meadow Valley Wash is perennial for much of its length with intermittent stream reaches occurring within the Lower Meadow Valley Wash. Clover Creek is a stream with an intermittent upper reach and perennial lower reach that headwaters in the Clover Mountains and is tributary to Meadow Valley Wash.

Regional flow directions are north to south, and flow out of this flow system is to the Muddy River Springs area and California Wash in the WRFS. The general regional flow directions are shown in Figure 5-2. The existing interpretations of interbasin flow are shown on Plate 1 and summarized in the following text.

The earliest and most detailed study of groundwater conditions for MVFS was conducted by Phoenix (1948). The basins included in MVFS, as defined by Phoenix (1948), are the same as in this study. Physiographic evidence indicates that the Meadow Valley Wash drainage pattern, with headwater starting from Spring Valley, possibly dates back well into the Pleistocene period (Phoenix, 1948).

Rush and Eakin (1963) constructed a cross section of the general topography and water table for Lake Valley. The cross section indicates that the general groundwater flow direction in Lake Valley is southward toward Patterson Wash (Patterson Valley in this study). Rush and Eakin (1963) estimated the annual volume of interbasin flow through this location at 3,000 afy.

Rush (1964) discussed groundwater conditions in basins of the MVFS that are connected by perennial or intermediate streams. This includes all basins of this flow system, except Lake Valley. During periods of spring snowmelt or flash floods, water of these streams flows to the mouth of Meadow Valley Wash and discharges into the Muddy River. However, most of the base flow in Meadow Valley Wash is from groundwater sources. Groundwater outflow from MVFS to the Muddy River Springs area occurs in two forms: underflow through the alluvium of lower Meadow Valley Wash and leakage through bedrock (Rush, 1964). The volume of this outflow was estimated as 7,000 afy based on the balance of recharge and discharge in the system.



Grid based on Universal Transverse Mercator projection, North American Datum 1983, Zone 11N meters. Hillshade developed from 30-m DEM, Sun Angle 45°, Azimuth 315°.

* Location Index and interbasin flow (afy) shown

** Name and number of hydrographic areas within flow system boundary shown

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Note: See Table 5-1 for sources of interbasin flow ranges.

Figure 5-6
Locations and Ranges of Interbasin Flow in Meadow Valley Flow System

Based on a mass-balance model of deuterium, Kirk and Campana (1990) and Thomas et al. (1996) estimated that 5,500 to 9,000 afy and 8,000 afy of Muddy River Springs discharge is from the southern MVFS, respectively. The RASA model simulated the contribution of MVFS water to the Muddy River Springs area at 13,000 afy (Prudic et al., 1995).

LVVWD (2001) estimated a large flow rate of 32,000 afy from MVFS into Lower Moapa Valley based on the water balance of updated annual recharge and discharge volumes. Based on Darcy flux calculations, Buqo (2002) estimated an annual volume of flow from Lower Meadow Valley Wash to the Muddy River Springs area ranging from 2,400 to 7,200 afy.

Synoptic discharge measurements conducted by Beck and Wilson (2006) along the Muddy River indicate that a gain of about 4,200 afy occurs in the Muddy River flow from a gage near Moapa to the Muddy River below Anderson Wash near a Logandale gage. Based on these synoptic discharge measurements, Beck and Wilson (2006) and SNWA (2007) estimated an annual flow volume of 9,200 afy from the MVFS to the Muddy River Springs area.

The conceptual model of groundwater flow in MVFS had been about the same until 2008 when BARCASS was published (Welch et al., 2008). In BARCASS, Lake Valley is included in the GSLDFS. An annual volume of 20,000 afy of groundwater was routed from Steptoe Valley to Lake Valley, and an annual volume of 29,000 afy was routed from Lake Valley to Spring Valley.

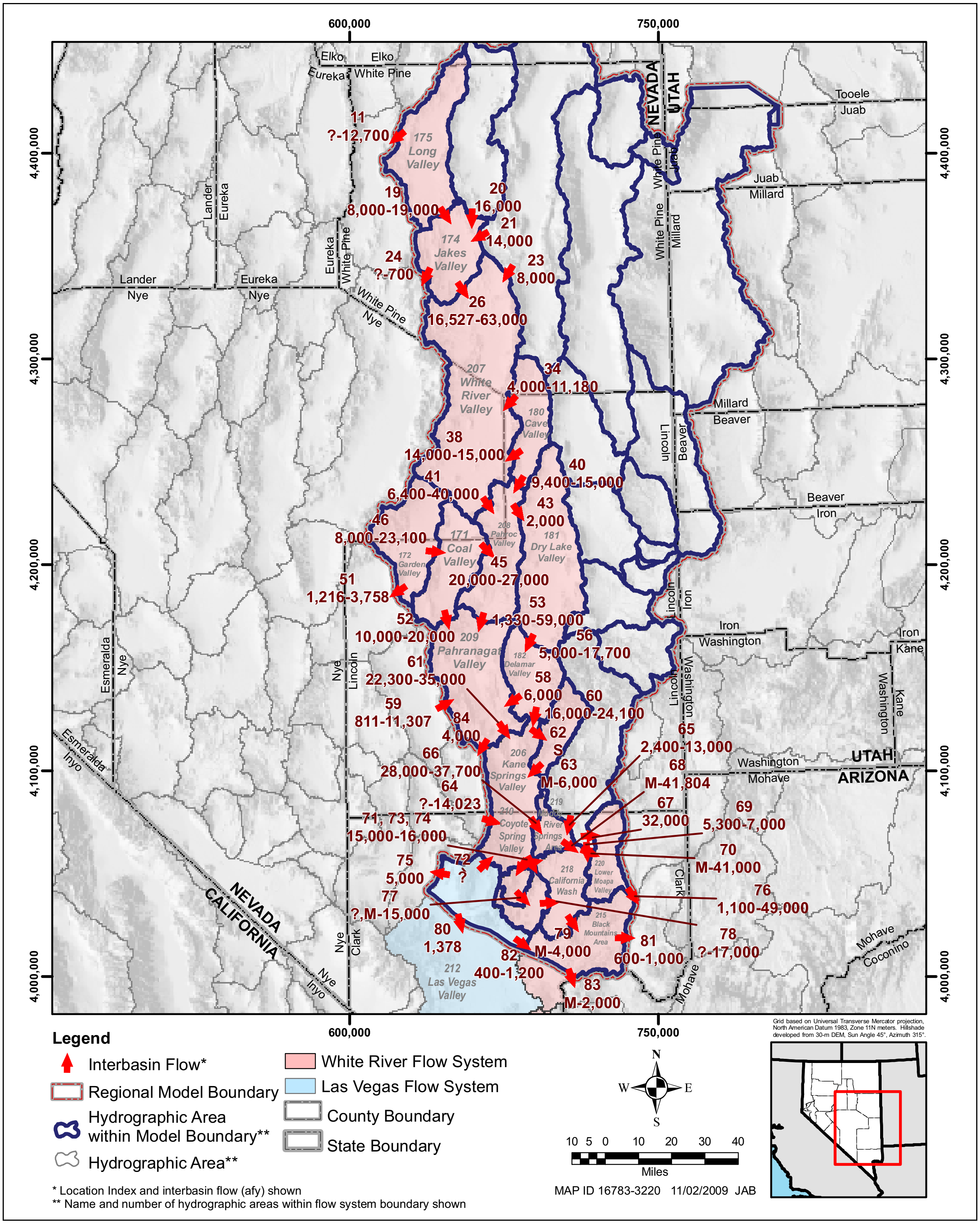
White River Flow System

The WRFS (Plate 1 and Figure 5-7) used in this study is approximately as defined by Eakin (1966) and Harrill et al. (1988). It is the longest flow system in Nevada. Prudic et al. (1995) consider this flow system to be part of the Colorado River Region. Their interpretation excludes Long and northern Jakes valleys from the WRFS. As part of BARCASS, the USGS (Welch et al., 2008) first extended the boundary to include a portion of southern Butte Valley South and south-central Steptoe Valley in the WRFS.

The WRFS is bounded by the Maverick Springs, White Pine, Grant, Quinn Canyon, Pahranagat, and Sheep Mountain ranges to the west, and by the Egan, Schell Creek, Bristol, Highland, and Chief ranges and the Clover, Delamar, and Muddy mountains to the east (Plate 1). The southern boundary of this flow system is Lake Mead.

Based on the interpretation of Eakin (1966), all groundwater recharge to the WRFS is from precipitation on the bordering mountains, especially in its northern basins. However, according to other interpretations such as that of Welch et al. (2008), some recharge may also occur by interbasin flow from Steptoe Valley.

Major groundwater discharge areas occur in the White River and Pahranagat valleys and the Muddy River Springs area. Other minor discharge areas include Long, Cave, and Garden valleys and the Black Mountains Area. Numerous regional springs located in areas from southern White River Valley to the Muddy River Springs area discharge important volumes of groundwater, which is lost to ET for the most part (Plate 1). Except for White River Valley and the Muddy River Springs area, spring discharge is assumed to be completely consumed by the phreatophytes within the groundwater



Grid based on Universal Transverse Mercator projection, North American Datum 1983, Zone 11N meters. Hillshade developed from 30-m DEM, Sun Angle 45°, Azimuth 315°.

* Location Index and interbasin flow (afy) shown

** Name and number of hydrographic areas within flow system boundary shown

Note: See Table 5-1 for sources of interbasin flow ranges.

Figure 5-7

Locations and Ranges of Interbasin Flow in White River Flow System

ET areas. The discharge from the regional springs of southern White River is also mostly consumed by phreatophytes. However, a portion of the discharge contributes to the interbasin outflow to Pahroc Valley (Maxey and Eakin, 1949). The Muddy River Springs, which are the largest springs in the WRFS, are located in the central part of the Muddy River Springs area (Upper Moapa Valley). The Muddy River Springs form the headwaters of the Muddy River, a tributary to Lake Mead on the Colorado River (Plate 1). Water from the Muddy River Springs contributes to the riparian ET areas located along the Muddy River, down-gradient from the springs.

The general groundwater flow direction in the regional part of the flow system is from areas of major recharge (north) to major areas of discharge (south). Regional groundwater movement is through the carbonate aquifer, which occurs throughout the flow system. The regional flow through the carbonate aquifer of the WRFS is facilitated by north-south faults (Plate 2 and Figure 5-2). Although there is general agreement on the general direction of regional groundwater flow, interbasin flow locations and volumes are subject to interpretation.

Eakin (1966) proposed the first regional groundwater flow system and named it the White River System. The system is based on a regional gradient derived from elevation of springs, water levels of groundwater wells, playas, and water budgets of several basins in southeastern Nevada. The direction of the regional gradient was inferred from the elevation of water levels in adjacent basins; principal springs in White River, Pahranagat, and Upper Moapa valleys; and playas in Cave, Coal, Dry Lake, Delamar valleys. Eakin (1966) subtracted the annual discharge volume from the annual recharge volume and routed the residual to down-gradient basins. Because the water level of Jakes Valley is unknown, Eakin (1966) estimated it to be as much as 400 ft below the playa surface. The lowest known water-level elevation beneath the playa of Long Valley is about 6,000 ft. The elevation of the water level in a well in Jakes Wash of northern White River Valley is about 5,780 ft, whereas the elevation at Preston Springs, about 12 mi farther south, is about 5,680 ft. This indicates that a potential southward gradient apparently exists through the carbonate rocks toward White River Valley.

A synoptic view of regional groundwater potential based on inference of the regional head from the surface elevation of thermal springs was first offered by Mifflin (1968). Hydraulically forced thermal springs are expressions of movement of water from a depth heated by the natural geothermal gradient. The numerous thermal springs present in the Great Basin region indicate the inherent, permeable nature of a significant network of vertical faults associated with the extensional block faulting of this region.

Harrill et al. (1988) used previous estimates of basin-water budgets in their interpretation of groundwater flow in the Great Basin region. They also considered the topographic and shallow water-level differences between basins for interpreting the direction of interbasin flow and regional groundwater potential. Harrill et al. (1988) included an interbasin flow arrow on the western boundary of Long Valley, Jakes Valley and Pahranagat Valley, but without a flow volume. The western and southern boundary of Coyote Spring Valley was also marked with an interbasin flow arrow into the valley without a flow volume on the map prepared by Harrill et al. (1988). No volume of interbasin flow was estimated by Harrill et al. (1988) from the MVFS to WRFS. Rush (1964) interpreted an annual volume of 7,000 afy of interbasin flow from the MVFS into the Muddy River Springs area.

Nichols (2000) estimated about 10,000 afy and 13,000 afy of interbasin flow from Long Valley to Newark Valley and Long Valley to Railroad Valley, respectively. Nichols (2000) also estimated about 700 afy of interbasin flow from Jakes Valley to Newark Valley. In addition, he estimated a contribution of about 51,200 afy of interbasin flow from both Long and Jakes valleys to White River Valley.

The Muddy River Springs are the dominant hydrologic feature of the Muddy River Springs Area. Measurements of the discharge at a gaging station near Moapa have ranged from 43.5 cfs in 1930 to 49.6 cfs in 1958 (Eakin, 1964). Small variations in spring discharge exclude contributions of surface runoff that is highly variable and correlated to precipitation events. However, the exact sources of water discharging at the Muddy River Springs are not definitely known. Based on previous studies, the main source of water discharging from the Muddy River Springs is recharge occurring in the northern WRFS (Eakin, 1966; Harrill et al., 1988; Kirk and Campana, 1990; Thomas et al., 1996; and SNWA, 2007).

As part of a groundwater modeling study of the DVFS, which is located immediately to the west of the CCRP model area, estimated interbasin flow between the two flow systems was reported as (1) 811 afy to 11,307 afy from the DVFS into the WRFS at Pahranagat Valley; (2) 5,513 afy to 14,012 afy to Coyote Springs Valley from Tikaboo Valley South; and (3) 1,216 afy to 3,758 afy of interbasin flow from the WRFS to the DVFS at Garden Valley (San Juan et al., 2004; Faunt et al., 2004).

SNWA (2007) estimated the total outflow from the WRFS at 25,000 afy, which includes spring discharge from the Muddy Springs, Rogers Spring, and Blue Point Spring, and subsurface outflow from Lower Moapa Valley to the Colorado River.

In BARCASS, 16,000 afy of interbasin flow was routed into the WRFS from Butte Valley South and 22,000 afy was routed in from Steptoe Valley. About 5,000 afy interbasin flow was routed out of WRFS from Long Valley (Welch et al., 2008).

5.2.2.2.3 Las Vegas Flow System

The portion of Las Vegas Valley that includes the area located north of the LVVSZ is included in the model domain and is shown with the WRFS in Figure 5-7.

The LVVSZ is a west-northwest-striking fault with a traceable length of about 120 km. The western segment of the LVVSZ separates the highly extended Sheep Range detachment system to the north from the unextended Spring Mountain block to the south (Guth, 1981, 1990). The central segment of the LVVSZ forms the northern boundary of the Las Vegas Valley (Longwell, 1960; Campana and Levandowski, 1991). The eastern segment of the LVVSZ separates the highly extended Boulder Basin block to the south from the weakly extended Muddy Mountains block to the north (Duebendorfer and Black, 1992). The LVVSZ acts as not only a tectonic divide but also as a hydraulic barrier (SNWA, 2005).

The western hydrographic boundary of this portion of the Las Vegas Flow System consists of thick carbonate and alluvial deposits, so it is permeable. Harrill et al. (1988) routed 5,000 afy of groundwater through this boundary out of Las Vegas Valley. Harrill et al. (1988) also routed 1,200 afy of groundwater out of this portion along the LVVSZ to Black Mountains Area and an unknown amount of groundwater to Coyote Spring Valley.

San Juan et al. (2004) did not depict any interbasin flow arrows into this portion of Las Vegas Valley. Thus, the actual groundwater flow direction in this portion of the flow system is not known.