8.0 SELECTED INTERBASIN FLOW LOCATIONS

As stated in Section 5.0, locations, directions, and rates of interbasin flow in the model area are uncertain in many locations. However, it was necessary to quantify interbasin flow at specific locations for two reasons: (1) to use them as constraints in the groundwater-balance method of calculating recharge, and (2) to define boundary conditions for the numerical model. The implementation of the groundwater-budget-method described in Section 9.0 required the selection of specific flow-routing patterns. The groundwater-budget method calculations yielded a recharge distribution, more refined estimates on interbasin flow at selected locations, and groundwater budgets for the model area. Boundary conditions were defined in the numerical model for sufficiently transmissive portions of the model external boundary.

8.1 Location Selection

Potential, regional groundwater flow within the flow systems of the study area occurs through the geologic units present along basin boundaries. Potential locations of boundary segments where interbasin flow could occur within the study area were identified based on the three-dimensional hydrogeologic framework described in SNWA (2008a). The lithology and structure along each of the basin boundaries were examined to assess the likelihood of interbasin groundwater flow across them. Each basin boundary was classified, based on its potential for flow, as likely, permissible, or unlikely (SNWA, 2008a, Volume 1, Figure 4-10).

The basin boundaries through which flow was deemed likely or permissible were further examined for their likelihood to transmit groundwater flow, using the available potentiometric data (SNWA, 2008a, Volume 2).

Arrows in the direction of flow potential were posted on basin boundaries across which a hydraulic potential exists to represent locations where interbasin flow likely occurs under natural conditions (Plate 1).

Thus, some interbasin flow directions were selected over others in areas of conflicting interpretations. However, no single interpretation was dismissed from this study. Rather, interpretations not used to derive initial recharge distributions and groundwater budgets were included in the uncertainty envelope of the conceptual model. The final interbasin flow directions and volumes were derived from the calibrated numerical model.

8.2 Estimates of Interbasin Flow Rates

A subset of the interbasin flow locations shown on Plate 1 were selected for the purpose of estimating flow rates. The selected flow-routing configuration (Figure 8-1) matches the interpretation of Harrill et al. (1988) for the most part. Interbasin flow volumes across the external boundaries of the model area were estimated using Darcy's equation and Monte Carlo simulations. Others were estimated using available information from the literature. These methods are presented within this section.

8.2.1 Estimates of Interbasin Flow by Monte Carlo Method

Flux through each RMU present across a flow-boundary segment was calculated using Darcy's equation:

$$Q = T \times I \times W \qquad \text{(Eq. 8-1)}$$

where,

Q = Flow rate (ft^3/day)
T = Transmissivity (ft^2/day)
I = Hydraulic gradient
W = Flow width (ft)

Data requirements are as follows:

- Identification of potential flux boundaries
- Identification of RMUs present across each flux boundary
- Probability distributions of transmissivity (T) data for each RMU present
- Probability distributions of hydraulic gradient (I) across each flow-boundary segment
- Probability distributions of flow widths (W) along each flow-boundary segment

The method consisted of conducting multiple calculations of flux across a given flow-boundary segment to derive stochastic estimates of the flux. Each flux calculation is a Monte Carlo realization. A group of realizations constitutes a Monte Carlo simulation, and the simulations were implemented using the Crystal Ball software. A Monte Carlo simulation consisting of 10,000 realizations was conducted for each flow-boundary segment.

8.2.2 Description of Input Data

Estimates of lateral interbasin flow were derived for all external boundaries, except Las Vegas Valley, using the available information.

Probability distributions of transmissivities were derived from the hydraulic-property database described in Appendix C. For RMUs with sufficient data records, the probability distributions were confirmed to be log-normal. The statistics, means, and standard deviations were as calculated. For others, the probability distributions were assumed to also be log-normal.

Hydraulic gradients across permeable-basin boundary segments were derived from a combination of water-level data and previous interpretations of the potentiometric surface. Water-level data were used to calculate the hydraulic gradients. Potentiometric contours for the region (Prudic et al., 1995) were used to identify the approximate directions of groundwater flow. To approximate the regional hydraulic gradient between basins, water levels from the central parts of the basins were used rather than water levels on the mountain blocks. Because carbonate wells are scarce, water levels in the central parts of the basins were assumed to represent regional potentiometric levels, i.e., carbonate aquifer is connected to alluvial aquifers. Also, water levels from groups of wells, rather than single-well measurements, were preferred to capture the magnitude of the mean gradient. The probability distribution was assumed to be normal with COVs between 0.5 and 1. The input data are provided in Appendix H.

The flow widths across permeable segments of the model boundary were identified from a combination of information: (1) the map of permissible flow segments, (2) the regional potentiometric map (Prudic et al., 1995), and (3) the hydrogeologic map including the locations of major structural features. The probability distribution was assumed to be normal with COVs between 0.5 and 1.

8.2.3 Results

The estimates derived for each boundary segment using Darcy flux calculations coupled with Monte Carlo simulations are presented in Table 8-1. The table lists the simulated mean values and 95 percent confidence intervals.

Table 8-1
Estimates of Boundary Fluxes by the Monte Carlo Method

External Flow-Boundary Description	Flow Direction	Annual Volume (afy)			COV
		Mean	5th Percentile	95th Percentile	
Snake Valley to Tule Valley	Out	19,082	1,101	51,576	0.86
Long Valley to Newark Valley	Out	3,670	135	11,002	0.97
Butte Valley South to Butte Valley North	Out	4,006	768	8,426	0.60
Steptoe Valley to Goshute Valley	Out	5,861	2,297	10,152	0.41
Tippett Valley to Antelope Valley	Out	13,718	2,528	29,087	0.60
Snake Valley to Great Salt Lake Desert	Out	11,526	1,138	29,241	0.79
Tikaboo Valley South to Coyote Springs Valley	In	5,042	664	11,544	0.68
Lower Moapa Valley to Colorado River (pre-Lake Mead)	Out	14,727	4,771	27,109	0.48
Lower Moapa Valley to Lake Mead	Out	10,808	3,362	20,144	0.48

8.3 Estimates of Interbasin Flow for Other Boundary Segments

Interbasin flow for selected basin boundaries located on the outer boundaries of the flow systems, or internal to the flow system, was also estimated using the available information to be used in the groundwater-balance method calculations to derive a recharge distribution and groundwater budgets.

Descriptions of these estimates, including the information used to derive them, are provided in this section by flow system.

8.3.1 Goshute Valley Flow System

Interbasin flow may occur at one location within the GVFS (Figure 8-1): from Butte Valley South to Steptoe Valley. Prudic et al. (1995) simulated about 2,100 afy of interbasin flow from Butte Valley South to Steptoe Valley. In the solver, the annual volume of flow across this basin boundary was treated as a constrained unknown greater than zero.

8.3.2 Great Salt Lake Desert Flow System

Interbasin flow may occur at two locations within the GSLDFS (Figure 8-1): from Spring Valley to Hamlin Valley and from Tippett Valley to Spring Valley.

The amount of outflow from Spring Valley to Hamlin Valley has been estimated at 4,000 afy by Rush and Kazmi (1965) and Nichols (2000) and at 51,000 afy by Welch et al. (2008). For flow between North Spring Valley and South Tippet Valley, Scott et al. (1971) estimated 2,000 afy of inflow from Tippett Valley to Spring Valley. This estimate was also used by Harrill et al. (1988). In short, previous investigators estimated small volumes of flow in the same direction for both interbasin boundaries. Thus, the annual volume of flow across these basin boundaries was treated as constrained unknowns greater than zero in the solver.

8.3.3 White River Flow System

Reasonable ranges of flow may be derived from the available information for several interbasin flow locations internal to the WRFS. They are as follows, from north to south: (1) outflow from Cave Valley to White River Valley and Pahroc Valley, (2) outflow from White River Valley to Pahroc Valley, (3) outflow from Coyote Spring Valley to the Muddy River Springs area and other basins, and (4) inflow from Lower Meadow Valley Wash (Figure 8-1). Estimates of these interbasin flow volumes are summarized in this section.

1. Outflow from Cave Valley is most probably to the west and south. Outflow to the west is through Shingle Pass to White River Valley and has been estimated at 4,000 afy (SNWA, 2007). A detailed estimate is provided by SNWA (2007, Appendix D). The interbasin flow at this location was treated as a fixed constraint in the solver. Potentiometric contours also support flow from Cave Valley to the south to Pahroc Valley (Plate 1). The quantity of interbasin flow in this case was derived from the solution.

2. Outflow from Pahroc Valley is most probably to Dry Lake and Pahranagat valleys. Outflow to Dry Lake Valley has been estimated to be small at 2,000 afy (SNWA, 2007). A detailed estimate is provided by SNWA (2007, Appendix D). The interbasin flow at this location was treated as a fixed constraint in the solver. Potentiometric contours also support flow from Pahroc Valley to Pahranagat Valley (Plate 1). The quantity of interbasin flow in this case was derived from the solution.

3. Maxey and Eakin (1949) estimate the groundwater outflow from White River Valley to Pahroc Valley to be between about 6,300 and 19,000 afy. Their minimum estimate is based on the assumption that the outflow consists of spring flow. No evidence exists to substantiate this assumption. Thus, this flow was set to be unknown in the solver with a flow range constrained to vary between 0 and 40,000 afy.

4. Outflow from Coyote Spring Valley is likely to occur within the carbonate-rock aquifer. Most of this outflow probably enters the Muddy River Springs area. The rest of it probably moves into California Wash, Garnet Valley, and Hidden Valley (Plate 1). These quantities were set as constrained unknowns in the solver. The outflow from Coyote Spring Valley to Muddy River Springs area was constrained to be between 28,000 and 40,000 afy. The 28,000 afy is the difference between the spring discharge (34,000 afy) and the inflow from Lower Meadow Valley Wash (6,000 afy). The 40,000 afy is the sum of the spring discharge and the volume of groundwater ET from the Muddy River Springs area. The outflow to the other three basins was constrained to be greater than 2,000 afy, based on the discharge of Rogers and Blue Point springs. A hydraulic link between the Muddy River and Rogers springs is uncertain because of the difference in the geochemistry of their waters. This outflow was then subdivided equally among the three basins.

5. A portion of the flow into the WRFS originates from the MVFS. This inflow is from Lower Meadow Valley Wash to the Muddy River Springs Area and California Wash. The two annual inflow volumes were treated as constrained unknowns in the solver. The total flow volume was constrained to be between 2,400 and 13,000 afy. Buqo (2002) estimated the interbasin flow from Lower Meadow Valley Wash to the Lewis Farm area (California Wash) to range between 2,400 and 7,200 afy. In the same report, Buqo (2002) also suggested that, if the groundwater fluxes through the deep Tertiary units and the thick upper carbonate aquifer are taken into consideration, appreciably more subsurface flow through the area could occur at depth. Based on the RASA model, Prudic et al. (1995) found that 13,000 afy of Muddy River Springs area water may originate from the MVFS. Using isotope-balance models, Thomas et al. (1996) and Kirk and Campana (1990) derived an estimate of interbasin flow from the MVFS that falls within the 2,400–13,000-afy range. LVVWD (2001) estimated an interbasin flow rate of 32,000 afy from the MVFS to Lower Moapa Valley.

8.3.4 Las Vegas Valley

No consensus exists about flow across the boundary between the model area and the rest of the Las Vegas Valley. To account for the diverging interpretations, the flow is assumed to be zero with an uncertainty range of ±3,000 afy. The magnitude of the uncertainty range is based on the recharge volume estimated for the portion of the Las Vegas Valley located in the model area.

8.4 Flow Summary

The interbasin flow volumes described above are summarized in Table 8-2. For comparison purposes, the estimates reported in the literature are also listed in this table. The ranges of lateral flow across the external boundaries of the four flow systems along with selected internal locations of internal basin flow were used in the Excel® Solver to derive the solutions described in Section 9.0. The interbasin flow locations and constraints on the annual flow volumes are shown in Figure 8-1. The estimated ranges of lateral flow along the external boundary of the model area were used in the numerical model. Their locations are shown in Figure 8-2. The corresponding estimated fluxes are listed in Table 8-3.

Table 8-2
Estimated Interbasin Flow Volumes and Reported Values
(Page 1 of 2)

Flow Section	This Study	Reported	Source
Goshute Valley Flow System			
Outflow (afy)			
Butte Valley South to Butte Valley North	1,000 to 8,000	8,000	Welch et al. (2008)
		~3,000[a]	Glancy (1968)
		~1,000[b]	Harrill et al. (1988)
Steptoe Valley to Goshute Valley	2,000 to 10,000	7,000	Welch et al. (2008)
		4,000	Nichols (2000)
		~1,000	Eakin et al. (1967)
		Minor (1,000)	Harrill et al. (1988)
		~1,000 (some)	Scott et al. (1971)
		2,130 to 5,330	Frick (1985)
Butte Valley South to Jakes Valley	NE	16,000	Welch et al. (2008)
Steptoe Valley to Jakes Valley	NE	14,000	
Steptoe Valley to White River Valley	NE	8,000	
Steptoe Valley to Lake Valley	NE	20,000	
Steptoe Valley to Spring Valley	NE	4,000	
Inflow (afy)			
NA	NA	NA	NA
Great Salt Lake Desert Flow System			
Outflow (afy)			
Snake Valley to Great Salt Lake Desert	1,000 to 30,000	29,000	Welch et al. (2008)
		10,000	Hood and Rush (1965)
		10,000	Gates and Kruer (1981)
		10,000	Harrill et al. (1988)
Tippett Valley to Antelope Valley	3,000 to 29,000	12,000	Welch et al. (2008)
		5,000	Scott et al. (1971)
		5,000	Harrill et al. (1988)
		5,000	Harrill (1971)
Snake Valley to Tule Valley	1,000 to 52,000	22,000 to 42,000 (33,000)	Harrill et al. (1988)
		15,000	Hood and Rush (1965)
		15,000[c]	Gates and Kruer (1981)
Inflow (afy)			
Steptoe Valley to Spring Valley	NE	4,000	Welch et al. (2008)
Lake Valley to Spring Valley	NE	29,000	
Wah Wah Valley to Snake Valley	NE	9,750[d]	Harrill et al. (1988)
Pine Valley to Snake Valley	NE		
Lower Meadow Valley Flow System			
Outflow (afy)			
Lake Valley to Spring Valley	NE	29,000	Welch et al. (2008)
Lower Meadow Valley Wash to WRFS	2,400 to 13,000	13,000	Prudic et al. (1995)
		2,400 to 7,200	Buqo (2002)
		7,000	Rush (1964)
		8,000	Thomas et al. (1996)
		5,500 to 9,000	Kirk and Campana (1990) as reported by Thomas et al. (1996)
		32,000	LVVWD (2001)
Inflow (afy)			
Steptoe Valley to Lake Valley	NE	20,000	Welch et al. (2008)

Table 8-2
Estimated Interbasin Flow Volumes and Reported Values
(Page 2 of 2)

Flow Section	This Study	Reported	Source
White River Flow System			
Outflow (afy)			
Long Valley to Newark Valley or Railroad Valley	0 to 12,000	NE	Harrill et al. (1988)
		10,000	Nichols (2000)
		13,000	
		5,000	Welch et al. (2008)
		12,700	Prudic et al. (1995)
Garden Valley to Three Lakes Valley	-1,000 to 1,000	1,226	San Juan et al. (2004)
Pahranagat Valley to Tikaboo Valley South	NE	7,000	Thomas et al. (1996)
		0	Thomas et al. (2001) and Thomas et al. (2006)
		6,000	D'Agnese et al. (1997)
		3,700 to 4,600	Kirk and Campana (1990)
Lower Moapa Valley and Black Mountain to Colorado River	5,000 to 28,000	NE	Harrill et al. (1988)
		1,100	Scott et al. (1971)
		1,100	Rush (1968b)
		3,000	Prudic et al. (1995)
Groundwater Components in the stream	6,600 to 7,400	10,000	Scott et al. (1971)
		10,000	Rush (1968b)
Rogers and Blue Point Springs	1,500 to 1,700	---	---
Total outflow (Lower Moapa and Black Mt.)	13,000 to 37,000	49,000	LVVWD (2001)
Inflow (afy)			
Lower Meadow Valley Wash to WRFS	2,400 to 13,000	7,000	Harrill et al. (1988)
		7,000	Scott et al. (1971)
		7,000	Rush (1968b)
		8,000	Welch (1988) as reported by Thomas et al. (1996)
		13,000	Prudic et al. (1995)
		2,400 to 7,200	Buqo (2002)
		32,000	LVVWD (2001)
		8,000	Thomas et al. (1996)
		5,500 to 9,000	Kirk and Campana (1990) as reported by Thomas et al. (1996)
Tikaboo Valley North to Pahranagat Valley	NE	824	San Juan et al. (2004)
Tikaboo Valley South to Coyote Springs Valley	1,000 to 12,000	5,551	
Muddy River Spring Discharge			
Inflow to Muddy River Spring Area	28,000 to 40,000	37,000	Harrill et al. (1988)
		37,000	Scott et al. (1971)
		28,000	Thomas et al. (1996)
		37,000	Thomas et al. (2001)
		35,000	Eakin (1966)
		16,500 to 19,100	Kirk and Campana (1990) as reported by Thomas et al. (1996)
Las Vegas Flow System			
Outflow (afy)			
Las Vegas to Three Lakes	-3,000 to 3,000	5,000	Harrill et al. (1988)
		5,000	Scott et al. (1971)
Inflow (afy)			
Three Lakes to Las Vegas	NA	1,355	San Juan et al. (2004)

NA = Not applicable, NE = Not estimated

[a] Value estimated as recharge minus discharge.

[b] Reported value is the flow volume out of Butte Valley North.

[c] Reported value is for flow from Snake Valley to possibly Fish Springs Flat.

[d] Reported value is half of the total flow volume into Snake Valley from Pine and Wah Wah valleys (19,500 afy).

Table 8-3
External Boundary Flux Estimates for Numerical Model

Lateral Flow-Boundary Description	Flow Direction	Estimated Flux (afy)			Comment
		Expected	Minimum[a]	Maximum	
Pine Valley to south Snake Valley	In/Out	0	-5,000	5,000	Boundary permeable but no hydraulic gradient across, under predevelopment conditions. Flux is estimated.
Wah Wah Valley to south Snake Valley	In/Out	0	-5,000	5,000	
Snake Valley to Tule Valley	Out	21,000	1,000	52,000	Expected value from solver solution. Range rounded from Monte Carlo analysis results.
Long Valley to Newark Valley	Out	0	0	12,000	
Butte Valley South to Butte Valley North	Out	1,000	1,000	8,000	
Steptoe Valley to Goshute Valley	Out	2,000	2,000	10,000	
Tippett Valley to Antelope Valley	Out	3,300	3,000	29,000	
Snake Valley to Great Salt Lake Desert	Out	13,000	1,000	30,000	
Tikaboo Valley South to Coyote Springs Valley	In	5,000	1,000	12,000	
Garden Valley to Three Lakes Valley	In/Out	0	-1,000	1,000	Boundary permeable but no hydraulic gradient across, under predevelopment conditions. Flux is estimated.
Las Vegas Valley to Three Lakes Valley	In/Out	0	-3,000	3,000	Based on recharge volume estimated for portion of Las Vegas Valley in model area.
Lower Moapa Valley to Colorado River (pre-Lake Mead)	Out	16,000	5,000	28,000	Range rounded from Monte Carlo analysis results. Hydraulic gradient observed between wells in Lower Moapa Valley and St. Thomas Well. Includes spring flow of 2,000 afy and stream flow of 7,000 afy.
Black Mountain to Colorado River (pre-Lake Mead)	Out	0	0	2,000	Flux is estimated.
Lower Moapa Valley to Colorado River (post-Lake Mead)	Out	11,000	3,000	20,000	Expected value, range rounded from Monte Carlo analysis results. Does not include spring flow and stream flow. Hydraulic gradient observed between wells in Lower Moapa Valley and mean Lake Mead water level.
Black Mountain to Colorado River (post-Lake Mead)	Out	0	0	1,000	Flux is estimated.

[a] Negative values are shown where flow direction may be in or out at the same volume.