Appendix H

Interbasin Flow

H.1.0 Interbasin Flow

This appendix contains reported estimates of interbasin flow for the basins in the study area and estimates of subsurface flow through the external boundary of the model area using the Monte Carlo method.

H.1.1 Reported Estimates of Interbasin Flow

A literature review was conducted to compile estimates of interbasin flow for all basins in the study area to support the discussion presented in the main text. The locations of interbasin flow are shown in Figure H-1. The reported values and overall ranges of flow across each segment boundary are presented in Table H-1.

H.1.2 External Boundary Flow–Monte Carlo Method

Interbasin flow volumes across most external boundaries of the model area were estimated using Darcy's equation and the Monte Carlo method. The method consisted of conducting Monte Carlo simulations using Crystal Ball software to generate stochastic estimates of total flux across each flow-boundary segment.

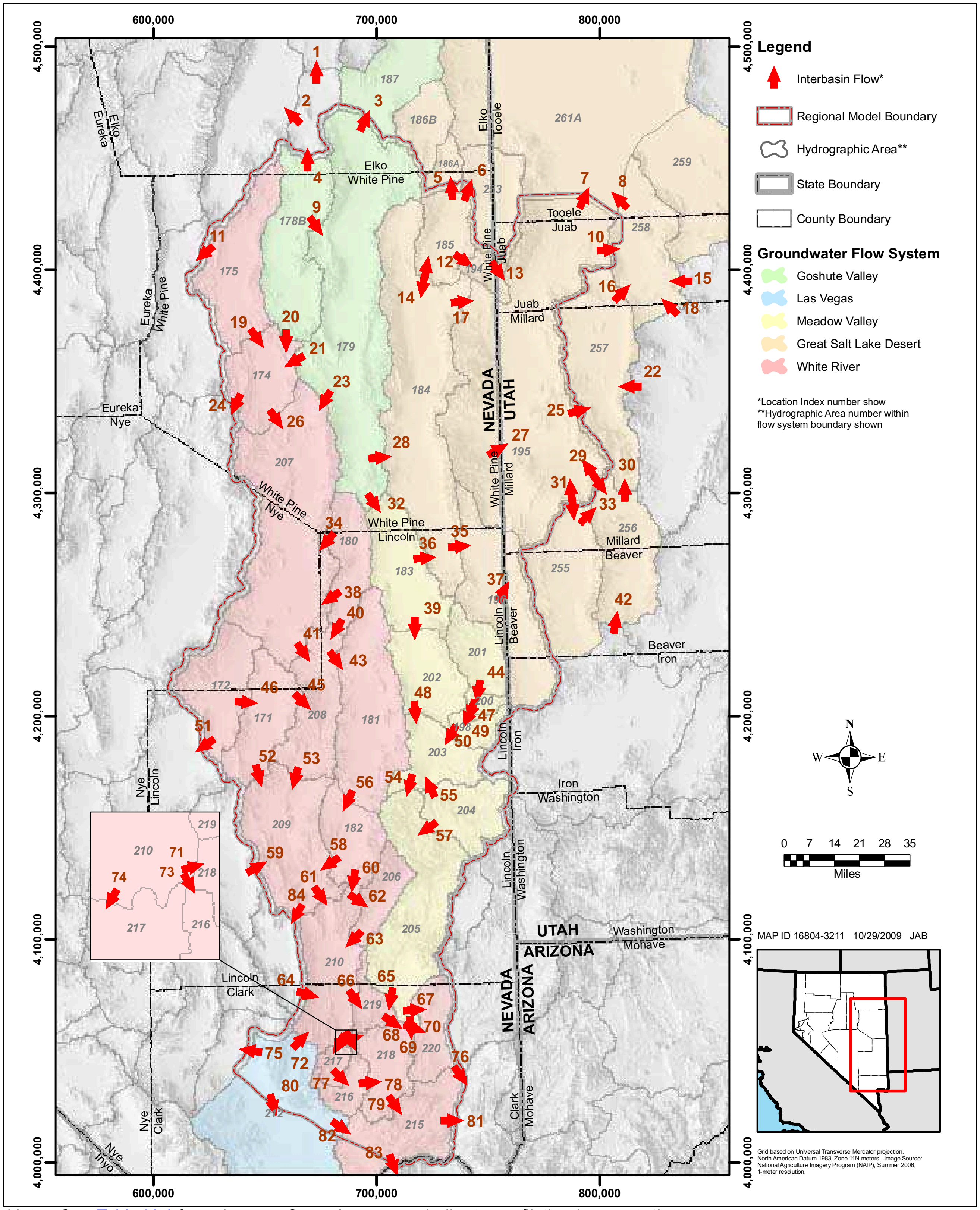
The analysis process included the following steps:

1. Began with the approximate locations of flow-boundary segments where groundwater flow is permissible (SNWA, 2008). Permissible means only that the flow-boundary segment is permeable, not that flow actually occurs through it under predevelopment conditions.

2. Extracted the RMU column from the simplified hydrogeologic framework model for each permeable flow-boundary segment.

3. Prepared input data (see Section H.1.3):

   - Estimated mean transmissivities and standard deviations using the available hydraulic head data.
   - Using the surficial RMU map and the available potentiometric maps, estimated the flow width of each permeable boundary segment.
   - Using the same maps as above and measured water levels, estimated the hydraulic gradient across each permeable flow-boundary segment.



Note: See Table H-1 for volumes. Opposing arrows indicate conflicting interpretations.

Figure H-1
Locations of Interbasin Flow within Study Area

Table H-1
Reported Volumes of Interbasin Flow in Study Area
(Page 1 of 7)

Location Index[a]	Interbasin Flow Range (afy)	Interbasin Flow (afy)	Sources
1	22,500	22,500	Nichols (2000)
2	800 to 2,000	800	Scott et al. (1971)
		1,000	Harrill et al. (1988)
		2,000	Nichols (2000)
3	M to 7,000	M	Harrill et al. (1988)
		S	Scott et al. (1971)
		2,130 to 5,330	Frick (1985)
		4,000	Nichols (2000)
		7,000	Welch et al. (2008)
4	3,000 to 8,000	3,000	Glancy (1968)
		8,000	Welch et al. (2008)
5	3,000	3,000	Harrill et al. (1988)
6	2,000 to 12,000	2,000	Harrill et al. (1988)
		6,000	Nichols (2000)
		12,000	Welch et al. (2008)
7	3,500 to 29,000	3,500	Carlton (1985)
		10,000	Hood and Rush (1965)
		10,000	Gates and Kruer (1981)
		10,000	Harrill et al. (1988)
		29,000	Welch et al. (2008)
8	1,000 to 8,500	1,000	Harrill et al. (1988)
		8,500	Carlton (1985)
9	?	?	Harrill et al. (1988)
10	? to 18,500	?	Harrill et al. (1988)
		15,000?	Gates and Kruer (1981)
		18,500	Carlton (1985)
11	? to 12,700	?	Harrill et al. (1988)
		5,000	Welch et al. (2008)
		8,000	Thomas et al. (2001)
		10,000	Nichols (2000)
		12,700	Prudic et al. (1995)
12	3,600	3,600	Nichols (2000)
13	3,000	3,000	Scott et al. (1971)
14	-2,000 to 2,000	-2,000	Welch et al. (2008)
		2,000	Harrill (1971)
		2,000	Harrill et al. (1988)
15	6,000	6,000	Carlton (1985)
16	25,500 to 27,000	25,500	Carlton (1985)
		27,000	Harrill et al. (1988)
17	4,000 to 16,000	4,000	Nichols (2000)
		16,000	Welch et al. (2008)
18	?	?	Harrill et al. (1988)

Table H-1
Reported Volumes of Interbasin Flow in Study Area
(Page 2 of 7)

Location Index[a]	Interbasin Flow Range (afy)	Interbasin Flow (afy)	Sources
19	8,000 to 19,000	8,000	Eakin (1961)
		8,000	Eakin (1966)
		8,000	Harrill et al. (1988)
		8,000	Scott et al. (1971)
		12,000	LVVWD (2001)
		12,000	Thomas et al. (2001)
		14,000	Nichols (2000)
		16,900	Thomas and Mihevc (2007)
		19,000	Welch et al. (2008)
20	16,000	16,000	Welch et al. (2008)
21	14,000	14,000	Welch et al. (2008)
22	5,500 to 9,000	5,500	Carlton (1985)
		9,000	Harrill et al. (1988)
23	8,000	8,000	Welch et al. (2008)
24	? to 700	?	Harrill et al. (1988)
		700	Nichols (2000)
25	15,000 to 42,000	15,000	Hood and Rush (1965)
		22,000 to 42,000	Harrill et al. (1988)
26	16,527 to 63,000	16,527 to 27,145	Kirk and Campana (1990)
		25,000	Eakin (1966)
		25,000	Scott et al. (1971)
		28,800	Thomas and Mihevc (2007)
		35,000	LVVWD (2001)
		35,000	Thomas et al. (2001)
		51,200	Nichols (2000)
		63,000	Welch et al. (2008)
27	30,000	30,000	Scott et al. (1971)
28	4,000	4,000	Welch et al. (2008)
29	-4,250 to 4,000	-4,250	Harrill et al. (1988)[b]
		4,000	Carlton (1985)
30	4,250 to 26,500	4,250	Harrill et al. (1988)[b]
		26,500	Carlton (1985)
31	-5,500 to 16,500	-5,500	Harrill et al. (1988)[b]
		16,500	Carlton (1985)
32	20,000	20,000	Welch et al. (2008)
33	5,500 to 30,000	5,500	Harrill et al. (1988)[b]
		30,000	Carlton (1985)
34	4,000 to 11,180	4,000	Thomas and Mihevc (2007)
		9,000	Welch et al. (2008)
		8,571 to 11,180	Kirk and Campana (1990)

Table H-1
Reported Volumes of Interbasin Flow in Study Area
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Location Index[a]	Interbasin Flow Range (afy)	Interbasin Flow (afy)	Sources
35	4,000 to 33,000	4,000	Rush and Kazmi (1965)
		4,000	Gates and Kruer (1981)
		4,000	Harrill et al. (1988)
		4,000	Scott et al. (1971)
		10,000	Nichols (2000)
		33,000	Welch et al. (2008)
36	29,000	29,000	Welch et al. (2008)
37	10,000	10,000	Scott et al. (1971)
38	14,000 to 15,000	14,000	Eakin (1962)
		14,000	Eakin (1966)
		14,000	Harrill et al. (1988)
		14,000	Scott et al. (1971)
		15,000	LVVWD (2001)
39	3,000 to 17,000	3,000	Rush and Eakin (1963)
		3,000	Harrill et al. (1988)
		3,000	Scott et al. (1971)
		5,600	Thomas and Mihevc (2007)
		17,000	LVVWD (2001)
		17,000	Thomas et al. (2001)
40	9,400 to 15,000	9,400	Thomas and Mihevc (2007)
		15,000	Thomas et al. (2001)
41	6,400 to 40,000	6,400	Thomas and Mihevc (2007)
		17,000	Thomas et al. (2001)
		32,000	LVVWD (2001)
		39,000	Welch et al. (2008)
		40,000	Eakin (1966)
		40,000	Harrill et al. (1988)
		40,000	Scott et al. (1971)
42	1,500	1,500	Carlton (1985)
43	2,000	2,000	Thomas and Mihevc (2007)
44	M to 15,000	M	Scott et al. (1971)
		M	Harrill et al. (1988)
		7,200	Thomas and Mihevc (2007)
		15,000	LVVWD (2001)
		15,000	Thomas et al. (2001)
45	20,000 to 27,000	20,000	LVVWD (2001)
		27,000	Thomas and Mihevc (2007)
46	8,000 to 23,100	8,000	Eakin (1966)
		8,000	Harrill et al. (1988)
		8,000	Scott et al. (1971)
		14,000	LVVWD (2001)
		14,000	Thomas et al. (2001)
		23,100	Thomas and Mihevc (2007)

Table H-1
Reported Volumes of Interbasin Flow in Study Area
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Location Index[a]	Interbasin Flow Range (afy)	Interbasin Flow (afy)	Sources
47	0 to 16,000	0	Scott et al. (1971)
		1,000	Harrill et al. (1988)
		8,300	Thomas and Mihevc (2007)
		16,000	LVVWD (2001)
		16,000	Thomas et al. (2001)
48	9,000 to 28,000	9,000	Harrill et al. (1988)
		9,000	Scott et al. (1971)
		14,900	Thomas and Mihevc (2007)
		28,000	LVVWD (2001)
		28,000	Thomas et al. (2001)
49	0 to 16,000	0	Scott et al. (1971)
		7,900	Thomas and Mihevc (2007)
		16,000	LVVWD (2001)
		16,000	Thomas et al. (2001)
50	7,400 to 16,000	7,400	Thomas and Mihevc (2007)
		16,000	LVVWD (2001)
		16,000	Thomas et al. (2001)
51	1,216 to 3,758	1,216	San Juan et al. (2004
		3,758	Faunt et al. (2004)
52	10,000 to 20,000	10,000	Eakin (1963)
		10,000	Eakin (1966)
		10,000	Harrill et al. (1988)
		10,000	Scott et al. (1971)
		20,000	Thomas et al. (2001)
53	1,330 to 59,000	1,330 to 1,970	Kirk and Campana (1990)
		39,000	Thomas et al. (2001)
		42,000	Eakin (1966)
		42,000	Harrill et al. (1988)
		42,000	Scott et al. (1971)
		45,300	Thomas and Mihevc (2007)
		59,000	LVVWD (2001)
54	M to 36,000	M	Harrill et al. (1988)
		8,900	Thomas and Mihevc (2007)
		27,000	LVVWD (2001)
		36,000	Thomas et al. (2001)
55	M to 9,000	M	Scott et al. (1971)
		9,000	Thomas et al. (2001)
56	5,000 to 17,700	5,000	Eakin (1966)
		5,000	Harrill et al. (1988)
		5,000	Scott et al. (1971)
		12,000	LVVWD (2001)
		12,000	Thomas et al. (2001)
		17,700	Thomas and Mihevc (2007)

Table H-1
Reported Volumes of Interbasin Flow in Study Area
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Location Index[a]	Interbasin Flow Range (afy)	Interbasin Flow (afy)	Sources
57	9,000 to 9,700	9,000	LVVWD (2001)
		9,700	Thomas and Mihevc (2007)
58	6,000	6,000	Eakin (1966)
		6,000	Harrill et al. (1988)
		6,000	Scott et al. (1971)
59	811 to 11,307	811	San Juan et al. (2004)
		11,307	Faunt et al. (2004)
60	16,000 to 24,100	16,000	Thomas et al. (2001)
		16,000	LVVVWD (2001)
		24,100	Thomas and Mihevc (2007)
61	22,300 to 35,000	22,300	Thomas and Mihevc (2007)
		27,247 to 29,370	Kirk and Campana (1990)
		28,000	LVVWD (2001)
		28,000	Thomas et al. (2001)
		35,000	Eakin (1966)
		35,000	Scott et al. (1971)
		35,000	Harrill et al. (1988)
62	S	S	Scott et al. (1971)
63	M to 6,000	M	Scott et al. (1971)
		M	Harrill et al. (1988)
		4,200	Thomas and Mihevc (2007)
		6,000	LVVWD (2001)
		6,000	Thomas et al. (2001)
64	? to 14,023	5,513	San Juan et al. (2004)
		14,023	Faunt et al. (2004)
		?	Harrill et al. (1988)
65	2,400 to 13,000	2,400 to 7,200	Buqo (2002)
		4,000	Thomas and Mihevc (2007)
		8,000	Thomas et al. (1996)
		5,500 to 9,000	Kirk and Campana (1990) as reported by Thomas et al. (1996)
		13,000	Prudic et al. (1995)
66	28,000 to 37,700	28,000	Thomas et al. (1996)
		37,000	Eakin (1966)
		37,000	Harrill et al. (1988)
		37,000	LVVWD (2001)
		37,000	Scott et al. (1971)
		37,000	Thomas et al. (2001)
		37,700	Thomas and Mihevc (2007)
67	32,000	32,000	LVVWD (2001)
		32,000	Thomas et al. (2001)

Table H-1
Reported Volumes of Interbasin Flow in Study Area
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Location Index[a]	Interbasin Flow Range (afy)	Interbasin Flow (afy)	Sources
68	M to 41,804	M	Rush (1968)
		M	Scott et al. (1971)
		1,700	Thomas and Mihevc (2007)
		32,000	LVVWD (2001)
		32,000	Thomas et al. (2001)
		34,700	Eakin (1966)
		35,843 to 41,804	Kirk and Campana (1990)
69	5,300 to 7,000	5,300	Thomas and Mihevc (2007)
		7,000	Rush (1968)
		7,000	Harrill et al. (1988)
		7,000	Scott et al. (1971)
70	M to 41,000	M[c]	Rush (1968)
		M[c]	Harrill et al. (1988)
		6,000	Thomas et al. (2001)
		18,900	Thomas and Mihevc (2007)
		41,000	LVVWD (2001)
71, 73, 74	15,000 to 16,000	15,000	Thomas and Mihevc (2007)
		16,000	Thomas et al. (2001)
		16,000	LVVWD (2001)
72	?	?	Harrill et al. (1988)
75	5,000	5,000	Harrill et al. (1988)
76	1,100 to 49,000	1,100	Scott et al. (1971)
		11,100[d]	Rush (1968)
		15,300	Thomas and Mihevc (2007)
		26,000	Thomas et al. (2001)
		49,000[e]	LVVWD (2001)
77	?,M to 15,000	?	LVVWD (2001)
		M	Harrill et al. (1988)
		300	Thomas et al. (2001)
		400	Rush (1968)
		400	Scott et al. (1971)
		15,000	Thomas and Mihevc (2007)
78	? to 17,000	?	LVVWD (2001)
		800	Rush (1968)
		800	Scott et al. (1971)
		1,000	Harrill et al. (1988)
		15,100	Thomas and Mihevc (2007)
		17,000	Thomas et al. (2001)
79	M to 4,000	M	Scott et al. (1971)
		2,000	Thomas and Mihevc (2007)
		2,300	LVVWD (2001)
		4,000	Thomas et al. (2001)
80	1,378	1,378	San Juan et al. (2004)

Table H-1
Reported Volumes of Interbasin Flow in Study Area
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Location Index[a]	Interbasin Flow Range (afy)	Interbasin Flow (afy)	Sources
81	600 to 1,000	600	Thomas and Mihevc (2007)
		1,000	LVVWD (2001)
82	400 to 1,200	400	Rush (1968)
		1,200	Harrill et al. (1988)
83	M to 2,000	M	Scott et al. (1971)
		2,000	Thomas et al. (2001)
84	4,000	4,000	Kirk and Campana (1990)

[a]Location of interbasin flow is shown on Figure H-1 with arrows.
[b]The reported interbasin flow was evenly distributed among multiple flowpaths.
[c]This value doesn't include stream flow.
[d]This value includes 10,000 afy of stream flow that is considered as groundwater here (Rush, 1968).
[e]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 currently available to make an estimate (Scott et al., 1971).

4. Set up an Excel® file containing all data necessary to calculate fluxes in the Crystal Ball software.

5. Ran 10,000 Monte Carlo simulations using the Crystal Ball software.

H.1.3 Description of Input Data Preparation

Estimates of lateral interbasin flow were derived for all external boundaries, except Las Vegas Valley, using the available information. The required data consist of estimates of the probability distributions of the transmissivity, flow widths, and hydraulic gradients across the flow-boundary segment.

Probability distributions of transmissivities were derived from the hydraulic-property database described in Appendix C. Records in the database containing transmissivity values were extracted to form a data subset. If several records were available for a single location, they were reduced to one value by averaging. The reduced data set was then sorted by RMU, and the derived data were analyzed by RMU.

For RMUs with sufficient constant-rate pumping tests, records of other types of tests were removed from the data set. All records were kept for all other RMUs. Except for the carbonate aquifer, the remaining data sets were used for the statistical analyses. For the carbonate aquifers, low and high values were eliminated from the reduced data set prior to the analysis. Low transmissivity values represent matrix-only carbonate rocks, and high transmissivity values represent faults or highly fractured carbonate rocks. 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 other RMUs, the probability distributions were assumed to also be log-normal.

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 hydrogeology map including the locations of major structural features. The three maps were superposed, and the most probable flow width was identified and measured. The probability distribution was assumed to be normal with COV values ranging from 0.5 to 1.

Hydraulic gradients across permeable-segment boundaries were derived from a combination of water-level data and previous interpretations of the potentiometric surface. Potentiometric contours for the entire region (Prudic et al., 1995) were used to identify the approximate directions of groundwater flow. Water-level data were used to actually calculate the hydraulic gradients. 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 of the scarcity of carbonate wells, 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 COV values ranging between 0.5 and 1.

The input data are presented in Table H-2. The last column is not part of the input but provides a deterministic Darcy flux value of the flow rate across each boundary segment and each RMU, using the listed input data.

Table H-2
Input Data for Monte Carlo Simulations of Boundary Fluxes

Boundary Segment	HGU	Transmissivity (ft^2/day)		Hydraulic Gradient (ft/ft)		Flow Width (ft)		Flux (ft^3/day)
		Geometric Mean	STD	Mean	STD	Mean	STD	
Snake Valley to Tule Valley	LC3	6,000	10	0.0045	0.0034	65,617	49,213	1,772,029
Butte Valley South to Butte Valley North	UVF	3,500	10	0.0014	0.0010	19,685	14,764	93,763
	LVF	1,500	10	0.0014	0.0010	19,685	14,764	40,184
	UC	6,000	10	0.0014	0.0010	19,685	14,764	160,737
	UA	50	30	0.0014	0.0010	19,685	14,764	1,339
	LC3	6,000	10	0.0014	0.0010	19,685	14,764	160,737
Steptoe Valley to Goshute Valley	UVF	3,500	10	0.0025	0.0013	16,404	8,202	143,789
	LVF	1,500	10	0.0025	0.0013	16,404	8,202	61,624
	UC	6,000	10	0.0025	0.0013	16,404	8,202	246,495
	UA	50	30	0.0025	0.0013	16,404	8,202	2,054
	LC3	6,000	10	0.0025	0.0013	16,404	8,202	246,495
Tippett Valley to Antelope Valley	UVF	3,500	10	0.0028	0.0021	32,808	24,606	319,695
	LVF	1,500	10	0.0028	0.0021	32,808	24,606	137,012
	UC	6,000	10	0.0028	0.0021	32,808	24,606	548,049
	UA	50	30	0.0028	0.0021	32,808	24,606	4,567
	LC3	6,000	10	0.0028	0.0021	32,808	24,606	548,049
Snake Valley to Great Salt Lake Desert	UVF	3,500	10	0.0004	0.0004	262,467	262,467	346,228
	LVF	1,500	10	0.0004	0.0004	262,467	262,467	148,383
	LC3	6,000	10	0.0004	0.0004	262,467	262,467	593,534
Tikaboo Valley South to Coyote Springs Valley	LC2	6,000	10	0.0076	0.0038	12,467	6,234	570,147
Lower Moapa Valley to Lake Mead	UVF	3,500	10	0.0030	0.0015	39,370	19,685	413,386
	LVF	1,500	10	0.0030	0.0015	39,370	19,685	177,165
	Kps2	1	10	0.0030	0.0015	39,370	19,685	118
	LC3	6,000	10	0.0030	0.0015	39,370	19,685	708,661
Lower Moapa Valley to Colorado River (pre-Lake Mead)	UVF	3,500	10	0.0040	0.0020	39,370	19,685	551,181
	LVF	1,500	10	0.0040	0.0020	39,370	19,685	236,220
	Kps2	1	10	0.0040	0.0020	39,370	19,685	157
	LC3	6,000	10	0.0040	0.0020	39,370	19,685	944,882

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