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A Deuterium Mass-balance Interpretation of Groundwater Sources and Flows in Southeastern Nevada

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May 2001

Publication No. 41169

Prepared by
Division of Hydrologic Sciences
Desert Research Institute
University and Community College System of Nevada

Prepared for
Las Vegas Valley Water District

EXECUTIVE SUMMARY

Deuterium data were used to evaluate new groundwater recharge and discharge (evapotranspiration) rate estimates developed by the Southern Nevada Water Authority (LVVWD, 2001) for regional groundwater flow systems in southeastern Nevada. A deuterium-calibrated mass-balance model was constructed for the White River, Meadow Valley Wash, and Lake Mead groundwater flow systems. This model was used to evaluate if proposed groundwater recharge rates, evapotranspiration rates, sources, and mixing are possible or not. If model-calculated deuterium values for groundwater in the regional aquifers match measured values (within 2 permil), then proposed recharge rates, evapotranspiration rates, sources, and mixing for these flow systems are possible. However, the deuterium mass-balance model developed for the water budget of these flow systems produces a non-unique solution, because a proportionate decrease or increase in both recharge and ET rates, or a different combination of groundwater sources and mixing, can produce the same results.

Results of the deuterium mass-balance model show that:

- New estimates of groundwater recharge and evapotranspiration rates (LVVWD, 2001), and proposed groundwater sources and mixing for the White River, Meadow Valley Wash, and Lake Mead flow systems are consistent with the results of a deuterium-calibrated mass-balance model.
- The White River Flow System acts as one continuous carbonate-rock aquifer from Long Valley in the north to Upper Moapa Valley (Muddy River Springs area) in the south.
- The results of the deuterium mass-balance model of the White River Flow System are consistent with 53,000 acre-feet per year (afy) of groundwater flowing out of Coyote Springs Valley to the Muddy River Springs area in Upper Moapa Valley (37,000 afy) and to the south-southeast in the carbonate-rock aquifers (16,000 afy).
- The Meadow Valley Wash Flow System acts as a two-layer flow system with a carbonate-rock aquifer flow system to the north and west and a volcanic-rock alluvial-fill aquifer system to the east and south that overlies the carbonate-rock aquifer flow system.
- The results of the deuterium mass-balance model of the Meadow Valley Wash Flow System are consistent with measured deuterium values in Panaca Valley for a two-layer regional flow system, but deuterium data are lacking for the underlying carbonate-rock aquifer in Lower Meadow Valley Wash, so the estimated 32,000 afy of groundwater flowing out of Lower Meadow Valley Wash to Upper Moapa Valley cannot be evaluated.
- The Lake Mead Flow System is primarily a carbonate-rock aquifer flow system that transports groundwater from the White River and Meadow Valley Wash flow systems to Lake Mead.
- The results of the deuterium mass-balance model of the Lake Mead Flow System are consistent with 16,000 afy of groundwater flowing from the Coyote Springs Valley-Upper Moapa Valley area to the Hidden Valley-Garnet Valley-California Wash Valley area.

- The deuterium mass-balance model of the Lake Mead Flow System cannot evaluate the inflow of 32,000 afy from Lower Meadow Valley Wash and 8,000 afy from California Wash Valley to Upper Moapa Valley because of the lack of deuterium data for groundwater in the carbonate-rock aquifer in Upper Moapa Valley.
- The deuterium mass-balance model of the Lake Mead Flow System indicates that groundwater discharging in the Rogers and Blue Point springs area is mostly regional groundwater flow in the carbonate-rock aquifers with some local recharge. However, on the basis of deuterium data, another water source for the spring area from Upper Moapa Valley cannot be ruled out.
- Preliminary analyses of oxygen-18 and geochemical data show that these data are consistent with the deuterium mass-balance model of the regional flow systems.
- More work needs to be done to better define deuterium compositions of recharge-area groundwaters (many recharge areas have little or no data) and the variability of deuterium values of springs in recharge areas over time.

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INTRODUCTION

Carbonate-rock aquifers that underlie southeastern Nevada allow for groundwater flow across topographic divides resulting in regional groundwater flow systems that encompass numerous basins and may extend more than 200 miles in length. These regional groundwater flow systems in southern Nevada were first identified by Eakin (1966) on the basis of water levels and spring flow rates. Following this original study, numerous investigators have examined regional groundwater flow in southeastern Nevada (Mifflin, 1968; Winograd and Friedman, 1972; Winograd and Thordarson, 1975; Hess and Mifflin, 1978; Dettinger, 1989; Kirk and Campana, 1990; Prudic et al., 1993; Dettinger et al., 1995; Thomas et al., 1996; Pohlmann et al., 1998).

The purpose of this study is to use stable isotope data to evaluate new recharge and evapotranspiration (ET) estimates [Southern Nevada Water Authority (LVVWD), 2001] for regional flow systems in southeastern Nevada. The study area includes the White River and Meadow Valley Wash regional flow systems and flow from these regional systems to the Lake Mead area of southeastern Nevada (Figure 1). The objective of this study is to combine deuterium data, for groundwater samples in recharge areas, with new recharge and ET estimates to construct deuterium mass-balance models for water budgets of regional flow systems in southeastern Nevada. Flow-weighted deuterium values for warm spring discharge areas and deuterium data for wells completed in carbonate-rock aquifers are compared to values calculated using deuterium mass-balance models to evaluate new recharge and ET estimates for these regional flow systems. Additionally, a preliminary evaluation of oxygen-18 and geochemical data was conducted to help evaluate the validity of the deuterium mass-balance models.

Deuterium data used to construct the mass-balance models presented in this report are primarily historical data from Desert Research Institute and U.S. Geological Survey reports and databases (Winograd and Friedman, 1972; Emme, 1986; Kirk and Campana, 1990; Thomas et al., 1991; Dettinger et al., 1995; Thomas et al., 1996; Pohlmann et al., 1998).

Methods

Environmental isotopes, deuterium (^{2}H) and oxygen-18 (^{18}O), are used for isotopic mass-balance calculations that involve water. These isotopes are used because they are part of the water molecule (H_2O) and they are stable (their concentration does not change over time by radioactive decay). Deuterium is reported as the ratio of $^{2}H/^{1}H$ relative to a standard (VSMOW, Vienna Standard Mead Ocean Water) in parts per thousand (permil). Oxygen-18 is reported as the ratio of $^{18}O/^{16}O$ relative to the VSMOW standard in permil. Because deuterium and oxygen-18 are part of the water molecule, they are ideal tracers for fingerprinting water masses as they flow from recharge areas and mix with other groundwaters before discharging from the flow system. Deuterium and oxygen-18 in precipitation can change (fractionate) during recharge because of physical processes. Precipitation can evaporate during the recharge process, which will cause a change in deuterium and oxygen-18 compositions (they will become less negative) and the isotopes will vary together in a predictable way. However, after precipitation moves beneath the land surface only mixing with isotopically different water, or geothermal heating, can change these values. Thus, deuterium and oxygen-18 are ideal for identifying groundwater sources and mixing.

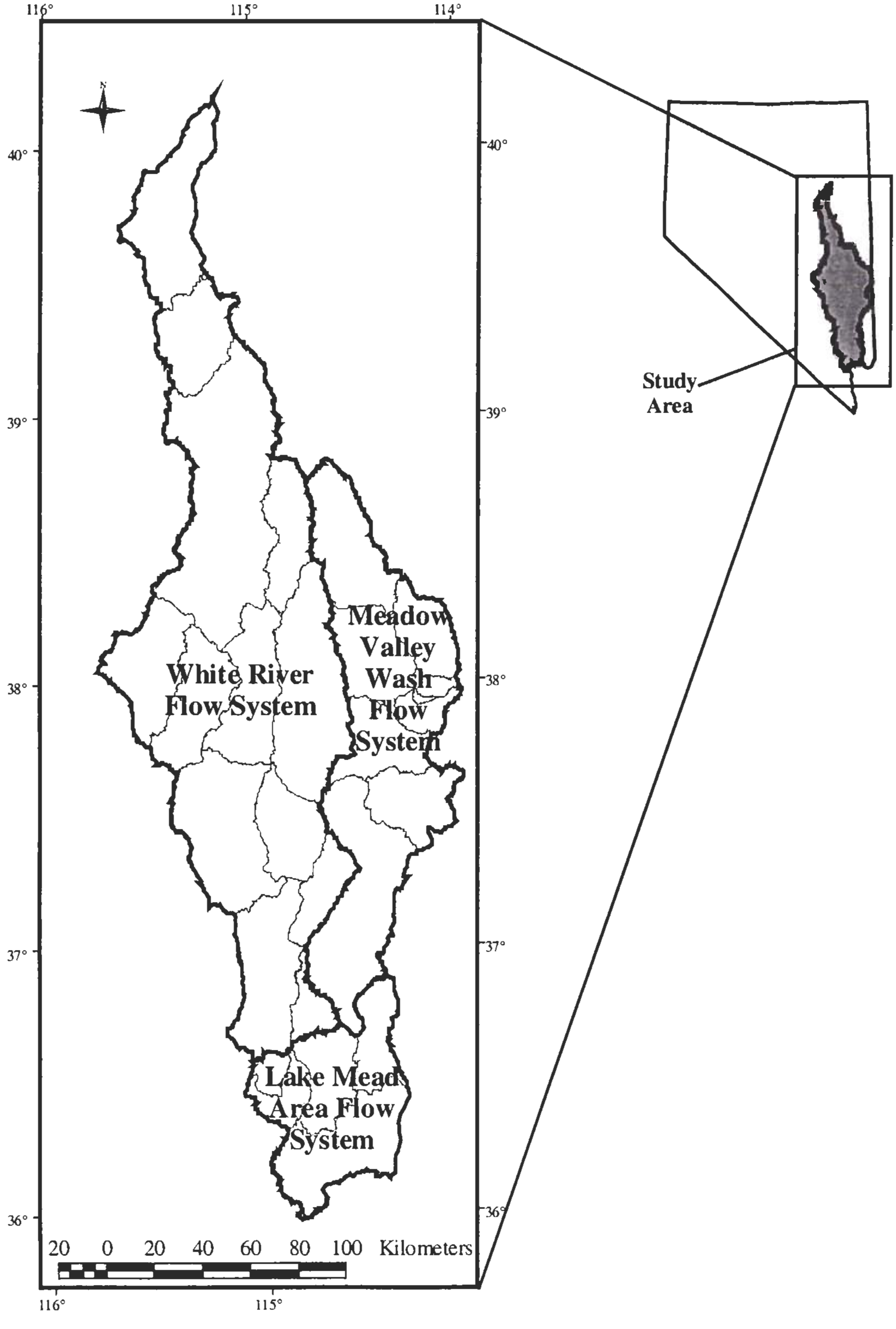

Figure 1. Study area location showing regional ground water flow systems.

Deuterium data are used in this study for isotopic mass-balance calculations. Mass-balance calculations using oxygen-18 are also shown in the tables and appendices, but because oxygen-18 undergoes greater relative change during evaporation than deuterium and can be altered in geothermal systems by water-rock interactions, deuterium mass-balance models will be used in this report.

Deuterium mass-balance models can be used to evaluate the contributions of numerous recharge areas and inflow from other valleys to a regional flow system within a valley. The total estimated recharge to a valley from several recharge areas, and potentially inflow from other valleys, can be validated using deuterium concentrations measured in regional springs or wells completed in regional aquifers. Regional springs in this report are defined as springs flowing from carbonate-rock aquifers that have a water temperature that exceeds 20°C, which indicates that the water has circulated thousands of feet below land surface. To be a valid deuterium mass-balance model, the mixture of recharge inputs, and, if applicable, groundwater inflow, needs to have a calculated deuterium composition (weighted by the amount of recharge or inflow) the same as is measured at a regional spring or well completed in the carbonate-rock aquifers. If more than one spring is present in a discharge area, the flow-weighted average deuterium value of the springs is used as the average measured value. This approach can determine if the proposed recharge areas, and potentially groundwater inflow, are realistic for a flow system and it can also eliminate mixing of different waters when calculated deuterium values do not match measured values. As noted before, a calculated deuterium value that matches a measured value is not a unique solution; varying recharge (or inflow) and ET amounts by the same proportion will result in the same mass-balance calculated deuterium value.

Deuterium Composition of Recharge Waters

Recharge amounts and average deuterium composition were assigned to each mountain range surrounding a valley. The recharge amounts assigned to individual mountain ranges are new recharge estimates from LVVWD (2001). The average deuterium value for each recharge area was determined by first compiling all available isotopic data for springs, wells, streams, and snowmelt runoff within the study area (Appendices 1 and 2). Then, a recharge area deuterium value was calculated by averaging all the deuterium values for sample sites within a recharge area. If a site had more than one deuterium value, then the average deuterium value for the site was used to calculate the average recharge deuterium value for the recharge area.

The majority of isotopic data in recharge areas is for springs. Springs are good samples for representing the isotopic composition of a recharge area, because water discharging from a spring is an integrated sample that may represent several storms, recharge from a season, or even several years of recharge and include precipitation that falls over several thousand feet in elevation. For example, Wiregrass Spring, a high-altitude spring in the Sheep Range, was sampled nine times between 1981 and 1988 (Appendix 2). Samples were collected during different times of the year and the deuterium concentration ranged from -97.0 to -91.5 permil. This 5.5-permil range over an eight-year period showed no discernible pattern.

Limited data within the study area also exist for wells (seven samples), streams (four samples), and snowmelt runoff (one sample, site 224) in recharge areas (Figure 2, located in back pocket of this report). These data were also used to determine the deuterium composition of recharge waters, because of limited data within study area recharge areas and because their deuterium values were similar to springs within the same or nearby recharge areas.

Most recharge areas had some isotopic data that could be used to calculate an average deuterium value (Figure 2). In recharge areas with no data, the nearest similar altitude recharge area with stable isotope data was used to represent average isotopic values for these recharge areas. Most sites were only sampled once, so variability of deuterium recharge values could not be evaluated in this study.

Samples with significantly evaporated isotopic data were excluded in determining the average isotopic composition of a recharge water. These data were kept in the database, but they were noted as evaporated. Groundwaters were considered significantly evaporated if deuterium calculated from the measured oxygen-18 value was greater than 10 permil more positive than the measured deuterium value. A deuterium value was calculated from an oxygen-18 value using the global relationship $\delta D = \delta^{18}O + 10$ (Craig, 1961). Precipitation in southern Nevada generally falls along the global meteoric water line indicating that evaporation of precipitation is negligible (Milne et al., 1987; Ingraham et al., 1991; McKinley and Oliver, 1994; Winograd et al., 1998). Thus, evaporated samples must undergo evaporation after precipitation reaches land surface and before the water recharges an aquifer. ?

Isotopic Variability in Recharge

Variability of deuterium values in recharge areas over time in southern Nevada is likely small as indicated by data for sites that were sampled for both deuterium and carbon-14. Groundwaters derived entirely from recharge in the Spring Mountains have carbon-14 concentrations that vary from 2 to 100 percent modern carbon, yet the deuterium content of these samples vary only 6 permil and randomly with carbon-14 concentration for 25 samples (Thomas et al., 1996; Figure 22 and Appendices A and B). A similar observation is made for recharge originating in the Sheep Range, although only five samples with carbon-14 and deuterium data are available for this comparison (Thomas et al., 1996; Figure 23 and Appendices A and B). Groundwater that originates in the Sheep Range has carbon-14 that varies from 14 to 97 percent modern carbon, while the average deuterium value of these samples varies only 1.2 permil. The wide range in carbon-14 content with a correspondingly small range in deuterium for the two major recharge areas in southern Nevada indicates that the isotopic composition of recharge in southern Nevada has varied little over time. However, the wide range in carbon-14 values may only represent several thousand years of age when the carbon-14 data are corrected for geochemical reactions, rather than a range of about 25,000 years for uncorrected carbon-14 ages (Thomas et al., 1996).

Most springs in recharge areas have only one deuterium value, so variability of deuterium values on a time scale of several years for springs in recharge areas cannot be well constrained. As noted in the previous section, nine samples from Wiregrass Spring in the Sheep Range show a non-systematic 5.5-permil range in deuterium over an eight-year period.

Deuterium Composition of Regional Warm Springs

In the regional flow systems of southeastern Nevada most regional warm (>20°C) spring areas have more than one spring discharging from the carbonate-rock aquifers and several of the regional springs usually have been sampled more than once (Appendix 2). The maximum range in deuterium composition for multiple samples for a spring, or for a group of springs in a warm springs area, is 7.0 permil and most regional warm spring areas have deuterium values that vary only about 3 permil. The range in deuterium content of regional warm springs is -126.0 to -121.0 permil (5 samples) for northern White River warm springs, -120.0 to -118.0 permil (3 samples) for southern White River warm springs, -112.0 to -105.0 permil (18 samples) for Pahranagat Valley warm springs, -99.0 to –96.5 permil (12 samples) for the Muddy River springs area warm springs, -109.0 to –106.0 permil (5 samples) for Panaca and Caliente warm springs in Panaca Valley, and –93.5 to-91.0 permil (7 samples) for Rogers and Blue Point springs in the Black Mountains area. In addition to small variations in deuterium content, the water temperature of the regional warms springs also varies little (Appendix 2). Regional warm spring temperatures vary by less than 2°C for all springs, except for Ash Spring (site 110) in Pahranagat Valley. The small variations in deuterium content and temperature of the regional warm springs indicates well-mixed recharge waters that circulate thousands of feet below land surface.

Recharge and Discharge Estimates

Recharge and discharge (ET) estimates used in this report are new estimates developed by LVVWD (2001). Recharge estimates are from new altitude-precipitation relationships and the Maxey-Eakin recharge efficiencies (Maxey and Eakin, 1949). The ET estimates are for pre-development conditions and include ET from spring discharge (assumes all spring flow is either evaporated or consumed by vegetation) and shallow groundwater. In valleys with regional spring discharge, natural ET exceeds the Eakin (1966) carbonate-rock aquifer discharge value, because Eakin's values were based solely on spring discharge and did not account for the total ET in these areas. Eakin (1966) did include ET in some valleys that did not have regional spring discharge. For a detailed description of recharge and ET calculations see LVVWD (2001).

For the isotopic water mass-balance calculations in this study, the recharge amounts were separated by valley and then within each valley they were separated into individual mountain recharge areas. Thus, most valleys were separated by their general north-south drainage into east and west recharge areas (Figure 2). Some valleys with more than one continuous mountainous recharge area, for example White River Valley, were divided into several recharge areas.

ET values were assigned within each valley and these values were the total for the valley. The one exception was White River Valley, where ET was divided between a northern and southern part (Table 1 and Appendix 1).

Table 1. Summary of isotopic mass balance.

Section	Name	Volume Acre-ft/yr	# of Samples	Obs. δD	Obs. $\delta^{18}O$	Calc. δD	Calc. $\delta^{18}O$
White River Flow System							
175	Long Valley						
TR	Total Recharge	31,000	4	-127.4	-16.6		
ET	ET	11,000				-127.4	-16.6
OUT	GW Flow out of System	8,000				-127.4	-16.6
174	GW Outflow (Jakes)	12,000				-127.4	-16.6
174	Jakes Valley						
175	Inflow (Long)	12,000		-127.4	-16.6		
TR	Total Recharge	24,000	2	-125.2	-16.4		
ET	ET	600				-125.9	-16.4
207N	GW Outflow (NWRV)	35,000				-125.9	-16.4
180	Cave Valley						
TR	Total Recharge	20,000	2	-104.3	-13.8		
ET	ET	5,000				-104.3	-13.8
208	GW Outflow (Pahroc)	15,000				-104.3	-13.8
207N	North White River Valley						
174	Inflow (Jakes)	35,000		-125.9	-16.4		
TR	Total Recharge	36,000	2	-111.1	-14.6		
DWS	Discharge Warm Springs (Avg)	8,900	4	-124.3	-15.8	-125.9	-16.4
ET	ET	58,000				-118.4	-15.5
207S	GW Outflow (SWRV)	13,000				-118.4	-15.5
207S	South White River Valley						
207N	Inflow (NWRV)	13,000		-118.4	-15.5		
TR	Total Recharge	26,000	2	-107.5	-14.3		
DWS	Discharge Warm Springs (Avg)	13,200	4	-118.5	-15.6	-118.4	-15.5
ET	ET	22,000				-111.1	-14.7
208	GW Outflow (Pahroc)	17,000				-111.1	-14.7
172	Garden Valley						
TR	Total Recharge	19,000	3	-103.9	-13.9		
ET	ET	5,000				-103.9	-13.9
171	GW Outflow (Coal)	14,000				-103.9	-13.9
171	Coal Valley						
172	Inflow (Garden)	14,000		-103.9	-13.9		
TR	Total Recharge	7,000	2	-100.2	-12.1		
CW	Carbonate Well (Avg)		1	-110.0	-14.6	-109.2	-14.6
ET	ET	1,000				-102.6	-13.3
209	GW Outflow (Pahranagat)	20,000				-102.6	-13.3
208	Pahroc Valley						
207S	Inflow (SWRV)	17,000		-111.1	-14.7		
180	Inflow (Cave)	15,000		-104.3	-13.8		
TR	Total Recharge	8,000	2	-91.6	-12.3		
ET	ET	1,000				-104.7	-13.9
209	GW Outflow (Pahranagat)	39,000				-104.7	-13.9
209	Pahranagat Valley						
208	Inflow (Pahroc)	39,000		-104.7	-13.9		
TR	Total Recharge	7,000	2	-93.9	-12.7		
DWS	Discharge Warm Springs (Avg)	25,400	4	-108.8	-14.2	-104.7	-13.9
ET	ET	38,000				-102.9	-13.6
171	Inflow (Coal)	20,000		-102.6	-13.3		
210	GW Outflow (Coyote Spr)	28,000				-102.9	-13.6
181	Dry Lake Valley						
TR	Total Recharge	13,000	4	-97.6	-13.1		
CW	Carbonate Well (Avg)		1	-108.0	-14.2	-106.6	-14.2
ET	ET	1,000				-97.6	-13.1
182	GW Outflow (Delamar)	12,000				-97.6	-13.1

Section	Name	Volume Acre-ft/yr	# of Samples	Obs. δD	Obs. $\delta^{18}O$	Calc. δD	Calc. $\delta^{18}O$
182	Delamar Valley						
181	Inflow (Dry Lake)	12,000		-97.6	-13.1		
TR	Total Recharge	5,000	2	-88.4	-11.9		
ET	ET	1,000				-94.9	-12.7
210	GW Outflow (Coyote Spr)	16,000				-94.9	-12.7
206	Kane Springs Valley						
TR	Total Recharge	7,000	2	-87.4	-12.0		
ET	ET	1,000				-87.4	-12.0
210	GW Outflow (Coyote Spr)	6,000				-87.4	-12.0
210	Coyote Springs Valley						
209	Inflow (Pahranagat)	28,000		-102.9	-13.6		
182	Inflow (Delamar)	16,000		-94.9	-12.7		
206	Inflow (Kane Springs)	6,000		-87.4	-12.0		
TR	Total Recharge	4,000	5	-91.4	-12.6		
CW	Deep Carbonate Well (Avg)		3	-101.0	-13.0	-100.0	-13.3
ET	ET	1,000				-98.0	-13.1
219	SW Outflow (Muddy)	37,000				-98.0	-13.1
216	GW Outflow (Garnet)	16,000				-98.0	-13.1
219	Upper Moapa (Muddy) Valley						
210	Inflow (Coyote)	37,000		-98.0	-13.1		
TR	Total Recharge	300	2	-100.0	-13.0		
DWS	Discharge Warm Springs (Avg)	6,100	5	-97.8	-12.9	-98.0	-13.1
CW	Deep Carbonate Well (Avg)		2	-98.0	-12.9	-98.0	-13.1
ET	ET	5,000				-98.0	-13.1
	Gage	31,000				-98.0	-13.1
218	SW Outflow (California Wash)	32,000				-98.0	-13.1
Meadow Valley Wash Flow System							
183	Lake Valley						
TR	Total Recharge	41,000	4	-105.1	-14.1		
ET	ET	24,000				-105.1	-14.1
202	GW Outflow (Patterson)	17,000				-105.1	-14.1
202	Patterson Valley						
183	Inflow (Lake)	17,000		-105.1	-14.1		
TR	Total Recharge	16,000	2	-98.0	-13.3		
ET	ET	5,000				-101.6	-13.7
203	GW Outflow (Panaca)	28,000				-101.6	-13.7
201	Spring Valley						
TR	Total Recharge	16,000	2	-101.0	-13.1		
ET	ET	1,000				-101.0	-13.1
200	GW Outflow (Eagle)	15,000				-101.0	-13.1
200	Eagle Valley						
201	Inflow (Spring)	15,000		-101.0	-13.1		
TR	Total Recharge	2,000	2	-101.0	-13.4		
ET	ET	1,000				-101.0	-13.1
199	GW Outflow (Rose)	16,000				-101.0	-13.1
199	Rose Valley						
200	Inflow (Eagle)	16,000		-101.0	-13.1		
TR	Total Recharge	300	2	-101.0	-13.4		
ET	ET	700				-101.0	-13.1
198	GW Outflow (Dry)	16,000				-101.0	-13.1
198	Dry Valley						
199	Inflow (Rose)	16,000		-101.0	-13.1		
TR	Total Recharge	4,000	2	-101.0	-13.4		
ET	ET	4,000				-101.0	-13.2
203	GW Outflow (Panaca)	16,000				-101.0	-13.2
204	Clover Valley						
TR	Total Recharge	11,000	2	-89.4	-12.1		

Section	Name	Volume Acre-ft/yr	# of Samples	Obs. δD	Obs. $\delta^{18}O$	Calc. δD	Calc. $\delta^{18}O$
ET	ET	2,000				-89.4	-12.1
205	GW Outflow (Panaca Valley)	9,000				-89.4	-12.1
203	Panaca Valley						
202	Inflow (Patterson)	28,000		-101.6	-13.7		
198	Inflow (Dry)	16,000		-101.0	-13.2		
TR	Total Recharge	9,000	2	-99.4	-13.4		
	Discharge Warm Springs (Avg)		1	-106.9	-14.0	-105.1	-14.1
ET	ET	26,000				-101.1	-13.5
205	Inflow (Clover Valley)	9,000				-89.4	-12.1
205	GW Outflow (Lower Meadow VW)	36,000				-98.2	-13.2
205	Lower Meadow Valley Wash						
203	Inflow (Panaca)	36,000		-98.2	-13.2		
TR	Total Recharge	23,000	4	-87.2	-11.9		
ET	ET	27,000				-88.8	-12.1
220	GW Outflow (L. Moapa)	32,000				-98.2	-13.2
Lake Mead Area Flow System							
217	Hidden Valley						
TR	Total Recharge	300	2	-81.0	-10.6		
ET	ET					-81.0	-10.6
216	GW Outflow (Garnet)	300				-81.0	-10.6
216	Garnet Valley						
217	Inflow (Hidden)	300		-81.0	-10.6		
210	Inflow (Coyote Spr)	16,000		-98.0	-13.1		
TR	Total Recharge	400	2	-81.0	-10.6		
	Wells (Avg)		4	-96.9	-13.3	-98.0	-13.1
ET	ET					-97.2	-13.0
218	GW Outflow (California Wash)	17,000				-97.2	-13.0
218	California Wash						
219	Surface Water Inflow (Muddy)	32,000		-98.0	-13.1		
216	Inflow (Garnet)	17,000		-97.2	-13.0		
TR	Total Recharge	300	2	-82.0	-10.6		
ET	ET	5,000				-97.0	-12.9
220	GW Outflow (L. Moapa)	8,000				-97.0	-12.9
215	GW Outflow (Black Mtn Area)	4,000				-97.0	-12.9
215	Black Mountains Area						
218	Inflow (California Wash)	4,000		-97.0	-12.9		
TR	Total Recharge	500	3	-81.0	-10.6		
	Carbonate Spr (Avg)	1,663		-91.9	-12.3		
ET	ET	2,000				-95.2	-12.7
	GW Outflow (Lake Mead)	2,000				-95.2	-12.7
220	Lower Moapa Valley						
218	GW Inflow (California Wash)	8,000		-97.0	-12.9		
218	SW Inflow (California Wash)	32,000		-98.0	-13.1		
205	GW Inflow (Lower Meadow VW)	32,000		-98.2	-13.2		
TR	Total Recharge	1,000	2	-88.7	-12.2		
ET	ET	15,000				-97.7	-13.1
	GW Outflow (Lake Mead)	26,000				-97.7	-13.1

Groundwater Flow Directions used in This Study

Groundwater flow directions used in this study are based on previous studies (Eakin, 1966; Kirk and Campana, 1990; Thomas et al., 1996: Pohlmann et al., 1998), geologic interpretations of aquifer structure and continuity (Dettinger et al., 1995; LVVWD, 2001), and groundwater levels (Thomas et al., 1986; and more recent water-level data primarily from the U.S. Geological Survey). The groundwater flow directions used in this study are shown on Figures 2, 3 (Figures 2 and 3, located in back pocket of this report), and 4.

WHITE RIVER FLOW SYSTEM

The White River Flow System (WRFS) (Figure 1) was originally described by Eakin (1966). Eakin postulated that some of the water discharging from the Muddy River Springs area in southeastern Nevada originated more than 200 miles north of the spring area and that this regional interbasin flow included 13 valleys. Eakin reached these conclusions on the basis of "preliminary appraisals of the distribution and quantities of the estimated groundwater recharge and discharge within the region, the uniformity of discharge of the principal springs, the compatibility of the potential hydraulic gradient with regional groundwater movement, the relative hydrologic properties of the major rock groups in the region, and to a limited extent, the chemical character of water issuing from the principal springs." The main conclusions of his study were (1) Paleozoic carbonate rocks form the regional aquifer, (2) recharge and discharge estimates balance within the flow system, and (3) the principal discharging springs have a uniform discharge rate, indicating a regional rather than local water source.

Kirk and Campana (1990) constructed a deuterium-calibrated mixing cell (water budget) model of the WRFS. Their mixing cell model was calibrated using average deuterium values for the model cells. The mixing cell model was a two-layer model with an upper layer representing basin-fill aquifers and a second layer representing the carbonate-rock aquifer. The cells were basically defined as the individual valleys within the WRFS, although not all valleys had a sufficient alluvial aquifer to warrant an upper layer cell in the model. The mixing model used the spring flow and ET estimates from Eakin (1966) and initially set recharge to Maxey-Eakin values but then let the model calculate new recharge values. The calculated recharge values were similar to initial Maxey-Eakin recharge estimates. Three different models were developed for the WRFS. The results of the Kirk and Campana (1990) study that are important to water budget issues of the WRFS are: (1) recharge from the Sheep Range to Coyote Springs Valley is greater (5,000 to 6,000 acre feet per year (afy)) than the Maxey-Eakin estimate of 2,000 afy; (2) the Lower Meadow Valley Wash-Kane Springs Valley area contributes 5,500 to 9,000 afy to the Muddy River Springs discharge area as compared to the Maxey-Eakin Kane Springs Valley recharge estimate of about 1,000 afy; and (3) 4,000 afy of groundwater is routed out of the WRFS in the Pahranagat Valley area to the west [similar to the 6,000 afy proposed by Winograd and Friedman (1972) and 7,000 afy proposed by Thomas et al. (1996)].

Thomas et al. (1996) used the average deuterium composition of water discharging from Big Muddy Spring, the largest discharging spring in the Muddy River springs area, to calculate a deuterium water mass-balance budget needed to match the discharge rate and deuterium composition of springs in the Muddy River Springs area. For a Muddy River Springs area discharge rate of 36,000 afy (Eakin and Moore, 1964), this calculation resulted in an input of 14,000 afy of recharge from the Sheep Range, 14,000 afy of inflow from Pahranagat Valley, and 8,000 afy of inflow from the Lower Meadow Valley Wash-Kane Springs Valley area.

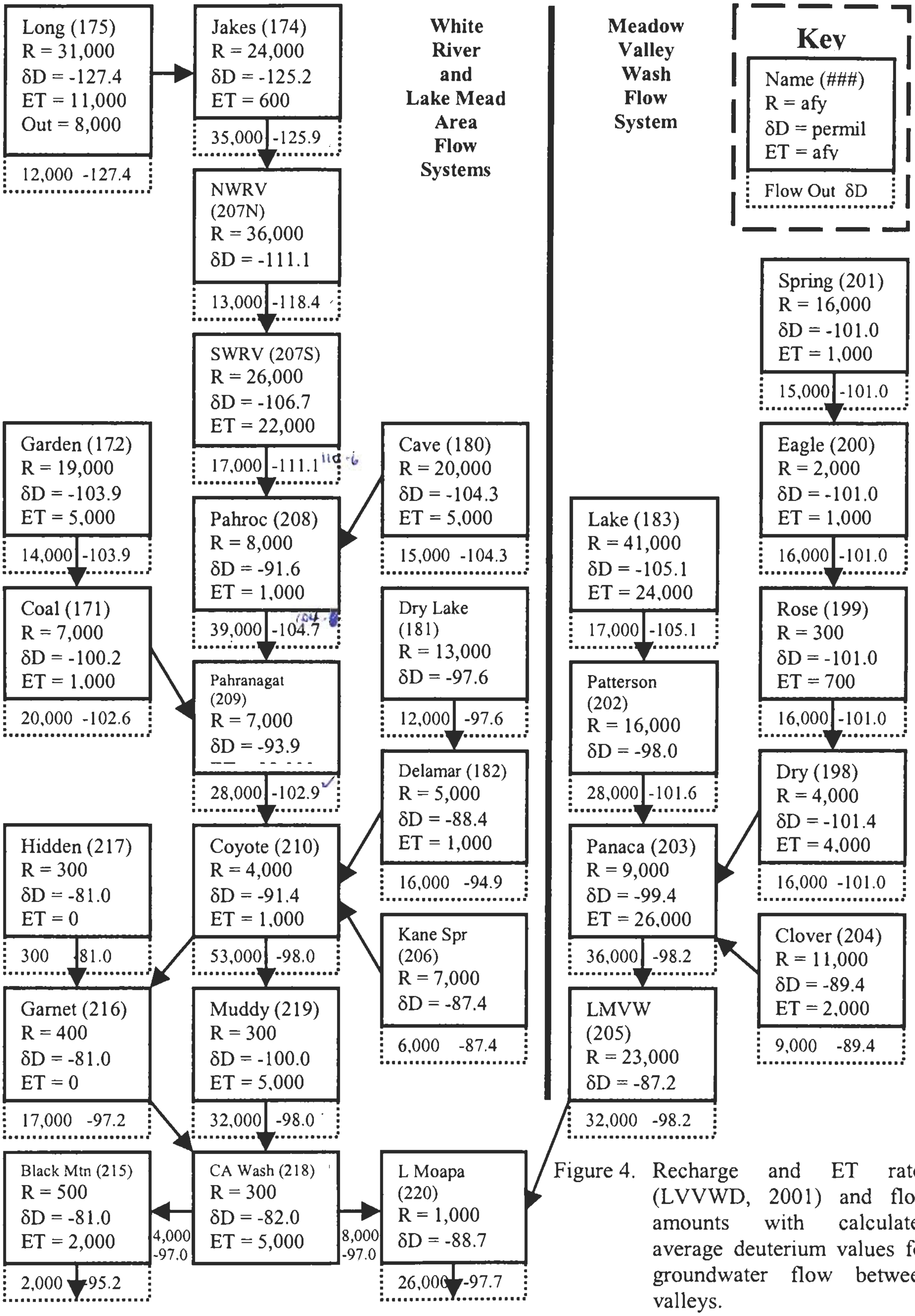

Figure 4. Recharge and ET rates (LVVWD, 2001) and flow amounts with calculated average deuterium values for groundwater flow between valleys.

Isotopic Mass Balance

This study used the approach of assigning average deuterium compositions to recharge areas to construct a deuterium mass-balance water-budget model for the entire WRFS. In the mass-balance model, the amount of recharge assigned to each recharge area and ET rate estimated for each valley are the values calculated by LVVWD (2001). The ET values are for pre-development conditions and do not include ET from fields irrigated by groundwater pumpage, but they do include spring discharge. Within each valley, the amount of recharge plus groundwater inflow greater than the amount of groundwater consumed by ET was assumed to flow to the next downgradient valley. This groundwater outflow was assigned a deuterium value calculated from all recharge and inflow amounts to the valley. The average deuterium value for outflow was calculated by weighting the deuterium composition by the recharge amount from each recharge area within the valley or the inflow amount and dividing by the total recharge plus inflow to the valley. These calculations are carried throughout the flow system producing an isotopic mass-balance model for the entire flow system (Table 1 and Appendix 1).

This isotopic mass-balance approach for evaluating the WRFS water budget can be used to determine if estimated recharge and ET rates and flow directions and mixing of groundwater within the carbonate-rock aquifers are consistent with the deuterium data. If mass-balance model calculated deuterium values are within 2 permil of measured values (analytical precision is + or – 1.5 permil) for regional springs discharging from, or wells completed in, the carbonate-rock aquifers, then estimated recharge and discharge rates and proposed flow directions and mixing are consistent with the deuterium data. The isotopic mass-balance model cannot determine how much recharge should be assigned to each recharge area or ET assigned to each valley; rather, the model evaluates whether the assigned recharge and ET values are consistent with the deuterium data for the proposed flow directions and water mixing within the WRFS. As stated previously, the isotopic mass-balance model is non-unique; a reasonable result confirms the viability of a proposed water-budget model but does not prove that the model is correct. An isotopic mass-balance model can be used to eliminate unrealistic water budget estimates or flow directions and mixing.

An evaluation of the proposed water budget of the WRFS, using LVVWD (2001) estimated recharge and ET rates, was conducted from north to south along the direction of groundwater flow in the WRFS (Figure 2). A plot of deuterium versus oxygn-18 (Figure 5) shows that isotopic compositions increase (become less negative) from north to south. This 40-permil increase in recharge deuterium values, from -127 permil in Long Valley in the northern WRFS to -87 permil in Kane Springs Valley in the southern WRFS (Figure 2), makes deuterium an excellent tracer for water budget mass-balance calculations in the WRFS. Going from north to south, the first regional spring discharge area in the WRFS is in White River Valley. This is a large valley with warm springs (>20°C) in the north-central and south-central parts of the valley and valley-floor cold springs (<20°C) along the eastern part of the valley. Temperatures >20°C indicate that the groundwater has circulated thousands of feet deep as regional flow in the carbonate-rock aquifers. Given the large size of the valley and the two warm spring discharge areas with an approximately 6-permil difference in deuterium values, the valley was divided east west into two parts. In the deuterium mass-balance model of the WRFS, the spring flow rates used to calculate flow-weighted deuterium values were for flows measured in the winter months (November to February) to avoid ET and pumping that might reduce spring flow. However, a comparison of average winter flow rates with the average yearly flow rates did not show a significant difference in spring flows for most springs (U.S. Geological Survey spring-flow data).

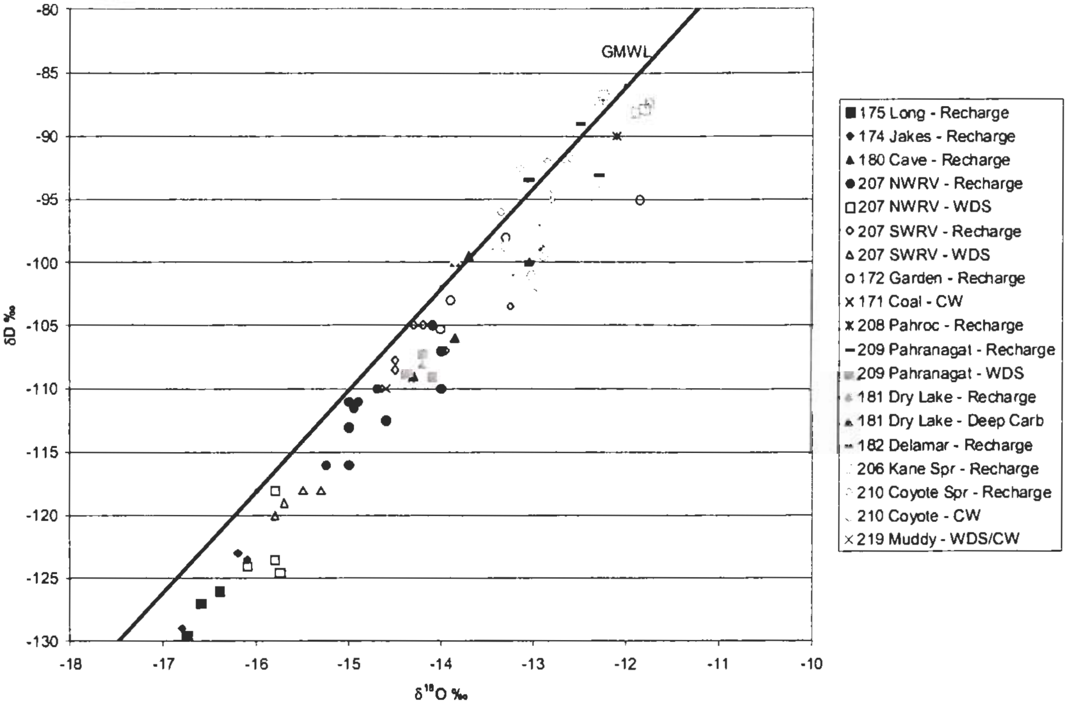

Figure 5. Deuterium versus oxygen-18 for groundwater in the WRFS.

In northern White River Valley, three warm springs (Figure 2; sites 227, 230, 231) have a significantly lighter (more negative) discharge-weighted average deuterium composition of -124.3 permil than local recharge (Appendix 1: -112.1 permil for the northern Egan Range and -110.2 permil for the White Pine Range). The source of these warm springs is not local recharge from mountains surrounding northern White River Valley; rather, the source is recharge upgradient of the warm springs in Jakes and Long valleys. An estimated 35,000 afy of groundwater flows into northern White River Valley from Jakes Valley with a mass-balance calculated average deuterium value of -125.9 permil (Table 1). The calculated isotopic composition of this inflow is similar to the warm springs value of -124.3 permil (within 2 permil), indicating that this inflow is the likely source of most of the groundwater discharging from the warm springs in northern White River Valley.

The average deuterium value of -112.1 permil for Egan Range recharge (17,000 afy) is for seven sites (Figure 2; sites 221-223, 2333, 235-237). This average value includes a cold (<20°C) spring in the valley, Lund Spring (Figure 2; site 221). Lund Spring has a variable flow rate, ranging from 4,000 to 8,000 afy, even in the winter months (U.S. Geological Survey data). The deuterium compositions of two samples from the spring is -113.0 and -112.0 permil, which is similar to the average deuterium value of the other six sites in the adjacent northern Egan Range (-112.1 permil). The average deuterium value of -110.2 permil for White Pine Range recharge (19,000 afy) is for five sites (Figure 2; sites 217, 220, 224-226).

Pre-development ET in northern White River Valley is estimated to be 58,000 afy (LVVWD, 2001). Thus, with an estimated inflow of 35,000 afy from Jakes Valley plus local recharge of 36,000 afy to northern White River Valley, the outflow from northern to southern White River Valley is estimated to be 13,000 afy. The mass-balance calculated average deuterium composition of this outflow is -118.4 permil (Table 1 and Appendix 1).

The warm springs in southern White River Valley are more spread out than the warm springs in northern White River Valley (Figure 2). However, their deuterium compositions only range from -120.0 to -118.0 permil with a discharge weighted average value of -118.5 permil (Figure 2; sites 192, 197, 205; site 198 is a well near spring 197, so it is not used in calculating the average deuterium value). The mass-balance model calculated deuterium value for these springs is -118.5 permil, which is within 0.1 permil of the groundwater inflow from northern White River Valley in the carbonate-rock aquifers (Table 1). These similar values indicate that inflow from northern to southern White River Valley is the likely source of most of the groundwater discharging from the warm springs in southern White River Valley.

Local recharge to the southern part of White River Valley (26,000 afy) is from the southern Egan Range on the eastern side of the valley and the Grant Range on the western side of the valley (Table 1). The average deuterium value for the southern Egan Range is -105.3 permil (Figure 2; sites 201-203, 207). Three of these sites are cold springs on the valley floor (sites 201, 202, 207). Site 201 (Flag Spring #3) is included as a cold spring despite a measured water temperature of 22.8°C, because the spring is adjacent to site 202 (Butterfield Spring), which has a temperature of 16.3°C, and the two springs' isotopic and chemical compositions are essentially the same (Appendix 2).

Similar gross chem could be result of rock dissolution

Pre-development ET in southern White River Valley is estimated to be 22,000 afy (LVVWD, 2001), so including the inflow from northern White River Valley (13,000 afy) and the local recharge to southern White River Valley (26,000 afy) yields an outflow of 17,000 afy from southern White River Valley to Pahroc Valley. The average deuterium composition of this outflow is -111.1 permil (Table 1 and Appendix 1).

Groundwater from a well in northwest Dry Lake Valley (Figure 2; site 179) completed in the carbonate-rock aquifers has a deuterium value of -108.0 permil. Water-level data (Thomas et al., 1986) indicate that this water is probably a mixture of groundwater from southern White River Valley, Cave Valley, and northern Dry Lake Valley. A flow-weighted deuterium value assuming groundwater flowing out of southern White River Valley (17,000 afy; -111.1 permil) mixes with groundwater flowing out of Cave Valley (15,000 afy; -104.3 permil) and groundwater flowing out of northern Dry Lake Valley (6,000 afy; -99.8 permil) would be -106.6 permil. The measured and model-calculated values are within 2 permil indicating that these proposed mixtures of water are possible sources for the groundwater at site 179.

A well in northwest Coal Valley (Figure 2; site 176) is also completed in the carbonate-rock aquifers. The deuterium value of water sampled from this well is -110.0 permil. Water-level data (Thomas et al., 1986) indicate that this water is likely recharge from the south Grant Range, which has an average deuterium value of -109.2 permil. The measured and model-calculated values are within 2 permil indicating that Grant Range recharge is a possible source of this water. Another possibility is that groundwater flowing out of southern

White River Valley (17,000 afy; -111.1 permil) mixes with groundwater flowing into Coal Valley from Garden Valley (14,000 afy; -102.5 permil) to the west. This mixture of groundwaters would result in a calculated deuterium value of -107.2 permil. This value is slightly more than 2 permil greater than the measured value, making this proposed mixture of waters a less likely source of site 176 groundwater than recharge from the south Grant Range. Additionally, these sources of groundwater are not likely, given that most recharge to Garden Valley should flow to the southeast toward Pahranagat Valley and not northwest toward northern Coal Valley (Thomas et al., 1986).

The next downgradient area in the WRFS with regional groundwater flow that has been sampled is the regional warm springs area (25,000 afy) in Pahranagat Valley (Figure 2; sites 110, 111, 116, 122). The flow-weighted average deuterium value of these springs is -108.8 permil (Appendix 1). The most likely sources of groundwater discharging from these springs, based on hydrologic data (Thomas et al., 1986), are inflow from Pahroc and Coal valleys. Pahroc Valley receives inflow from southern White River Valley (17,000 afy; -111.1 permil) and Cave Valley (15,000 afy; -104.3 permil). Pahroc Valley also receives an estimated 8,000 afy of local recharge (LVVWD, 2001) with an average deuterium value of -91.6 permil (Table 1 and Appendix 1). A mixture of these three waters produces an average deuterium value of -104.7 permil. ET in Pahroc Valley is estimated to be 1,000 afy (LVVWD, 2001), so groundwater outflow from Pahroc Valley to Pahranagat Valley is estimated to be 39,000 afy with an average deuterium value of -104.7 permil.

Coal Valley receives groundwater inflow from Garden Valley. Garden Valley has no known groundwater inflow, but the valley does receive local recharge from: (1) the Quinn Canyon Range to the west (14,000 afy; -104.1 permil, sites 177 and 182; the isotope sample from site 171 is significantly evaporated and is not used in calculating the average deuterium value); (2) the Golden Gate Range to the east (3,000 afy; -107.0 permil, site 167); and (3) the Worthington Mountains to the south (2,000 afy; -98.0 permil, site 136). ET in Garden Valley is estimated to be 5,000 afy (LVVWD, 2001). Thus, Garden Valley groundwater inflow to Coal Valley is estimated to be 14,000 afy with an average deuterium value of -103.9 permil (Table 1 and Appendix 1).

Local recharge in Coal Valley is estimated to be 7,000 afy, 4,000 afy from the Golden Gate Range to the west and 3,000 afy from the Seaman Range to the east (LVVWD, 2001). The average deuterium value for local recharge in Coal Valley is -100.2 permil (Golden Gate Range, -107.0 permil, site 167; Seaman Range, -90.0 permil, site 154; the isotope sample from site 161 is significantly evaporated and is not used for calculating an average deuterium value for the Seaman Range). ET in Coal Valley is estimated to be 1,000 afy (LVVWD, 2001), so groundwater inflow from Coal Valley to Pahranagat Valley is estimated to be 20,000 afy with a model mass-balance calculated deuterium value of -102.6 permil (Table 1 and Appendix 1).

A mixture of groundwater inflow from Pahroc (-104.7 permil) and Coal (-102.6 permil) valleys results in a mass-balance calculated deuterium value of -104.0 permil for groundwater in the carbonate-rock aquifer of Pahranagat Valley. This calculated value is 4.8 permil heavier (more positive) than the measured flow-weighted average value of -108.8 permil (Table 1 and Appendix 1). This 4.8 permil difference between model mass-balance calculated and measured values for the Pahranagat Valley warm springs indicates that (1) the proposed mixtures of groundwater inflow to Pahranagat Valley are not likely; or (2) limited deuterium data used to define average deuterium recharge values are not sufficient to adequately define deuterium recharge values; or (3) recharge and/or ET rate estimates are incorrect; or (4) some combination of 1-3. Another possibility is that Cave Valley inflow and local recharge to Pahroc Valley are not mixing with groundwater in the carbonate-rock aquifers before it discharges from Pahranagat Valley warm springs. This would result in inflow from southern White River and Cave valleys being the only sources of Pahranagat Valley warm springs groundwater. This mixture would produce a model-calculated deuterium value of –107.9 permil, which is within 1 permil of the measured value.

Coal Valley inflow to Pahranagat Valley not mixing with groundwater flowing from the warm springs is possible. The warm springs in Pahranagat Valley discharge from carbonate rocks located along the eastern side of the valley (Thomas et al., 1986). These spring locations coupled with complex geologic structure between Coal Valley to the west and Pahranagat Valley (the Timpahute Shear Zone and associated north-south trending faults; Gary Dixon, written communication, 2001) may result in groundwater flow from Coal Valley entering Pahranagat Valley south of the warm springs.

Local recharge in Pahroc Valley not being part of the mixture of water discharging from the warm springs in Pahranagat Valley would require that local recharge not reach the carbonate-rock aquifer. There is no information to support this local flow in a flow system that essentially acts as one continuous regional aquifer.

Pre-development ET in Pahranagat Valley is estimated to be 38,000 afy, so including inflow from Pahroc Valley (39,000 afy), local recharge (7,000 afy), and inflow from Coal Valley (20,000 afy) the outflow from Pahranagat Valley to Coyote Springs Valley is 28,000 afy. The model-calculated average deuterium composition of this outflow would be -102.9 permil (Table 1 and Appendix 1).

Groundwater flows into Coyote Springs Valley from Delamar (16,000 afy) and Pahranagat (28,000 afy) valleys to the north, as indicated by water-level data (Thomas et al., 1986). Three wells in Coyote Springs Valley are completed in the carbonate-rock aquifers (Appendix 1). These three wells have an average deuterium composition of -101.0 permil. The inflow-weighted average deuterium value for Coyote Springs Valley groundwater is -100.0 permil for inflow from Pahranagat Valley (-102.9 permil) and Delamar Valley (-94.9 permil). This value is within 1 permil of the average value measured in samples from the wells completed in the carbonate-rock aquifers (-101.0 permil), indicating that the inflow sources to Coyote Springs Valley are reasonable.

Other groundwater sources contributing to Coyote Springs Valley are local recharge within the valley (4,000 afy), primarily from the Sheep Range to the west, and recharge to from Kane Springs Valley to the northeast (6,000 afy) (Table 1 and Appendix 1). Kane Springs Valley is treated as local recharge to Coyote Springs Valley because the valley is a continuation of Coyote Springs Valley to the northeast. Local recharge is not mixing with regional flow in the carbonate-rock aquifers until groundwater flows out of the eastern or southern parts of the valley (Thomas et al., 1996). This conclusion is supported by a groundwater sample from a well completed in the alluvial aquifer adjacent to one of the wells completed in the carbonate-rock aquifers. The water level in the alluvial aquifer was about 60 feet higher than that in the carbonate-rock aquifer and the alluvial groundwater had an isotopic content (-94.0 permil) similar to local Sheep Range recharge (-93.1 permil). In comparison, the carbonate groundwater (-101.0 permil) is 7.0 permil lighter than the alluvial groundwater. Local recharge to Kane Springs Valley probably enters Coyote Springs Valley along its eastern boundary near the Muddy River Springs area, because large fault structures extend the entire length of eastern Kane Springs Valley (LVVWD, 2001).

The pre-development ET rate in Coyote Springs Valley is estimated to be 1,000 afy (LVVWD, 2001), so including the inflow from Pahranagat Valley (28,000 afy), Delamar Valley (16,000 afy), Kane Springs Valley (6,000 afy), and local recharge (4,000 afy) the outflow from Coyote Springs Valley is estimated to be 53,000 afy (LVVWD, 2001). The average deuterium composition of this outflow is -98.0 permil (Table 1 and Appendix 1). The majority of this outflow, 37,000 afy, is assumed to flow to Upper Moapa Valley and the Muddy River Springs discharge area and the remainder of this outflow, 16,000 afy, is assumed to flow south and southeast to Hidden, Garnet, and California Wash valleys (LVVWD, 2001). This southern flow component will be discussed in the Lake Mead Area Flow System part of this report.

Upper Moapa Valley contains the main discharge area of the WRFS, the Muddy River Springs area. The total groundwater loss from the carbonate-rock aquifers in the Muddy River Springs area is estimated by LVVWD (2001) to be 37,000 afy, similar to the historical total spring discharge in the area of 36,000 afy (Eakin and Moore, 1964). The source of this groundwater is inflow from Coyote Springs Valley in the carbonate-rock aquifers. The average deuterium composition of the regional springs is -97.8 permil (weighted for spring flow) and of two wells completed in the carbonate-rock aquifers is -98.0 permil (Table 1 and Appendix 1). The model-calculated deuterium composition of water entering Upper Moapa Valley from Coyote Springs Valley is -98.0 permil. The close match, within 0.2 permil, of the model-calculated and measured deuterium values for groundwater in the Muddy River Springs area indicates that new estimates of recharge and ET rates (LVVWD, 2001), and mixing and flow directions for this deuterium mass-balance model of the WRFS water budget, are reasonable. However, as stated earlier, the relative (percent of) recharge and ET rates for the different mountains and valleys are reasonable for this flow routing and mixing of groundwaters as shown by the deuterium data, but the measured groundwater deuterium values in the Muddy River Springs area could also be matched by other combinations of flow due to the non-uniqueness of the problem.

All WRFS groundwater entering Upper Moapa Valley, plus the approximately 300 afy of local recharge (LVVWD, 2001), is assumed to discharge to the surface as spring flow or is lost by ET. No groundwater is assumed to flow out of Upper Moapa Valley; rather, groundwater entering Upper Moapa Valley that discharges as spring flow leaves the valley as stream flow in the Muddy River. This is shown in Table 1 and Appendix 1 as 32,000 afy of surface-water outflow to California Wash Valley.

Geochemistry

A preliminary evaluation of geochemical data for groundwater in the WRFS was performed by plotting geochemical data on a trilinear diagram. A trilinear diagram of water chemistry data for cold (<20°C) and warm (>20°C) springs discharging from and wells completed in the carbonate-rock aquifers of the WRFS (Figure 6) shows that the water chemistry is generally similar from north to south down the flow system until reaching Coyote Springs Valley. Groundwater flowing down the WRFS is generally a Ca-Mg-HCO_3

type water until the groundwater encounters evaporative salts, likely gypsum or anhydrite and halite, in the southern part of the flow system. As groundwater flows through Coyote Springs Valley and into Upper Moapa Valley evaporative salts are added to the water before it discharges in the Muddy River Springs area. This is observed on the trilinear plot as the concentrations of sodium (Na), sulfate (SO_4), and chloride (Cl) increase from the warm springs in Pahranagat Valley to the carbonate wells in Coyote Springs Valley to the warm springs and wells completed in the carbonate-rock aquifer in the Muddy River springs area.

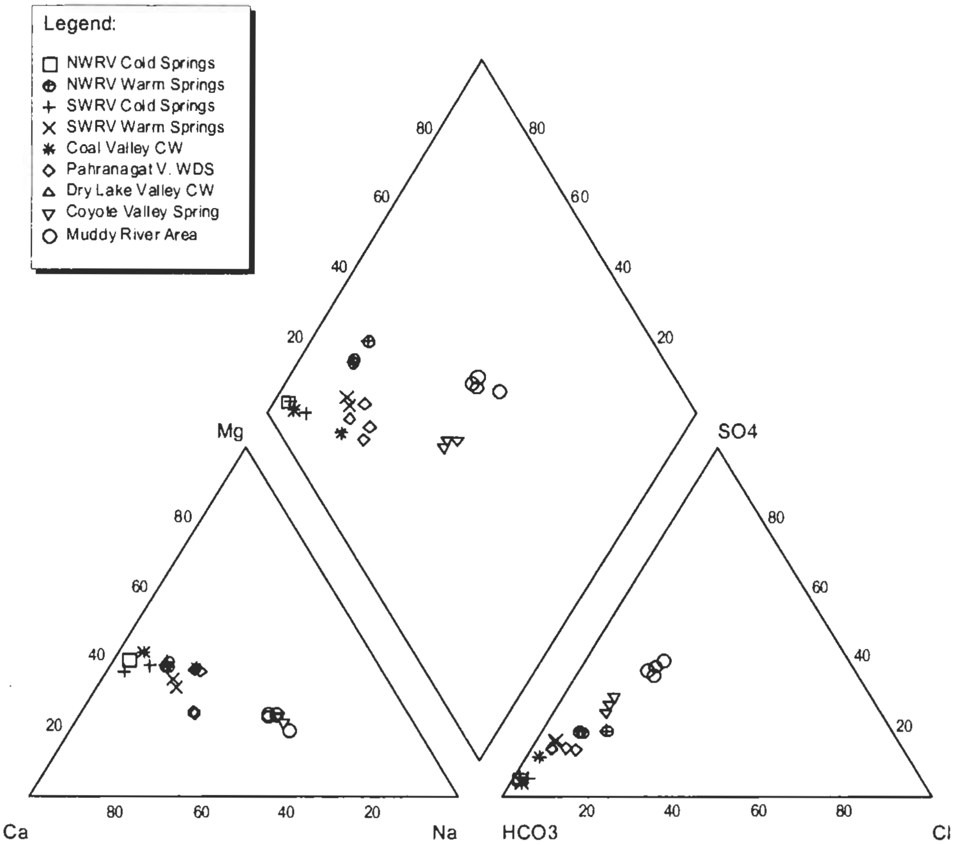

Figure 6. Trilinear plot of chemistry for groundwater in the WRFS.

Summary

A deuterium mass-balance model of the WRFS was developed to evaluate LVVWD (2001) estimates of groundwater recharge and ET rates, along with proposed groundwater sources and mixing. Using the estimated recharge and ET rates, with model-calculated average deuterium values for recharge areas and interbasin groundwater flow to develop a deuterium mass-balance model, produces a model with calculated deuterium values that agree with measured deuterium values for the WRFS within 2 permil, with the exception of regional warm springs in Pahranagat Valley. Hence, a deuterium-calibrated mass-balance model can be developed that is consistent with the estimated recharge and ET rates (LVVWD, 2001) and proposed sources and mixing of groundwater for the WRFS. This is a non-unique solution, so proportionate changes in recharge and ET rates, or another combination of groundwater sources and mixing, could produce the same results.

A preliminary evaluation of oxygen-18 data, which should give similar mass-balance results as deuterium data because of their natural co-variance, shows that oxygen-18 mass-balance calculations produce results that are similar to the deuterium mass-balance model (Table 1 and Appendix 1). Analytical precision of oxygen-18 is + or - 0.15 permil, so calculated and measured oxygen-18 values should agree within 0.3 permil for a reasonable mass-balance water budget model. Model calculated oxygen-18 values are 0.61 permil lighter (more negative) for warm springs in northern White River Valley and 0.53 permil heavier (more positive) for warm springs in Pahranagat Valley than measured values. These differences may indicate the greater sensitivity of oxygen-18 to evaporation, or greater variability in oxygen-18 in recharge area waters, than deuterium. Of note, is that the heavier calculated oxygen-18 value, as compared to the average measured value, for warm springs in Pahranagat Valley is comparable to the 4.8 permil heavier calculated than measured deuterium value. Thus, similar to the deuterium mass-balance model, an oxygen-18 mass-balance model also indicates that other groundwater sources, or a disproportionate change in recharge or ET rates, or different average recharge isotope values, or some combination of these three changes, are needed for model-calculated values to match measured values. Mass-balance calculated oxygen-18 values agree within 0.3 permil of average measured values for the remainder of carbonate-aquifer groundwaters measured within the WRFS, indicating that oxygen-18 model-calculated values generally support the deuterium mass-balance model.

A comparison of this study's results with the water budget study for the WRFS by Eakin (1966) and the deuterium-mixing model of the WRFS by Kirk and Campana (1990) show that:

1. Total recharge for the WRFS in these previous studies was estimated to be 104,000 afy (variable but slightly less for models in Kirk and Campana, 1990), as compared to 199,000 afy estimated by LVVWD (2001) that was evaluated in this study.

what about the 2009 AFY line

2. Discharge (ET) estimates in the previous studies were based solely on regional spring flow and a minor amount of ET in non-regional spring discharge areas and was estimated to be 102,000 afy, as compared to the 183,000 afy estimated by LVVWD (2001) for pre-development ET rates and evaluated in this study. The new ET rates estimated by LVVWD (2001) include spring flow.
3. Instead of obtaining a water budget balance of about zero for the WRFS (Eakin, 1966; Kirk and Campana, 1990), the water budget used in this study has an additional 16,000 afy of groundwater that is not discharged at Muddy River Springs but instead flows past the spring area to the south-southeast.
4. The water budget model evaluated in this report has 8,000 afy of outflow from Long Valley that does not remain in the WRFS, whereas Eakin (1966) included all Long Valley recharge in his WRFS water budget and Kirk and Campana (1990) excluded all, or almost all, Long Valley recharge from their models.
5. In Kirk and Campana (1990), recharge from the Sheep Range to Coyote Springs Valley is greater (5,000 to 6,000 afy) than the Maxey-Eakin estimate of 2,000 afy used by Eakin (1966) and the 2,300 afy evaluated in this study.
6. Kirk and Campana (1990) include Kane Springs Valley inflow of 5,500 to 9,000 afy to the Muddy Springs discharge area as compared to 1,000 afy used by Eakin (1966).

This study uses 6,000 afy of inflow from Kane Springs Valley that is estimated from a local recharge value of 7,000 afy minus 1,000 afy of ET (LVVWD, 2001).

7. Kirk and Campana (1990) have 4,000 afy of groundwater flowing out of the WRFS in the Pahranagat Valley area to the west, whereas this study assumes no flow out of the WRFS in the Pahranagat Valley area.

To summarize, the differences between the original WRFS water budget study by Eakin (1966) and the deuterium mixing cell model of Kirk and Campana (1990) with this evaluation of LVVWD recharge and ET rate estimates using a deuterium-calibrated mass-balance model, the new recharge and ET estimates are significantly higher than previous estimates, but except for the warm springs in Pahranagat Valley, the mass-balance model produces a consistent water budget for the WRFS. The fact that an almost doubling of recharge and ET rates can produce a deuterium-calibrated mixing model that is consistent with measured deuterium values is an indication of the non-uniqueness of the WRFS water budget for the currently available information.

A deuterium-calibrated mass-balance model was developed for the lower part of the WRFS by Thomas et al. (1996). The main differences between the conclusions of the study presented in this report and the one by Thomas et al. (1996) are the amounts of recharge attributed to the Sheep Range and underflow from Pahranagat Valley to Coyote Springs Valley. These differences arise because of the different approaches used to calculate the water budget for the lower WRFS. Thomas et al. (1996) determined a water budget using the Muddy River Springs area spring flow (36,000 afy) as the total groundwater flow in the southern WRFS and the deuterium and chemical compositions of Big Muddy Spring to calculate inputs from different groundwater sources. In contrast, this study used the average deuterium composition of recharge sources to evaluate whether estimated recharge and ET rates would produce the average measured deuterium composition of regional springs discharging from and wells completed in the carbonate-rock aquifers throughout the entire WRFS. The 2,300 afy recharge rate calculated for the Sheep Range by LVVWD (2001) is about 12,000 afy less than that used in the study by Thomas et al. (1996) and the deuterium mass-balance model calculated inflow to Coyote Springs Valley is 28,000 afy as compared to 14,000 afy calculated by Thomas et al. (1996). Besides the new recharge and ET rates estimated by LVVWD (2001) that were evaluated in this study, other differences in the lower WRFS water budget are that Thomas et al. (1996) did not include inflow from Dry Lake Valley to Delamar Valley and a heavier deuterium value for groundwater flowing out of Pahranagat Valley was used in this study than in Thomas et al. (1996). Thomas et al. (1996) used the average deuterium value of the Pahranagat Valley springs (-109 permil) for their water balance calculations, whereas this study used an outflow deuterium value of –102.9 permil. The heavier value includes local recharge to Pahranagat Valley and all groundwater inflows to the valley for determining the deuterium composition of outflow from Pahranagat Valley. Despite different approaches, both studies have 6,000 to 8,000 afy of groundwater entering the lower WRFS from Kane Springs Valley. These dissimilar but valid results in terms of deuterium data highlight the non-uniqueness of water budgets evaluated for the WRFS.

MEADOW VALLEY WASH FLOW SYSTEM

The Meadow Valley Wash Flow System (MVWFS) is adjacent to the WRFS to the east. This flow system is less than half the size the WRFS and extends north from Lower Meadow Valley Wash to Lake Valley. The MVWFS is about 150 miles in length from north to south and includes nine valleys (Figure 1). Similar to the WRFS, groundwater flows primarily in carbonate-rock aquifers from north to south. The MWVFS is different from the WRFS in that volcanic rock aquifers are prevalent throughout the flow system. Much of the volcanic rocks are underlain by carbonate rocks, but the presence of volcanic rocks in recharge areas results in some of the potential recharge flowing out of the mountains as surface water. Carbonate rocks make up the majority of rock units in mountainous recharge areas in northern Lake Valley and the mountains along the western border of the MVWFS from Lake Valley through Patterson Valley to Panaca Valley. Mountains in the eastern part of the MVWFS are predominately volcanic as is Lower Meadow Valley Wash.

Unlike the WRFS, water budget studies of the entire MVWFS do not exist. Emme (1986) studied regional groundwater flow in the Upper Meadow Valley Wash area, Rush and Eakin (1963) performed a hydrologic reconnaissance study of Lake Valley, and Rush (1964) conducted a hydrologic reconnaissance study of the Meadow Valley Wash area including all but Lake Valley of the MVWFS.

Isotopic Mass Balance

The same method that was used to develop the WRFS deuterium mass-balance model is used to develop the MVWFS model (Table 1 and Appendix 1). In the mass-balance model, the amount of recharge assigned to each recharge area and ET rate estimated for each valley are the values calculated by LVVWD (2001). An evaluation of the LVVWD (2001) estimated water budget of the MVWFS was conducted from north to south along the direction of flow in the MVWFS (Figures 2-4). A plot of deuterium versus oxygen-18 shows that isotopic compositions generally increase (become less negative) from north to south (Figure 7). This approximate 30 permil increase in recharge deuterium values, from -113.0 permil for Lake Valley recharge in the northern MVWFS to -85.5 permil in Lower Meadow Valley Wash in the southern MVWFS, makes deuterium an excellent tracer for water budget mass-balance calculations in the MVWFS.

The northernmost valley in the MVWFS is Lake Valley. This is a large valley with numerous springs discharging in the northwestern part of the valley. Only one spring (Figure 2 and Appendix 2; site 211, Big Spring North) has a temperature that exceeds 20°C (20.5°C). The large variability in flow of the springs in Lake Valley (Rush and Eakin, 1963) indicates that their source is local recharge from the adjacent Schell Creek Range and water-level data (Thomas et al., 1986) also indicate that no underflow enters this valley from another valley. The isotopic composition of recharge from the Schell Creek Range (15,000 afy) to Lake Valley is calculated as the flow-weighted average of the cold springs (-108.3 permil; Figure 2; sites 210, 211, 213, 214). Recharge to Lake Valley also includes 9,000 afy from the Fortification Range (-113.0 permil; Figure 2; site 216) in the northeast part of the valley, 12,000 afy from the Wilson Creek Range (-97.5 permil; Figure 2; site 189) in the southeast part of the valley, and 6,000 afy from the Fairview Range (-100.7 permil, Figure 2; sites 188, 190, 191) in the west part of the valley. The average deuterium value of recharge for the entire valley weighted by recharge amount is -105.1 permil (Figure 3).

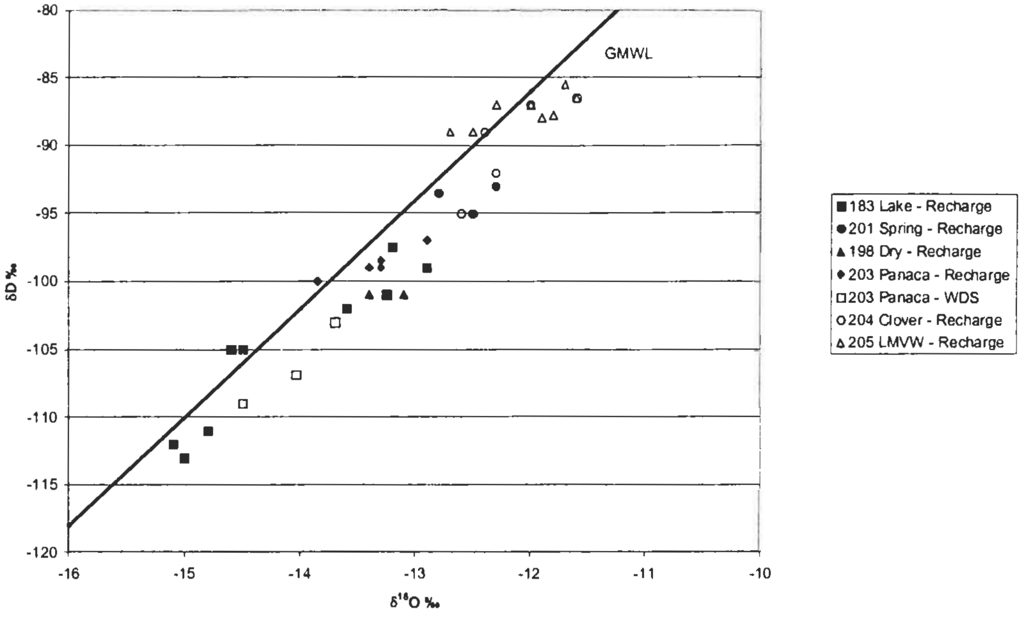

Figure 7. Deuterium versus oxygen-18 for groundwater in the MVWFS.

Pre-development ET in Lake Valley is estimated to be 24,000 afy (LVVWD, 2001), so including all local recharge (41,000 afy), the outflow from Lake Valley to the south is 17,000 afy. The average deuterium composition of this outflow is -105.1 permil (Table 1 and Appendix 1).

The valley downgradient from Lake Valley is Patterson Valley. A sample from a well (Figure 2; site 185) just south of the topographic divide between Lake and Patterson valleys has a deuterium composition of -107.0 permil. This value is within 2 permil of the average recharge deuterium value of -105.1 permil for Lake Valley. Thus, this represents groundwater flowing out of Lake Valley and into Patterson Valley, as is also indicated by water-level data (Thomas et al., 1986). Local recharge to Patterson Valley consists of 10,000 afy from the Wilson Creek Range (-97.5 permil) to the east and 6,000 afy from the Bristol Range (-98.7 permil) to the west (Figure 3). Pre-development ET in Patterson Valley is estimated to be 5,000 afy (LVVWD, 2001). Including inflow from Lake Valley (17,000 afy) and local recharge (16,000 afy), the outflow from Patterson Valley to the south is estimated to be 28,000 afy. The average deuterium composition of this outflow is -101.6 permil (Table 1 and Appendix 1). Other than the one well near the Lake Valley-Patterson Valley topographic divide no other samples with deuterium data are available in Patterson Valley for deuterium mass-balance comparisons.

The valley downgradient of Paterson Valley is Panaca Valley. Panaca Valley also receives groundwater inflow from Dry Valley to the northeast (Figure 2; note this valley is different than Dry Lake Valley to the west). Dry Valley receives groundwater inflow that originates in three valleys upgradient of it, so before the deuterium mass-balance water budget of Panaca Valley is discussed, the deuterium mass balances of the northeastern valleys that contribute groundwater flow to Panaca Valley will be discussed.

Spring Valley is the northernmost valley that has groundwater recharge that eventually flows into Dry Lake Valley (Figures 2-4). Three springs in the volcanic rock recharge areas have deuterium values that range from -95.0 to -93.0 permil (Figure 2; sites 173, 180, 187). A well (Figure 2; site 175) in the valley has a deuterium value of -101.0 permil. Given that the recharge areas are volcanic rock, and unlike Lake and Patterson valleys, Spring Valley has perennial stream flow (Rush, 1964; Emme, 1986), indicating less recharge of precipitation and more runoff; the well sample is used to represent the average recharge deuterium value. Additionally, two springs in downgradient and nearby Dry Valley (Figure 2; sites 149 and 153) both have a deuterium value of -101.0 permil, the same as the groundwater sample from the well sample in Spring Valley. The total recharge to Spring Valley is estimated by LVVWD (2001) to be 16,000 afy (Table 1 and Appendix 1). Pre-development ET is estimated at 1,000 afy (LVVWD, 2001), so 15,000 afy of groundwater with an average deuterium value of -101.0 permil is calculated to flow from Spring Valley to Eagle Valley. Approximately 5,000 afy of perennial stream flow (U.S. Geological Survey data, 1962-74) out of Spring Valley is included in the 15,000 afy of groundwater discharge out of the valley, because the stream flow is primarily groundwater from spring discharge (Rush, 1964) and it recharges aquifers in valleys downgradient of Spring Valley.

Eagle Valley is downgradient from Spring Valley (Figure 2). Eagle, Rose, and Dry valleys are discussed together because of their small size and lack of isotopic data (only Dry Valley has groundwater samples with isotopic data). Total recharge to these valleys is 6,000 afy (Table 1 and Appendix 1). The average isotopic composition of this recharge is -101.0 permil. This value is the average of a spring located on the west side of the main surface water drainage in Dry Valley (Figure 2; site 149, -101.0 permil) and a spring located on an alluvial fan on the east side of the valley (Figure 2; site 153, -101.0 permil). Site 153 (Flatnose Spring) has a water temperature of 25°C, but is either local recharge or represents recharge from farther up in the flow system as indicated by its same deuterium value as a groundwater sample in Spring Valley (Figure 2; site 175) and the lack of inflow to the valley from the east as indicated by water-level data (Thomas et al., 1986). Pre-development ET for the three valleys is estimated to be 6,000 afy (LVVWD, 2001), so the total outflow from Dry Valley to Panaca Valley is 16,000 afy (because of rounding recharge and ET values 1,000 afy is gained through the three valleys, see Appendix 1). This outflow has an average deuterium value of -101.0 permil (Table 1 and Appendix 1). Similar to Spring Valley, groundwater outflow to Panaca Valley includes about 3,400 afy of stream flow whose source is groundwater discharge (Rush, 1964; 1945-49).

Panaca Valley receives groundwater inflow from Patterson Valley to the northwest (28,000 afy), Dry Valley to the northeast (16,000 afy), and Clover Valley to the southeast (9,000 afy) on the basis of LVVWD (2001) recharge and ET estimates (Figures 3 and 4 and Table 1). Local recharge in the valley is estimated to contribute 9,000 afy (LVVWD, 2001). As previously noted, inflow from the predominately volcanic valleys to the northeast includes stream flow from Dry Lake Valley, but there is no stream flow from Patterson Valley. Lake and Patterson Valleys contain large amounts of carbonate rock and precipitation easily enters the fractured carbonate rocks, and like the WRFS, is transported through regional carbonate-rock aquifers. Clover Valley, another valley of predominately volcanic rock, also has perennial stream flow (Rush, 1964; Emme, 1986; U.S. Geological Survey data 1958-1984).

In Panaca Valley, two warm (>20°C) groundwater discharge areas were sampled. These two areas are the Panaca Warm Spring area, where Panaca Warm Spring (Figure 2; site 144) flows about 8000 afy, and the Caliente Hot Spring area, which currently does not have spring flow. A sample from Bennett Spring (Figure 2; site 141) in western Panaca Valley also had a temperature of >20°C. The deuterium content of groundwater discharging from Panaca Warm Spring is -106.9 permil (average of three samples). The deuterium compositions of other groundwater samples in this area are -103.0 permil for site 142 (Lester Matthews Well; 20°C), -106.0 permil for site 143 (Panaca Town Well; 29.5°C), and -101.0 permil for site 147 (North Lee Well; 22°C). Panaca Warm Spring discharges from carbonate-rock aquifers. The deuterium content of this spring is 5.9 to 5.3 permil lighter than the model calculated groundwater inflow from the northeast (Dry Valley) and northwest (Patterson Valley), respectively. This lighter deuterium composition and the highly faulted carbonate rocks in the Pioche Hills (Panaca Spring discharges out of the south end of the Pioche Hills) indicate that this groundwater likely originates in Lake Valley, where the average deuterium value of groundwater recharge is -105.1 permil, and flows through Patterson Valley in carbonate-rock aquifers. The lack of deuterium data in Patterson Valley, (only one sample in the northern part of the valley with a deuterium content of -107.0 permil) prohibits the determination of a deuterium value for groundwater in the carbonate-rock aquifers in the valley. Other warm groundwaters in the Panaca Warm Spring area also represent carbonate-rock aquifer water discharging in this area, some of which mixes with volcanic-rock aquifer and alluvial aquifer groundwater flowing into the area from Patterson and Dry valleys.

A groundwater sample from site 129 (Caliente Hot Spring; 46.4°C) has a deuterium value of -109.0 permil. Three other groundwater samples in the area (sites 125, 24°C; 126, 39.7°C; 128, 62.8°C) are >20°C, but unfortunately they have no deuterium data. The source of the warm and isotopically light groundwater in the Caliente Hot Spring area must also be carbonate-rock aquifer water originating in Lake Valley and flowing through Patterson Valley.

Site 141 (Bennett Spring), along the western part of the valley, is also a warm spring (24°C), and has a deuterium value of -103.0 permil. The deuterium content of this warm spring is within 2 permil of the deuterium mass-balance model calculated groundwater inflow from upgradient Patterson Valley (-101.6 permil), so this groundwater likely represents inflow from Patterson Valley.

Cold (<20°C) groundwater in the Panaca Spring area (Figure 2; sites 137 and 140) has a measured deuterium content of -101.0 permil. This value is similar to model-calculated groundwater inflow from Patterson and Dry valleys (-101.6 to –101.0 permil), indicating that these groundwaters originate as inflow entering the valley from either the northwest or northeast, or both. These cold groundwaters likely represent shallow groundwater inflow to Panaca Valley, as compared to the warm deep groundwater inflow in the carbonate-rock aquifers.

Pre-development ET for Panaca Valley is estimated to be 26,000 afy (LVVWD, 2001). Total inflows to Panaca Valley (53,000 afy) plus local recharge (9,000 afy), on the basis of LVVWD (2001) recharge and ET estimates, yield a total groundwater input to Panaca Valley of 62,000 afy, so the total outflow from Panaca Valley to Lower Meadow Valley Wash is estimated to be 36,000 afy (Table 1). Approximately, 9,000 afy of this outflow is as stream flow in Meadow Valley Wash (Rush, 1964; Emme, 1986; U.S. Geological Survey data 1951-1983). The groundwater outflow has a model-calculated average deuterium value of -98.2 permil (Table 1 and Appendix 1), which is similar to a surface-water sample (Figure 2; site 130, -97.0 permil) collected in Meadow Valley Wash south of Caliente in December 1979 (Emme, 1986). The similarity between the model deuterium value and a measured surface-water sample, likely originating as groundwater discharge, indicates that the model deuterium value for groundwater flowing out of Panaca Valley is consistent with a deuterium surface-water sample.

Lower Meadow Valley Wash is downgradient of Panaca Valley. Local recharge to Lower Meadow Valley Wash is estimated by LVVWD (2001) to be 23,000 afy. This recharge would have an average deuterium value of -87.2 permil, with a range in deuterium values of only -89.0 to -85.5 permil (Figure 2 and Appendix 2). The majority of the recharge, 15,000 afy, originates in the northern part of the valley (LVVWD, 2001). Samples from wells completed in the alluvial aquifer along Meadow Valley Wash range in deuterium composition from -88.5 to -86.0 permil (Figure 2; sites 95, 100, 102, and 103), except for groundwater from the southernmost part of the valley (Figure 2; sites 57, 59, and 80). The origin of these southern groundwaters will be discussed later. The average deuterium value for samples from the four alluvial aquifer sites is -87.6 permil, which is within 0.4 permil of the average local recharge (-87.2 permil). Thus, groundwater in the Lower Meadow Valley Wash alluvial aquifer appears to be local recharge water. The alluvial aquifer groundwater is 10.6 permil heavier (more positive) than model-calculated values for groundwater flowing into Lower Meadow Valley Wash from Panaca Valley.

What happens to Panaca Valley groundwater flowing into Lower Meadow Valley Wash (likely in the carbonate-rock aquifers underlying volcanic-rock and alluvial aquifers)? Is groundwater recharge overestimated or ET underestimated in the MVWFS above Lower Meadow Valley? One possibility is that the groundwater sample from a well near Farrier (Figure 2; site 80) in southern Lower Meadow Valley Wash is the regional groundwater entering Lower Meadow Valley Wash from the north. The Farrier area is located about 3 miles south of Rox, an area in southern Lower Meadow Valley Wash where carbonate rocks are exposed at land surface. In this area, stream flow in Lower Meadow Valley Wash increases (Rush, 1964). The deuterium value of water sampled from the well at site 8 is -97.5 permil and the groundwater is warm (22.8°C). The deuterium value is only 0.7 permil heavier than the model-calculated deuterium value for inflow from Panaca Valley (-98.2 permil) and thus could be some of the inflow coming to the land surface. The deuterium value of Farrier groundwater is also similar to the -97.8-permil average deuterium value of water discharging from the Muddy Springs area of Upper Moapa Valley, thus the Farrier area groundwater may be from the WRFS. Finally, two wells in the southernmost part of Lower Meadow Valley Wash have similar isotopic compositions as the groundwater in the Farrier area (Figure 2; site 57, -96.5 permil, and site 59, -99.5 permil). These groundwaters could also be from either the MVWFS or the WRFS. Groundwater in southern Lower Meadow Valley Wash can be either inflow from Panaca Valley or the Muddy River Springs area, given the similar deuterium content of the two sources with groundwater in this area.

ET in Lower Meadow Valley Wash is estimated to be 27,000 afy (LVVWD, 2001), which exceeds the local recharge estimate by 4,000 afy. Thus, local recharge probably does not contribute to regional aquifer groundwater in Lower Meadow Valley Wash, but instead is removed by ET. Assuming local recharge is lost to ET, any outflow from Lower Meadow Valley Wash would be inflow from Panaca Valley, which has a model-calculated deuterium value of -98.2 permil. The deuterium composition of groundwater in the Farrier area and at sites 57 and 59 also indicates that local recharge is removed by ET. This conclusion is supported by the deuterium data for alluvial groundwaters in Lower Meadow Valley Wash, which are about 10 permil heavier than model-calculated deuterium values of regional groundwater inflow from Panaca Valley and in the same range as local recharge to Lower Meadow Valley Wash. The estimated groundwater outflow from Lower Meadow Valley Wash to Lower Moapa Valley of 32,000 afy based on LVVWD (2001) recharge and ET estimates, would likely have a deuterium composition of -98.2 permil (Table 1 and Appendix 1).

Geochemistry

A preliminary evaluation of geochemical data for groundwater in the MVWFS was performed by plotting geochemical data on a trilinear diagram. In contrast to groundwater chemistry in the WRFS, groundwater in the MVWFS shows marked differences because of the movement of groundwater through a large amount of volcanic rock (Figure 8). Groundwater in Lake Valley and the western mountains, which are predominately carbonate rock, is a Ca-Mg-HCO_3 water type, with the exception of one sample. Groundwater in the volcanic rocks of the MVWFS range from a Ca-Mg-HCO_3 type water to a more Na- and K-rich groundwater. Groundwater from alluvial wells has a chemical composition that overlaps that of the volcanic-rock groundwaters, but most samples contain more sulfate and chloride than either the volcanic rock or carbonate-rock groundwaters. The Panaca Warm Spring and Panaca Town well groundwaters have a mixed water chemistry with more Na and K and generally more SO_4 than the carbonate-aquifer groundwaters (Figure 8 and Appendix 2). The increase in Na and K in the Panaca groundwaters as compared to other carbonate-rock aquifer groundwaters indicates that these waters have reacted with Na- and K-rich minerals or mixed with volcanic rock or alluvial-aquifer groundwater.

Summary

A deuterium mass-balance water-budget model developed to evaluate groundwater recharge and ET estimates by LVVWD (2001) shows that model-calculated deuterium values are consistent with measured values in the MVWFS. In contrast to the WRFS, which acts as one integrated carbonate-rock aquifer, the MVWFS has a regional carbonate-rock aquifer system and a mostly separate volcanic rock-alluvial aquifer system. The MVWFS has only one valley with a regional spring and another area with warm water to evaluate the deuterium mass-balance model, so this deuterium mass-balance model is much less constrained than the WRFS model. The deuterium mass-balance model is consistent with recharge and ET rates and proposed sources and mixing of groundwater within the MVWFS, if a regional carbonate-rock aquifer transports groundwater from the northwest and a volcanic rock-alluvial aquifer system transports water from the northeast and southeast into Panaca Valley.

A preliminary evaluation of oxygen-18 data shows that oxygen-18 mass-balance calculations produce results that are similar to the deuterium mass-balance model (Table 1 and Appendix 1). Panaca Warm Spring in Panaca Valley has a calculated oxygen-18 value within 0.2 permil of the measured value.

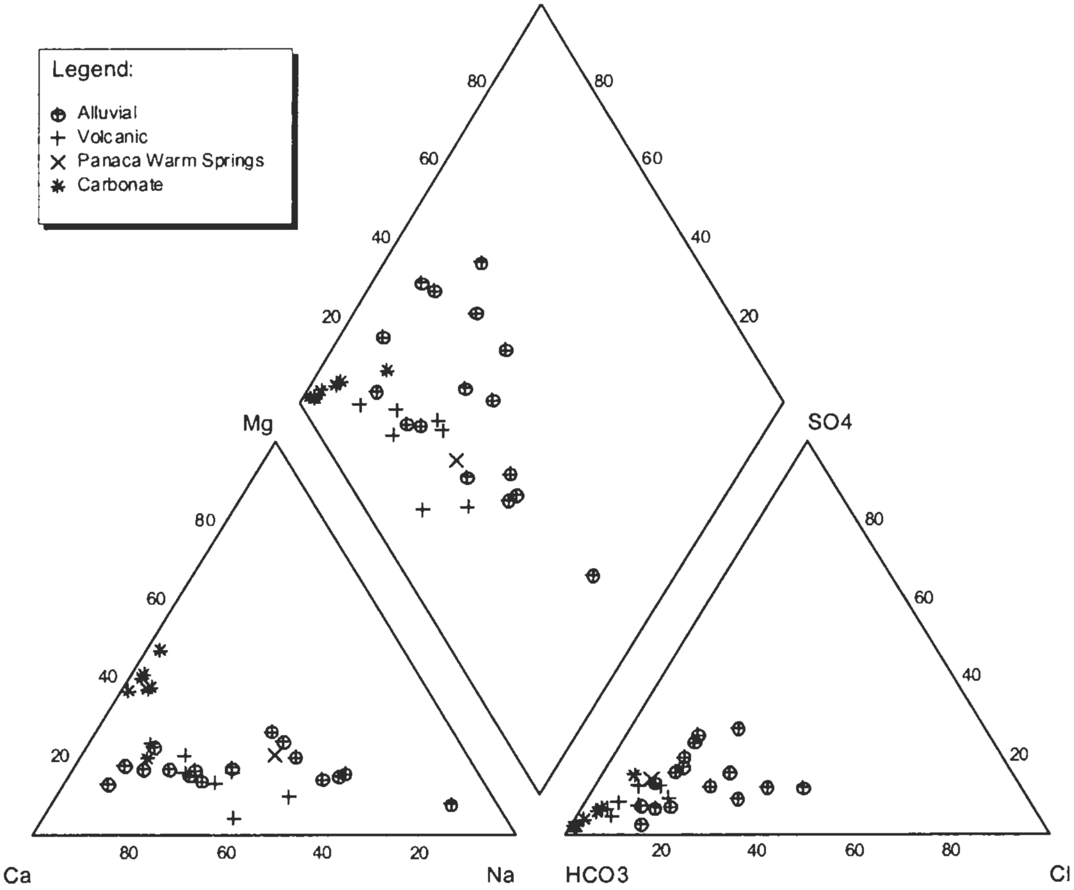

Figure 8. Trilinear plot of chemistry for groundwater in the MVWFS.

Emme (1986) developed a chloride and deuterium mass-balance water budget for the Upper Meadow Valley Wash Flow System. Similar to the results of this study, Emme (1986) concluded that a two-component flow system was needed to explain groundwater sources and flows within the Upper Meadow Valley Wash Flow System. Emme (1986) described a two-layer flow system consisting of a regional carbonate-rock flow system and a local volcanic-rock flow system. The main differences between this study and the study by Emme (1986) are the amounts of groundwater recharge and ET. Emme (1986) used the hydrologic reconnaissance studies recharge and ET estimates (Rush and Eakin, 1963; Rush, 1964). The reconnaissance studies recharge estimate for the entire MVWFS is 37,000 afy (Rush and Eakin, 1963; Rush 1964), as compared to an estimated 122,000 afy (LVVWD, 2001) evaluated with the deuterium mass-balance model in this study. The significantly higher recharge estimates by LVVWD (2001) are developed using Maxey-Eakin recharge efficiencies, the same approach as in the reconnaissance studies, but with a new altitude-precipitation relationship that has significantly more precipitation at similar altitudes than the reconnaissance report altitude-precipitation relationship. Total ET was estimated to be 32,000 afy by Rush and Eakin (1963) and Rush (1964), as compared to 91,000 afy estimated by LVVWD (2001). Rush (1964) estimated 7,000 afy of groundwater flowed out of Lower

Meadow Valley Wash to Upper Moapa Valley as compared to the LVVWD (2001) estimate of 32,000 afy. As stated earlier, the deuterium mass-balance model produces consistent results with the new recharge and ET rates evaluated in this study. The deuterium mass-balance model produces a non-unique solution, so proportionate changes in recharge and ET rates, or another combination of groundwater sources and mixing could produce the same results.

LAKE MEAD AREA FLOW SYSTEM

In this study, the Lake Mead Area Flow System (LMFS) is defined as the area from Upper Moapa Valley, where the Muddy River Springs discharge, and the southern end of Lower Meadow Valley Wash to Lake Mead, and extending west from Lake Mead to the topographic divide with Las Vegas Valley. This area includes five valleys: Hidden Valley, Garnet Valley, California Wash Valley, Black Mountains area, and Lower Moapa Valley (Figures 1 and 2). Groundwater inflow in the northwest part of the LMFS is from the Coyote Springs Valley area, where groundwater flows into the Hidden Valley-Garnet Valley-California Wash area. In the northern part of the LMFS, the Muddy River, fed by groundwater from the carbonate-rock aquifers in the Muddy River Springs area, flows across northeastern California Wash to Lower Moapa Valley. This surface-water flow is not included as groundwater inflow to Lower Moapa Valley. Groundwater flows into Lower Moapa Valley from California Wash Valley to the west and Lower Meadow Valley Wash to the north.

Isotopic Mass Balance

The 16,000 afy of groundwater in the regional carbonate-rock aquifers of the WRFS that are not discharged from the Muddy River Springs area, as estimated by LVVWD (2001), are assumed to flow south and southeast to Hidden Valley, Garnet Valley, and California Wash (Figures 2-4). This flow component is inferred on the basis of detailed hydrogeologic cross sections and large fault structures (LVVWD, 2001), and water-level data (Thomas et al., 1996). Deuterium data for the LMFS ranges from -103.0 permil for groundwater from the regional carbonate-rock aquifers to -79.0 permil for local recharge that has not been significantly evaporated (Figure 9), a difference of 24 permil. A model-calculated deuterium composition of groundwater flowing south and southeast of the Muddy River Springs area would be -98.0 permil, the same as groundwater discharging from regional springs in the Muddy River Springs area. Total local recharge in these three valleys is estimated to be 1,7000 afy (LVVWD, 2001), distributed almost equally among the three valleys (Appendix 1). Local recharge has a deuterium composition of -82.0 to -81.0 permil (Table 1 and Appendix 1).

In Hidden Valley, the only sample collected that can be used to evaluate potential inflow is from a well completed to a depth of 920 ft, with a depth to water of about 830 ft (Berger et al., 1988). Geophysical logs indicate that this well is completed in alluvial material. Unfortunately, even though the water sample is from greater than 830 ft bls, the sample from this well is significantly evaporated (deuterium is more than 10 permil heavier than a non-evaporated value calculated from the oxygen-18). Thus, no deuterium data are available to evaluate this proposed inflow to Hidden Valley. Pre-development ET in the valley is less than 100 afy, so any groundwater flowing in the carbonate-rock aquifers would pass through Hidden Valley to Garnet Valley or California Wash with little addition of local recharge.

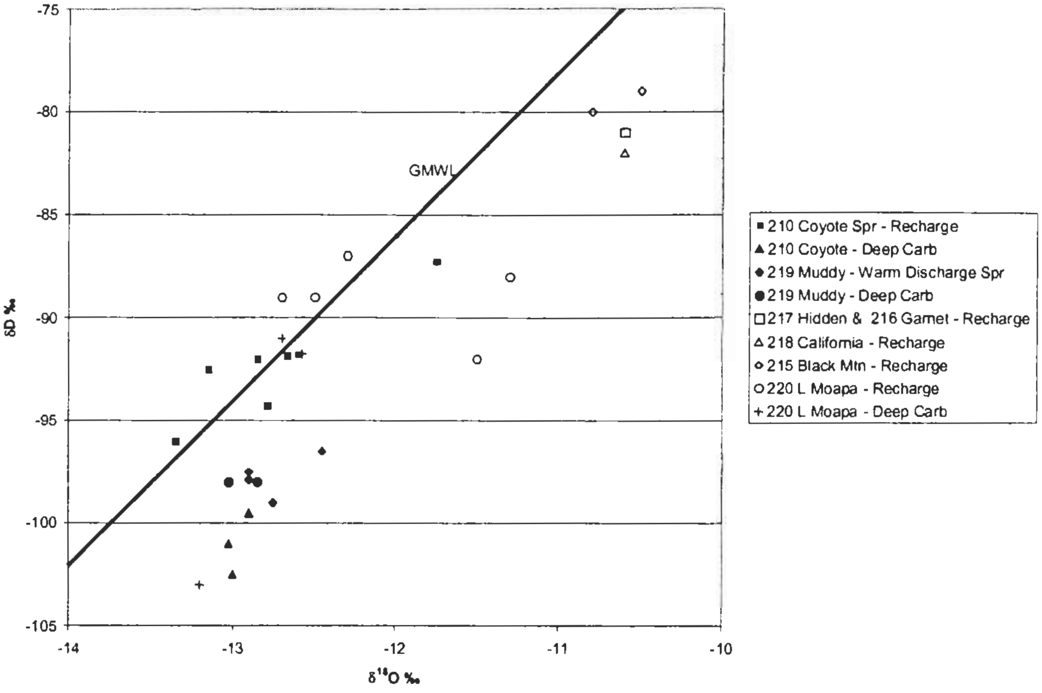

Figure 9. Deuterium versus oxygen-18 for groundwater in the LMFS.

Garnet Valley has five wells with deuterium data (Figure 2; sites 17, 24, 27, 34, and 37). The average deuterium composition of these wells is -96.9 permil (Table 1 and Appendix 1), which is within 2 permil of the model-calculated and Muddy River Springs area measured deuterium composition of groundwater flowing out of Coyote Springs Valley. These similar deuterium values for groundwater in Garnet Valley and groundwater outflow from Coyote Springs Valley indicate that groundwater in Garnet Valley originates from Coyote Springs Valley. Pre-development ET in the valley is less than 100 afy, so any groundwater flowing in the carbonate-rock aquifers would pass through Garnet Valley.

All of the estimated 16,000 afy of Coyote Spring Valley groundwater flowing to the south-southeast (LVVWD, 2001) is assumed to flow into California Wash Valley, either directly from Coyote Spring Valley or through Hidden and Garnet valleys. The regional groundwater flow would have a model-calculated deuterium value of -98.0 permil and with local recharge of 1,000 afy for Hidden, Garnet, and California Wash valleys (LVVWD, 2001), which has an average deuterium composition of -82.0; groundwater in California Wash Valley would have a deuterium value of -97.0 permil. Two groundwater samples in western California Wash Valley (Figure 2; sites 41 and 43) have deuterium compositions of -99.0 permil. This value is within 2 permil of the model-calculated value (Table 1), indicating that Coyote Springs Valley groundwater is a likely source of groundwater in California Wash Valley. This interpretation is consistent with hydrogeologic interpretations of groundwater flow directions (LVVWD, 2001).

Two samples in the northwest part of California Wash Valley (Figure 2; sites 54 and 55) have deuterium values of –99.0 and –95.5 permil. These samples are in the area where groundwater in California Wash Valley, Upper Moapa Valley, and Lower Meadow Valley Wash groundwaters all enter Lower Moapa Valley, thus the isotopic composition of these samples may be from any of these three sources.

Pre-development ET in California Wash Valley is estimated to be 5,000 afy (LVVWD, 2001), so with an estimated groundwater inflow of 16,000 afy plus local recharge of 1,000 afy, an estimated 12,000 afy of groundwater would flow out of California Wash Valley. The estimated 12,000 afy of groundwater outflow is assumed to flow out of the valley in two directions, on the basis of hydrogeologic interpretations (LVVWD, 2001): 8,000 afy would flow into Lower Moapa Valley and 4,000 afy would flow into the Black Mountains area (Figure 2 and Table 1).

Assuming groundwater flows from California Wash Valley to the Black Mountains area, this inflow has a model-calculated deuterium composition of -97.0 permil. Local recharge in the Black Mountains area, 500 afy (LVVWD, 2001), has an average deuterium value of -81.0 permil (Table 1 and Figure 2; sites 8, 10, 31). Groundwater discharging from the carbonate-rock aquifers as springs in the Rogers and Blue Point springs area (Figure 2; sites 19, 20, 21, 26, 28, 29, and 30), has a flow-weighted average deuterium composition of -91.9 permil (Appendix 1). This spring discharge cannot be solely from groundwater inflow from California Wash Valley because the springs are on average 5.1 permil heavier than the California Wash Valley groundwater. Thus, groundwater discharging from the springs has to include some local recharge with a heavier isotopic composition, or be from a source other than California Wash Valley. If the spring discharge is a mixture of California Wash Valley groundwater and local recharge, and assuming ET for the spring area is 2,000 afy (LVVWD, 2001), then a mixture of 68 percent (1,360 afy) California Wash groundwater (-97.0 permil) with 32 percent (640 afy) local recharge (-81.0 permil) would comprise the water discharging from springs in this area. If the entire inflow of 4,000 afy were mixed with local recharge before the spring area, then the above values would double (of significance is that local recharge would be 1,280 afy). This mixture of sources is based on limited deuterium data, so a large degree of variability is expected as more data are collected. The small range in deuterium values in groundwater from the carbonate-rock aquifers in this part of southern Nevada, -102.5 to -96.0 permil (Figure 2), indicates that a local recharge source is needed to account for the measured deuterium composition of the springs.

Measured average monthly flows for Rogers Spring for September 1985 to September 1999 (U.S. Geological Survey data) range from 880 to 1,650 afy, with most monthly flows ranging between about 1,000 and 1,300 afy. Of note, is that average July flows are generally the highest monthly flows for all years during this period of record and July contains the five highest average monthly flows measured for the 14 years of record. These data show a non-steady spring discharge, which is expected if local recharge were supplying part of the groundwater discharging from the spring. The largest unknown in the deuterium mass-balance model is the variability of the deuterium content of local recharge over time.

Another potential source of groundwater for the Rogers and Blue Point springs area is flow from northern Lower Moapa Valley along the numerous north-south-trending fault structures as proposed by Pohlmann et al. (1998). Groundwater samples from two wells in Weiser Wash (Figure 2; sites 56 and 61) have deuterium values of -91.8 and -91.0 permil. These values are similar to the flow-weighted average deuterium value of -91.9 permil of the springs discharging from the Rogers-Blue Point springs area. This source cannot be ruled out on the basis of water-level data and interpretations of hydrogeologic information (LVVWD, 2001).

Pohlmann et al. (1998) showed that the uranium concentration and uranium isotopic ratio ($^{234}U/^{238}U$) of groundwater discharging from Rogers and Blue Point springs are very similar to regional springs in the WRFS (Muddy River area and Pahranagat Valley warm springs). These data support inflow from Coyote Springs Valley being a major source of water discharging at Rogers and Blue Point springs, as is indicated by the deuterium data. Unfortunately, uranium data are lacking for the Valley of Fire well used as local recharge in the deuterium mass-balance model, so this component of the spring flow discharge cannot be evaluated with uranium data. However, uranium data for local springs in this area are available (Pohlmann et al., 1998). These springs (Figure 2; sites 8, 10, 14, 32, 35, 38, 40) all have uranium isotopic ratios less than those of Rogers and Blue Point springs and the WRFS springs and they generally have higher uranium concentrations. These data indicate little mixing of local recharge with regional groundwater flow discharging at Rogers and Blue Point springs. Uranium data are not available for Lower Moapa Valley groundwater to evaluate this potential source of groundwater to Rogers and Blue Point springs.

Another possible source of groundwater discharging from the Rogers and Blue Point springs area is the Sheep Range. The average deuterium value of recharge to the Sheep Range is -93.1 permil (Appendix 1), similar to the average deuterium value of -91.9 permil of the springs in the Rogers and Blue Point springs area. However, this potential source of water as the major component of spring discharge is not likely because of the presence of isotopically lighter water (-96.0 to -99.0 permil) extending from southwest Garnet Valley north to the Muddy River Springs area. The heavier Sheep Range water that would need to flow through this area to discharge at Rogers and Blue Point springs is not observed.

An additional 2,000 afy of groundwater not discharged from the Rogers-Blue Point spring area are assumed to discharge as inflow to Lake Mead. This underflow is based on the 4,000 afy of inflow to the Black Mountains area from California Wash and the estimated ET in the spring discharge area (LVVWD, 2001).

An estimated 8,000 afy of groundwater (LVVWD, 2001), with a model-calculated deuterium value of -97.0 permil, flow into Lower Moapa Valley from California Wash Valley (Table 1 and Appendix 1). As previously noted in the discussion of the MVWFS, 32,000 afy of groundwater with a deuterium value of -98.2 permil flow into Lower Moapa Valley from Lower Meadow Valley Wash. An additional 32,000 afy of surface-water flow in Muddy River also enter western Lower Moapa Valley from California Wash Valley. Thus, Lower Moapa Valley receives an estimated total 40,000 afy of groundwater inflow (LVVWD, 2001) and has an average model-calculated deuterium content of -98.0 permil. Local recharge is estimated to be 1,000 afy (LVVWD, 2001) and it has an average deuterium value of -88.7 permil (Figure 2; sites 35, 38, 84, 85, 90). Pre-development ET is estimated to be 15,000 afy (LVVWD, 2001), so an estimated 26,000 afy of groundwater flow out of Lower Moapa Valley to Lake Mead. Unfortunately, only one well (Figure 2; site 48), probably completed in the alluvial aquifer, has deuterium data that can be compared with the deuterium mass-balance model. A sample from the well has a deuterium value of -103.0 permil, which is 5 to 6 permil lighter than groundwater assumed to be entering the valley. No source for this water was identified. The deuterium mass-balance model produces consistent results with the new recharge and ET rates evaluated in this study, but critical data are lacking especially in Lower Moapa Valley.

Geochemistry

A preliminary evaluation of geochemical data for groundwater in the LMFS was performed by plotting geochemical data on a trilinear diagram. Groundwater in the LMFS varies considerably in their amount of total dissolved ions because of the presence of evaporative salts, primarily gypsum or anhydrite and halite, in much of the LMFS area (Appendix 2). The trilinear diagram shows that groundwater flowing into the LMFS from the Coyote Springs Valley area is already a mixed cation-anion type water because of the addition of Na and SO_4 to the carbonate-type water (Figure 10). A typical carbonate-rock aquifer Ca-HCO_3-type water is shown for Wamp Spring in the Sheep Range (Figure 2; site 52) in the LMFS. Groundwater samples from wells completed in carbonate rocks in the LMFS contain significant amounts of all major cations and anions, although Ca and Mg are more abundant than Na and K and the waters contain mostly SO_4 and Cl anions. Local recharge is a Ca-Mg-SO_4-type water and groundwater discharging in the Rogers-Blue Point springs area is a Ca-Na-SO_4-Cl-type water. Most changes in groundwater chemistry in the LMFS can be explained by the dissolution of evaporative salts, primarily gypsum or anhydrite and halite.

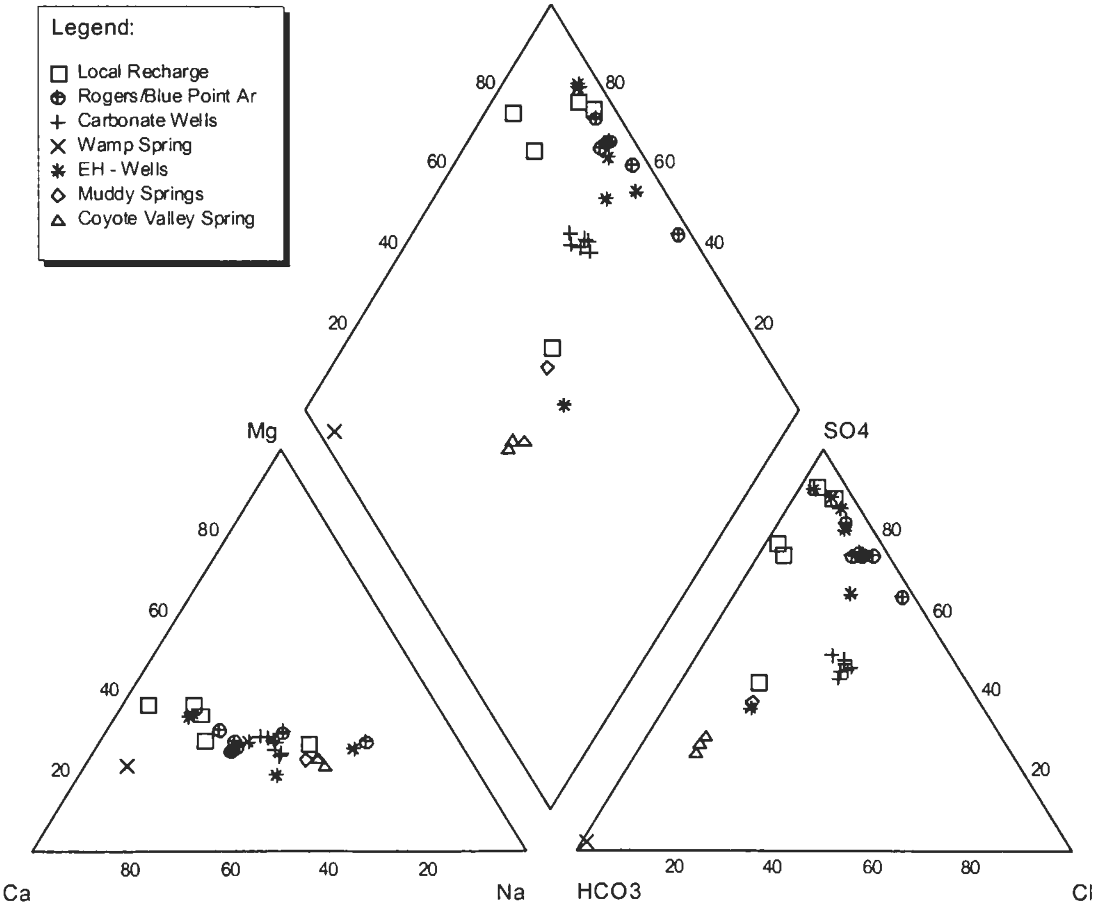

Figure 10. Trilinear plot of chemistry for groundwater in the LMFS.

Summary

The results of the deuterium mass-balance water-budget model used to evaluate recharge and ET rate estimates developed by LVVWD (2001), and assumed inflow rates from these estimates, for the LMFS, are consistent with limited deuterium data for groundwater in the carbonate-rock aquifers of the LMFS. Using the LVVWD (2001) estimated recharge and ET rates and resulting inflow rates; model-calculated deuterium values for wells completed in the carbonate-rock aquifers are similar to measured values (within 2 permil). Spring flow in the Rogers and Blue Point springs area is most likely a mixture of regional underflow from California Wash and local recharge, however, the Weiser Wash area in northern Lower Moapa Valley cannot be ruled out as a source of the springs as well. Unfortunately, no deuterium data for regional carbonate-rock aquifer groundwaters are available in Lower Moapa Valley to evaluate groundwater sources and mixing in this valley.

A preliminary evaluation of oxygen-18 data shows that oxygen-18 mass-balance calculations produce similar results as the deuterium mass-balance model (Table 1 and Appendix 1). The model-calculated oxygen-18 value for groundwater in Garnet Valley is less than 0.3 permil heavier than the average measured value for samples from wells completed in carbonate rock. In California Wash, model-calculated values are 0.46 and 0.56 permil heavier than measured groundwater values, indicating the models do not agree in this area. Finally, using deuterium mixing proportions of regional inflow and local recharge to produce the deuterium composition of the springs discharging in the Rogers and Blue Point springs area results in a model-calculated oxygen-18 value within 0.2 permil of the measured value. In comparison, the two Weiser Wash wells in northern Lower Moapa Valley are 0.36 and 0.26 permil lighter than the model-calculated value.

No water budget study exists for the LMFS prior to this study. However, Pohlmann et al. (1998) performed a study that identified water sources to springs in the Lake Mead area. Results reported herein are consistent with conclusions reached by Pohlmann et al. (1998) on sources of spring discharge in the Lake Mead area. However, a single model of spring sources cannot be developed with available data; at a minimum, the Rogers and Blue Point springs can be a mixture of regional groundwater flow and local recharge, or groundwater flow from the Weiser Wash area of Upper Moapa Valley.

CONCLUSIONS

Deuterium data were used to evaluate new estimates of recharge and ET rates developed by LVVWD (2001), and sources and mixing of groundwater in regional flow systems in southeastern Nevada. A deuterium mass-balance model was constructed for the White River, Meadow Valley Wash, and Lake Mead groundwater flow systems. A preliminary evaluation of geochemical and oxygen-18 data was performed to assess the consistency of this information with the deuterium mass-balance water-budget model developed to evaluate the regional flow systems.

An evaluation of the White River Flow System (WRFS) shows that this flow system acts as one integrated carbonate-rock aquifer flow system (consistent with Eakin, 1966; Kirk and Campana, 1990). A deuterium mass-balance model constructed using average measured deuterium values for recharge areas and recharge and ET estimates from LVVWD (2001) results in a deuterium-calibrated mass-balance model that is consistent with deuterium values for regional warm springs discharging from and wells completed in the carbonate-rock aquifers of the WRFS. Model-calculated deuterium values for regional springs and wells completed in the carbonate-rock aquifers are within 2 permil of measured values, except for regional springs in Pahranagat Valley. The deuterium mass-balance model is non-unique, so this agreement of model-calculated with measured deuterium values does not confirm that recharge and ET estimates are correct; it only shows that the deuterium data are consistent with the proposed rates, groundwater sources, and groundwater mixing. For example, a proportionate decrease or increase in both recharge and ET rates, or a different combination of groundwater sources and mixing, can produce the same results. The deuterium mass-balance model of the White River Flow System is consistent with 53,000 acre-feet per year (afy) of groundwater flowing out of Coyote Springs Valley to the Muddy River Springs area in Upper Moapa Valley (37,000 afy) and to the south-southeast in the carbonate-rock aquifers (16,000 afy). A preliminary analysis of geochemical and oxygen-18 data supports the deuterium mass-balance model.

A deuterium mass-balance model of the Meadow Valley Wash Flow System (MVWFS) indicates that the regional flow system is composed of a regional carbonate-rock aquifer flow system and a volcanic rock-alluvial aquifer system, in contrast to the WRFS, which acts as one continuous flow system. A deuterium mass-balance model of the MVWFS indicates that inflow of groundwater to Panaca Valley from Patterson Valley (28,000 afy) to the northwest is via a regional carbonate-rock aquifer, whereas groundwater inflow from Dry Valley (16,000 afy) to the northeast is via volcanic rock and alluvial aquifers. Groundwater in Meadow Valley Wash in volcanic-rock and alluvial aquifers is from local recharge. Groundwater inflow to Meadow Valley Wash from Panaca Valley (36,000 afy) is not observed for deuterium data in alluvial wells in the Wash and may be deeper in underlying carbonate-rock aquifers. A sample from the southern part of Meadow Valley Wash, in an area where groundwater from carbonate-rock aquifers flows to land surface, has a deuterium value similar to the model-calculated value of groundwater inflow from Panaca Valley, indicating that this sample may represent underflow in the regional carbonate-rock aquifers. Another equally plausible explanation for the measured deuterium value of this sample is that groundwater flow from the Muddy River Springs area of the WRFS extends into this area. A preliminary evaluation of geochemical and oyxgen-18 data is consistent with the deuterium mass-balance model. The MVWFS is more complex than the WRFS.

New recharge and ET rates estimated by LVVWD (2001) result in the Lake Mead Flow System (LMFS) receiving 16,000 afy of groundwater from the WRFS to the northwest, 32,000 afy of groundwater from the MVWFS to the north, and 2,000 afy of local recharge. A deuterium mass-balance model constructed to evaluate these new recharge and ET estimates is consistent with deuterium values for groundwater in wells completed in the carbonate-rock aquifers of the LMFS in Garnet and California Wash valleys. Model-calculated deuterium values are within 2 permil of measured values. Spring flow in the Rogers and Blue Point springs area is most likely a mixture of regional underflow from California Wash and local recharge, however, the Weiser Wash area in northern Lower Moapa Valley cannot be ruled out as a possible source of these springs. LVVWD (2001) estimates of groundwater inflow to Lower Moapa Valley from California Wash Valley (8,000 afy) and Lower Meadow Valley Wash (32,000 afy) cannot be evaluated with deuterium data because no samples from the regional aquifers are available in this valley. Besides estimated groundwater inflow to Lower Moapa Valley from California Wash Valley, 32,000 afy of stream flow in the Muddy River enter Lower Moapa Valley from California Wash. This is primarily the flow out of the

Muddy River Springs. An estimated groundwater outflow from Lower Moapa Valley to Lake Mead is 26,000 afy. A preliminary analysis of geochemical and oxygen-18 data is consistent with the deuterium-calibrated mass-balance model.

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APPENDIX 1: DETAILED ISOTOPIC MASS BALANCE SHOWING ALL THE SITES USED IN THE MODEL MASS-BALANCE CALCULATIONS.

Section	Name	Volume Acre-ft/yr	# of Samples	Site #	Site Type	Obs. δD	Obs. $\delta^{18}O$	Calc. δD	Calc. $\delta^{18}O$
White River Flow System									
175	Long Valley								
175 NE	Butte Mtn. (N)	4,500				-127.4	-16.6		
175 NW	Maverick Springs	14,000				-128.3	-16.7		
175 SE	Butte Mtn. (S)	7,800				-126.0	-16.4		
175 SW	Alligator Rdg.	4,900				-127.4	-16.6		
TR	Total Recharge	31,000	4			-127.4	-16.6		
SE	Thirty Mile Spring		1	242	Spring	-126.0	-16.4		
NW	Well at Alligator Ridge		1	243	Well	-127.0	-16.6		
NW	Ram. Res. Wtr Supply Well		1	244	Well	-129.5	-16.8		
ET	ET	11,000						-127.4	-16.6
OUT	GW Flow out of System	8,000						-127.4	-16.6
174	GW Outflow (Jakes)	12,000						-127.4	-16.6
174	Jakes Valley								
175	Inflow (Long)	12,000				-127.4	-16.6		
174 E	HW Illipah Cr.	8,400				-125.2	-16.4		
174 W	Egan Rng. @ Ruth	15,800				-125.2	-16.4		
TR	Total Recharge	24,000	2			-125.2	-16.4		
W	Sand Spring		1	239	Spring	-123.0	-16.2		
W	WildHorse Spring		1	240	Spring	-129.0	-16.8		
W	Upper Illipah Crk		2	238	Surface	-123.5	-16.1		
ET	ET	600						-125.9	-16.4
207N	GW Outflow (NWRV)	35,000						-125.9	-16.4
180	Cave Valley								
180 E	S. Schell Cr. Rng	8,200				-99.8	-13.5		
180 W	S. Egan Rng	11,400				-107.5	-14.1		
TR	Total Recharge	20,000	2			-104.3	-13.8		
E	Sidehill Spring		1	200	Spring	-100.0	-13.1		
E	Cave Spring		1	209	Spring	-100.0	-13.9		
E	Sheep Spring		1	212	Spring	-99.5	-13.7		
W	Chimney Rock Spring		1	219	Spring	-109.0	-14.3		
W	Big Spring (Egan Range)		1	206	Spring	-106.0	-13.9		
ET	ET	5,000						-104.3	-13.8
208	GW Outflow (Pahroc)	15,000						-104.3	-13.8
207N	North White River Valley								
174	Inflow (Jakes)	35,000				-125.9	-16.4		
207 NE	Egan Rng North	16,600				-112.1	-14.9		
207 NW	White Pine Rng.	19,100				-110.2	-14.4		
TR	Total Recharge	36,000	2			-111.1	-14.6		
NE	Second Sawmill Spring		1	222	Spring	-110.0	-14.7		

Section	Name	Volume Acre-ft/yr	# of Samples	Site #	Site Type	Obs. δD	Obs. δ^{18}O	Calc. δD	Calc. δ^{18}O
NE	Water Canyon		2	233	Surface	-116.0	-15.3		
NE	Lone Pine Spring		1	223	Spring	-111.5	-15.0		
NE	Gubler Canyon Creek Spring		1	235	Spring	-111.0	-14.9		
NE	South Spring		1	236	Spring	-111.0	-15.0		
NE	North Spring		1	237	Spring	-113.0	-15.0		
NW	Snowmelt Below Duckwater Peak		1	224	Spring	-105.0	-14.1		
NW	Spring below Currant Mtn		1	226	Spring	-107.0	-14.0		
NW	Little Currant Creek		1	217	Surface	-113.0	-15.0		
NW	Secret Spring		1	220	Spring	-110.0	-14.0		
NW	Saddle Spring		1	225	Spring	-116.0	-15.0		
NE Valley Cold	Lund Spring	5,700	2	221	Spring	-112.5	-14.6		
Warm	Nicholson Spring	2,000	1	227	Spring	-124.0	-16.1		
Warm	Cold Spring, Preston	1,000	2	230	Spring	-123.5	-15.8		
Warm	Preston Big Spring	5,900	2	231	Spring	-124.5	-15.8		
Warm	William Hot Spring		1	232	Spring	-118.0	-15.8		
	Discharge Warm Springs (Avg)	8,900	4			-124.3	-15.8	-125.9	-16.4
ET	ET	58,000						-118.4	-15.5
207S	GW Outflow (SWRV)	13,000						-118.4	-15.5
207S	South White River Valley								
207N	Inflow (NWRV)	13,000				-118.4	-15.5		
180	Inflow (Cave - No)								
207 SE	Egan Rng South	11,700				-105.3	-14.1		
207 SW	Grant Rng	14,700				-109.2	-14.6		
TR	Total Recharge	26,000	2			-107.5	-14.3		
SE	Shingle Spring		1	203	Spring	-103.5	-13.3		
SW	Albert Spring		1	204	Spring	-107.0	-14.0		
SW	Forest Home Spring		1	195	Spring	-108.5	-14.5		
SW	Big Spring (Grant Range)		1	194	Spring	-112.0	-15.2		
SE Valley Cold	Flag Spring #3	4,000	1	201	Spring	-105.0	-14.3		
SE Valley Cold	Butterfield Spring	1,900	1	202	Spring	-105.0	-14.2		
SE Valley Cold	Emigrant Spring	1,600	2	207	Spring	-107.8	-14.5		
Warm	Hot Creek Spring	10,000	1	197	Spring	-118.0	-15.5		
Warm	Hot Creek Campground Well		1	198	Well	-118.0	-15.3		
Warm	Moon River Spring	2,800	1	192	Spring	-120.0	-15.8		
Warm	Moorman Spring	400	1	205	Spring	-119.0	-15.7		
	Discharge Warm Springs (Avg)	13,200	4			-118.5	-15.6	-118.4	-15.5
ET	ET	22,000						-111.1	-14.7
208	GW Outflow (Pahroc)	17,000						-111.1	-14.7
172	Garden Valley								
172 NE	Golden Gate Rng	2,800				-107.0--			
172 NW	Quinn Cyn @ Adavan	14,100				-104.1	-14.0		
172 SE	Worthington Mountains	2,200				-98.0	-13.3		
TR	Total Recharge	19,000	3			-103.9	-13.9		
NE	SK-13		1	167	Spring	-107.0--			
SE	The Seep Spring		1	136	Spring	-98.0	-13.3		
Evaporated	Carpenter Spring		1	171	Spring	-95.0	-11.9		

Section	Name	Volume Acre-ft/yr	# of Samples	Site #	Site Type	Obs. δD	Obs. $\delta^{18}O$	Calc. δD	Calc. $\delta^{18}O$
NW	Adaven Spring		2	177	Spring	-105.3	-14.0		
NW	Lower Little Cherry Cr Spring		1	182	Spring	-103.0	-13.9		
ET	ET	5,000						-103.9	-13.9
171	GW Outflow (Coal)	14,000						-103.9	-13.9
171	Coal Valley								
172	Inflow (Garden)	14,000				-103.9	-13.9		
171 E	Seaman Rng	2,800				-90.0	-12.1		
171 W	Golden Gate Rng	4,200				-107.0--			
TR	Total Recharge	7,000	2			-100.2	-12.1		
W	SK-13		1	167	Spring	-107.0--			
E	White Rx Spring		1	154	Spring	-90.0	-12.1		
Evaporated	Oceana Spring		2	161	Spring	-86.2	-10.2		
Carb Well	USGS-MX C.V. Well (CV-DT-1)		1	176	Well	-110.0	-14.6		
	Carbonate Well (Avg)		1			-110.0	-14.6	-109.2	-14.6
ET	ET	1,000						-102.6	-13.3
209	GW Outflow (Pahranagat)	20,000						-102.6	-13.3
208	Pahroc Valley								
207S	Inflow (SWRV)	17,000				-111.1	-14.7		
180	Inflow (Cave)	15,000				-104.3	-13.8		
171	Inflow (Coal - No)								
208 E	N. Pahroc Rng.	3,700				-93.3	-12.6		
208 W	Seaman Rng.	3,800				-90.0	-12.1		
TR	Total Recharge	8,000	2			-91.6	-12.3		
E	Mustang Spring		1	135	Spring	-91.0	-12.6		
E	Black Rock Spring		1	158	Spring	-94.0	-12.3		
E	Coyote Spring		1	169	Spring	-95.0	-12.8		
W	White Rx Spring		1	154	Spring	-90.0	-12.1		
ET	ET	1,000						-104.7	-13.9
209	GW Outflow (Pahranagat)	39,000						-104.7	-13.9
209	Pahranagat Valley								
208	Inflow (Pahroc)	39,000				-104.7	-13.9		
209 E	S. Pahroc Rng.	3,000				-93.9	-12.7		
209 W	Mt. Irish/Pahranagat Rng.	4,400				-93.9	-12.7		
TR	Total Recharge	7,000	2			-93.9	-12.7		
E	Hells Acres Gulch Spring		1	109	Spring	-93.0	-12.3		
E	Sixmile Canyon Spring		1	112	Spring	-93.4	-13.1		
E	Sidehill Spring		1	200	Spring	-100.0	-13.1		
E	Pahroc Spring		1	131	Spring	-89.0	-12.5		
Warm	Ash Spring	12,400	4	110	Spring	-109.0	-14.1		
Warm	Little Ash Spring	500	1	111	Spring	-107.2	-14.2		
Warm	Crystal Spring	8,200	6	116	Spring	-108.7	-14.4		
Warm	Hiko Spring	4,300	7	122	Spring	-108.7	-14.4		
	Discharge Warm Springs (Avg)	25,400	4			-108.8	-14.2	-104.7	-13.9
ET	ET	38,000						-102.9	-13.6
171	Inflow (Coal)	20,000				-102.6	-13.3		

Section	Name	Volume Acre-ft/yr	# of Samples	Site #	Site Type	Obs. δD	Obs. δ^{18}O	Calc. δD	Calc. δ^{18}O
210	GW Outflow (Coyote Spr)	28,000						-102.9	-13.6
181	Dry Lake Valley								
181 NE	Fairview Rng.	6,100				-99.8	-13.4		
181 E	Bristol/Highland Rng.	800				-99.8	-13.4		
181 SE	Chief Rng.	1,900				-99.8	-13.4		
181 W	N. Pahroc Rng.	4,500				-93.3	-12.6		
TR	Total Recharge	13,000	4			-97.6	-13.1		
E, NE	Bennett Spring		1	141	Spring	-103.0	-13.7		
E, NE	Upper Conner Spring		1	156	Spring	-100.0	-13.9		
E, NE	Pine Spring		1	157	Spring	-99.0	-13.4		
E, NE	Lime Spring		1	160	Spring	-97.0	-12.9		
E, NE	Deadman Spring		1	162	Spring	-99.0	-13.3		
E, NE	Highland Spring		1	163	Spring	-98.5	-13.3		
E, NE	Steward Ranch Spring		1	188	Spring	-102.0	-13.6		
E, NE	Lower Pony Spring		2	190	Spring	-101.0	-13.3		
E, NE	Upper Pony Spring		1	191	Spring	-99.0	-12.9		
W	Mustang Spring		1	135	Spring	-91.0	-12.6		
W	Black Rock Spring		1	158	Spring	-94.0	-12.3		
W	Coyote Spring		1	169	Spring	-95.0	-12.8		
Carb Well	Fugro Dry Lake V Deep Well		1	179	Well	-108.0	-14.2		
	Carbonate Well (Avg)		1			-108.0	-14.2	-106.6	-14.2
ET	ET	1,000						-97.6	-13.1
182	GW Outflow (Delamar)	12,000						-97.6	-13.1
182	Delamar Valley								
181	Inflow (Dry Lake)	12,000				-97.6	-13.1		
182 E	Delamar Mtns.	3,000				-86.6	-11.5		
182 W	S. Pahroc Rng.	1,600				-91.6	-12.6		
TR	Total Recharge	5,000	2			-88.4	-11.9		
E	Grassy Spring		1	117	Spring	-85.0	-10.9		
E	Bishop Spring		1	107	Spring	-85.5	-11.7		
E	Stock Well (Delamar Wash)		1	101	Well	-88.0--			
E	Upper Riggs Spring		1	105	Spring	-88.0	-11.9		
W	Hells Acres Gulch Spring		1	109	Spring	-93.0	-12.3		
W	Sixmile Canyon Spring		1	112	Spring	-93.4	-13.1		
W	Pahroc Spring		1	131	Spring	-89.0	-12.5		
W	Mustang Spring		1	135	Spring	-91.0	-12.6		
ET	ET	1,000						-94.9	-12.7
210	GW Outflow (Coyote Spr)	16,000						-94.9	-12.7
206	Kane Springs Valley								
206 E	Meadow Valley Mtns.	900				-87.8	-11.8		
206 W	Delamar Mtns.	5,800				-87.3	-12.1		
TR	Total Recharge	7,000	2			-87.4	-12.0		
E	Grapevine Spring (KSV-2)		2	93	Spring	-87.8	-11.8		
W	Willow Spring (KSV-1)		2	92	Spring	-87.3	-11.8		
W	Kane Springs (KSV-3)		2	97	Spring	-86.8	-12.3		

Section	Name	Volume Acre-ft/yr	# of Samples	Site #	Site Type	Obs. δD	Obs. $\delta^{18}O$	Calc. δD	Calc. $\delta^{18}O$
W	Boulder Spring (KSV-4)		2	98	Spring	-87.3	-12.3		
W	Upper Riggs Spring		1	105	Spring	-88.0	-11.9		
ET	ET	1,000						-87.4	-12.0
210	GW Outflow (Coyote Spr)	6,000						-87.4	-12.0
210	Coyote Springs Valley								
209	Inflow (Pahranagat)	28,000				-102.9	-13.6		
182	Inflow (Delamar)	16,000				-94.9	-12.7		
206	Inflow (Kane Springs)	6,000				-87.4	-12.0		
210 E	S. Meadow Valley Mtns.	100				-91.4	-12.6		
210 NE	S. Delamar Mtns.	900				-87.3	-11.8		
210 NW	S. of Maynard Lake	100				-91.4	-12.6		
210 SE	Arrow Canyon Rng.	500				-91.4	-12.6		
210 W	Sheep Range	2,300				-93.1	-12.9		
TR	Total Recharge	4,000	5			-91.4	-12.6		
W	Cow Camp Spring		2	47	Spring	-91.8	-12.6		
W	Mormon Well Spring		3	53	Spring	-91.8	-12.7		
W	Wiregrass Spring		9	49	Spring	-94.3	-12.8		
W	Sheep Spring		1	83	Spring	-96.0	-13.4		
W	Sawmill Spring		1	58	Spring	-92.0	-12.9		
W	Lamb Spring		1	86	Spring	-92.5	-13.2		
NE	Willow Spring (KSV-1)		2	92	Spring	-87.3	-11.8		
Evaporated	White Rock Spring		2	64	Spring	-83.5	-9.9		
Carb Well	CE-VF-2 Well		1	81	Well	-101.0	-13.0		
Carb Well	Fugro CV Deep Well CE-DT-5		1	77	Well	-99.5	-12.9		
Carb Well	CE-DT-4		1	78	Well	-102.5	-13.0		
	Deep Carbonate Well (Avg)		3			-101.0	-13.0	-100.0	-13.3
ET	ET	1,000						-98.0	-13.1
219	SW Outflow (Muddy)	37,000						-98.0	-13.1
216	GW Outflow (Garnet)	16,000						-98.0	-13.1
219	Upper Moapa (Muddy) Valley								
210	Inflow (Coyote)	37,000				-98.0	-13.1		
219 N	Wildcat Wash	200				-100.0	-13.0		
219 S	E. Arrow Canyon?	100				-100.0	-13.0		
TR	Total Recharge	300	2			-100.0	-13.0		
Warm	Iverson's Spring		1	65	Spring	-97.0--			
Warm	Pederson's Warm Spring (M-13)	400	5	67	Spring	-97.5	-12.9		
Warm	M-8 Spring		1	68	Spring	-99.0	-12.8		
Warm	Big Muddy Spring	5,500	4	69	Spring	-97.9	-12.9		
Warm	M-9 Spring	200	1	70	Spring	-96.5	-12.5		
	Discharge Warm Springs (Avg)	6,100	5			-97.8	-12.9	-98.0	-13.1
Carb Well	CE-DT-6 Well		1	72	Well	-98.0	-13.0		
Carb Well	CSV-2 Well		1	76	Well	-98.0	-12.9		
	Deep Carbonate Well (Avg)		2			-98.0	-12.9	-98.0	-13.1
ET	ET	5,000						-98.0	-13.1
Gage	Gage	31,000						-98.0	-13.1
218	SW Outflow (California Wash)	32,000						-98.0	-13.1

Section	Name	Volume Acre-ft/yr	# of Samples	Site #	Site Type	Obs. δD	Obs. δ^{18}O	Calc. δD	Calc. δ^{18}O
Meadow Valley Wash Flow System									
183	Lake Valley								
183 NE	Fortification Rng.	8,800				-113.0	-15.0		
183 NW	Cen. Schell Cr. Rng	14,800				-108.3	-14.8		
183 SE	Wilson Cr. Rng. @ Atlanta	11,900				-97.5	-13.2		
183 SW	Fairview Rng.	5,800				-100.7	-13.3		
TR	Total Recharge	41,000	4			-105.1	-14.1		
NE	Unnamed Well		1	216	Well	-113.0	-15.0		
NW	North Creek Spring	1,200	1	214	Spring	-105.0	-14.6		
SE	Wilson Creek		1	189	Surface	-97.5	-13.2		
SW	Steward Ranch Spring		1	188	Spring	-102.0	-13.6		
SW	Lower Pony Spring		2	190	Spring	-101.0	-13.3		
SW	Upper Pony Spring		1	191	Spring	-99.0	-12.9		
Alluvial Well	Lake Valley Well		1	193	Well	-111.0	-14.7		
NW Valley Cold	Big Spring South	1,600	1	210	Spring	-111.0	-14.8		
NW Valley Cold	Big Spring North	700	1	211	Spring	-112.0	-15.1		
NW Valley Cold	Geyser Spring	340	1	213	Spring	-105.0	-14.5		
ET	ET	24,000						-105.1	-14.1
202	GW Outflow (Patterson)	17,000						-105.1	-14.1
202	Patterson Valley								
183	Inflow (Lake)	17,000				-105.1	-14.1		
202 E	Wilson Cr. Rng. @ Mt. Wilson	9,800				-97.5	-13.2		
202 W	Bristol Rng.	5,900				-98.7	-13.4		
TR	Total Recharge	16,000	2			-98.0	-13.3		
E	Wilson Creek		1	189	Surface	-97.5	-13.2		
W	Upper Conner Spring		1	156	Spring	-100.0	-13.9		
W	Pine Spring		1	157	Spring	-99.0	-13.4		
W	Lime Spring		1	160	Spring	-97.0	-12.9		
W	Deadman Spring		1	162	Spring	-99.0	-13.3		
W	Highland Spring		1	163	Spring	-98.5	-13.3		
Alluvial Well	Dodge Well		1	185	Well	-107.0	-14.2		
ET	ET	5,000						-101.6	-13.7
203	GW Outflow (Panaca)	28,000						-101.6	-13.7
201	Spring Valley								
201 E	White Rock Mtns.	8,700				-101.0	-13.1		
201 W	Wilson Cr. Rng. @ Parsnip Pk.	7,400				-101.0	-13.1		
TR	Total Recharge	16,000	2			-101.0	-13.1		
E	Spring below Reed Summit		1	173	Spring	-95.0	-12.5		
E	Burnt Canyon Spring		1	187	Spring	-93.0	-12.3		
W	Parsnip Spring		1	180	Spring	-93.5	-12.8		
Alluvial Well	White Rock Well		1	175	Well	-101.0	-13.1		
Surface	Camp Creek		1	184	Surface	-102.0	-14.0		
Surface	MVW above Eagle Canyon		1	168	Surface	-93.0	-12.0		
ET	ET	1,000						-101.0	-13.1

Section	Name	Volume Acre-ft/yr	# of Samples	Site #	Site Type	Obs. δD	Obs. $\delta^{18}O$	Calc. δD	Calc. $\delta^{18}O$
200	GW Outflow (Eagle)	15,000						-101.0	-13.1
200	Eagle Valley								
201	Inflow (Spring)	15,000				-101.0	-13.1		
200 E	E. Eagle (Ursine) Valley	1,900				-101.0	-13.4		
200 W	W. Eagle (Ursine) Valley	500				-101.0	-13.4		
TR	Total Recharge	2,000	2			-101.0	-13.4		
E	Flatnose Spring	600	1	153	Spring	-101.0	-13.4		
ET	ET	1,000						-101.0	-13.1
199	GW Outflow (Rose)	16,000						-101.0	-13.1
199	Rose Valley								
200	Inflow (Eagle)	16,000				-101.0	-13.1		
199 E	E. Rose Valley	200				-101.0	-13.4		
199 W	W. Rose Valley	100				-101.0	-13.4		
TR	Total Recharge	300	2			-101.0	-13.4		
E	Flatnose Spring	600	1	153	Spring	-101.0	-13.4		
ET	ET	700						-101.0	-13.1
198	GW Outflow (Dry)	16,000						-101.0	-13.1
198	Dry Valley								
199	Inflow (Rose)	16,000				-101.0	-13.1		
198 E	E. Dry Valley	3,700				-101.0	-13.4		
198 W	W. Dry Valley	500				-101.0	-13.1		
TR	Total Recharge	4,000	2			-101.0	-13.4		
E	Flatnose Spring	600	1	153	Spring	-101.0	-13.4		
W	Delmues Spring	20	2	149	Spring	-101.0	-13.1		
Alluvial Well	Oxborrow Well		1	150	Well	-92.0	-11.8		
ET	ET	4,000						-101.0	-13.2
203	GW Outflow (Panaca)	16,000						-101.0	-13.2
204	Clover Valley								
204 N	South of Beaver Dam	5,400				-92.0	-12.4		
204 S	North of Jack's Mtn	5,200				-86.8	-11.8		
TR	Total Recharge	11,000	2			-89.4	-12.1		
N	Ramone Mathews Well		1	115	Well	-92.0	-12.3		
N	Acoma Well		1	118	Well	-95.0	-12.6		
N	Clover Creek Valley Well		1	120	Well	-89.0	-12.4		
S	Unnamed Spring		1	113	Spring	-86.5	-11.6		
S	Sheep Spring		1	108	Spring	-87.0	-12.0		
Alluvial Well	Clover Creek Valley Well		1	114	Well	-84.0	-11.7		
ET	ET	2,000						-89.4	-12.1
205	GW Outflow (Panaca Valley)	9,000						-89.4	-12.1
203	Panaca Valley								
202	Inflow (Patterson)	28,000				-101.6	-13.7		
198	Inflow (Dry)	16,000				-101.0	-13.2		
203 E	Condor Canyon	3,700				-99.4	-13.4		

Section	Name	Volume Acre-ft/yr	# of Samples	Site #	Site Type	Obs. δD	Obs. $\delta^{18}O$	Calc. δD	Calc. $\delta^{18}O$
203 W	Cathedral Gorge	5,400				-99.4	-13.4		
TR	Total Recharge	9,000	2			-99.4	-13.4		
W	Pine Spring		1	157	Spring	-99.0	-13.4		
W	Lime Spring		1	160	Spring	-97.0	-12.9		
W	Deadman Spring		1	162	Spring	-99.0	-13.3		
W	Highland Spring		1	163	Spring	-98.5	-13.3		
W	Upper Conner Spring		1	156	Spring	-100.0	-13.9		
Warm	Bennett Spring	20	1	141	Spring	-103.0	-13.7		
Warm	Panaca Warm Spring	7,700	3	144	Spring	-106.9	-14.0		
Warm	Caliente Hot Spring		1	129	Spring	-109.0	-14.5		
Outflow	Discharge Warm Springs (Avg)		1			-106.9	-14.0	-105.1	-14.1
Surface Water	Meadow Valley Wash, Cal.		1	130	Surface	-97.0	-13.1		
	Weaver Well		1	137	Well	-101.0	-13.1		
	John Wadsworth		1	140	Well	-101.0	-12.9		
Warm	Lester Mathews Well		1	142	Well	-103.0	-13.3		
Warm	Panaca Town Well		1	143	Well	-106.0	-14.0		
Warm	North Lee Well		1	147	Well	-101.0	-13.3		
Alluvial Well	Caliente City Well		1	124	Well	-89.0	-12.4		
ET	ET	26,000						-101.1	-13.5
205	Inflow (Clover Valley)	9,000						-89.4	-12.1
205	GW Outflow (Lower Meadow VW)	36,000						-98.2	-13.2
205	Lower Meadow Valley Wash								
203	Inflow (Panaca)	36,000				-98.2	-13.2		
205 NE	Clover Mountains	8,600				-86.8	-11.8		
205 NW	Delamar Mtns.	6,400				-86.8	-11.8		
205 SE	Mormon Mtns.	3,800				-88.3	-12.5		
205 SW	Meadow Valley Mtns.	4,100				-87.8	-11.8		
TR	Total Recharge	23,000	4			-87.2	-11.9		
NE	Unnamed Spring		1	113	Spring	-86.5	-11.6		
NE	Sheep Spring		1	108	Spring	-87.0	-12.0		
NW	Bishop Spring		1	107	Spring	-85.5	-11.7		
NW	Upper Riggs Spring		1	105	Spring	-88.0	-11.9		
SE	Hackberry Spring		1	84	Spring	-87.0	-12.3		
SE	Horse Spring		1	85	Spring	-89.0	-12.7		
SE	Davies Spring		1	90	Spring	-89.0	-12.5		
SW	Grapevine Spring (KSV-2)		2	93	Spring	-87.8	-11.8		
Alluvial Well	Railroad Well (Farrier, NV)		1	80	Well	-97.5	-12.5		
Alluvial Well	Jenson Well		1	95	Well	-88.5	-11.6		
A Well by river	Randono Well		1	100	Well	-87.5	-11.7		
A Well by river	Bradshaw Well		1	102	Well	-88.5	-11.4		
A Well by river	Railroad Well		1	103	Well	-86.0	-11.6		
ET	ET	27,000						-88.8	-12.1
220	GW Outflow (L. Moapa)	32,000						-98.2	-13.2

Section	Name	Volume Acre-ft/yr	# of Samples	Site #	Site Type	Obs. δD	Obs. δ^{18}O	Calc. δD	Calc. δ^{18}O
Lake Mead Area Flow System									
217	Hidden Valley								
217 E	E. Hidden					-81.0	-10.6		
217 W	W. Hidden	300				-81.0	-10.6		
TR	Total Recharge	300	2			-81.0	-10.6		
W	Wamp Spring		1	52	Spring	-81.0	-10.6		
Evaporated	USBLM SHV-1, South H.V. Well		1	46	Well	-90.5	-11.2		
ET	ET							-81.0	-10.6
216	GW Outflow (Garnet)	300						-81.0	-10.6
216	Garnet Valley								
217	Inflow (Hidden)	300				-81.0	-10.6		
210	Inflow (Coyote Springs)	16,000				-98.0	-13.1		
216 E	Apex	100				-81.0	-10.6		
216 W	Las Vegas Range	300				-81.0	-10.6		
TR	Total Recharge	400	2			-81.0	-10.6		
W	Wamp Spring		1	52	Spring	-81.0	-10.6		
Carbonate Well	GP Apex Well		3	17	Well	-97.2	-13.5		
Carbonate Well	Unnamed Well		1	24	Well	-96.0	-13.7		
Carbonate Well	US Lime Well (Genstar)		1	27	Well	-97.0	-12.8		
	Dry Lake Valley Well		1	34	Well	-97.5	-13.3		
Carbonate Wells	Wells (Avg)		4			-96.9	-13.3	-98.0	-13.1
ET	ET							-97.2	-13.0
218	GW Outflow (California Wash)	17,000						-97.2	-13.0
218	California Wash								
219	Surface Water Inflow (Muddy)	32,000				-98.0	-13.1		
216	Inflow (Garnet)	17,000				-97.2	-13.0		
218 E	Moapa Paiutes	200				-82.0	-10.6		
218 W	Muddy Mtns.	100				-82.0	-10.6		
TR	Total Recharge	300	2			-82.0	-10.6		
W	Valley of Fire Well		1	31	Well	-82.0	-10.6		
Carb Well	Moapa Well		1	41	Well	-99.0	-13.4		
Carb Well	Calpine Test Well 1a		1	43	Well	-99.0	-13.5		
ET	ET	5,000						-97.0	-12.9
220	GW Outflow (L. Moapa)	8,000						-97.0	-12.9
215	GW Outflow (Black Mtn Area)	4,000						-97.0	-12.9
215	Black Mountains Area								
218	Inflow (California Wash)	4,000				-97.0	-12.9		
215 NE	Muddy Mtns.	300				-82.0	-10.6		
215 SE	Black Mtns.	100				-79.5	-10.7		
215 W	Gypsum Wash	100				-79.5	-10.7		
TR	Total Recharge	500	3			-81.0	-10.6		
SE	Cottonwood Spring		1	8	Spring	-80.0	-10.8		
SE	Sandstone Spring		1	10	Spring	-79.0	-10.5		
NE	Valley of Fire Well		1	31	Well	-82.0	-10.6		

Section	Name	Volume Acre-ft/yr	# of Samples	Site #	Site Type	Obs. δD	Obs. $\delta^{18}O$	Calc. δD	Calc. $\delta^{18}O$
Alluvial Spring	Bitter Spring	5	1	14	Spring	-77.0	-9.9		
Evaporated	Gypsum Spring		1	9	Spring	-75.0	-9.2		
Highly Evaporated	Getchel Spring		1	32	Spring	-83.0	-8.6		
Carb Spr	Corral Spring		1	19	Spring	-91.5	-12.1		
Carb Spr	Scirpus Spring		1	20	Spring	-90.0	-12.0		
Carb Spr	Rogers Spring	1,200	3	21	Spring	-91.7	-12.3		
Carb Spr	Blue Point Spring	440	4	26	Spring	-92.5	-12.4		
Carb Spr	VF Spring 1		1	28	Spring	-88.0	-11.2		
Carb Spr	VF Spring 2	6	1	29	Spring	-92.0	-11.8		
Carb Spr	VF Spring 3	17	1	30	Spring	-93.0	-12.2		
CARB	Carbonate Spr (Avg)	1,663				-91.9	-12.3		
ET	ET	2,000						-95.2	-12.7
	GW Outflow (Lake Mead)	2,000						-95.2	-12.7
220	Lower Moapa Valley								
218	GW Inflow (California Wash)	8,000				-97.0	-12.9		
218	SW Inflow (California Wash)	32,000				-98.0	-13.1		
205	GW Inflow (Lower Meadow VW)	32,000				-98.2	-13.2		
220 N	S. Mormon Mtns.	1,000				-88.3	-12.5		
220 S	Valley of Fire	300				-90.0	-11.4		
TR	Total Recharge	1,000	2			-88.7	-12.2		
S	Unnamed, Kaolin Wash		1	35	Spring	-88.0	-11.3		
S	Unnamed, Magnesite Wash		1	38	Spring	-92.0	-11.5		
N	Hackberry Spring		1	84	Spring	-87.0	-12.3		
N	Horse Spring		1	85	Spring	-89.0	-12.7		
N	Davies Spring		1	90	Spring	-89.0	-12.5		
Well	Unnamed Well		1	48	Well	-103.0	-13.2		
Carb Well	EH-7		6	56	Well	-91.8	-12.6		
Carb Well	EH-3		4	61	Well	-91.0	-12.7		
ET	ET	15,000						-97.7	-13.1
	GW Outflow (Lake Mead)	26,000						-97.7	-13.1

APPENDIX 2: ISOTOPIC AND MAJOR-ION CHEMISTRY FOR ALL SITES WITHIN THE STUDY AREA. Note, this information is on a disk and is located in the back pocket of this report.

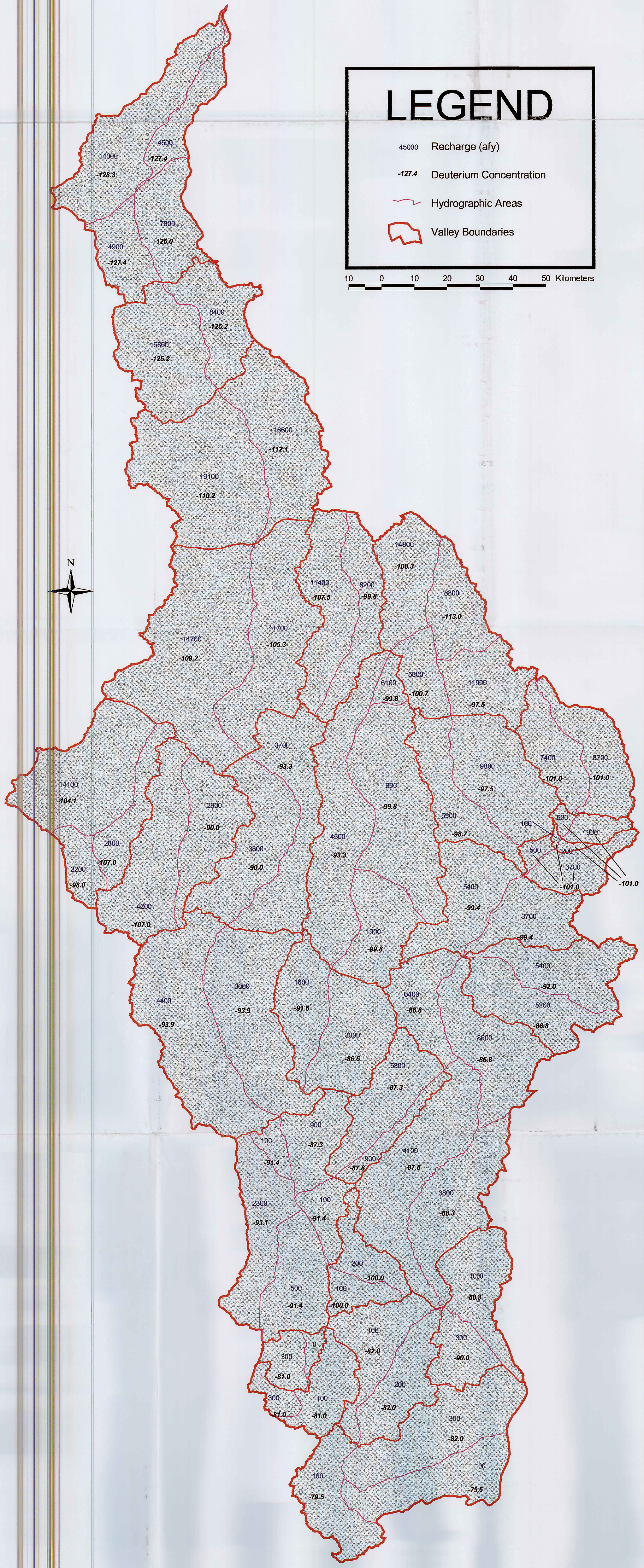

Figure 3A. Average deuterium values and recharge rates estimated by SNWA (2001) for recharge areas.

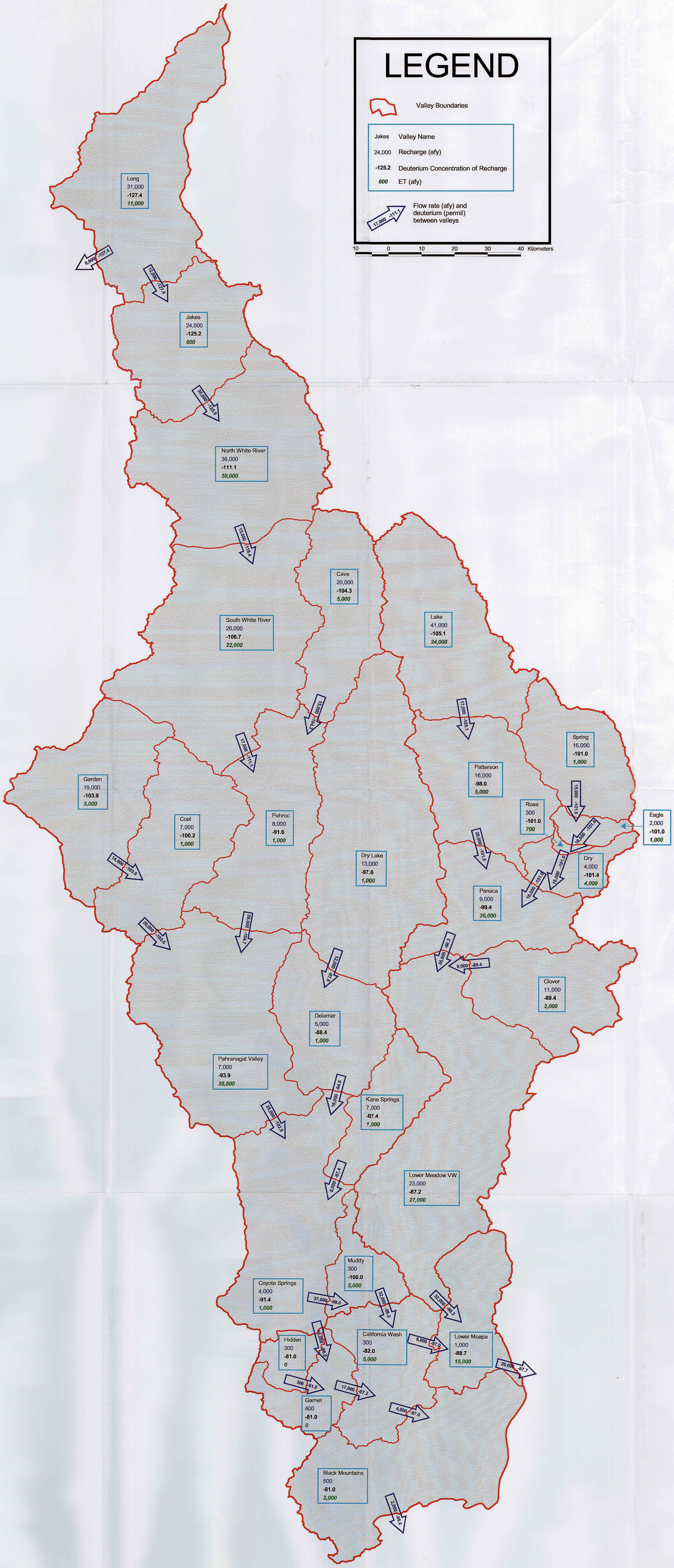

Figure 3B. Average recharge and ET rates for valleys estimated by SNWA (2001) and flow amounts with model calculated average deuterium values for groundwater flow between valleys.

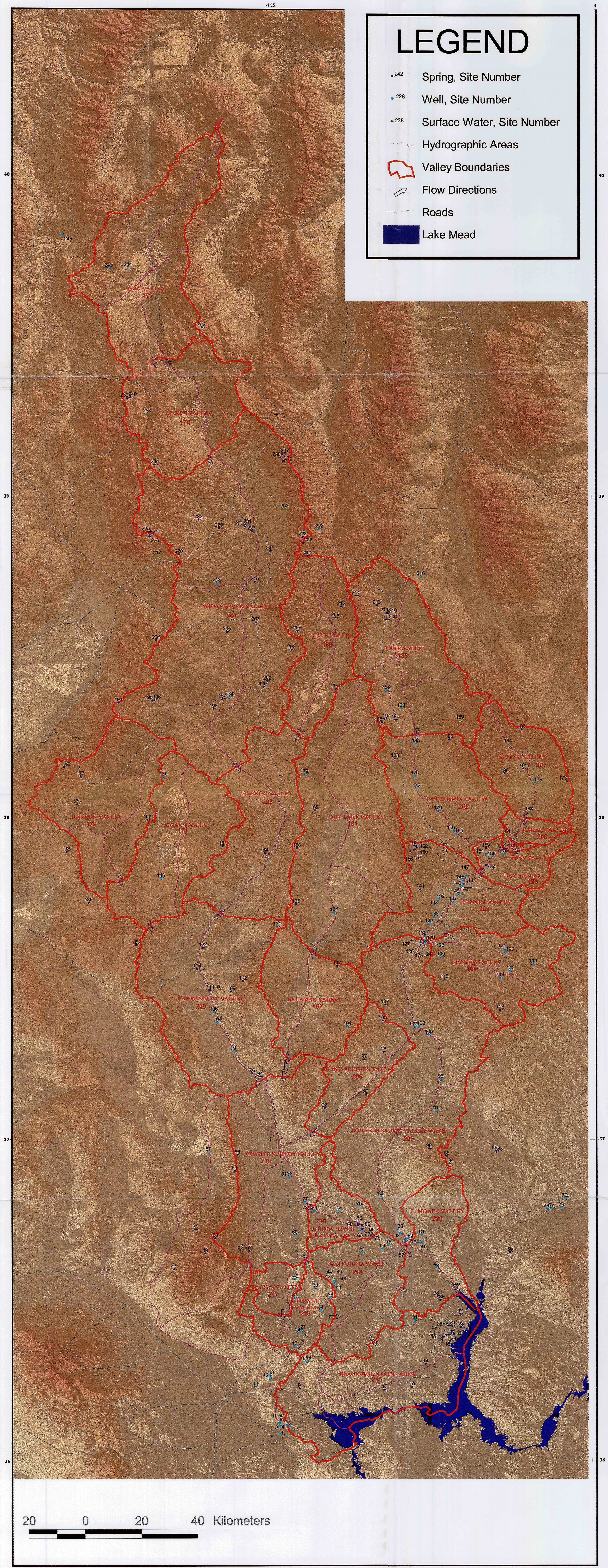

Figure 2A. Sample locations and proposed groundwater flow directions.

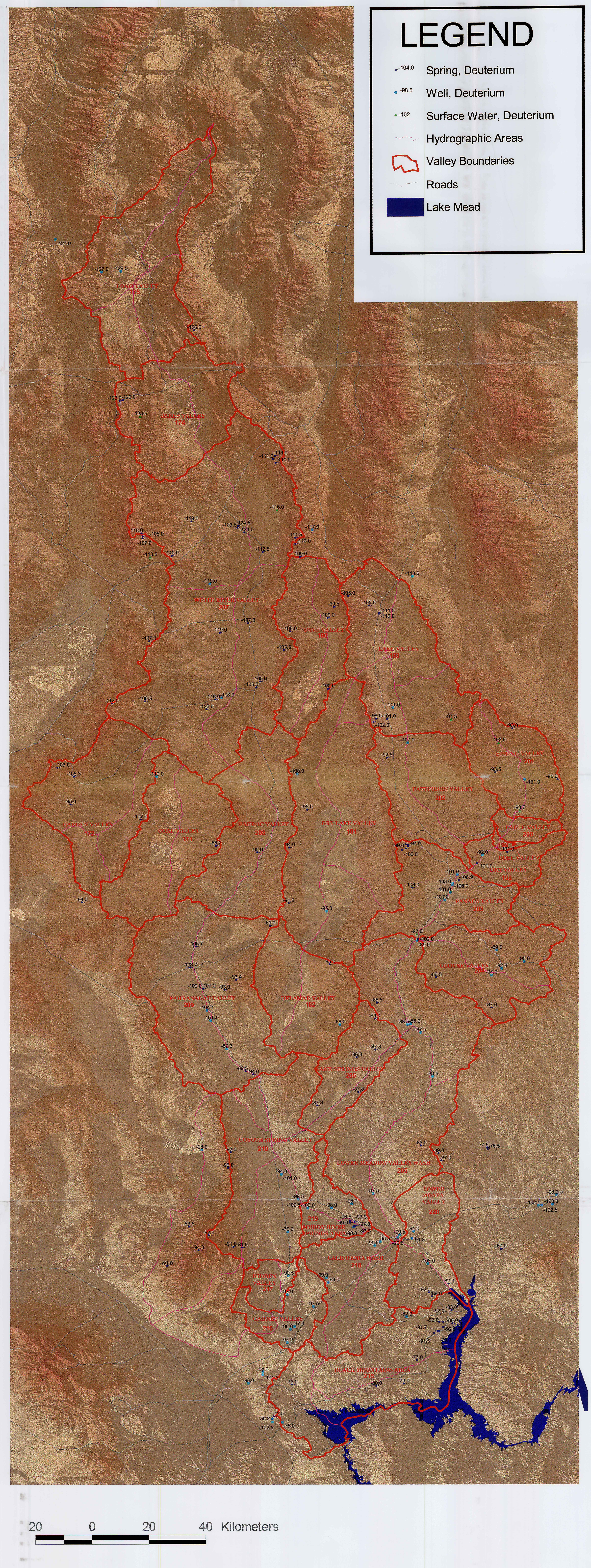

Figure 2B. Deuterium values for the study area.