Case No. 84739

IN THE SUPREME COURT OF THE STATE OF NEVADA

Electronically Filed
Nov 08 2022 04:38 p.m.
Elizabeth A. Brown
Clerk of Supreme Court

ADAM SULLIVAN, P.E., NEVADA STATE ENGINEER, et al.

Appellants,

vs.

LINCOLN COUNTY WATER DISTRICT, et al.

JOINT APPENDIX

VOLUME 22 OF 49

desert research institute

University and Community College System of Nevada

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

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May 2001

Publication No. 41169

Prepared by
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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.

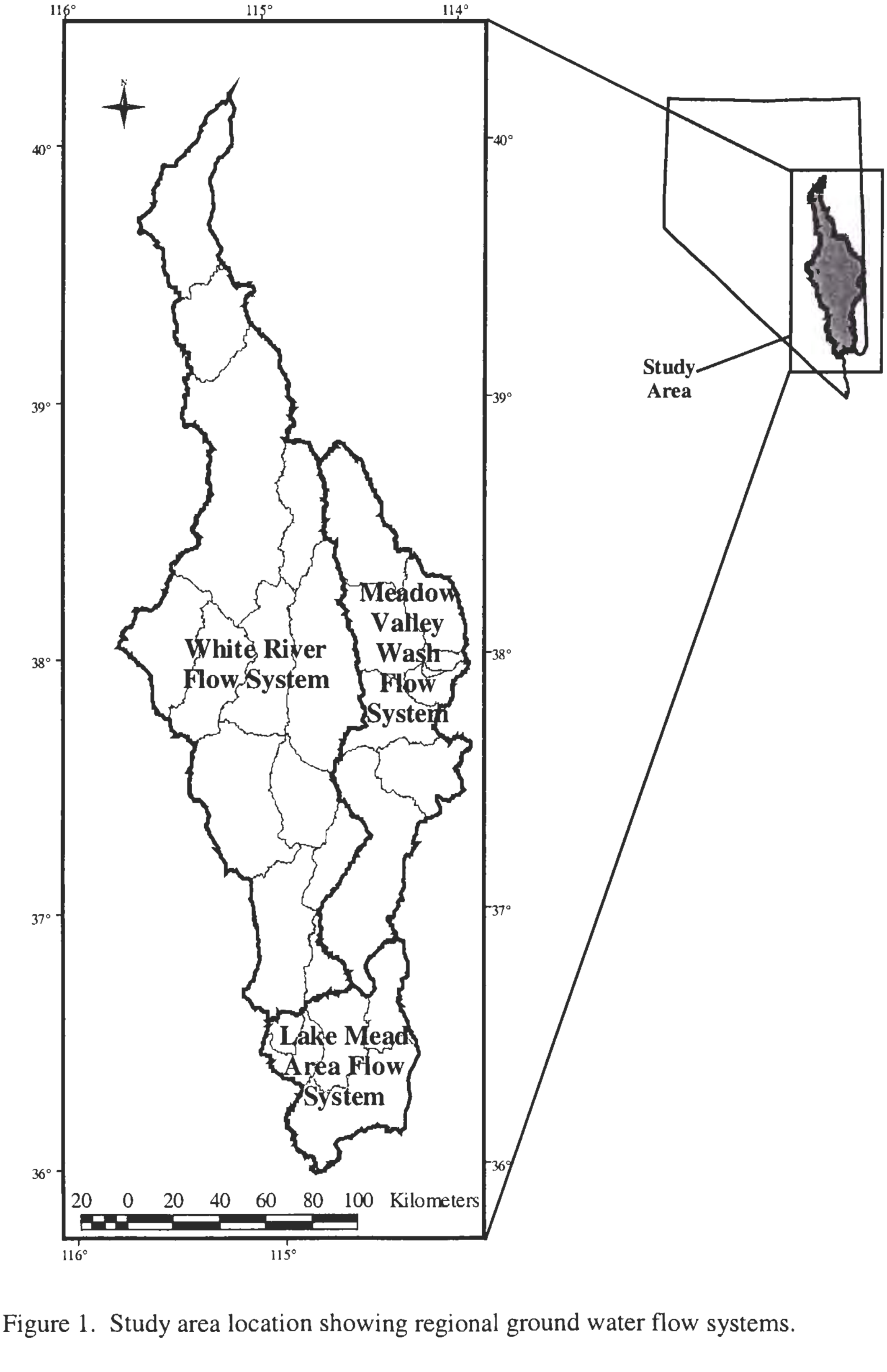

Figure 1. Study area location showing regional ground water flow systems.

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.

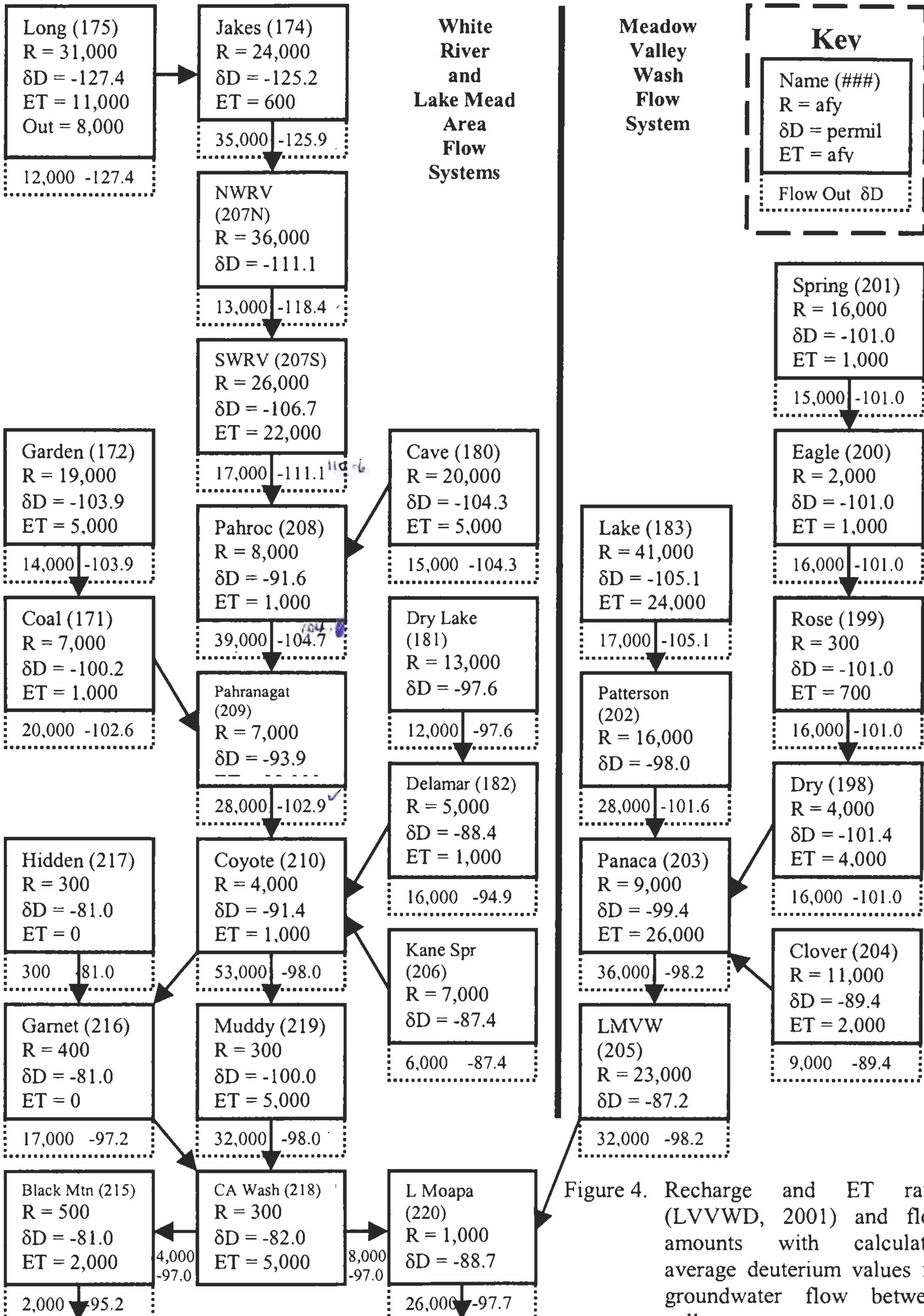

Figure 4. Recharge and ET rates (LVVWD, 2001) and flow amounts with calculated average deuterium values for groundwater flow between valleys.

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).

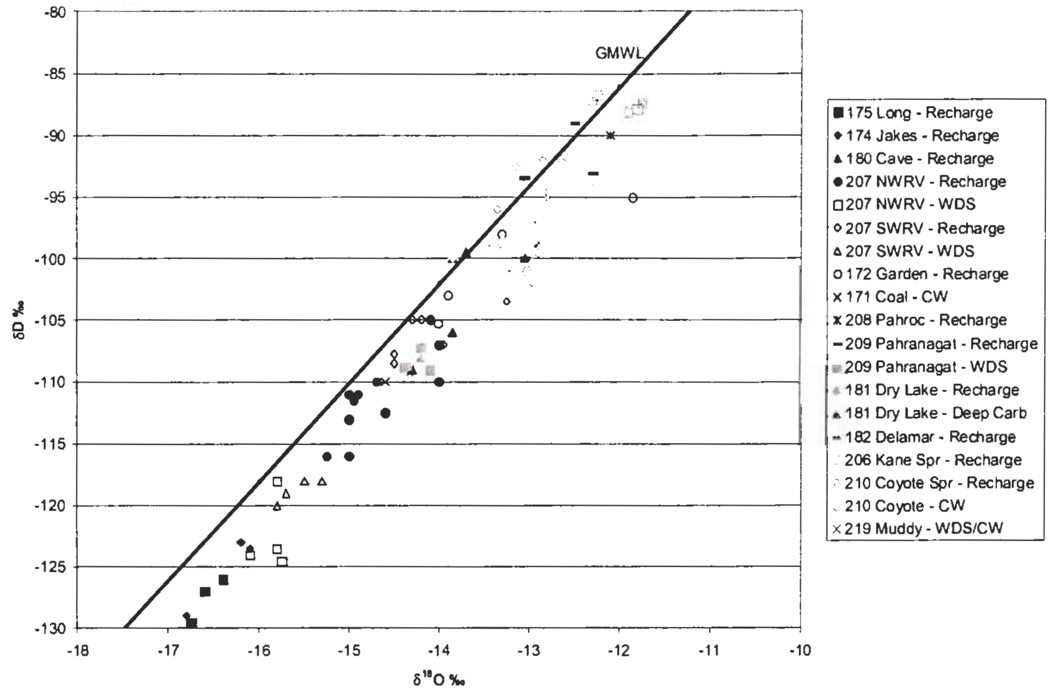

Figure 5. Deuterium versus oxygen-18 for groundwater in the WRFS.

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 Whiter 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 gw's chem due to 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.

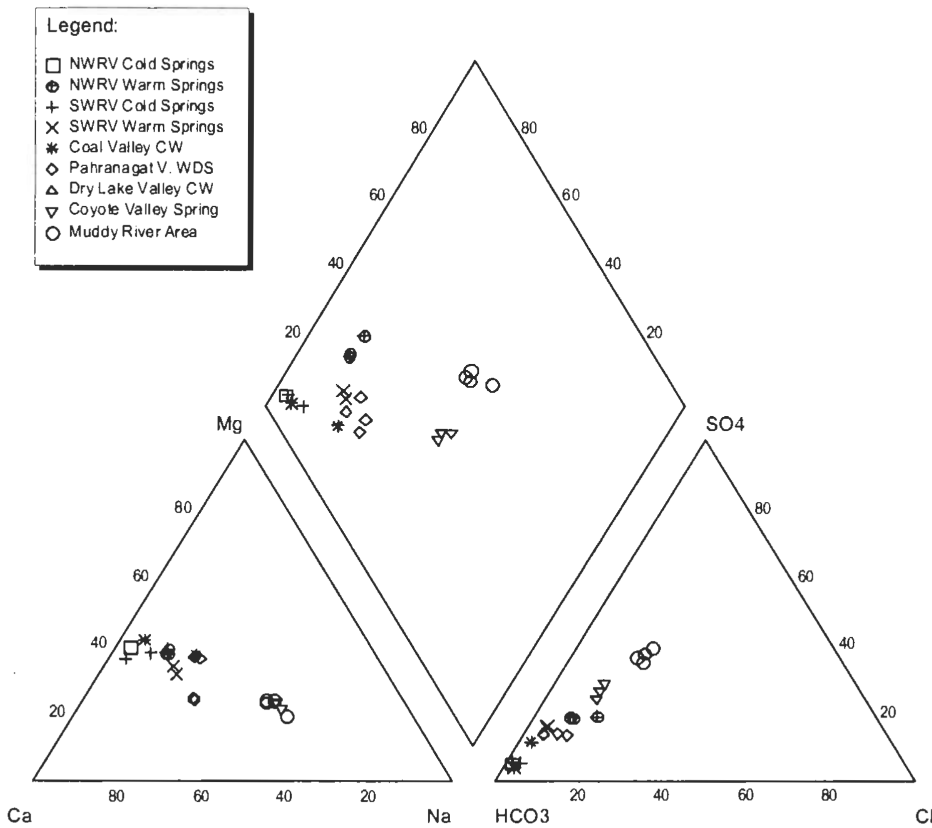

Figure 6. Trilinear plot of chemistry for groundwater in the WRFS.

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.

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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).

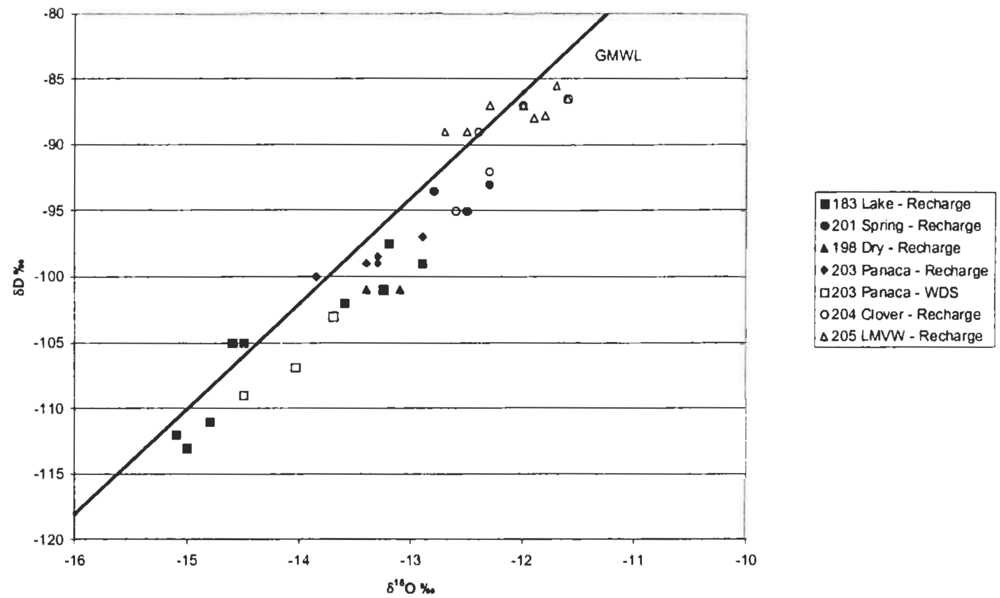

Figure 7. Deuterium versus oxygen-18 for groundwater in the MVWFS.

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.

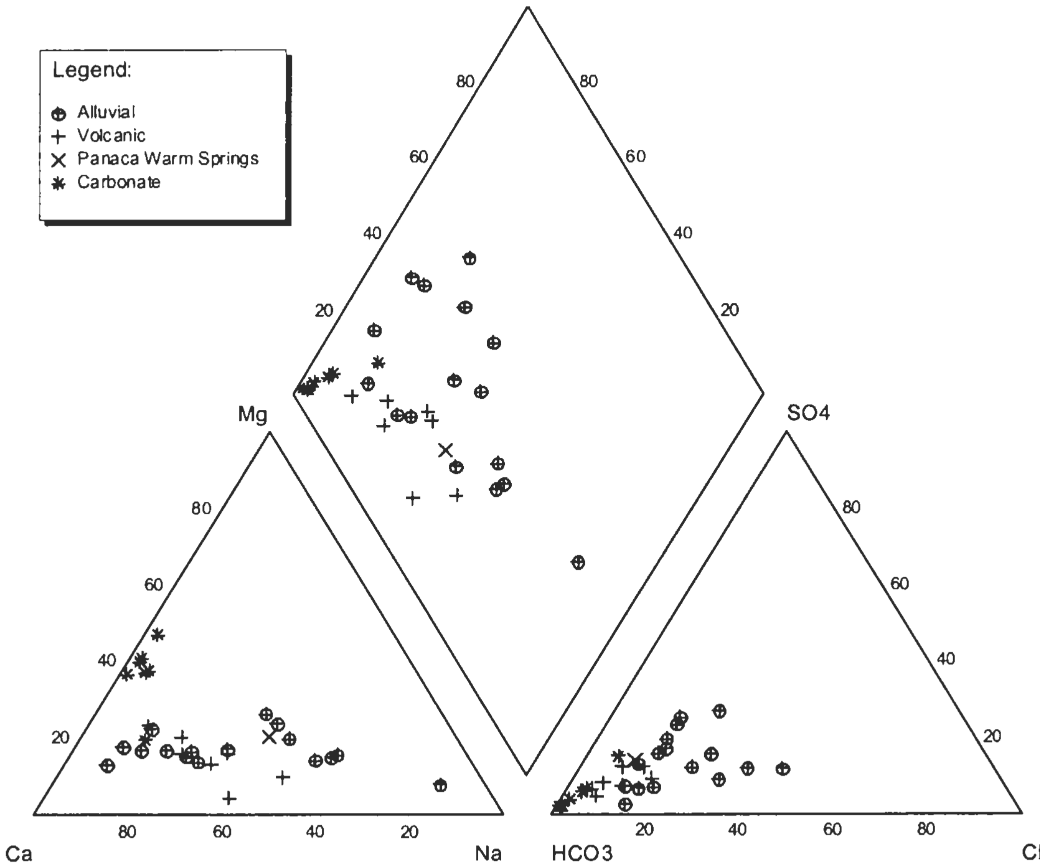

Figure 8. Trilinear plot of chemistry for groundwater in the MVWFS.

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.

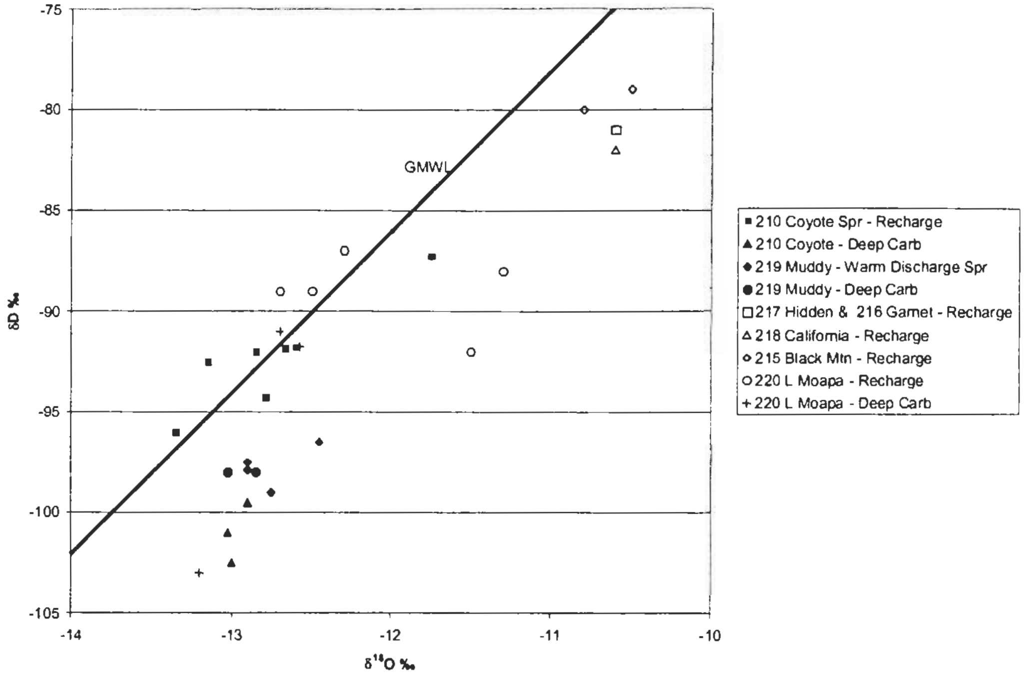

Figure 9. Deuterium versus oxygen-18 for groundwater in the LMFS.

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.

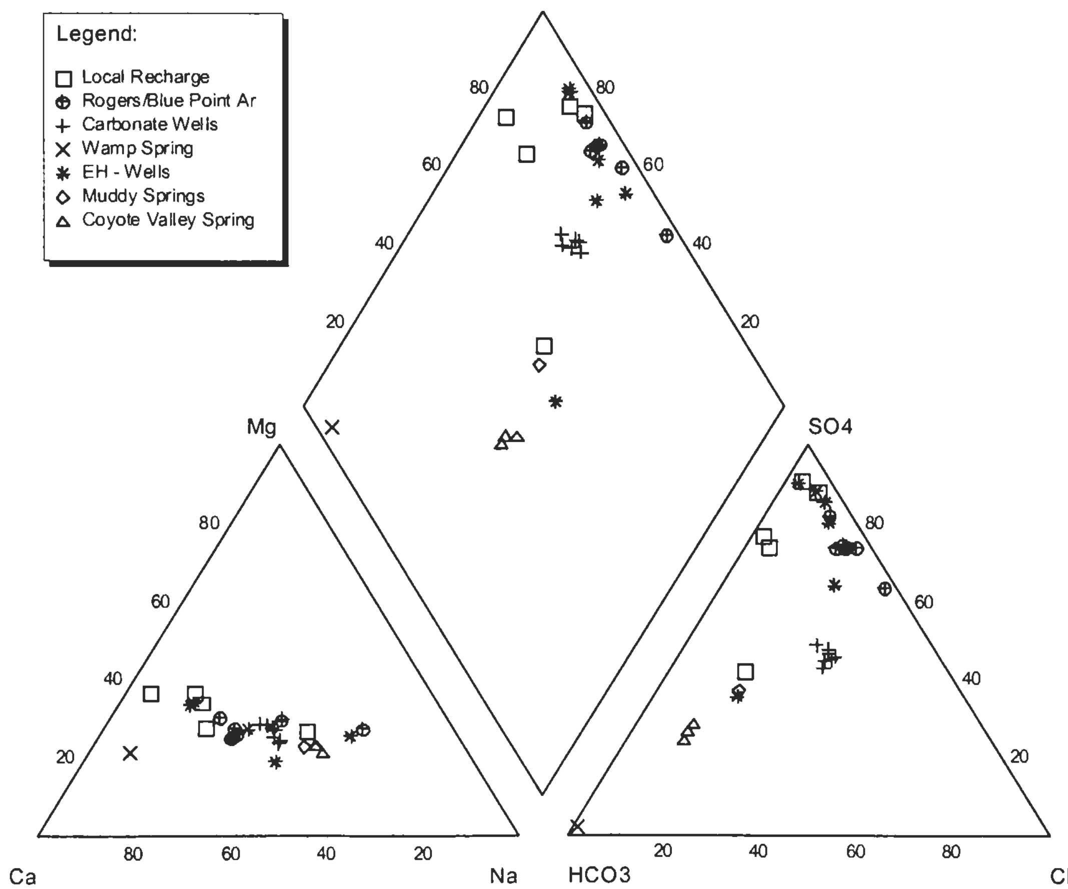

Figure 10. Trilinear plot of chemistry for groundwater in the LMFS.

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.

REFERENCES CITED

Berger, D.L., K.C. Kilroy and D.H. Schaefer, 1988. Geophysical logs and hydrologic data for eight wells in the Coyote Spring Valley area, Clark and Lincoln Counties, Nevada. U.S. Geological Survey Open-File Report 87-679: 59 p.

Craig, H., 1961. Isotopic variations in meteoric waters. *Science*, 133: 1702-1703.

Dettinger, M.D., 1989. Distribution of carbonate-rock aquifers in southern Nevada and the potential for their development—Summary of findings, 1985-1988. Carson City, Nev., Program for the Study and Testing of Carbonate-Rock Aquifers in Eastern and Southern Nevada, Summary Report No. 1: 37 p.

Dettinger, M.D., D.L. Schmidt, J.R. Harrill and J.W. Hess, 1995. Distribution of carbonate-rock aquifers and the potential for their development, southern Nevada and parts of Arizona, California, and Utah. U.S. Geological Survey Water-Resources Investigations Report 91-4146: 100 p.

Eakin, T.E., 1966. A regional interbasin ground-water system in the White River areas, southeastern Nevada. *Water Resources Research*, 2: 251-271.

Eakin, T.E. and D.O. Moore, 1964. Uniformity of discharge of Muddy River Springs, southeastern Nevada, and relation to interbasin movement of ground water. U.S. Geological Survey Professional Paper 501-D: 171-176.

Emme, D.H., 1986. Delineation of subsurface flow in the upper Meadow Valley Wash Area, southeastern Nevada. University of Nevada-Reno, unpublished masters thesis: 90 p.

Hess, J.W. and M.D. Mifflin, 1978. A feasibility study of water production from deep carbonate aquifers in Nevada. Desert Research Institute Publication #41054: 125 p.

Ingraham, N.L., B.F. Lyles, R.L. Jacobson and J.W. Hess, 1991. Stable isotopic study of precipitation and spring discharge in southern Nevada. *Journal of Hydrology*, 125: 243-258.

Kirk, S.T. and M.E. Campana, 1990. A deuterium-calibrated groundwater flow model of a regional carbonate-alluvial system. *Journal of Hydrology*, 119: 357-388.

Las Vegas Valley Water District, 2001. Water resources and ground-water modeling in the White River and Meadow Valley Wash flow systems, White Pine, Lincoln, Nye, and Clark Counties, Nevada (in press).

Maxey, G.B. and T.E. Eakin, 1949. Ground water in White River Valley, White Pine, Nye, and Lincoln Counties, Nevada. Nevada State Engineer Water Resources Bulletin 8: 59 p.

McKinley, P.W. and T.A. Oliver, 1994. Meteorological, stream-discharge, and water-quality data for 1986 through 1991 from two small basins in central Nevada. U.S. Geological Survey Open-File Report 93-651: 167 p.

Mifflin, M.D., 1968. Delineation of ground-water flow systems in Nevada. Desert Research Institute, Technical Report Series H-W, Publication #4: 100 p.

Milne, W.K., L.V. Benson and P.W. McKinley, 1987. Isotope content and temperature of precipitation in southern Nevada, August 1983-August 1986. U.S. Geological Survey Open-File Report 87-463: 32 p.

Pohlmann, K.F., D.J. Campana, J.B. Chapman and S. Earman, 1998. Investigation of the origin of springs in the Lake Mead National Recreation Area. Desert Research Institute Publication #41161: 92 p.

Prudic, D.E., J.R. Harrill and T.J. Burbey, 1993. Conceptual evaluation of regional ground-water flow in the carbonate rock province of the Great Basin, Nevada, Utah, and adjacent states. U.S. Geological Survey Open-File Report 93-17-D: 103 p.

Rush, F.E., 1964. Ground-water appraisal of the Meadow Valley area, Lincoln and Clark Counties, Nevada. Nevada Department of Conservation and Natural Resources, Water Resources Reconnaissance Report 27: 43 p.

Rush, F.E. and T.E. Eakin, 1963. Ground-water appraisal of Lake Valley in Lincoln and White Pine Counties, Nevada. Nevada Department of Conservation and Natural Resources, Water Resources Reconnaissance Report 24: 29 p.

Thomas, J.M., B.F. Lyles and L.A. Carpenter, 1991. Chemical and isotopic data collected for water from wells, springs, and streams in carbonate-rock terrain of southern Nevada, 1985-88. U.S. Geological Survey Open-File Report 89-422: 24 p.

Thomas, J.M., J.L. Mason and J.D. Crabtree, 1986. Ground-water levels in the Great Basin Region of Nevada, Utah, and adjacent states. U.S. Geological Survey Hydrologic Investigations Atlas HA-694-B: 2 plates.

Thomas, J.M., A.H. Welch and M.D. Dettinger, 1996. Geochemistry and isotope hydrology of representative aquifers in the Great Basin Region of Nevada, Utah, and adjacent states. U.S. Geological Survey Professional Paper 1409-C: 100 p.

Winograd, I.J. and I. Friedman, 1972. Deuterium as a tracer of regional ground-water flow, southern Great Basin, Nevada and California. *Bulletin of the Geological Society of America,* 83: 3691-3708.

Winograd, I.J., A.C. Riggs and T.B. Coplen, 1998. The relative contributions of summer and cool-season precipitation to groundwater recharge, Spring Mountains, Nevada, USA. *Hydrogeology Journal,* 6: 77-93.

Winograd, I.J. and W. Thordarson, 1975. Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada-California, with special reference to the Nevada Test Site. U.S. Geological Survey Professional Paper 712-C: 126 p.

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. $\delta^{18}O$	Calc. δD	Calc. $\delta^{18}O$
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. $\delta^{18}O$	Calc. δD	Calc. $\delta^{18}O$
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. $\delta^{18}O$	Calc. δD	Calc. $\delta^{18}O$
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. $\delta^{18}O$	Calc. δD	Calc. $\delta^{18}O$
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.

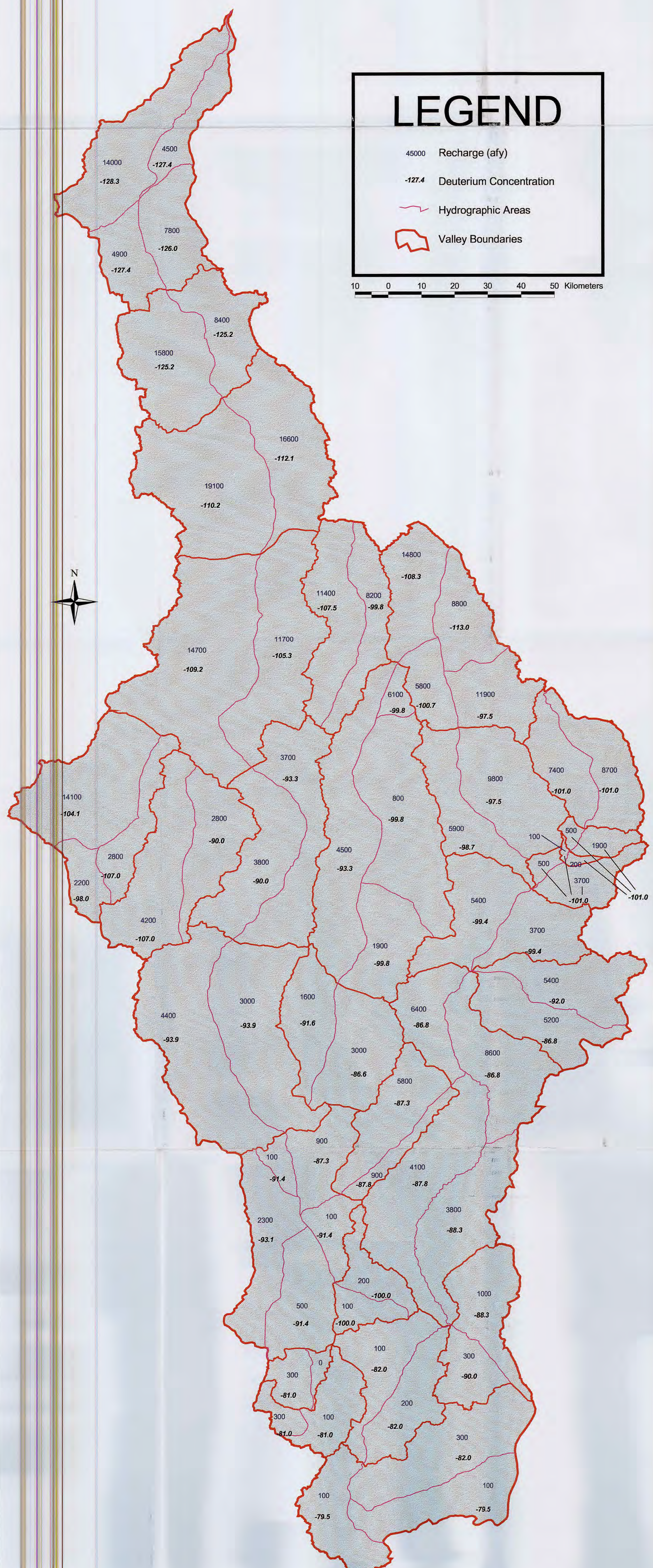

Figure 3A. Average deuterium values and recharge rates estimated by SNWA (2001) for recharge areas.

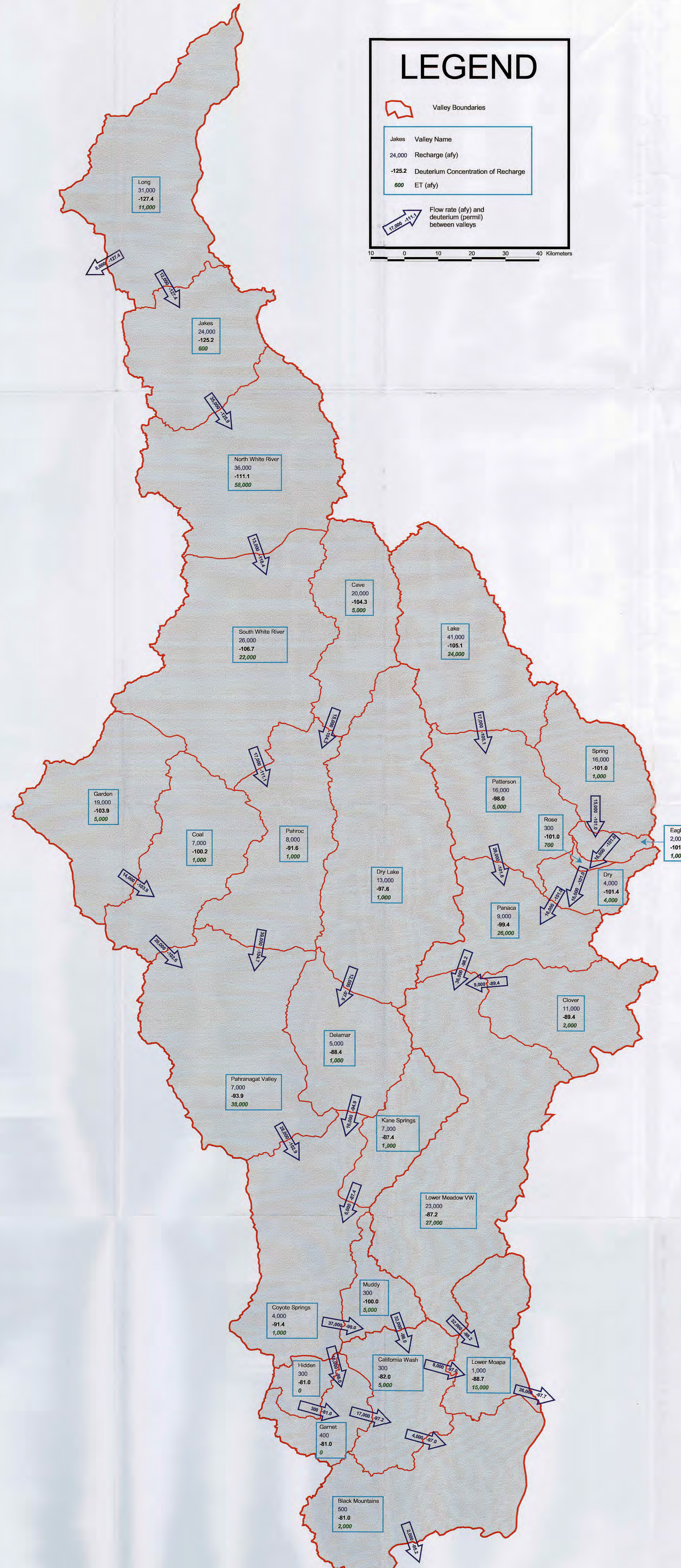

Figure 3B. Average recharge and ET rates for valleys estimated by SNWA (2001) and flow amounts with model calculated average deuterium values for groundwater flow between valleys.

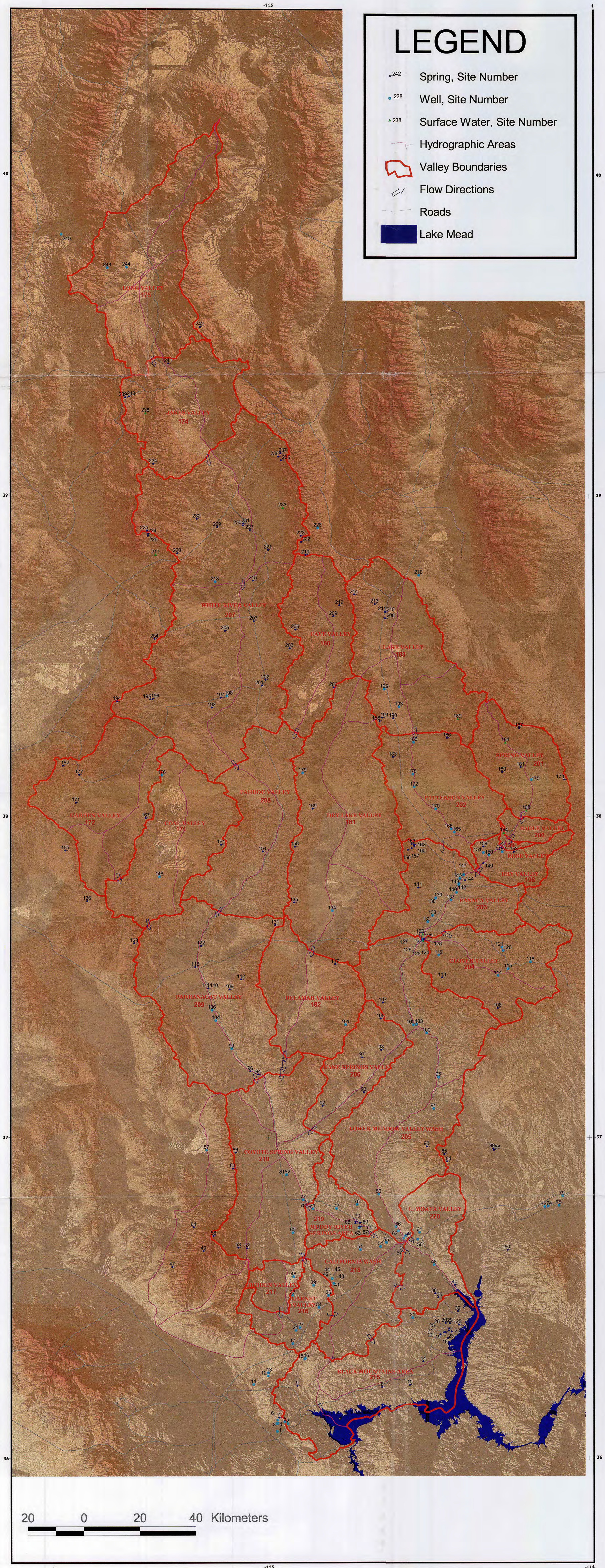

Figure 2A. Sample locations and proposed groundwater flow directions.

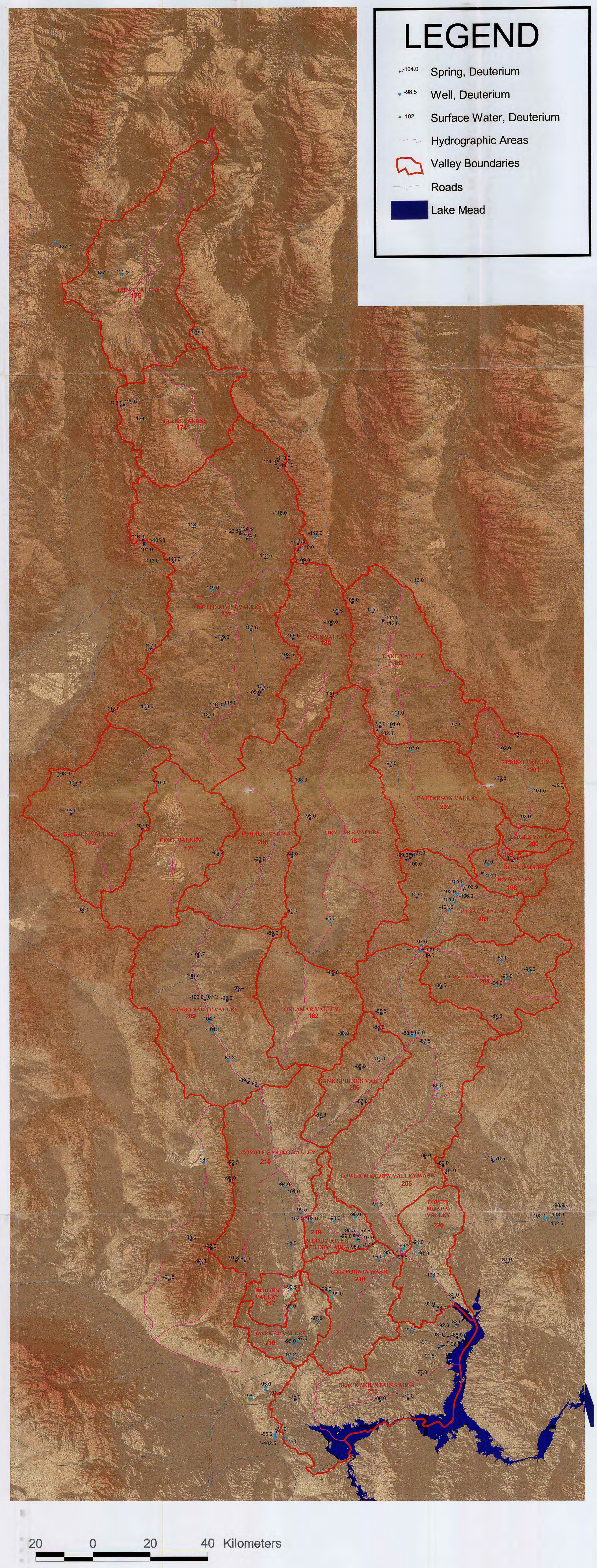

Figure 2B. Deuterium values for the study area.

Evaluation of Groundwater Origins, Flow Paths, and Ages in East-Central and Southeastern Nevada

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May 2011

Publication No. 41253

prepared by

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EXECUTIVE SUMMARY

This report evaluates groundwater sources and flow paths in the Delamar, Dry Lake, and Cave valleys (DDC) area using deuterium (δD) and oxygen-18 ($\delta^{18}O$) data combined with hydrogeologic information. The DDC area is part of the larger White River Flow System (WRFS), so this report also evaluates groundwater flow from the DDC area to other adjacent valleys in the WRFS. Carbon-14 corrected groundwater ages were also estimated for the regional warm spring areas of the WRFS to provide information on recharge timing and groundwater travel times within the WRFS.

Evaluation of isotopic variability of recharge area springs and regional warm springs shows that variability is small over a period of several years up to 40 years, for samples collected throughout all four seasons. Variability of four recharge area monitoring springs have standard deviations that range from 0.7 to 1.1 permil (‰) and 0.07 to 0.11‰ (except for one site with a value of 0.33), for δD and $\delta^{18}O$, respectively. This range in variability is for flows ranging from about 100 to 5,000 gallons per minute and with one site having 7 years of data and two of the three sites having 6 years of data. Isotopic variability of 10 regional warm springs had a standard deviation ranging from 0.5 to 1.9‰ for δD and 0.05 to 0.21‰ (except for one site with a value of 0.67) for $\delta^{18}O$. Spatial variability of recharge area sites was larger than the temporal variation, with standard deviations ranging from 1.8 to 4.2‰ and 0.35 to 0.70‰ for δD and $\delta^{18}O$, respectively. Thus, this low variability of δD and $\delta^{18}O$ groundwater data shows that they are an appropriate tool to evaluate sources and flow paths of groundwater in eastern and southeastern Nevada.

The δD and $\delta^{18}O$ data combined with mountain block recharge rates show that groundwater in the DDC area is supplied by local recharge from the mountain block recharge areas of the valleys. There is little, if any, interbasin flow into the most upgradient of these three valleys, Cave Valley. Groundwater flows out of Cave Valley into southeastern White River Valley and northeastern Pahroc Valley. Potentially a small amount (up to 2,000 acre-feet per year) of groundwater may flow into northwest Dry Lake Valley from northeast Pahroc Valley. Groundwater in Dry Lake Valley flows south into Delamar Valley. Groundwater flows south, or southwest, out of Delamar Valley to Coyote Springs Valley, although some groundwater may flow through the very southern part of Pahranagat Valley along the Pahranagat Valley Shear Zone before entering Coyote Springs Valley.

Isotopic data show that groundwater originating in the DDC area supplies little, if any, water to the warm springs in southern White River Valley. These data also show that groundwater discharging from warm springs in Pahranagat Valley are a mixture of waters recharged in numerous valleys north of Pahranagat Valley, which likely includes Cave Valley.

The δD and $\delta^{18}O$ data, tritium data, and carbon-14 corrected groundwater ages show that groundwater in the WRFS, which includes Delamar, Dry Lake, and Cave valleys, is recharged under current climatic conditions. Carbon-14 corrected groundwater ages also show that it can take thousands of years for groundwater from mountainous recharge areas to flow through numerous basins and discharge in warm spring areas throughout the WRFS.

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INTRODUCTION

This report focuses on groundwater flow through the Delamar, Dry Lake, and Cave valleys (DDC) area in east central Nevada. These three valleys are part of the larger White River Flow System (WRFS), which is a regional groundwater flow system in east-central Nevada (Figure 1). The primary objectives of this report are to: 1) evaluate groundwater sources and flow paths of the DDC area, with particular interest in potential flow from the DDC area to springs in adjacent valleys of the WRFS, primarily regional warm springs in White River and Pahranagat valleys; and 2) evaluate recharge timing to the WRFS, which also provides information on groundwater travel times within the WRFS.

This report is based on the Thomas and Mihevc (2007) report, but includes significant revisions. The revisions include: (1) the inclusion of new data collected since the 2007 report and additional data from the SNWA geochemical and isotopic database; (2) the addition of the calculation of carbon-14 corrected groundwater ages, which provides information on recharge timing and groundwater travel times within the WRFS; and (3) this report only focuses on groundwater sources and flow paths for the DDC area, so the isotope mass-balance model for the WRFS presented by Thomas and Mihevc (2007) was not updated or included in this study. Although this report focuses on the DDC area and does not include a discussion of the entire WRFS, carbon-14 corrected groundwater ages are presented for the regional warm springs in White River, Pahranagat, and Upper Moapa valleys of the WRFS.

The stable isotopes deuterium ($^{2}H/^{1}H$) and oxygen-18 ($^{18}O/^{16}O$), reported as δD and $\delta^{18}O$ in permil (parts per thousand; ‰), respectively, are used to evaluate groundwater sources and flow paths for the DDC area. This evaluation includes potential groundwater flow from the DDC area to adjacent valleys within the WRFS. δD and $\delta^{18}O$ are ideal natural tracers to evaluate water sources and flow paths of groundwater because they are part of the water molecule, rather than being dissolved in the water like all other potential tracers. Thus, δD and $\delta^{18}O$ values are only affected by physical processes, such as evaporation, and are unchanged under low to moderate temperatures by geochemical processes such as dissolution or precipitation, which affects other potential groundwater tracers. The ratio of the mass difference of ^{2}H as compared to ^{1}H (2/1) is significantly greater than that of ^{18}O to ^{16}O (18/16), so the change in deuterium values is greater than the change in oxygen-18 values during physical processes. Water that has undergone any significant evaporation is easily identified because of this mass-ratio difference. A change in δD and $\delta^{18}O$ values that result from the mass differences during physical processes is called isotopic fractionation. This fractionation is known and can be easily calculated for physical processes.

The timing of groundwater recharge and the travel time of groundwater along flow paths in the WRFS were evaluated using: (1) stable isotopes of water that is recharged and discharged all along the WRFS from its headwaters in Long Valley to the Muddy Springs discharge area in Upper Moapa Valley (Thomas and Mihevc, 2007); and (2) carbon-13 and carbon-14 data for dissolved inorganic carbon in groundwater of the WRFS. δD and $\delta^{18}O$ data provide information on the timing of recharge to the WRFS, as indicated by both recharge and regional spring isotopic values. Carbon-14 and carbon-13 data are used to estimate groundwater ages that are corrected for reactions involving solid and gas phases that contain carbon [such as calcite ($CaCO_3$) with no carbon-14 (rock sources) or atmospheric or soil zone CO_2 gas with modern or elevated carbon-14 values].

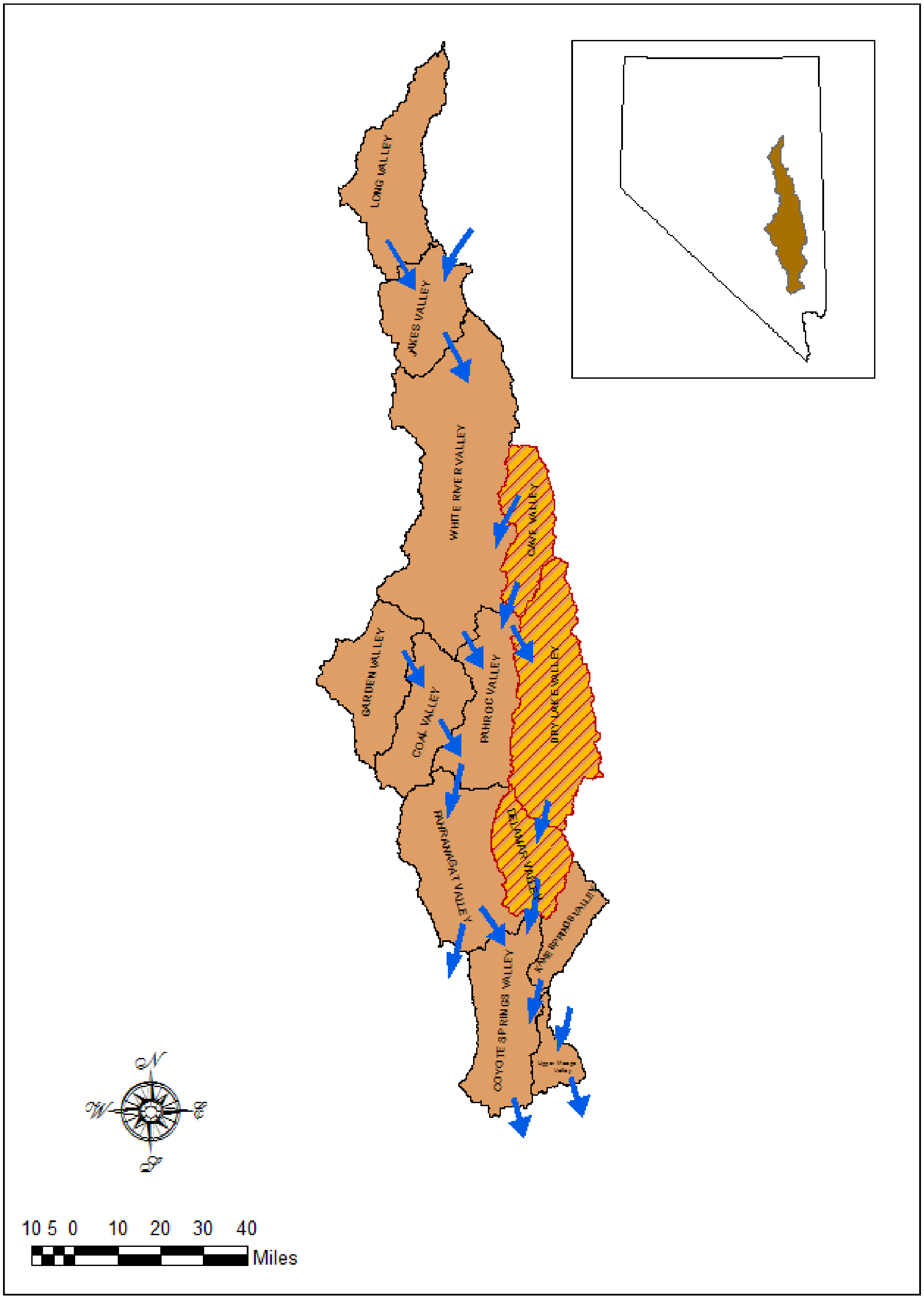

Figure 1. Study area location showing the White River Flow System (WRFS), which includes Delamar, Dry Lake, and Cave valleys (DDC area is shaded). General groundwater flow directions are from Burns and Drici (2011) and are shown by arrows.

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Study Area Description

The focus area of this project is the DDC area, but it also includes the WRFS because groundwater flows from the DDC area to other valleys of the WRFS (Figure 1). The regional WRFS extends from Long Valley in the north to the Muddy River Springs area in Upper Moapa Valley in the south, with the DDC valleys located in the eastern middle part of the WRFS. A groundwater hydraulic gradient extends from Long Valley in the north to the Muddy River Springs area of Upper Moapa Valley in the south (Eakin, 1966; Mifflin, 1968; Thomas et al. 1986; 1996; 2001; Kirk and Campana, 1990; Thomas and Mihevc, 2007). Groundwater flow directions for the entire WRFS, including the DDC area, are shown in Figure 1.

Groundwater flows from north to south down the WRFS primarily in carbonate rock aquifers that underlie the area (Eakin, 1966; Mifflin, 1968; Thomas et al. 1986; 1996; Kirk and Campana, 1990; Plume and Carlton, 1988; Plume, 1996; Welch et al., 2007). Groundwater flows between valleys along the hydraulic gradient, and this interbasin flow is discharged from regional warm (> 20^{o}C) springs in White River, Pahranagat, and Upper Moapa valleys (Eakin, 1966; Mifflin, 1968; Kirk and Campana, 1990; Thomas et al., 1996; 2001; Thomas and Mihevc, 2007). Groundwater is recharged in mountains of the WRFS, which are generally along the eastern and western sides of the valleys, and this local recharge mixes with interbasin flow as it passes from one topographic valley to the next. Groundwater is discharged from local springs supplied by water from the adjacent mountain block recharge areas and from regional warm spring areas that include a mixture of groundwater from many recharge areas and valleys. Groundwater is also discharged in phreatophytic areas in some valleys of the WRFS, some of which are associated with warm spring discharge areas and others that are not part of the regional warm spring discharge areas but instead are supplied by recharge to that valley.

Water Chemistry and Isotope Data

Most of the water chemistry and isotopic data used in this report were collected by Desert Research Institute (DRI), U.S. Geological Survey (USGS), and Southern Nevada Water Authority (SNWA) personnel. Most of the water chemistry samples were analyzed at the DRI Water Quality Laboratory, in Reno, Nevada, or the USGS Central Water Quality Laboratory, in Denver, Colorado. Recent δD and $\delta^{18}O$ samples were analyzed at the University of Nevada, Reno Isotope Laboratory. Historic δD and $\delta^{18}O$ data used in this report are from samples analyzed at the DRI Isotope Laboratory in Las Vegas, Nevada; the USGS Isotope Laboratories in Reston, Virginia and Menlo Park, California; and the Waterloo Isotope Laboratory in Waterloo, Canada. Recent carbon-13 and carbon-14 isotopic data are from samples analyzed at the University of Arizona Accelerator Facility in Tucson, Arizona. Historic carbon isotope data are from samples analyzed at the DRI Isotope Laboratory in Las Vegas, Nevada, and the USGS Isotope Laboratories in Reston, Virginia and Menlo Park, California. All data used in this report are provided in Appendix 1. Appendix 1 was developed for isotopic and chemical studies for east-central and southeastern Nevada, so it also contains data outside of the area of this study that were not used in this report.

USING STABLE ISOTOPE DATA TO EVALUATE GROUNDWATER SOURCES AND FLOW PATHS

δD and $\delta^{18}O$ have been used to evaluate groundwater sources and flow paths because they are part of the water molecule. Once water recharges an aquifer, its isotopic signature (δD and $\delta^{18}O$ values) travels with the water and remains unchanged unless the water mixes with water from another source(s) with different δD and $\delta^{18}O$ values, or the groundwater undergoes evaporation (Kirk and Campana, 1990; Thomas et al., 1996; 2001; Clark and Fritz, 1997; Lundmark et al., 2007; Thomas and Mihevc, 2007). Thus, if the isotopic values of the recharge waters are known, and they differ for different recharge areas, then the source(s) of water in an aquifer can be identified. δD and $\delta^{18}O$ are conservative, so that they can also be used to evaluate amounts of groundwater mixing from different sources along a groundwater flow path.

In this study, the stable isotopes of water (δD and $\delta^{18}O$) are used to evaluate sources of groundwater in Delamar, Dry Lake, and Cave valleys and groundwater discharging from springs in adjacent valleys of the WRFS. As noted above, the δD and $\delta^{18}O$ values change only during evaporation and are not involved in chemical reactions that could change their values. Any groundwater that has undergone significant evaporation is not included in the isotope evaluations of water sources and flow paths and is not included in Appendix 1. A groundwater sample is assumed to have undergone significant evaporation if the predicted δD value as calculated from the measured $\delta^{18}O$ value of the sample is 10‰, or more, positive than the measured deuterium value. These samples are easily identified on a δD versus $\delta^{18}O$ plot because they plot 10‰ below (to the right of) of the global meteoric water line defined by the equation $\delta D = 8\delta^{18}O + 10$ (Craig, 1961). The global meteoric water line is a regression line that represents un-evaporated precipitation from all over the world, ranging from the equator to the Arctic and Antarctica. A local meteoric water line is sometimes developed for studies in Nevada, but these lines generally include groundwater samples that have undergone some evaporation or sublimation prior to recharge, thus they are highly influenced by the evaporated less negative samples. A study of isotopic values of precipitation in southern Nevada showed that precipitation values plot close to the global meteoric line, except for the lightest storms (<0.25 cm) which were highly evaporated, and snow samples plot along the global meteoric water line (Benson and Klieforth, 1989).

Groundwater sources and flow paths were evaluated by calculating the average δD and $\delta^{18}O$ values of mountain block recharge areas in a valley. Valleys in east-central and southeastern Nevada generally have two main recharge areas, a mountain block on the east side and a mountain block on the west side of the valley. However, no matter if there are two, or more than two, recharge areas within a topographic basin (valley), they are treated separately and assigned their own average δD and $\delta^{18}O$ values. δD and $\delta^{18}O$ values are assigned to recharge areas by taking the average stable isotope values of all the springs sampled in a recharge area. If a spring site contains more than one sample, then the average δD and $\delta^{18}O$ values for the site is used in calculating the average stable isotope value of the recharge area.

Recharge-area springs are used to represent the isotopic composition of groundwater recharge to a mountain block because they represent an integration of many recharge events and generally integrate recharge over large areas. Recharge-area springs are great integrators and represent precipitation that becomes groundwater recharge because they: (1) average the isotopic composition of all precipitation events that become recharge, (2) do not contain water, and its isotopic signature, that is lost by sublimation, evaporation, and transpiration, and (3) represent a larger area than a single measurement point, such as precipitation collected at a single location.

The δD and $\delta^{18}O$ values of groundwater discharging from springs, or in wells, on the valley floor can be used to evaluate the source(s) of water supplying them. Springs and wells on valley floors that contain cool (< $20^{o}C$) groundwater can be used to evaluate sources of water recharging a basin. The source(s) of this cool water is generally local recharge to the adjacent mountain blocks, as indicated by the average isotopic composition of springs in mountain-block recharge areas weighted by the amount of recharge to each individual mountain block. If the δD and $\delta^{18}O$ values of water in a spring or well on a valley floor are similar to the average δD and $\delta^{18}O$ values of the recharge to the valley (within 2‰ δD and 0.2‰ $\delta^{18}O$) then the most likely groundwater source(s) is the local recharge to the mountain blocks within the valley. If the groundwater isotopic values are significantly different than the average recharge values, then the groundwater may include interbasin flow from an upgradient valley(s). Springs and wells on valley floors that contain warm groundwater [> $20^{o}C$, which represents an average flow depth of several thousand feet (Acheampong et al., 2005)] can be used to evaluate water sources and interbasin flow. The warm springs usually include flow from an upgradient basin(s) that flows at depth into the valley. The δD and $\delta^{18}O$ values of groundwater flowing out of an upgradient basin(s), along with δD and $\delta^{18}O$ values of local recharge, are used to identify the source(s) of groundwater discharging from warm spring areas. All four warm spring areas in White River, Pahranagat, and Upper Moapa valleys of the WRFS are isotopically much lighter (more negative) than local recharge in the adjacent mountain block recharge areas, supporting interbasin groundwater flow to these springs from upgradient basins (Plate 2; Appendix 1).

Deuterium and Oxygen-18 Variability

An important consideration in using δD and $\delta^{18}O$ values to evaluate the source(s) of water discharging from valley springs, or in wells, is their natural variability. This variability includes; (1) changes in recharge area spring isotopic values over time; (2) potential stable isotope differences with altitude in recharge areas; (3) the spatial distribution of stable isotope values of springs in mountain block recharge areas; and (4) changes in regional warm spring isotopic values over time. Ideally, isotopic variability will be small so that isotope values for springs in recharge areas and for springs and wells on the valley floor do not have a large uncertainty associated with them. If uncertainty of isotopic values for these springs and wells is small, then the measured isotopic values are appropriate indicators for determining present day recharge sources, as well as, historic recharge sources for springs and wells on valley floors. The analytical (measurement) precision for δD is +/– 1.0‰ and for $\delta^{18}O$ is +/– 0.10‰. (Analytical precision values represent one standard deviation; Simon Poulson, University of Nevada, Reno Isotope Laboratory, oral communication, 2007.)

<u>Isotopic Variability Over Time of Springs in Recharge Areas</u>

A large amount of isotopic data has been collected in recharge areas of the WRFS, including the DDC area (Figure 1; Plates 1 and 2; Appendix 1). Three springs in major recharge areas of the WRFS [Monitoring Spring WR1 in the White Pine Range (site 320), Upper Terrace Spring WR2 in the Egan Range (site 270), and Patterson Pass Spring WR3 in the Schell Creek Range (site 305)] have been continuously monitored for flow, water temperature, and electrical conductance. These springs have also been sampled on an approximately quarterly basis (access permitting) for δD, $\delta^{18}O$, pH, and major-ion chemistry from October of 2003 to November 2009, with WR1 also having a sample collected in June 2010. In addition, one recharge area spring [Upper Riggs Spring, WR4 in the Delamar Mountains (site 105)] was monitored and sampled from April 2004 to February 2005 until the monitoring site was destroyed by a flood. This monitoring site also has a sample from February 1984. Bulk precipitation amount was also measured at the spring monitoring sites and precipitation samples were collected for δD and $\delta^{18}O$ analysis. These data are presented in Appendix 2. Numerous recharge-area springs were also sampled for stable isotopes and major-ion chemistry to provide information for recharge areas that had little or no isotopic data in the Thomas et al. (2001) study and to provide more data for all recharge areas throughout the WRFS (Plates 1 and 2; Appendix 1).

Continuous flow and approximately quarterly deuterium data for recharge-area monitoring springs are shown in Figures 2, 3, and 4 ($\delta^{18}O$ is not shown on the plots because it is strongly correlated with δD and follows the same trend as δD). As is observed in all three figures, the δD composition of the springs varies little with change in flow or season. For example, δD values for Monitoring Spring WR1 in the White Pine Range only varies between -116.2 and -111.2‰ for a range in flow of about 100 to 5,000 gallons per minute and for the time period October 2003 to June 2010 (Figure 2; Table 1). Oxygen-18 for these same samples varies between -15.90 and -15.32‰. During this period, 25 samples were collected with an average δD value of -114.0‰ and a standard deviation of 1.1‰ and an average $\delta^{18}O$ value of -15.63‰ with a standard deviation of 0.11‰ (Table 1). A similar pattern is observed for the other three recharge-area monitoring springs in the WRFS (Figures 3 and 4; Table 1). Table 1 presents a summary of the data in Figures 2, 3, and 4 and data for the shorter record at Upper Riggs Spring WR4 in the Delamar Range, with minimum, maximum, median, mean, and standard deviation values for the isotopic data for all four recharge area monitoring sites. The greatest range in δD values that was observed for all four sites is 5.0‰ for the Monitoring Spring WR1 in the White Pine Range and the smallest range is 1.8‰ for five samples for the Upper Riggs Spring WR4 monitoring site in the Delamar Mountains (Table 1). All of the standard deviations of the spring δD data are about 1‰ with the highest standard deviation being 1.1‰ for Monitoring Spring WR1 and the lowest being 0.7‰ for Upper Riggs Spring. $\delta^{18}O$ data follows a similar pattern with the standard deviation ranging from 0.07 to 0.11‰ (except for Upper Riggs Spring with a value of 0.33‰) for the four recharge-area monitoring sites (Table 1). These standard deviations are about the same as the analytical uncertainty of the δD and $\delta^{18}O$ water analysis.

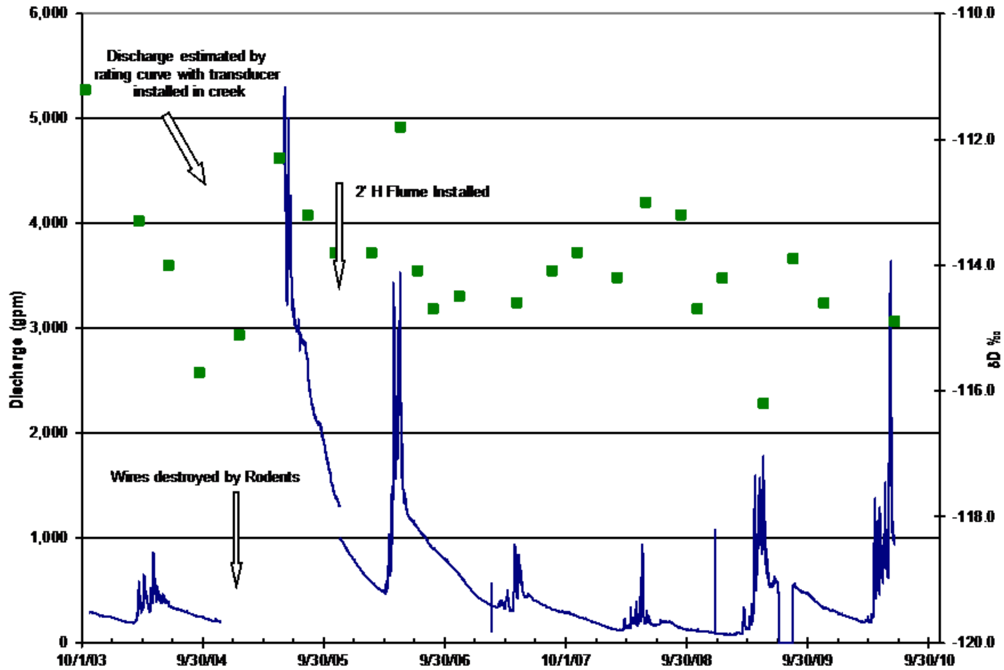

Figure 2. Deuterium and flow data for Monitoring Spring WR1 in the White Pine Range in northwestern White River Valley. Green squares are the deuterium data, which have an analytical uncertainty of +/- 1.0‰. Blue line is spring flow. The high spring flows in the spring of 2005 are estimated from a rating curve developed from continuous stream-height data and flow measurements (flow exceeded the flume capacity).

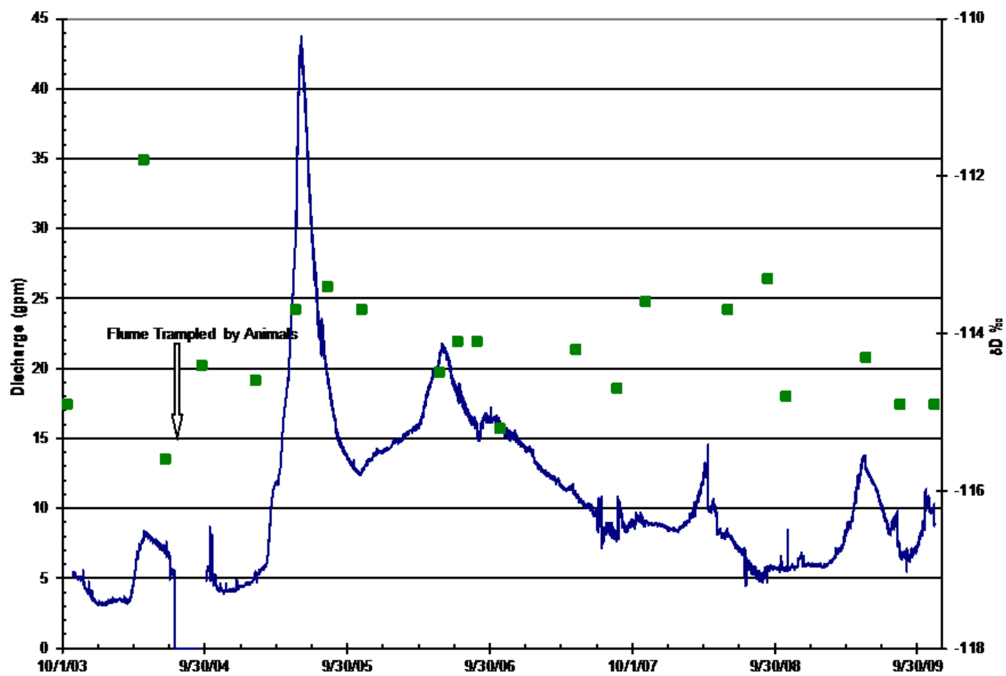

Figure 3. Deuterium and flow data for Upper Terrace Spring WR2 in the Egan Range in northeastern White River Valley. Green squares are the deuterium data, which have an analytical uncertainty of +/- 1.0‰. Blue line is spring flow.

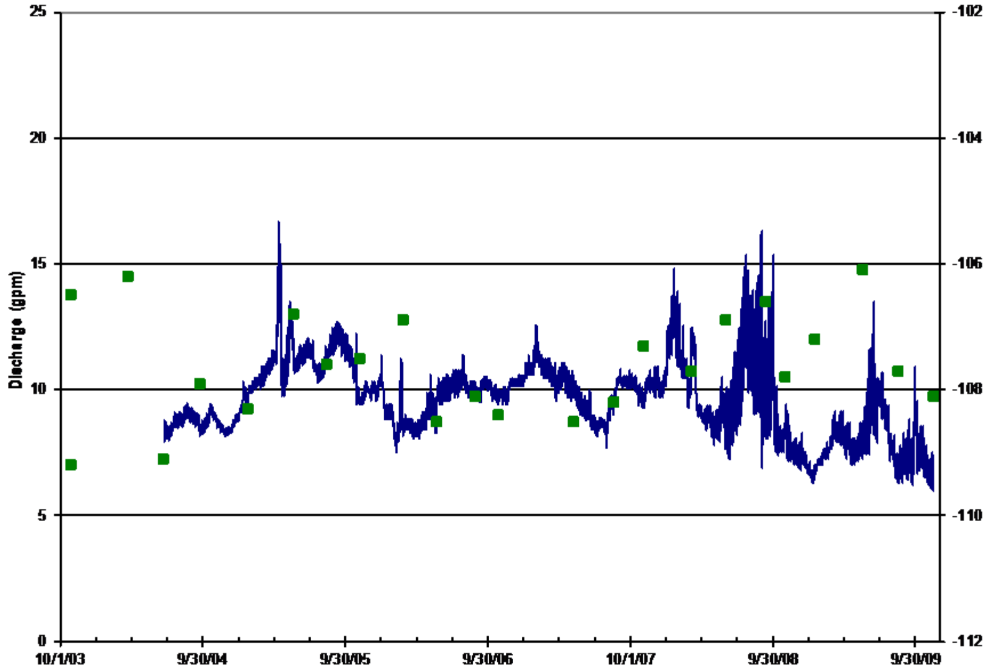

Figure 4. Deuterium and flow data for Patterson Pass Spring WR3 in the Schell Creek Range in western Lake Valley. Green squares are the deuterium data, which have an analytical uncertainty of +/- 1.0‰. Blue line is spring flow.

Table 1. Variability of δD and $\delta^{18}O$ in recharge-area springs of the WRFS. Values are reported in permil.

Site Name		Number of Samples	Minimum	Maximum	Median	Mean	Standard Deviation
			White Pine Range				
Monitoring Spring WR1	δD	25	-116.2	-111.2	-114.1	-114.0	1.1
Monitoring Spring WR1	$\delta^{18}O$	25	-15.90	-15.32	-15.64	-15.63	0.11
			Egan Range				
Upper Terrace Spring WR2	δD	21	-115.6	-111.8	-114.3	-114.2	0.8
Upper Terrace Spring WR2	$\delta^{18}O$	21	-15.64	-15.24	-15.46	-15.45	0.08
			Schell Creek Range				
Patterson Pass Spring WR3	δD	24	-109.1	-106.1	-107.8	-107.6	0.8
Patterson Pass Spring WR3	$\delta^{18}O$	24	-14.96	-14.71	-14.90	-14.88	0.07
			Delamar Mountains				
Upper Riggs Spring WR4	δD	5	-88.0	-86.2	-87.0	-87.0	0.7
Upper Riggs Spring WR4	$\delta^{18}O$	5	-12.46	-11.55	-11.90	-11.95	0.33

Isotopic Variability with Altitude of Springs in Recharge Areas

The potential for variability of stable isotope values with altitude also needs to be considered, because if stable isotope values become more depleted (more negative) with increasing altitude in the recharge areas, this would need to be accounted for in assigning average stable isotope values to recharge areas (the amount of precipitation and the percent of precipitation that becomes recharge increases with increasing altitude). The altitudes of the springs were used in these evaluations, although the average recharge altitude of the source of the spring water would be a better altitude value to use than the spring altitude (Russell et al., 2007). One could estimate the average altitude of recharge represented by the spring using the methods of Russell et al. (2007), or by simply taking the average altitude of the catchment above the spring because according to Russell et al. (2007), page 48 ―Uncertainty in the actual elevation of the recharge basin tended to pull the mean elevation toward the middle of that slope." In the Russell et al. (2007) report ―that slope" was the slope between the spring and the highest point in the watershed above the spring. However, this approach was not taken in this study because of the unknown source of recharge to the springs (they could be derived from recharge to the mountain block anywhere above the spring) and precipitation amounts for the elevation gradients within the watershed would have to be known to correctly estimate the average recharge altitude based on a precipitation weighted altitude relationship (because of the increase in precipitation with altitude in mountainous recharge areas of Nevada). Finally, using the average altitude of the spring catchment would have little effect on the trends of the plots presented in Figures 5 through 8, and any effect would likely be to increase the lower-spring altitudes relative to the higher-spring altitudes (since many of the springs would have a similar ridge line altitude for their catchments). Incorporating average recharge altitudes for springs would likely reduce any potential altitude-stable isotope relationship.

The relationship between δD and altitude was evaluated for four major recharge areas in the study area that contained 14, or more, springs. In the northern part of the WRFS, the White Pine Range and Central Egan Range δD data were plotted as a function of altitude (Figures 5 and 6). There are very weak relationships (R^2 values of 0.066 and 0.018) of δD as a function of altitude in these plots and the strongest relationship, which is for the White Pine Range, shows a negative slope for δD as a function of altitude (δD values increase with increasing altitude). In the central and southern part of the WRFS, δD data were plotted as a function of altitude for the Fairview and Bristol Ranges and the Delamar Mountains (Figures 7 and 8). There is a very weak relationship of δD with altitude for the Fairview and Bristol Ranges (R^2 value of 0.026). There is a stronger observed relationship for the Delamar Range (R^2 value of 0.366) than the other three recharge areas, with δD values becoming more positive with decreasing altitude (Figures 5-8). Using the average value of all the springs may result in a more positive δD recharge value for the Delamar Range than the actual δD recharge value, so this relationship could shift the average isotopic recharge value for the Delamar Range to an isotopic value that is 2 to 3‰ more negative. This shift would have no effect on the interpretations in this report. Although a decrease in δD values with increasing altitude is observed on the western side of the Sierra Nevada, as storm tracks originating from the Pacific Ocean move inland and ascend to the Sierra crest (Smith et al., 1979), this effect is not assumed to occur in eastern and southeastern Nevada because cloud

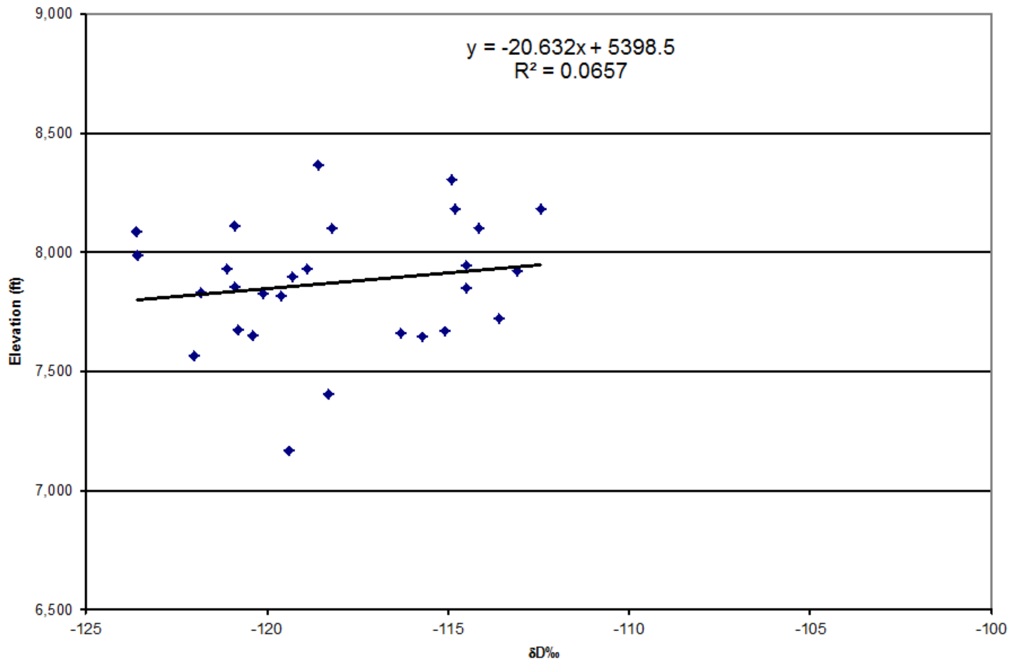

Figure 5. Deuterium as a function of altitude in the White Pine Range. δD data have an analytical uncertainty of +/- 1.0‰.

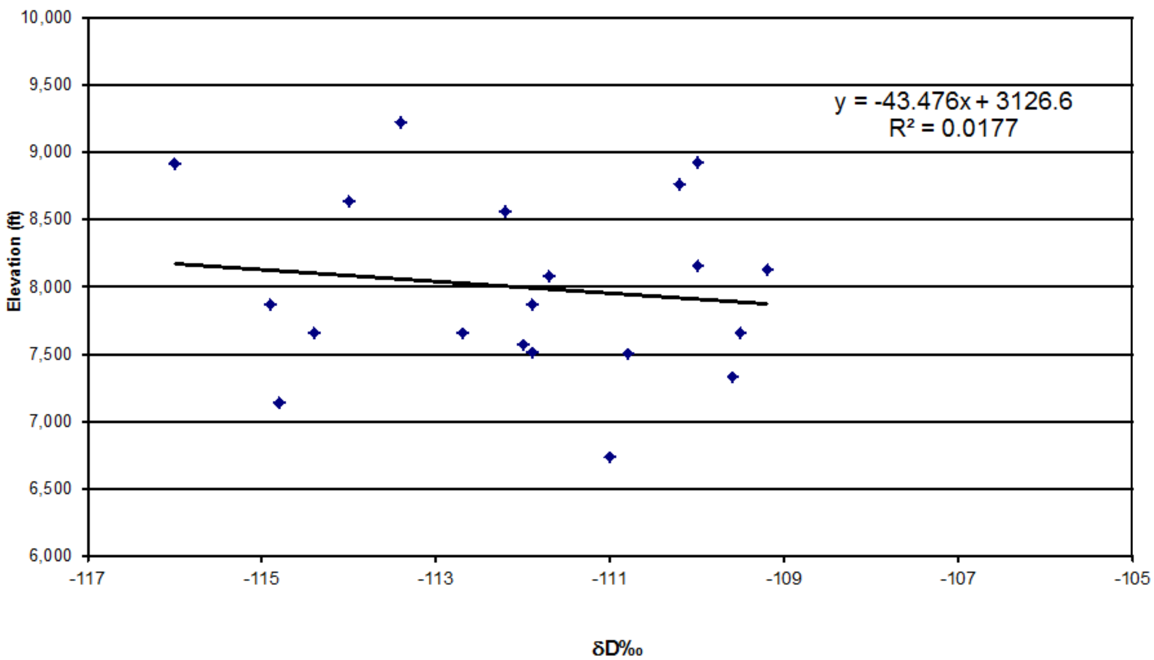

Figure 6. Deuterium as a function of altitude in the Central Egan Range. δD data have an analytical uncertainty of +/- 1.0‰.

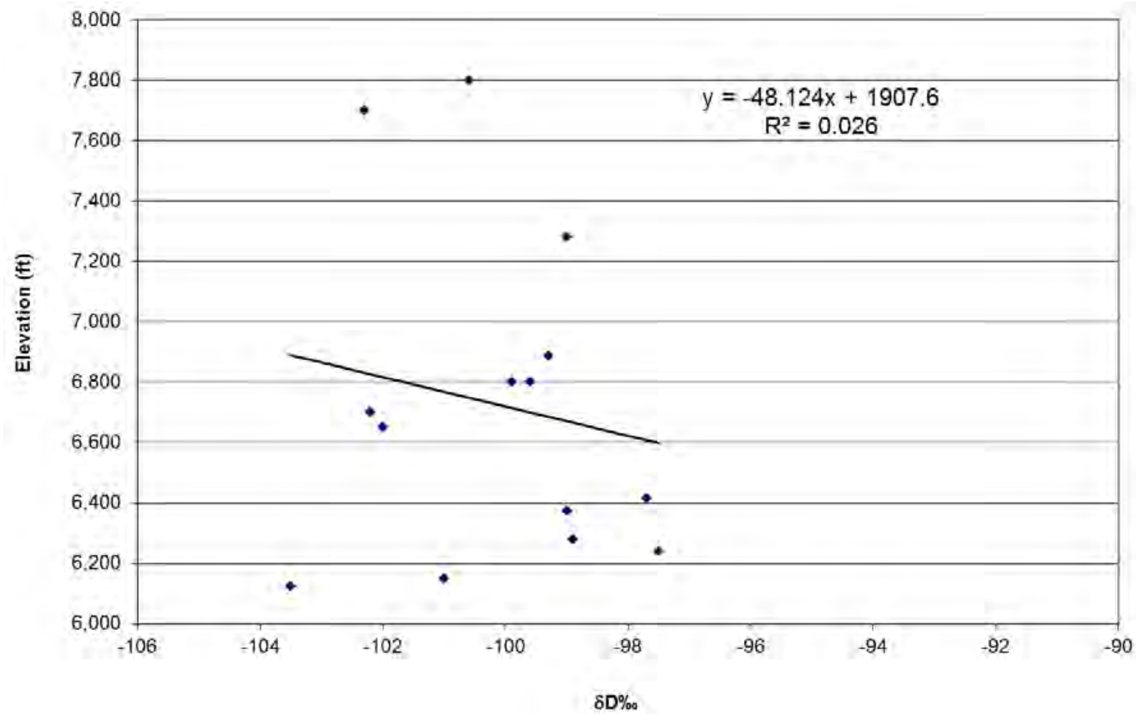

Figure 7. Deuterium as a function of altitude in the Highland and Fairview Ranges. δD data have an analytical uncertainty of +/- 1.0‰.

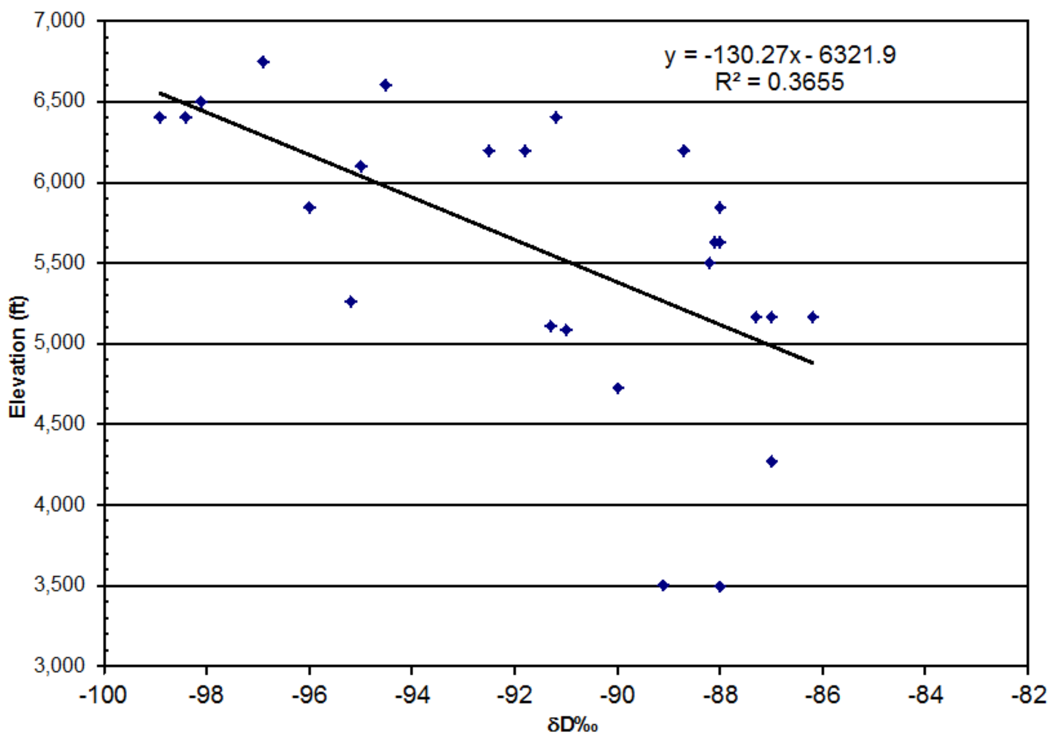

Figure 8. Deuterium as a function of altitude in the Delamar Mountains. δD data have an analytical uncertainty of +/- 1.0‰.

base levels may be similar across the Great Basin. The lack of an apparent δD with altitude relationship in all but the Delamar Range in the four WRFS recharge areas is consistent with the results of Thomas et al. (1996; Figure 21) for the Spring Mountains in southern Nevada. They found no δD-altitude relationship for samples ranging in altitude from about 4,400 to 10,300 feet in the Spring Mountains. The significance of a lack of a δD-altitude relationship is that isotopic values in recharge areas can simply be averaged to obtain the recharge isotopic signature for a mountain block recharge area.

Spatial Isotopic Variability of Springs in Recharge Areas

The spatial variability of δD values in recharge areas is presented in Table 2. The range in δD values for the recharge areas is 4.8 to 11.9‰ and the standard deviations of these recharge area springs range from 1.8 to 4.2‰ (Table 2). These ranges in δD and standard deviation values are greater than the range in spring δD temporal values presented in Table 1. Given that δD values of groundwater in valleys adjacent to these recharge areas, that have cool temperatures (< 20^{o}C) and variable flow rates indicating that they are derived from local recharge, have similar δD values to that of the average value of springs in the adjacent recharge areas indicates that they are appropriate values to represent recharge in the mountain block recharge areas (see discussion later in this report in section titled ―Isotopic Evaluation of Groundwater Sources and Flow Paths"). This similarity of the average δD value of springs in recharge areas with that of locally derived groundwater in adjacent valleys, combined with the small variability of spring δD values over time and large flow fluctuations, shows that springs in mountain block recharge areas provide good representative δD values for DDC recharge areas.

Isotopic Variability of Regional Warm Springs

Regional warm (> 20^{o}C) springs in the WRFS have consistent isotopic values and flow rates over time, have average flow depths of several thousand feet (Acheampong et al., 2005), and contain significantly more negative isotopic values than local recharge to the basin that they are in, so they provide valuable information needed to evaluate interbasin groundwater flow in the WRFS. Thus, it is important that isotopic variability of these springs is known, and if this variability is large, then the water sources supplying regional warm springs would need to be considered under transient, rather than steady-state, conditions. Table 3 presents minimum, maximum, median, mean, and standard deviation values for δD and $\delta^{18}O$ for the warm spring provinces (discharge areas) of the WRFS. Analysis of data are presented for individual springs within a warm spring province if three or more analyses are available and for the average of all warm springs in a warm spring province (Table 3). For example, in northern White River Valley, Preston Big Spring (Appendix 1 and Plate 1; site 231) is a warm spring in the Preston warm spring province that has 13 samples, so the variability of stable isotopic data for this spring was analyzed. Additionally, there are two other warm springs in the warm spring province, Nicholas (Appendix 1 and Plate 1; site 227) and Cold (Appendix 1 and Plate 1; site 230) springs. Cold Spring is a warm (21.8^{o}C) spring despite its name. So, the statistical values for Preston Big Spring data and also for the average values of the three springs in the Preston warm spring

Table 2. Spatial variability of δD and $\delta^{18}O$ in mountain block recharge areas of the DDC area. Values are reported in permil. NA: not applicable.

Site Name		**Number of Samples**	**Minimum**	**Maximum**	**Median**	**Mean**	**Standard Deviation**
			Cave Valley				
South Schell Creek Range	δD	6	-109.5	-99.5	-106.2	-105.0	4.0
South Schell Creek Range	$\delta^{18}O$	6	-14.88	-13.17	-14.47	-14.21	0.64
South Egan Range	δD	8	-111.4	-103.4	-106.6	-106.9	3.3
South Egan Range	$\delta^{18}O$	8	-15.04	-13.32	-14.21	-14.15	0.70
			Dry Lake Valley				
South Schell Creek Range	δD	1	-100.9	-100.9	-100.9	-100.9	NA
South Schell Creek Range	$\delta^{18}O$	1	-13.17	-13.17	-13.17	-13.17	NA
North Pahroc Range	δD	8	-97.3	-90.5	-94.1	-94.3	2.4
North Pahroc Range	$\delta^{18}O$	8	-13.06	-11.76	-12.43	-12.39	0.42
Fairview Range	δD	13	-103.5	-97.4	-98.9	-99.5	2.0
Fairview Range	$\delta^{18}O$	13	-13.60	-12.34	-12.73	-12.88	0.44
Bristol and Highland Ranges	δD	6	-101.2	-95.0	-99.1	-98.9	2.2
Bristol and Highland Ranges	$\delta^{18}O$	6	-13.87	-12.07	-13.36	-13.28	0.66
Chief Range	δD	9	-98.9	-88.2	-95.0	-94.6	3.9
Chief Range	$\delta^{18}O$	9	-12.98	-11.69	-12.32	-12.36	0.52
			Delamar Valley				
Delamar Range	δD	17	-98.9	-87.0	-91.8	-92.4	4.2
Delamar Range	$\delta^{18}O$	17	-12.98	-11.46	-12.47	-12.32	0.49
South Pahroc Range	δD	8	-97.4	-92.6	-94.2	-94.6	1.8
South Pahroc Range	$\delta^{18}O$	8	-13.24	-12.30	-12.84	-12.81	0.35

Table 3. Variability of δD and $\delta^{18}O$ of regional warm (> 20°C) springs in the WRFS. Values are reported in permil.

Site Name		Number of Samples	Minimum	Maximum	Median	Mean	Standard Deviation
			North White River Valley				
Preston Big Spring	δD	13	-126.0	-120.0	-121.8	-122.0	1.5
Preston Big Spring	$\delta^{18}O$	13	-15.99	-15.60	-15.88	-15.87	0.12
North White River Valley	δD	3	-124.0	-121.8	-123.5	-123.1	1.2
North White River Valley	$\delta^{18}O$	3	-16.10	-15.80	-15.88	-15.93	0.16
			South White River Valley				
Hot Creek Springs	δD	12	-120.5	-117.4	-119.1	-119.1	0.9
Hot Creek Springs	$\delta^{18}O$	12	-15.82	-15.50	-15.71	-15.69	0.10
South White River Valley	δD	4	-120.0	-118.0	-119.4	-119.2	0.9
South White River Valley	$\delta^{18}O$	4	-15.80	-15.30	-15.65	-15.60	0.21
			Pahranagat Valley				
Crystal Springs	δD	18	-111.0	-106.9	-109.0	-109.0	1.0
Crystal Springs	$\delta^{18}O$	15	-14.53	-14.23	-14.41	-14.40	0.08
Hiko Spring	δD	7	-110.5	-105.0	-109.5	-108.7	1.9
Hiko Spring	$\delta^{18}O$	4	-15.30	-13.80	-14.23	-14.39	0.67
Ash Springs	δD	6	-112.0	-107.0	-108.7	-109.1	1.8
Ash Springs	$\delta^{18}O$	3	-14.20	-14.03	-14.10	-14.11	0.09
Pahranagat Valley	δD	4	-109.1	-107.2	-108.9	-108.5	0.9
Pahranagat Valley	$\delta^{18}O$	4	-14.40	-14.11	-14.29	-14.27	0.14

Table 3. Variability of δD and $\delta^{18}O$ of regional warm (> 20°C) springs in the WRFS (continued).

Site Name		Number of Samples	Minimum	Maximum	Median	Mean	Standard Deviation
		Upper Moapa Valley (Muddy Springs area)					
Baldwin Spring	δD	9	-98.6	-96.3	-97.9	-97.6	0.8
Baldwin Spring	$\delta^{18}O$	9	-13.05	-12.91	-12.95	-12.97	0.05
Big Muddy Spring	δD	6	-99.0	-96.5	-98.0	-97.9	0.8
Big Muddy Spring	$\delta^{18}O$	5	-13.05	-12.75	-12.89	-12.89	0.11
Jones Spring Pumphouse	δD	6	-98.9	-97.3	-97.9	-97.9	0.5
Jones Spring Pumphouse	$\delta^{18}O$	6	-13.10	-12.99	-13.07	-13.05	0.05
Pederson's East	δD	9	-98.7	-97.0	-97.7	-97.8	0.6
Pederson's East	$\delta^{18}O$	9	-13.06	-12.89	-12.98	-12.98	0.06
Pederson's Warm Spring (M-13)	δD	15	-99.0	-96.5	-97.4	-97.5	0.6
Pederson's Warm Spring (M-13)	$\delta^{18}O$	13	-13.05	-12.75	-12.91	-12.93	0.09
Upper Moapa Valley	δD	9	-99.0	-96.5	-97.8	-97.7	0.7
Upper Moapa Valley	$\delta^{18}O$	8	-13.05	-12.45	-12.94	-12.87	0.19

province are presented in Table 3. δD values for Preston Big Spring range from -126.0 to -120.0‰, with a mean value of -122.0‰ and a standard deviation of 1.5‰. δD values range from -124.0 to -121.8‰, with a standard deviation of 1.2‰ for the average values of the three springs in the Preston warm spring province. In general, the standard deviations for the individual warm spring δD data and for the average values of all springs with isotopic data in a warm spring province are about 1‰ (Table 3). δ^{18}O data follow a similar pattern, with standard deviations ranging from 0.05 to 0.21‰ (except for one site with a standard deviation of 0.67‰). The variability of the warm spring isotopic data is similar to the analytical uncertainly of δD (1.0‰) and δ^{18}O (0.1‰). This low variability of the stable isotopic data shows that the stable isotopic composition of regional warm springs provides an appropriate means for evaluating groundwater sources and flow paths for the springs.

It is important to understand that the small degree of isotopic variation in some samples from warm springs is over a period lasting from 20 to 40 years. For example, isotopic data was first collected for Big Muddy Spring, in Upper Moapa Valley, in March 1970 and six samples from 1970 to 2004 have a range of only -99.0 to -96.5‰. Similarly, Hiko, Crystal, and Ash springs in Pahranagat Valley have isotopic data that were first collected in 1968. For all three springs during the time period of 1968 to 2006, δD only varied by 5.5‰. Preston Big Spring in northern White River Valley and Hot Creek Spring in southern White River Valley have samples that span 24 and 26 year periods with a range in δD values of 6.0 and 3.1‰, respectively (Table 3).Summary of Isotopic Variability

The small range in isotopic values and standard deviations of the recharge area and regional warm spring data shows that δD and δ^{18}O are appropriate tracers of groundwater in the WRFS that can be used to evaluate sources and flow paths. If temporal variability of δD and δ^{18}O of recharge area monitoring springs and regional warm springs had been high, then the uncertainty associated with using them to evaluate water sources and flow paths in regional flow systems would have also been high.

Isotopic Evaluation of Groundwater Sources and Flow Paths

The WRFS shown in Figure 1 and Plate 1 has a hydraulic gradient that extends from Long Valley in the north to Upper Moapa Valley (Muddy River Springs) in the south (Eakin, 1966; Mifflin, 1968; Kirk and Campana, 1990; Thomas et al., 1996; 2001; Thomas and Mihevc, 2007). Groundwater in this regional flow system flows primarily through carbonate-rock aquifers (Eakin, 1966; Mifflin, 1968; Thomas et al. 1986; 1996; Plume and Carlton, 1988; Kirk and Campana, 1990; Plume, 1996; Welch et al., 2007), although volcanic rocks are also present as is observed for parts of the DDC area of the White River Flow System (Plume and Carlton, 1988; Plume, 1996; Rowley and Dixon, 2011).

If δD and δ^{18}O data are going to be used to evaluate groundwater sources and flow paths, including interbasin flow, then these data have to be significantly different for the different recharge areas and for groundwater within each valley. Thomas and Mihevc (2007) showed that the δD and δ^{18}O values of groundwater in the northern part of the WRFS were 50 and 6.5‰ more negative, respectively, than groundwater in the southern part of the WRFS. Although the DDC area only extends through the middle and eastern part of the WRFS (Figure 1), δD and δ^{18}O data for the DDC area have a range of 24.4 and 3.35‰, respectively, from northern Cave Valley to southern Delamar Valley (Figure 9). Since, the analytical uncertainty of δD is +/- 1‰ and $\delta^{18}O$ is +/- 0.1‰, these differences in δD and $\delta^{18}O$ values observed for the DDC area are significant, so δD and $\delta^{18}O$ values can be used to evaluate sources and flow paths of groundwater in the DDC area and potential flow to adjacent valleys.

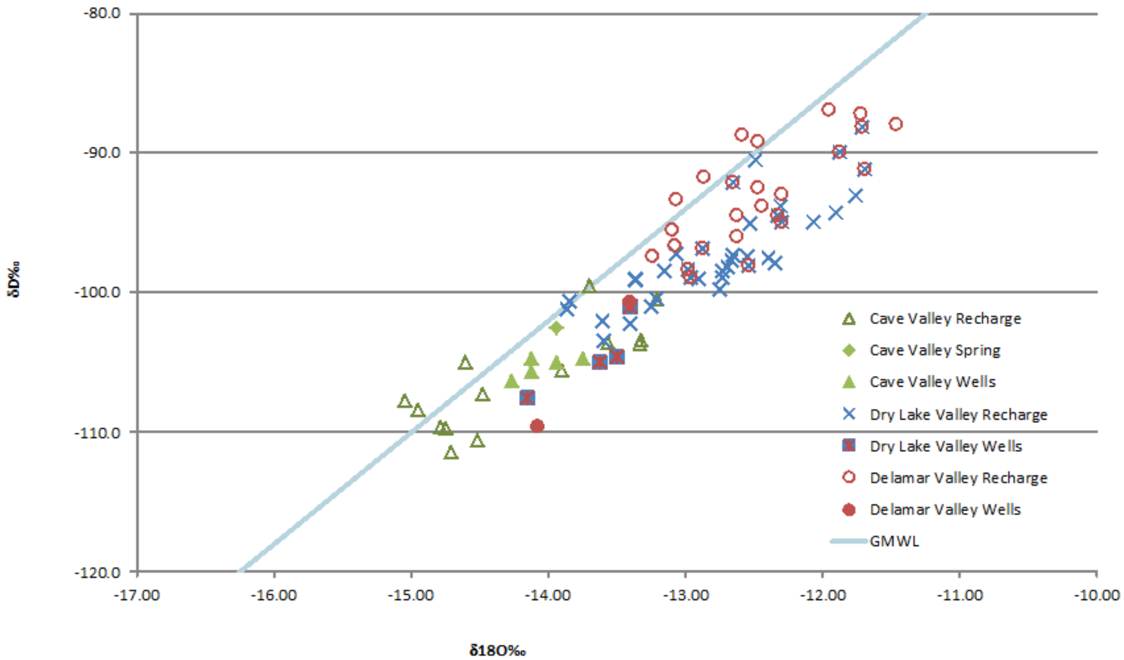

Figure 9. Plot of deuterium versus oxygen-18 for samples in the DDC area. GMWL is the Global Meteoric Water Line from Craig (1961).

Groundwater discharging from springs and in wells on the valley floors outside of recharge areas can be used to evaluate groundwater sources and flow paths. Two types of springs exist in the WRFS: (1) cool (< 20°C) springs that receive recharge from adjacent mountain block recharge areas surrounding a valley; and (2) warm (> 20°C) springs that have deep groundwater flow (thousands of feet below the land surface; Acheampong et al., 2005) and generally have interbasin flow as part, if not all, of their discharge. In the DDC area, cool springs and wells on the valley floors are present, but there are no warm springs in this area. However, regional warm springs are present in valleys adjacent to the DDC area, so isotopic data for warm springs in White River and Pahranagat valleys are used to evaluate potential groundwater flow from the DDC area to these regional warm springs.

Delamar, Dry Lake, and Cave Valleys

The DDC area has groundwater flow primarily in carbonate-rock aquifers underlying the three valleys and unconsolidated basin-fill aquifers within the valleys (Burns and Drici, 2011). There are also areas of volcanic rock in the DDC area that may contain local aquifers (Plume, 1996; Rowley and Dixon, 2011). A hydraulic gradient extends from Cave Valley (highest water level elevations) to Dry Lake Valley to Delamar Valley (lowest water level elevations; Figure 1 and Plate 1; Burns and Drici, 2011). Thus, potentially groundwater could flow from Cave to Dry Lake to Delamar valleys from north to south down the hydraulic gradient. However, due to geologic and structural controls in the central and southern parts of Cave Valley, groundwater in northwestern Cave Valley is thought to flow toward the southwest into southeastern White River Valley (along the Shingle Pass Fault system) and groundwater in northeastern and southern Cave Valley is thought to flow toward the southwest into northeastern Pahroc Valley (Eakin, 1966; Kirk and Campana, 1990; Thomas and Mihevc, 2007; Burns and Drici, 2011; Rowley and Dixon, 2011). Hydrogeologic data indicates that groundwater does flow from northern Dry Lake Valley to the south through Dry Lake Valley and into northern Delamar Valley. Groundwater in northern Delamar Valley flows to the south and eventually out of the southern end of the valley into Coyote Springs Valley. Groundwater in southern Delamar Valley also potentially flows to the southwest along the Pahranagat Valley Shear Zone and into the very southern end of Pahranagat Valley and northern Coyote Springs Valley (Eakin, 1966; Kirk and Campana, 1990; Thomas and Mihevc, 2007; Burns and Drici, 2011).

The δD and $\delta^{18}O$ data of mountain block recharge areas can be used with recharge estimates, evapotranspiration (ET) estimates, and groundwater flow directions to evaluate the sources, flow paths, and mixing of groundwater in the DDC area. Recharge to the southern Egan and southern Schell Creek ranges provide recharge to Cave Valley aquifers (Figure 10). The southern Egan Range recharge has average δD and $\delta^{18}O$ values of -106.9 and -14.15‰, respectively (Tables 2 and 4). The southern Schell Creek Range has average δD and $\delta^{18}O$ values of -105.0 and -14.21‰, respectively (Tables 2 and 4). The mixture of these two recharge sources to Cave Valley produces an average annual recharge to the valley of 13,700 acre-feet per year (afy) with an average isotopic composition of -105.9 and -14.18‰ (Table 4). There is an estimated 1,300 afy of groundwater lost by ET from shallow groundwater in Cave Valley (Burns and Drici, 2011). Thus, 12,400 afy of groundwater flows out of Cave Valley to southeastern White River Valley and northeastern Pahroc Valley. This groundwater has an isotopic signature of -105.9 and -14.18‰ for δD and $\delta^{18}O$, respectively.

The δD and $\delta^{18}O$ data for groundwater in springs and wells located on the valley floor of Cave Valley are used to evaluate the sources of groundwater supplying the aquifers of Cave Valley. If the mixture of water from the two main recharge areas is the only source supplying groundwater to Cave Valley aquifers, then groundwater in the valley should have similar δD and $\delta^{18}O$ values as the mixture of recharge waters. Groundwater discharging from Cave Spring (Appendix 1; plates 1 and 2; site 209) has average δD and $\delta^{18}O$ values of -102.5 and -13.94‰, respectively, for four samples. Groundwater in five wells (Appendix 1; plates 1 and 2; sites 600, 601, 620, 625, 627) have δD values ranging from -106.3 to -104.7‰ and $\delta^{18}O$ values ranging from -14.27 to -13.75‰, respectively (Plates 1 and 2; Appendix 1). Ideally, δD and $\delta^{18}O$ values would be within 2.0 and 0.2‰, respectively, of the proposed sources of water for the valley aquifers if these are the sources supplying all of the water to the valley aquifers (Thomas et al., 2001; Thomas and Mihevc, 2007). The average δD value of water flowing from Cave Spring is 3.4‰ more positive, and the average $\delta^{18}O$ value is 0.24‰ more positive, than that of the average recharge values. These Cave Spring values are 1.4 and 0.04‰ more positive than the ideal range of δD and $\delta^{18}O$ values, respectively, for supporting local recharge water as the sole source of water for the spring. However, these values are within the range of spring values in the Cave Valley recharge areas (Figure 9). In

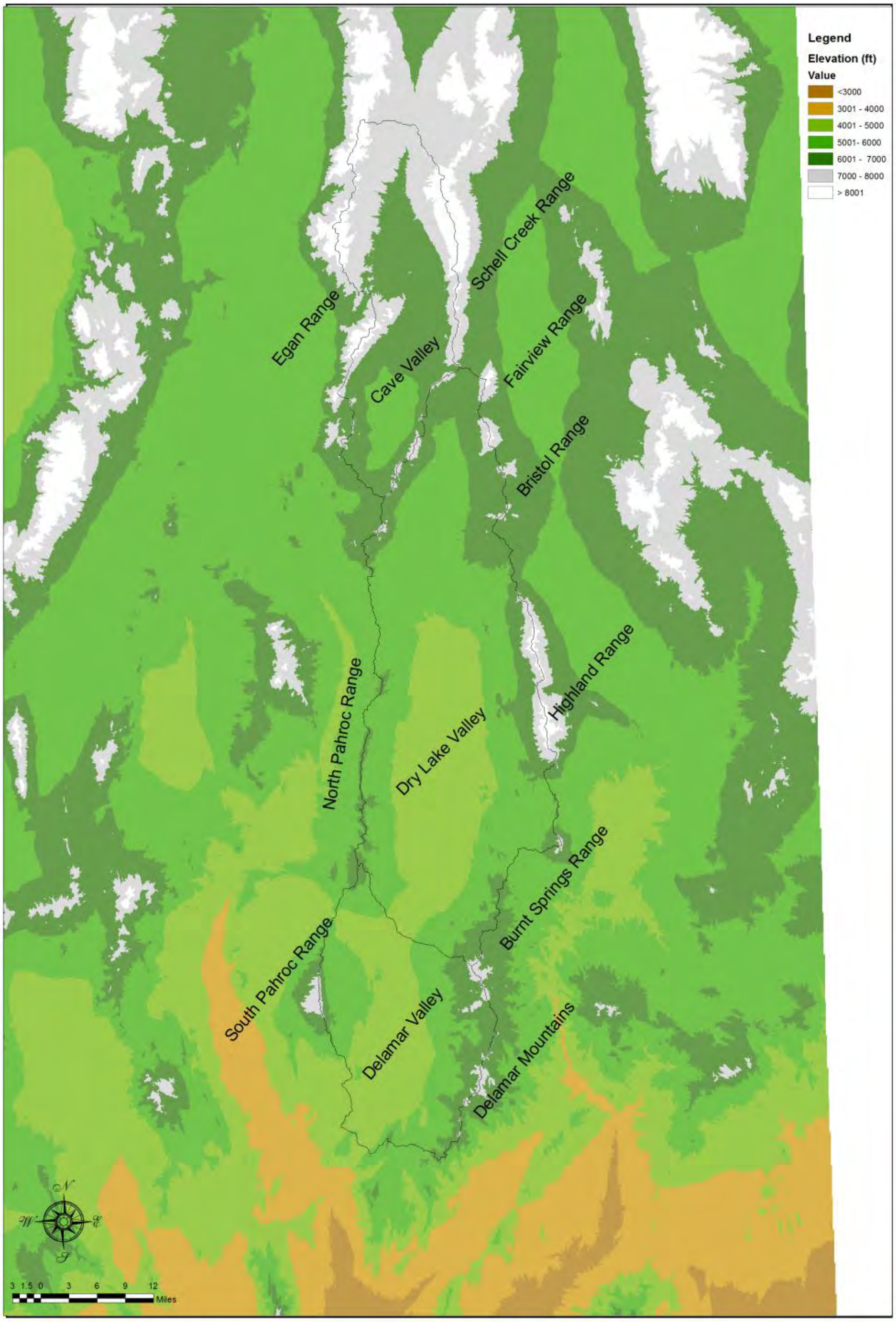

Figure 10. DDC area showing the mountain ranges that comprise the mountain block recharge areas for the three valleys.

Table 4. DDC area average isotopic values for mountain block recharge areas, valley groundwaters, and inflows and outflows to the valleys; and estimated recharge and evapotranspiration (ET) average annual rates, and outflow and inflow rates to valleys. δD and $\delta^{18}O$ values are in permil and recharge and ET values are in acre-feet per year. Recharge and ET values are from Burns and Drici (2011).

Site Name	δD	$\delta^{18}O$	Recharge/ET
	Cave Valley		
South Schell Creek Range	-105.0	-14.21	6,800
South Egan Range	-106.9	-14.15	6,900
Recharge to Cave Valley	-105.9	-14.18	13,700
ET from Cave Valley	-105.9	-14.18	1,300
Flow out of Cave Valley to southeastern White River Valley and northeastern Pahroc Valley	-105.9	-14.18	12,400
	Dry Lake Valley		
South Schell Creek Range	-100.9	-13.17	2,200
North Pahroc Range	-94.3	-12.39	1,000
Fairview Range	-99.5	-12.88	3,700
Bristol and Highland Ranges	-98.9	-13.28	7,600
Chief and Burnt Spgs Ranges	-94.6	-12.36	1,800
Recharge to Dry Lake Valley	-98.6	-13.02	16,300
Inflow to Dry Lake Valley from NE Pahroc Valley	-105.9	-14.18	2,000
ET from Dry Lake Valley			0
Flow out of Dry Lake Valley to Delamar Valley	-99.4	-13.15	18,300
	Delamar Valley		
Delamar Range	-92.4	-12.32	5,600
South Pahroc Range	-94.6	-12.81	1,000
Recharge to Delamar Valley	-92.8	-12.39	6,600
Inflow to Delamar Valley	-99.4	-13.15	18,300
ET from Delamar Valley			0
Flow out of Delamar Valley to Coyote Springs Valley	-97.6	-12.95	24,900

comparison, δD of groundwater for the five wells are within 2‰ of the average δD value of recharge to the valley and the values only vary by 1.6‰, although these values represent only one sample per well so the variability of groundwater isotopic values in these wells over time is not known. The $\delta^{18}O$ values of these wells varies by 0.52‰ and the most positive value is 0.43‰ more positive than the average recharge value, but all values fall within the range of recharge area spring values. Thus, although some of the groundwater δD and $\delta^{18}O$ values in Cave Valley fall outside the ideal range of recharge values, the isotopic data support local recharge from the mountain block recharge areas as the source of water in aquifers of the valley.

Although all available δD and $\delta^{18}O$ sample values are reported for wells drilled by SNWA in Appendix 1, if more than one sample is reported in Appendix 1 only the most recent sample is used in the evaluation of groundwater sources and flow paths. The most recent value is used instead of an average value, because a large amount of water from outside the valley was used to drill most of the wells and well development was likely not sufficient to remove this water in order to obtain representative isotopic values of groundwater in the aquifers (Jim Watrus, SNWA Hydrogeologist, oral communication, 2011). The most recent sample would have been collected after the most water had been pumped from the well and this sample would also have allowed time for any flushing of the well by water in the aquifer flowing through the well. These wells were drilled as observation wells to monitor groundwater levels rather than as potential production wells, so they were not extensively developed (Jim Watrus, SNWA Hydrogeologist, oral communication, 2011).

Lundmark et al. (2007), using a discrete-state compartment (DSC) model with δD as a calibration parameter, and based on the ability of Cave Valley's northern geologic boundary to allow groundwater flow between valleys (Welch et al., 2007), showed that Cave Valley could potentially receive groundwater flow from southern Steptoe Valley (the valley directly north of Cave Valley on Plates 1 and 2). However, the isotopic data presented in this report shows that little, if any interbasin flow enters Cave Valley from Steptoe Valley (Appendix 1 and Plate 2). If some groundwater does flow from southern Steptoe Valley to Cave Valley, then there would be water in addition to the local recharge in Cave Valley aquifers. Since the same mountain block recharge areas of Cave Valley extend north to form the western and eastern mountain block recharge areas of southernmost Steptoe Valley, recharge to these mountain blocks could have a similar isotopic composition as that of groundwater recharging Cave Valley. However, the average isotopic composition of groundwater recharging southern Steptoe Valley would be similar to groundwater recharging northern White River Valley because the two valleys receive recharge from the same part of the Egan Range. The average isotopic composition of this recharge is -112.3 and -15.15‰ for δD and $\delta^{18}O$, respectively (Thomas and Mihevc, 2007). These recharge isotopic values are 6.4 and 0.97‰ more negative than recharge to Cave Valley and Cave Valley groundwaters are slightly more positive than Cave Valley recharge. Thus, although recharge-area isotopic data do not preclude recharge to southernmost Steptoe Valley from flowing into Cave Valley, the amount of interbasin flow would be very limited based on the isotopic data.

Groundwater in Dry Lake Valley is derived from local recharge and potentially a small volume of flow (up to 2,000 afy) from northeast Pahroc Valley into northwest Dry Lake Valley (Burns and Drici, 2011). Recharge to Dry Lake Valley aquifers is received from the southern Schell Creek, north Pahroc, Fairview, Bristol, Highland, Chief, and Burnt Springs ranges (Plate 1 and Figure 10; Thomas and Mihevc, 2007; Burns and Drici, 2011). The total amount of recharge from the six mountain block recharge areas is 16,300 afy (Burns and Drici, 2011) with average δD and $\delta^{18}O$ values of -98.0 and -12.97‰, respectively. These recharge weighted average δD and $\delta^{18}O$ values are obtained by multiplying the average isotopic values for the recharge areas (Table 2) by the amount of recharge, adding up these values, and then dividing by the total amount of recharge to the valley (Table 4).

There are four wells in Dry Lake Valley that have been sampled for isotope analysis that can be used to evaluate the sources of groundwater for Dry Lake Valley aquifers. Along the northwest boundary of Dry Lake Valley that adjoins Pahroc Valley, the Fugro Dry Lake Valley Deep Well (Appendix 1 and Plate 1; site 179) was drilled and extensively developed by Fugro (a company that drilled the well for the proposed MX missile program). This well contains groundwater with average δD and $\delta^{18}O$ values of -107.5 and -14.16‰, respectively (Appendix 1). This groundwater contains significantly more negative isotopic values than the local recharge to northern Dry Lake Valley from the adjacent southern Schell Creek Range (Table 2; -100.9 and -13.17‰). The isotopic values of this groundwater are similar (within 2.0‰ δD and 0.2‰ $\delta^{18}O$) to that of groundwater flowing out of southwest Cave Valley to northeastern Pahroc Valley (-105.9 and -14.18‰). This similarity in δD and $\delta^{18}O$ values supports the hydrogeologic interpretation that groundwater flows from southwestern Cave Valley into northeastern Pahroc Valley. The hydrogeologic framework also supports groundwater flow from southern White River Valley to northern Pahroc Valley (Burns and Drici, 2011), so this could also be a source of groundwater flow from northeastern Pahroc Valley to northwestern Dry Lake Valley. However, any contribution of this flow reaching northern Dry Lake Valley would be limited because Thomas and Mihevc (2007) calculated groundwater flowing out of southern White River Valley would have an isotopic content of -113.6 and -15.04‰, which is significantly more negative than water in the Fugro well. The Fugro well in Dry Lake Valley (Appendix 1 and Plate 1; site 179) is located near the Dry Lake Valley-Pahroc Valley topographic divide (Plate 1), so groundwater in this area may continue to flow to the southwest into northeast Pahroc Valley or some (up to 2,000 afy) may flow southeast into central Dry Lake Valley.

Two wells located in central Dry Lake Valley, one on the east side of the valley (Vidler well PW-1; Appendix 1 and Plate 1; site 636) and one on the west side of the valley (SNWA well 181M-1; Appendix 1 and Plate 1; site 603) contain groundwater with δD and $\delta^{18}O$ values of -101 and -13.4‰ and -105.0 and -13.62‰, respectively. The hydrogeology indicates that these wells should receive most of their water from the southern Schell Creek, Fairview, Bristol, and Highland ranges (Burns and Drici, 2011). The recharge weighted average δD and $\delta^{18}O$ values for these four mountain block recharge areas is -99.4 and -13.15‰, respectively (Table 4). The isotopic values of water in the Vidler PW-1 well are very similar to the recharge values (1.6 and 0.25‰ different in δD and $\delta^{18}O$, respectively), so the isotopic data support the source of this water being local recharge. In contrast, the isotopic data for the SNWA well does not support local recharge as the main source of this water because the values are 5.4 and 0.47‰ more negative than the local recharge water. Local recharge to the adjacent northern Pahroc Range is even more positive than for the four northern recharge areas (Table 4), so this is not the source of the majority of water in this well either. This water may represent interbasin flow in the carbonate-rock aquifer. The δD value of this groundwater is only 0.9‰ more positive than groundwater inflow from northeast Pahroc Valley, but the $\delta^{18}O$ value is 0.56‰ more positive so only the δD value would support this groundwater being interbasin flow. Because this well is a new SNWA well that has not been extensively developed (Jim Watrus, SNWA Hydrogeologist, oral communication, 2011), the water in this well may contain mostly water used in drilling the well rather than primarily native groundwater in the aquifer.

SNWA well 181W909M and well SK-18 (Appendix 1 and Plate 1; sites 604 and 134) are located in the southern part of Dry Lake Valley, so their isotopic data can be used to evaluate the source(s) and flow paths of water in this part of the valley. The δD and $\delta^{18}O$ values for SNWA well 181W909M are -104.6 and -13.50‰, respectively. These values are significantly less than average recharge values for Dry Lake Valley (Table 4), so this sample may represent interbasin flow in the carbonate-rock aquifer (1.3 and 0.68‰ more positive in δD and $\delta^{18}O$, respectively, as compared to inflow from northeastern Pahroc Valley). The groundwater in this well has similar isotopic values of that of SNWA well 181M-1, so like groundwater in well 181M-1 the δD value would support interbasin flow, but the $\delta^{18}O$ value does not. This well also has not been extensively developed so the water in this well likely contains mostly water used in drilling the well rather than primarily native groundwater in the aquifer. Water in well SK-18 has a δD value of -95‰ (Kirk and Campana, 1990). Unfortunately, this sample does not have a $\delta^{18}O$ value, so it cannot be determined if groundwater in this well is significantly evaporated. If this groundwater has not undergone significant evaporation, then it is similar to the δD value of the average recharge to the valley and almost the same as recharge to the Chief, Burnt Springs and North Pahroc ranges in the southern part of the valley (Table 4). Thus, this sample indicates that local recharge to Dry Lake Valley is the primary source of groundwater in this part of the valley.

The hydrogeology of the DDC area indicates that groundwater in Delamar Valley is derived from interbasin flow from Dry Lake Valley and local recharge (Thomas and Mihevc, 2007; Burns and Drici, 2011). There are two wells with isotopic data that are available to evaluate groundwater sources and flow paths in Delamar Valley. These wells are SNWA well 182M1 (Appendix 1 and Plate 1; site 606) with δD and $\delta^{18}O$ values of -109.6 and -14.07‰, respectively, and SNWA well 182W906M (Appendix 1 and Plate 1; site 607) with δD and $\delta^{18}O$ values of -100.7 and -13.40‰, respectively. The water in well 182W906M is isotopically similar to the mixture of inflow from Dry Lake Valley with local recharge to Delamar Valley, but it is 3.1 and 0.45‰ more negative in δD and $\delta^{18}O$, respectively (Table 4), than the mixture of water in Delamar Valley. Thus, the isotopic data of groundwater in this well supports a mixture of local recharge and interbasin flow from Dry Lake Valley as the main source of water in this well. The slightly more negative isotope values may indicate more interbasin flow than local recharge reaches this well as presented in Table 4, or more likely that water used to drill the well has not been completely removed from the aquifer. The water in well 182M1 is likely almost all water used in drilling the well, since the isotopic data is similar to the isotopic values of the water used in drilling this well (Pahranagat Valley water) and the well has undergone little development because it is a low yielding well drilled for water level observation rather than water production (Jim Watrus, SNWA Hydrogeologist, oral communication, 2011).

In summary, δD and $\delta^{18}O$ data show that groundwater in the DDC area is supplied by local recharge from the mountain block recharge areas of the valleys. There is little, if any, interbasin flow from Steptoe Valley to the north into the most upgradient of these three valleys, Cave Valley. Groundwater in Cave Valley is derived from local recharge to the valley. Groundwater flows out of Cave Valley into southeastern White River Valley and northeastern Pahroc Valley. All of the groundwater in Dry Lake Valley is derived from local recharge to the valley, except for the potential of up to 2,000 afy of inflow to northwest Dry Lake Valley from northeast Pahroc Valley. All groundwater in Dry Lake Valley flows down gradient to the south to Delamar Valley. Delamar Valley aquifers also receive groundwater recharge from mountain block recharge areas in the valley that mixes with the groundwater flowing into the valley from Dry Lake Valley. All groundwater in the valley flows south out of southern Delamar Valley to northern Coyote Springs Valley. Although, some groundwater may flow southwest out of Delamar Valley along the Pahranagat Valley Shear Zone into the very southern part of Pahranagat Valley before flowing into northern Coyote Springs Valley (Burns and Drici, 2011). Potential groundwater flow from the DDC area to adjacent valleys is described in more detail in following sections of this report.

Potential Groundwater Flow from the DDC Area to White River Valley

The WRFS (Figure 1) was originally described by Eakin (1966). Eakin postulated that some of the water discharging from the Muddy River Springs area in Upper Moapa Valley originated more than 200 miles north of the spring area and that this regional interbasin flow system 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 of the WRFS, (2) recharge and discharge estimates balance within the flow system, and (3) the principal discharging springs (warm springs in this report) have a uniform discharge rate, indicating a regional rather than local water source.

As noted earlier in this report, based on structural and geologic controls, groundwater in northwestern Cave Valley flows southwest into southeastern White River Valley (Burns and Drici, 2011; Rowley and Dixon, 2011). In southeastern White River Valley, three springs—Emigrant (site 207), Butterfield (site 202), and Flag #3 (site 201)—are located along the range-bounding fault on the east side of the valley (Plate 1). Flag Spring #3 has a water temperature of 22.8^{o}C; but because of its location, and similar isotopic and water chemistry content to that of Emigrant and Butterfield springs (Appendix 1); it is included with the other two cool springs along the range- bounding fault in our analysis. These three springs have isotopic values that range from -107.8 to -105.0‰ for δD and -14.50 to -14.20‰ for $\delta^{18}O$. These values are similar to the average isotopic composition of recharge to the southern Egan Range in southern White River Valley and western Cave Valley, δD and $\delta^{18}O$ of -106.9 and -14.15‰, respectively (Table 4; Appendix 1; Thomas and Mihevc, 2007). Thus, the southern Egan Range is the most likely source of water supplying these springs (Plates 1 and 2; Figure 10). This includes recharge from the Egan Range to northwestern Cave Valley which could flow into southeastern White River Valley along the Shingle Pass fault system. Thus, outflow from northwestern Cave Valley could supply some of the flow observed at Emigrant, Butterfield and Flag #3 springs in southeastern White River Valley.

Two warm springs in southern White River Valley, Hot Creek Spring (site 197) and Moon River Spring (site 192) (Appendix 1; Plates 1 and 2), could potentially contain groundwater from Cave Valley since there is outflow from northwestern Cave Valley to southeastern White River Valley. The isotopic composition of these two warm springs ranges from -120.0 to -118.9‰ for δD and -15.80 to -15.69‰ for $\delta^{18}O$. Since the average isotopic composition of northwestern Cave Valley groundwater outflow (recharge to the southern Egan Range) is -106.9‰ for δD and -14.15‰ for $\delta^{18}O$, little, if any, Cave Valley groundwater could be supplying flow to these two warm springs. Additionally, local recharge to southern White River Valley from the southern Egan and Grant Ranges has average δD values ranging from -106.9 to -106.5‰ and $\delta^{18}O$ values ranging from -14.23 to -14.15‰ (Thomas and Mihevc, 2007), so this also is not a source of water for the regional warm springs. Thus, the source of the southern White River Valley warm springs is groundwater from the north of this area that has more negative isotopic values (Thomas and Mihevc, 2007; Appendix 1 and Plate 2 this report).

Potential Groundwater Flow from the DDC Area to Pahranagat Valley

The regional warm springs in Pahranagat Valley discharge interbasin flow from several valleys. Pahroc Valley is the valley directly upgradient from Pahranagat Valley and it receives inflow from Cave, White River (which receives inflow from Jakes, Long, and southern Butte valleys), and Coal (which receives inflow from Garden Valley) valleys (Figure 1; Thomas and Mihevc, 2007). Thus, some of the groundwater discharging from Hiko (site 122), Crystal (site 116), Ash (site 110), and Little Ash (site 111) warm springs in Pahranagat Valley (Plate 1) likely originates in Cave Valley. Groundwater flow from northwestern Cave Valley to southeastern White River Valley is discharged by cool springs along the range-bounding fault of the Egan Range and is lost by evapotranspiration in the valley, so little, if any, of this groundwater would flow into Pahranagat Valley. Groundwater flow from southwestern Cave Valley that enters northeastern Pahroc Valley likely becomes part of the mixture of regional groundwater flow in the WRFS that contributes to groundwater inflow into Pahranagat Valley. Part of the groundwater inflow to Pahranagat Valley discharges from Pahranagat Valley warm springs, although the sources and flow paths of groundwater supplying the Pahranagat Valley warm springs are not well understood (Thomas and Mihevc, 2007). Groundwater flowing out of southwest Cave Valley has δD and $\delta^{18}O$ values of -105.9 and -14.18‰, respectively (Table 4). These values fall within the range of δD values -112.0 to -105.0‰ and $\delta^{18}O$ values -15.30 to -13.80‰ for the Pahranagat Valley warm springs and are similar to the average values of -108.5 and -14.27‰ for these springs (Table 3). Thus, the isotopic data indicate that some of the groundwater flowing out of southwestern Cave Valley likely contributes to Pahranagat Valley warm spring discharge. Some groundwater originating in Cave Valley likely flows south past the Pahranagat Valley warm springs as part of the mixture of regional groundwater flow in the WRFS.

RECHARGE TIMING AND GROUNDWATER TRAVEL TIMES

Understanding the timing of recharge to springs in the mountain block recharge areas and the time it takes groundwater to flow (travel time) from recharge areas to valleys and between valleys (interbasin flow) is important for determining if δD and $\delta^{18}O$ data in the WRFS represent current climatic conditions or past cooler and wetter climatic conditions. If groundwater discharging from regional warm springs contains a significant amount of groundwater recharged during a past cooler climate then the δD and $\delta^{18}O$ data used for determining sources and flow paths would need to be adjusted to account for more negative recharge isotopic values during this time.

Recharge Timing Based on Stable Isotope and Tritium Data

δD and $\delta^{18}O$ data for regional groundwater flow systems can be used to evaluate recharge timing irrespective of whether a regional flow system is responding to current climatic conditions or past climatic conditions. If recharge and discharge rates and flow directions are known for a regional groundwater flow system, then δD and $\delta^{18}O$ data can be used to evaluate if a flow system contains a significant amount of groundwater flowing through it that was recharged during a past (i.e., different) climatic condition. For the WRFS, the most recent past climatic condition that would have significantly different δD and $\delta^{18}O$ recharge values than present day conditions would be the cooler and wetter last glacial period, which ended about 12,000 to 16,000 years ago in southern Nevada. If the four main regional warm spring areas of the WRFS were discharging a significant amount of water from the last glacial period, then the isotopic composition of the springs would be at a minimum 10 and 1.2‰ more negative in δD and $\delta^{18}O$ composition, respectively, than present day recharge (Winograd et al., 1992; 2006), and could be as much as 16 and 2.0‰ more negative (Benson and Klieforth, 1989). Thus, if any significant portion of groundwater in the WRFS was recharged during the last glacial period, regional warm springs would be 10 to 20‰ more negative in δD and 1.0 to 2.0‰ more negative in $\delta^{18}O$ than present day values.

δD and $\delta^{18}O$ groundwater data for the WRFS combined with recharge and ET estimates (Thomas and Mihevc, 2007; Burns and Drici, 2011) show that the WRFS is responding to current climate conditions and not a past wetter and cooler climate. This is supported by the fact that if warm springs in the WRFS were discharging a significant amount of groundwater recharged under a cooler and wetter climate than the current climate, the isotopic values of the regional spring discharge would be significantly more negative than is currently measured. These regional warm springs are supported by interbasin flow that has groundwater with isotopically more negative values than the local recharge (Thomas and Mihevc, 2007). Thus, regional warm springs would have significantly more negative values than is measured today. Even during wetter climatic periods, there would not be sufficient local recharge to Pahranagat and Upper Moapa valleys to supply the warm spring discharge in these valleys, so interbasin flow would be needed to maintain even current flow conditions at these regional spring discharge areas, much less the increased flow expected for a cooler and wetter climate.

Tritium can be used to determine if recharge area springs are representative of present day climate conditions and also if present day recharge is entering valley aquifers. Groundwater that contains measureable tritium indicates that the water is less than about 60 years old and thus would represent present day climatic conditions. Tritium may also indicate mixing of young (< 60 year old) groundwater with older groundwater. Tritium data for groundwater in the WRFS shows that springs in mountain block recharge areas are discharging groundwater that was recharged within the last 60 years, because they contain measurable tritium (Thomas et al. 1996; Hershey et al., 2007). Lund, Butterfield, and Emigrant springs on the valley floor along the eastern side of White River Valley and Cave Spring in Cave Valley contain 1.2 to 17.4 tritium units (TU) of tritium (Table 5; Hershey et al., 2007), indicating that mountain block recharge that is < 60 years old is entering the valley aquifers. In contrast, none of the regional warm springs has tritium above 1.0 tritium units, indicating that all of the water discharging from regional warm springs was recharged before the early 1950s (Table 5).

Table 5. Tritium and carbon isotope data (when more than one sample is used to obtain a value, the number of samples is shown in parentheses and the reported value is an average value for all the samples and for the warm springs is weighted by the flow rates) and saturation indices for calcite, dolomite, and gypsum calculated in NETPATH. Mineral saturation indices (SI) values are negative for under saturation (mineral will dissolve) and positive for over saturation (mineral will precipitate from the water).

Site Name	Tritium (TU)	Carbon-13 (permil)	Carbon-14 (pmc)	Calcite (SI)	Dolomite (SI)	Gypsum (SI)
Recharge Groundwaters						
Lund Spring	1.9	-8.1	41.6	0.14	0.16	-2.62
Emigrant Spring	17.4	-9.2	55.7	-0.14	-0.45	-2.46
Butterfield Spring	1.2	-8.5	30.3	-0.18	-0.46	-2.81
Ave spring recharge	6.8 (3)	-8.60 (3)	42.5 (3)	-0.06	-0.24	-2.61
Northern White River Valley Warm Springs						
Preston Big Spring	<1	-5.7	11.2	-0.08	-0.19	-2.18
Nichols Spring	NA	-5.7	6.5	0.13	-0.23	-2.17
Preston Cold Spring	NA	-5.6	2.2	-0.11	-0.22	-2.20
Ave N. WRV warm Springs	<1 (1)	-5.69 (3)	9.2 (3)	0.00	-0.02	-2.18
Southern White River Valley Warm Springs						
Hot Creek Spring	<1	-4.26 (2)	5.0 (2)	0.02	0.03	-2.03
Moon River Spring	NA	-5.0	6.4	0.18	0.38	-2.06
Ave S. WRV warm springs	<1 (1)	-4.42 (2)	5.3 (2)	0.01	0.01	2.03
Pahranagat Valley Warm Springs						
Hiko Spring	<1	-6.45 (2)	6.1 (2)	0.23	0.52	-2.18
Crystal Spring	<1	-6.57 (4)	7.3 (3)	0.01	0.09	-2.24
Ash Spring	<1	-6.70 (2)	6.3 (3)	0.04	-0.10	-2.24
Ave Pahranagat V warm springs	<1 (3)	-6.61 (3)	6.6 (3)	-0.02	0.01	-2.23
Upper Moapa Valley Warm Springs						
Big Muddy Spring	<1 (2)	-5.90 (2)	8.2 (2)	0.00	0.03	-1.47

Carbon-14 Corrected Groundwater Ages and Travel Times

Cave, Dry Lake, and Delamar valleys are located within the larger WRFS and contribute to the overall groundwater resources of the WRFS. Understanding the time it takes groundwater to flow from recharge areas to valleys and between valleys (interbasin flow) within the WRFS is important for managing these groundwater resources. To estimate the time it takes groundwater to flow through aquifers in the WRFS, groundwater ages corrected for geochemical reactions and physical processes were determined by geochemical modeling using major ion chemistry and carbon-13 and carbon-14 isotopic data. The computer model NETPATH (Plummer et al., 1994; El-Kadi et al., 2010) was used to calculate carbon-14 corrected groundwater ages. Determining groundwater travel times in a regional flow system like the WRFS is complicated because every valley in the WRFS has local groundwater recharge that mixes with interbasin flow as groundwater flows from north to south down the

WRFS. Thus, groundwater travel times represent a central tendency of the actual recharge time for each recharge event. To evaluate groundwater travel times in the WRFS, carbon-14 corrected groundwater ages were determined for the four main warm spring discharge areas of the WRFS (see Thomas et al., 1996 and Hershey et al. 2007, for a detailed description of how carbon-14 corrected ages are calculated). Calculating carbon-14 corrected ages for regional warm springs is an effective way to evaluate groundwater travel times because these warm springs represent a mixture of up-gradient groundwaters that have traveled both a long distance -- generally tens of miles -- and to great depth -- generally thousands of feet -- before being discharged from the spring.

Groundwater carbon-14 data, reported as percent modern carbon (pmc), needs to be corrected for geochemical reactions and physical processes involving carbon in order to determine a realistic groundwater age. Some laboratories report carbon-14 ages for carbon-14 groundwater values, but these ages should never be used as groundwater ages because they do not account for reactions and processes that affect carbon-14 concentrations in the groundwater. For example, warm springs discharging from regional carbonate-rock aquifers in Ash Meadows in southern Nevada contain only 2 to 4 pmc carbon-14 (with one spring reaching 11 pmc), but these groundwaters are at most several thousand years old and could be as young as 1,000 years old (Winograd et al. 1992; 2006; Thomas et al., 1996). Thus, low carbon-14 values (< 15 pmc) in regional warm spring waters of the WRFS, which could indicate that these waters are more than 20,000 years old (Table 5; Thomas et al., 1996; Hershey et al., 2007), need to be corrected for geochemical reactions and physical processes in order to obtain realistic groundwater ages.

To obtain realistic groundwater ages using carbon isotope data (carbon-14 corrected ages), the dissolution of calcite and dolomite that comprise the carbonate-rock aquifers, dissolution or outgassing of CO_2, and adsorption and diffusion processes that remove carbon-14 from groundwater must be considered. Dissolution of calcite and dolomite add carbon to the water that contains no carbon-14. CO_2 may outgas or dissolve depending on the conditions near the spring area, but once water passing through the unsaturated zone (water will react with CO_2 gas in the unsaturated zone) reaches the saturated zone (i.e., the water table of an aquifer) there should be no additional dissolution or outgassing of CO_2 along a flow path, until the groundwater is discharged at the spring where some CO_2 may exsolve (degas from the water). Adsorption and diffusion processes can remove carbon-14 from groundwater (Hershey and Howcroft, 1998; Hershey et al., 2003; 2007). These reactions and processes involving phases that contain carbon (and carbon-13 and carbon-14 isotopes), need to be accounted for to obtain carbon-14 corrected groundwater ages. Regional warm springs in the WRFS are a mixture of flow that is contributed all along the regional flow system from many different recharge areas and valleys, so the age of water discharging from warm springs is an average age. Thus, a small percent of the water discharging from regional warm springs could have been recharged during the last glacial (or similar) period when the climate was cooler and wetter. However, the δD and $\delta^{18}O$ data; recharge and discharge estimates; and interbasin flow supported by the hydrogeologic framework for the WRFS do not support any significant amount of recharge from a cooler and wetter climate (this report; and Thomas et al., 1996, 2001; Thomas and Mihevc, 2007; Hershey et al., 2007).

Carbon-14 and carbon-13 isotopes of inorganic carbon dissolved in groundwater can be used to estimate groundwater ages by using geochemical models that account for all reactions and processes involving carbon from a recharge area to a sample location along a flow path. The change in isotopic composition between phases, such as differences in carbon-13 and carbon-14 values between carbon dissolved in water and calcite precipitated from water, is called isotopic fractionation. Groundwater ages calculated using geochemical models that account for changes in water chemistry and isotopic fractionations along a flow path, and from mixing of waters with different chemistries, are called carbon-14 corrected ages. These model calculated ages are called carbon-14 corrected ages because they account for the addition or removal of carbon (and carbon-14) to the groundwater and the changes (fractionations) of the isotope values as they change from one phase to another. Geochemical models that calculate carbon-14 corrected groundwater ages are only valid if the modeled carbon-13 value matches the carbon-13 value measured in the groundwater sample at the end of the flow path. Carbon-14 is radioactive and naturally decays over time, whereas carbon-13 is stable and does not decay (change) over time. The only way that a carbon-13 concentration can change is by mixing two, or more, waters with different carbon-13 values or by geochemical reactions that add or remove carbon to or from the water. Carbon-13 will fractionate as it reacts and moves from one phase to another; for example carbon dissolved in water can precipitate as calcite, and this can easily and accurately be accounted for if the pH, temperature and dissolved carbon content of the water sample is known (Deines et al., 1974; Wigley et al., 1978; Mook, 1980; Plummer et al., 1983; 1994).

Carbon-14 corrected groundwater ages and travel times have been previously calculated by Thomas et al. (1996) and Hershey et al. (2007) for groundwater discharging from regional warm springs in the WRFS. Thomas et al. (1996) and Hershey et al. (2007) used the same approach as was used in this report for calculating groundwater ages. Groundwater ages calculated for regional warm springs in Pahranagat and Upper Moapa valleys ranged from 4,800 to 8,500 years (Thomas et al., 1996; Table 18 model 3 and Figure 26). Groundwater travel time from the warm springs in northern White River Valley to the warm springs in southern White River Valley, based on groundwater ages calculated for a mixture of water containing 40 to 60 percent recharge water (with modern carbon-14 values of about 100 pmc) with northern White River Valley warm spring water, produced an average groundwater travel time for this mixture of water of 12,000 to 16,000 years (Hershey et al., 2007).

The NETPATH models used in this study are based on the same assumptions as those used by Thomas et al. (1996) and Hershey et al. (2007). The only difference in the NETPATH models used in this study, besides any new data that would be included in Table 3 and Appendix 1, is a simpler model using only calcite, dolomite, CO_2 gas, and gypsum. This simpler model was used because the goal of this study was to determine the carbon-14 corrected groundwater age and not to explain all major ion chemistry changes in the water along flow paths of the WRFS. Gypsum was included in this simple carbon model to account for calcium added to the water by gypsum dissolution, which can result in more calcite precipitation and dolomite dissolution. This process of gypsum dissolution producing more calcite precipitation and dolomite dissolution is called dedolomitization (Back et al., 1983). The water chemistry data used for NETPATH modeling is the average water chemistry for a site using the data presented in Appendix 1. The carbon isotope data used for the NETPATH modeling is presented in Table 5 and is from USGS, DRI, and SNWA sample collection and analysis at USGS, DRI, and the University of Arizona isotope laboratories.

Carbon-14 age dating model results are presented in Table 6. Columns two through five in the table present the mass transfer of calcite, dolomite, gypsum, and CO_2 gas needed to produce the water chemistry for the regional warm springs from an initial carbonate recharge water (see next paragraph for a description of this water). Minerals that are under saturated in the water [negative saturation indices (SI) values in Table 5] should dissolve, and those that are saturated (positive SI values) should precipitate from the water. The NETPATH model results in Table 6 are supported by the SI values in Table 5. Similar to the modeling approach used by Thomas et al. (1996) and Hershey et al. (2007), if carbon is added to the water along a flow path (a positive CO_2 mass transfer value > 0.30 millimoles per liter) this amount of carbon was added to the recharge water. The reason this CO_2 carbon is added to the recharge water is because once the water becomes isolated from the unsaturated zone, there should be little, or no, interaction with unsaturated zone CO_2 gas, and a previous study has shown that there is likely CO_2 outgassing in some of the recharge spring areas (Thomas et al., 1996). Column six in Table 6 shows the amount of calcite that is exchanged between the water and the aquifer (calcite dissolved and precipitated due to temperature and pressure changes as groundwater flows through the regional aquifers) to obtain modeled carbon-13 values that match measured values.

Table 6. NETPATH model results showing the mass transfer of calcite, dolomite, gypsum, and CO_2 gas in millimoles per liter (positive values indicate that the phase is entering the water and negative values indicate that the phase is being removed from the water). The carbon-14 corrected age is the age calculated after correcting for all carbon entering or leaving the water along the flow path and the fractionations associated with these reactions. All flow paths use the recharge waters listed in Table 3 as the initial water chemistry for a flow path. The final water along the flow path is listed in this table. A carbon-14 corrected age that is modern is less than about 1,000 years old.

Final Flow Path Site	**Calcite (mmoles/L)**	**Dolomite (mmoles/L)**	**Gypsum (mmoles/L)**	**CO_2 (mmoles/L)**	**Calcite cycled (mmoles/L)**	**Corrected Carbon-14 age (years)**
Northern White River Warm Springs	-0.51	-0.14	0.29	-1.15	1.3	10,000
Southern White River Warm Springs	-0.27	-0.05	0.36	0.24	>10	modern
Pahranagat Valley Warm Springs	-0.41	-0.12	0.24	0.20	4.2	8,700
Big Muddy Warm Spring	-1.82	0.16	1.85	0.00[a]	6.5	3,300

a—The original NETPATH model for Big Muddy Warm Spring had 1.25 mmoles/L of CO_2 being added to the water along the flow path. So in following the Thomas et al. (1996) and Hershey et al. (2007) modeling approach, this amount of CO_2 was added to the recharge waters so that the amount of CO_2 mass transfer along the flow path is 0.00 mmoles/L.

All of the NETPATH models assume that the water chemistry and isotope values of Lund, Emigrant, and Butterfield springs (Table 5), which are located along the eastern side of White River Valley, are representative of present day recharge to carbonate aquifers of the WRFS. These springs were chosen to represent groundwater recharging the carbonate rock aquifers of the WRFS because: 1) they occur along the eastern range-bounding fault of White River Valley so they represent recharge from the carbonate rock-dominated Egan Range that flows from the mountain block into the carbonate rock aquifers of the WRFS; 2) all three springs contain measureable tritium (Table 5), indicating that these groundwaters have been recharged since the 1950s; 3) they have carbon-14 and carbon-13 values in the ranges expected for recharging groundwaters that have been isolated from atmospheric CO_2 gas, and dissolved calcite and dolomite; 4) they have δD and δ18O values that represent local recharge to the adjacent Egan Range; and 5) groundwater flow from these springs, at least for Lund Spring, is highly variable indicating that they respond to local recharge from the adjacent mountains.

The carbon-14 corrected groundwater ages range from modern (< 1,000 years old) to 10,000 years old. These ages represent the average age of groundwater discharging from the regional warm springs. The discharge-weighted average carbon-14 values of the four regional warm springs in the WRFS range only from 5.3 to 9.2 pmc, but carbon-13 values range from -6.61 to -4.42 permil. This range in carbon-13 values for groundwaters that have similar chemistries results in this about 10,000 year range of groundwater ages. Of note, it is the more positive carbon-13 values of the southern White River Valley warm spring waters (Table 5), as compared to the other warm spring area groundwaters, which result in this warm spring area having a carbon-14 corrected age that is modern. It is important to consider that these carbon-14 corrected groundwater ages likely overestimate the age of the groundwater flowing from the regional warm springs because they do not account for diffusion processes which have been shown to be important in carbonate rock aquifers in southern Nevada (Hershey and Howcroft, 1998; Hershey et al., 2003; 2007). Correcting the model ages for diffusion processes is beyond the scope of this report.

If groundwater flowed from northern White River Valley warm springs to Big Muddy Springs in Upper Moapa Valley without any recharge being added along this flow path then the difference in groundwater ages of these springs could be used to determine groundwater travel times in the WRFS. However, local recharge water within each basin mixes with interbasin flow between warm spring discharge areas. This is observed by water balance studies and supported by the fact that δD and $\delta^{18}O$ values become more positive in WRFS warm springs as groundwater flows from north to south down the WRFS (Thomas and Mihevc, 2007). Thus, carbon-14 corrected groundwater ages represent the mixture of recharge and interbasin flow groundwater at a regional warm spring and provide a range for the time that it takes groundwater to flow from recharge areas to regional warm springs and for interbasin flow from one warm spring area to another within the WRFS.

SUMMARY AND CONCLUSIONS

Deuterium and oxygen-18 data were used to evaluate groundwater sources and flow paths in the DDC area. In order to use δD and $\delta^{18}O$ data for groundwater source and flow path evaluations they need to; (1) show a range throughout the study area so that different recharge areas have different isotopic signatures; (2) have little variability within a recharge area; and (3) the isotopic signature in recharge areas has to be similar to the signature of the past. Temporal and spatial isotopic variability were evaluated in this study.

Temporal isotopic variability of four recharge area monitoring springs within the WRFS was relatively small with standard deviations of δD and $\delta^{18}O$ data ranging from 0.7 to 1.1‰ and 0.07 to 0.11‰ (except for one site with a value of 0.33‰), respectively. The range in standard deviation for the four sites is for samples taken quarterly throughout all four seasons; and with one site having 7 years of data and two of the three sites having 6 years of data. The isotopic composition of these springs varied little from season to season even though spring flow ranged from about 100 to 5,000 gallons per minute. This lack of temporal isotopic variability of recharge area springs is important because recharge area springs are used to determine the sources of groundwater in the DDC area.

Temporal isotopic variability of 10 regional warm springs in the WRFS is relatively small with the standard deviation of δD and $\delta^{18}O$ data ranging from 0.5 to 1.9‰ and 0.05 to 0.21‰ (except for one site with a standard deviation of 0.67‰), respectively. This range in values is for samples taken throughout all four seasons, with some regional warm spring data extending over 40 years and a significant number of springs having data that spans 20 to 25 years. This lack of temporal isotopic variability of regional warm springs is important for evaluating potential groundwater flow from the DDC area to the Hot Creek Spring area in southern White River Valley and regional warm springs in Pahranagat Valley.

Spatial isotopic variability within the mountain block recharge areas of the DDC area shows that the spatial variability is greater than the temporal variability. The range in standard deviation of spring isotopic values for nine mountain block recharge areas is 1.8 to 4.2‰ for δD and 0.35 to 0.70‰ for $\delta^{18}O$.

The relationship of stable isotopes with altitude was evaluated for four major recharge areas in the study area with 14, or more, springs. These four recharge areas include the White Pine and Central Egan ranges in the northern part of the study area, the Fairview and Bristol ranges in the central part of the study area, and the Delamar Mountains in the southern part of the study area. There is only very weak relationships of δD with altitude in three of the four recharge areas (R^2 values of 0.066, 0.018, and 0.026), and the strongest correlation (0.066) was for an increase in isotopic values with increasing altitude (the opposite relationship is expected, that is more negative δD values with increasing altitude). The southernmost and lowest altitude recharge area, the Delamar Range, showed a correlation of more negative δD with increasing altitude with an R^2 value of 0.366. This lack of a relationship between isotopic values and altitude in recharge areas, for most of the recharge areas, is important because the average isotopic composition of all sites in a recharge area can be used to determine the isotopic signature for a recharge area.

The average δD and $\delta^{18}O$ values for recharge areas, weighted by the amount of recharge for each individual mountain block, were calculated to determine the average isotopic values of local recharge to a valley. These average values were compared with valley groundwater values to evaluate sources and flow paths of groundwater in the DDC area and to adjacent valleys. δD and $\delta^{18}O$ data show that groundwater in the DDC area is supplied by local recharge from the mountain block recharge areas of the valleys. There is little, if any, interbasin flow into the most upgradient of these three valleys, Cave Valley. Groundwater flows out of Cave Valley into southeastern White River Valley and northeastern Pahroc Valley. Potentially a small amount (up to 2,000 acre-feet per year) of groundwater may flow into northwest Dry Lake Valley from northeast Pahroc Valley. All of the groundwater in Dry Lake Valley is derived from local recharge to the valley, except for the potential of up to 2,000 afy of inflow to northwest Dry Lake Valley. There is no groundwater ET in Dry Lake Valley (Burns and Drici, 2011), so all groundwater in Dry Lake Valley flows down gradient to the south to Delamar Valley. Delamar Valley aquifers also receive groundwater recharge from mountain block recharge areas in the valley that mixes with the groundwater flowing into the valley from Dry Lake Valley. There is no groundwater ET in Delamar Valley (Burns and Drici, 2011), so all groundwater in the valley flows south out of southern Delamar Valley to northern Coyote Springs Valley. Although, some groundwater may flow southwest out of Delamar Valley along the Pahranagat Valley Shear Zone into the very southern part of Pahranagat Valley before flowing into northern Coyote Springs Valley.

Isotopic data show that groundwater originating in the DDC area supplies little, if any, water to the warm springs in southern White River Valley. These data also show that groundwater discharging from warm springs in Pahranagat Valley are a mixture of waters recharged in numerous valleys north of Pahranagat Valley, which likely includes Cave Valley.

Deuterium and oxygen-18 data, tritium data, and carbon-14 corrected groundwater ages, show that groundwater in the White River Flow System, which includes Delamar, Dry Lake, and Cave valleys, is recharged under current climatic conditions. Carbon-14 corrected groundwater ages also show that it can take thousands of years for groundwater from mountainous recharge areas to flow through numerous basins and discharge in warm spring areas throughout the WRFS. Carbon-14 corrected groundwater ages of the four regional warm spring areas in the White River Flow system range from modern (<1,000 years) to 10,000 years. None of the regional warm springs has tritium above 1.0 tritium units, indicating that all of the water discharging from regional warm springs was recharged before the early 1950s.

REFERENCES

Acheampong, S.Y., J.M. Thomas, and C.A. Cooper, 2005. Estimation of circulation depths of some low temperature thermal springs in east-central, Nevada. Nevada Water Resources Association 2005 Conference, Reno, Nevada.

Back, W.B., B. Hanshaw, L.N. Plummer, P.H. Rahn, C.T. Rightmire and M. Rubin, 1983. Process and rate of dedolomitization—Mass transfer and ^{14}C dating in a regional carbonate aquifer. *Geological Society of America Bulletin*, 94: 1415-1429.

Benson, L.V. and H. Klieforth, 1989. Stable isotopes in precipitation and ground water in the Yucca Mountain region, southern Nevada—Paleoclimatic implications, *in* Peterson, D.H., *ed.*, Aspects of climate variability in the Pacific and the western Americas: Geophysical Monograph 55, p. 41-59.

Burns A.G. and W. Drici, 2011. Hydrology and water resources of Spring, Cave, Dry Lake, and Delamar valleys, Nevada and vicinity: Presentation to the Office of the Nevada State Engineer: Southern Nevada Water Authority, Las Vegas, Nevada.

Clark, I. and P. Fritz, 1997. Environmental Isotopes in Hydrogeology. Lewis Publishers, NewYork, New York.

Craig, H., 1961. Isotopic variations in meteoric waters. *Science*, 133: 1702-1703.

Deines, P., D. Langmuir, and R.S. Harmon, 1974. Stable carbon isotope ratios and the existence of a gas phase in the evolution of carbonate ground waters. *Geochimica et Cosmochimica Acta*, 38: 1147-1164.

Eakin, T.E., 1966. A regional interbasin ground-water system in the White River area, southeastern Nevada. *Water Resources Research*, 2: 251-271.

El-Kadi, A.I., L.N. Plummer and P. Aggarwal, 2010. NETPATH-WIN: an interactive user version of the mass-balance model, NETPATH. *Groundwater*, doi:10.111/j.1745-6584.2010.00779.x.

Hershey, R.L. and W.D. Howcroft, 1998. Laboratory experiments evaluating carbon-14 retardation in a carbonate aquifer. Geological Society of America, Abstracts with Programs, Vol. 30, No. 7, p. A-278.

Hershey, R.L., W. Howcroft, and P.W. Reimus, 2003. Laboratory experiments to evaluate diffusion of ^{14}C into Nevada Test Site carbonate aquifer matrix. Desert Research Institute Publication No. 45180.

Hershey, R.L., D.L. Decker, S. Earman, J. Ryu, P. Reimus and E.S. Garcia, Jr., 2007. Laboratory experiments of carbon-14 uptake on calcite and dolomite. The 233rd American Chemical Society National Meeting, March 25-29, 2007, Chicago, IL, Abstract # NUCL 135 (http://oasys2.confex.com/acs/233nm/techprogram/).

Hershey, R.L., V.M. Heilweil, P. Gardner, B.F. Lyles, S. Earman, J.M. Thomas and K.W. Lundmark, 2007. Ground-water chemistry interpretations supporting the Basin and Range Regional Carbonate-Rock Aquifer System (BARCAS) study, eastern Nevada and Western Utah. Desert Research Institute Publication no. 41230.

Kirk, S.T. and M.E. Campana, 1990. A deuterium-calibrated groundwater flow model of a regional carbonate-alluvial system. *Journal of Hydrology*, 119: 357-388.

Lundmark, K.W., G.M. Pohll and R.W.H. Carroll, 2007. A steady-state water budget accounting model for the carbonate aquifer system in White Pine County, Nevada, and adjacent areas in Nevada and Utah. Desert Research Institute Publication no. 41235.

Mifflin, M.D., 1968. Delineation of ground-water flow systems in Nevada. Desert Research Institute Publication no. 42004.

Mook, W.G., 1980. Carbon-14 in hydrogeological studies. New York, Elsevier Scientific Publishing Company.

Plume, R.W., 1996. Hydrogeologic framework of the Great Basin region of Nevada, Utah, and adjacent states. U.S. Geological Survey Professional Paper 1409-B.

Plume, R.W. and S.M. Carlton, 1988. Hydrogeology of the Great Basin region of Nevada, Utah, and adjacent states. U.S. Geological Survey Hydrologic Investigations Atlas HA-694-A, scale 1:1,000,000.

Plummer, L.N., D.L. Parkhurst and D.C. Thorstenson, 1983. Development of reaction models for ground-water systems. *Geochimica et Cosmochimica Acta*, 47: 665-686.

Plummer, L.N., E.C. Prestermon and D.L. Parkhurst, 1994. An interactive code (NETPATH) for modeling net geochemical reactions along a flow path, Version 2.0. U.S. Geological Survey Water Resources Investigations Report 94-4169.

Rowley, P.D. and G.L. Dixon, 2011. Geology and Geophysics of Spring, Cave, Dry Lake, and Delamar valleys, White Pine and Lincoln Counties and adjacent areas, Nevada and Utah: The geologic framework of regional groundwater flow systems: Presentation to the Office of the Nevada State Engineer: Southern Nevada Water Authority, Las Vegas, Nevada.

Russell, C.E., S.A. Mizell and T.B. Minor, 2007. Estimation of ground water recharge in Steptoe Valley, Nevada, by the elevation-dependent chloride mass-balance approach. Desert Research Institute Publication no. 41241.

Smith, G.I., I. Friedman, H. Klieforth and K. Hardcastle, 1979. Areal distribution of deuterium in eastern California precipitation, 1968-1969. *Applied Meteorology*, 18:172-188.

Thomas, J.M., J.L. Mason and J.D. Crabtree, 1986. Ground-water levels in the Great Basin Region of Nevada, Utah, and adjacent states. U.S. Geological Survey Hydrologic Investigations Atlas HA-694-B: 2 plates, scale 1:1,000,000.

Thomas, J.M., 1996. Geochemical and isotopic interpretation of groundwater flow, geochemical processes, and age dating of groundwater in the carbonate-rock aquifers of the southern Basin and Range: University of Nevada, Reno, Ph.D. dissertation.

Thomas, J.M., A.H. Welch and M.D. Dettinger, 1996. Geochemistry and isotope hydrology of representative aquifers in the Great Basin Region of Nevada, Utah, and adjacent states. U.S. Geological Survey Professional Paper 1409-C.

Thomas, J.M., S.C. Calhoun and W.B. Apambire, 2001. A deuterium mass-balance interpretation of groundwater sources and flows in southeastern Nevada: Desert Research Institute Publication No. 41169.

Thomas, J.M. and T. Mihevc, 2007. Stable isotope evaluation of water budgets for the White River and Meadow Valley Wash regional groundwater flow systems in east central and southeastern Nevada. Desert Research Institute Letter Report.

Welch, A.H., D.J. Bright and L.A. Knochenmus, eds., 2007. Water resources of the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada and adjacent areas in Nevada and Utah. U.S. Geological Survey Scientific Investigations Report 2007-5261.

Wigley, T.M.L., L.N. Plummer and F.J. Pearson, Jr., 1978. Mass transfer and carbon isotope evolution in natural water systems. *Geochimica et Cosmochimica Acta,* 42: 1117-1139.

Winograd, I.J., T.B. Coplen, J.M. Landwehr, A.C. Riggs, K.R. Ludwig, BJ. Szabo, P.T. Kolesar and KM. Revesz, 1992. Continuous 500,000-year climate record from vein calcite in Devils Hole, Nevada. *Science,* 258: 255-260.

Winograd, I.J., J.M. Landwehr, T.B. Coplen, W.D. Sharp, A.C. Riggs, K.R. Ludwig and P.T. Kolesar, 2006. Devils Hole, Nevada, $\delta^{18}O$ record extended to the mid-Holocene. *Quaternary Research,* 66: 202-212.

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA.

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Abandoned Spring	37.49914	-114.72889	10.2	7.7	7.80	-12.32	-94.5	81.00	20.00	50.00	2.26	35.20	357.00	41.80	27.80	--	59699	--	Spring	266	03/26/04
Acoma Well	37.54861	-114.17306	17.0	--	7.70	-12.60	-95.0	38.00	5.30	21.00	7.00	17.00	149.00	10.00	54.00	0.3	244	GS91	Well	118	06/03/85
Adaven Spring	38.13861	-115.60139	12.5	6.9	7.54	-13.95	-103.0	63.00	25.00	14.00	2.20	4.80	324.00	18.00	28.00	0.2	341	GS131	Spring	177	07/31/85
Adaven Spring	38.13861	-115.60139	9.9		7.10	-14.07	-107.6	--	--	--	--	--	358.00	--	--	--	340	IT115	Spring	177	02/03/97
Alamo City Well #7	37.36222	-115.16833	18.5	--	7.57	-13.46	-101.1	61.42	56.00	96.30	13.73	54.60	454.00	188.00	59.13	1.3	205	IT116	Well	104	08/08/95
Albert Spring	38.56833	-115.36167	14.5	--	--	-13.95	-107.0	--	--	--	--	--	--	--	--	--	403	GS182	Spring	204	07/24/85
APCAR	36.71099	-114.71682	--	--	--	-12.94	-98.2	62.90	27.20	95.00	11.20	62.10	257.00	176.00	31.60	--	61616	--	Spring	292	10/19/04
Arrow Canyon	36.73421	-114.74778	--	--	--	-12.91	-99.4	--	--	--	--	--	--	--	--	--	SNWA	--	Well	619	02/01/06
Ash Springs	37.46361	-115.19250	--	--	--	--	-107.0	--	--	--	--	--	--	--	--	--	222	IT27	Spring	110	08/01/68
Ash Springs	37.46361	-115.19250	--	--	--	--	-109.0	--	--	--	--	--	--	--	--	--	223	IT28	Spring	110	01/01/69
Ash Springs	37.46361	-115.19250	--	--	--	--	-112.0	--	--	--	--	--	--	--	--	--	224	IT29	Spring	110	03/01/70
Ash Springs	37.46361	-115.19250	36.0	2.3	7.04	-14.10	-108.0	43.00	14.00	27.00	7.40	8.50	259.00	34.00	30.00	0.8	225	GS81	Spring	110	07/20/81
Ash Springs	37.46356	-115.19252	--	--	--	-14.03	-110.0	--	--	--	--	--	--	--	--	--	SNWA	--	Spring	--	05/24/04
Ash Springs	37.46361	-115.19250	34.0	1.6	7.42	-14.20	-108.4	46.40	16.80	28.40	7.26	8.60	248.00	32.80	32.70	--	61099	--	Spring	110	07/30/04
Aspen Springs South	39.21629	-115.39800	6.9	9.4	7.00	-16.02	-120.9	--	--	--	--	--	--	--	--	--	62721	DRI-WP-16	Spring	324	06/07/05
Aspen Springs North	39.22100	-115.39905	6.9	7.7	6.50	-15.84	-119.3	--	--	--	--	--	--	--	--	--	62716	DRI-WP-11	Spring	349	06/07/05
Bailey Spring (Fairview)	38.17593	-114.72829	18.9	7.0	7.77	-12.68	-98.5	86.40	21.40	29.80	2.10	48.30	331.00	26.60	32.40	--	60849	--	Spring	277	06/29/04
Bailey Spring (Fairview)	38.17593	-114.72829	10.7	6.0	6.99	-12.70	-97.9	96.20	25.80	42.40	1.66	70.30	327.00	49.70	33.10	--	62407	DRI-FR-5	Spring	277	05/01/05
Bailey Spring (Wilson Ck)	38.35295	-114.36718	17.9	6.4	7.84	-12.93	-102.0	45.00	9.43	18.50	2.06	40.60	135.00	16.10	36.70	--	60310	--	Spring	310	05/18/04
Baldwin Spring	36.72035	-114.72415	31.9	2.6	7.30	-12.95	-96.3	63.80	28.10	96.30	11.60	63.80	260.00	180.00	32.00	--	58496	DRI-MV-3	Spring	291	01/12/04
Baldwin Spring	36.72035	-114.72415	32.0	3.0	7.48	-12.93	-96.8	63.70	27.60	94.70	11.10	64.10	263.00	180.00	29.20	--	60309	DRI-MV-3	Spring	291	05/18/04
Baldwin Spring	36.72035	-114.72415	--	--	--	-12.96	-98.6	62.80	27.40	95.00	11.20	61.40	258.00	174.00	32.10	--	61620	DRI-MV-3	Spring	291	10/19/04
Baldwin Spring	36.72035	-114.72415	31.8	2.7	7.30	-12.94	-98.1	63.10	27.40	95.70	11.20	61.70	252.00	178.00	29.60	--	62034	DRI-MV-3	Spring	291	02/10/05
Baldwin Spring	36.72035	-114.72415	32.0	2.8	6.80	-12.94	-97.2	--	--	--	--	--	--	--	--	--	62035	DRI-MV-3	Spring	291	06/08/05
Baldwin Spring	36.72035	-114.72415	31.8	2.6	7.32	-13.05	-98.0	63.50	27.20	96.80	10.90	61.10	253.00	176.00	29.60	2.2	64174	DRI-MV-3	Spring	291	02/16/06
Baldwin Spring	36.72035	-114.72415	30.2	5.3	7.35	-13.03	-98.2	71.10	22.10	93.40	11.20	63.40	254.00	180.00	30.40	2.2	64903	DRI-MV-3	Spring	291	06/21/06
Baldwin Spring	36.72035	-114.72415	32.3	4.8	7.29	-13.03	-97.1	64.50	28.00	83.90	9.35	61.70	259.00	178.00	29.10	2.2	65284	DRI-MV-3	Spring	291	08/23/06
Baldwin Spring	36.72035	-114.72415	31.7	4.3	7.33	-12.91	-97.9	61.80	27.40	93.50	11.20	60.00	251.00	175.00	29.50	2.2	65662	DRI-MV-3	Spring	291	10/30/06
Barrel Spring	38.13105	-114.05505	9.8	6.2	7.72	-13.36	-100.5	55.70	6.12	16.50	0.52	18.80	193.00	10.70	22.90	--	60316	--	Spring	317	05/21/04
Bennett Spring	37.78417	-114.52806	24.0	--	7.50	-13.70	-103.0	56.00	26.00	6.50	1.50	7.90	318.00	6.90	14.00	<.1	288	GS103	Spring	141	04/10/85
Big Muddy Spring	36.72196	-114.71682	--	--	--	--	-98.0	--	--	--	--	--	--	--	--	--	121.2	--	Spring	69	3/00/70
Big Muddy Spring	36.72196	-114.71682	32.5	3.0	7.24	-12.90	-96.5	66.00	26.00	96.00	10.00	61.00	270.00	190.00	29.00	2.1	122	GS42	Spring	69	07/22/81
Big Muddy Spring	36.72196	-114.71682	--	--	--	-12.75	-98.0	--	--	--	--	--	--	--	--	--	125	--	Spring	69	10/30/85
Big Muddy Spring	36.72196	-114.71682	--	--	--	-13.05	-99.0	--	--	--	--	--	--	--	--	--	124	GS44	Spring	69	01/07/88
Big Muddy Spring	36.72196	-114.71682	31.0	--	--	-12.84	-98.4	64.40	27.60	99.90	10.90	64.20	270.00	198.00	29.90	--	60308	--	Spring	69	05/18/04
Big Muddy Spring	36.72196	-114.71682	--	--	--	-12.89	-97.6	63.40	27.00	99.10	10.90	64.50	255.00	178.00	32.60	--	61615	--	Spring	69	10/19/04

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Big Spring (Clover)	37.52781	-114.35258	17.2	7.4	7.32	-12.89	-94.2	27.30	4.26	9.50	2.58	7.30	111.00	3.90	48.20	--	61094	--	Spring	253	07/31/04
Big Spring (Clover)	37.52781	-114.35258	17.0	7.1	7.44	-12.89	-92.9	30.20	4.46	11.10	2.55	9.00	114.00	4.80	45.80	--	62401	DRI-CR-6	Spring	253	04/30/05
Big Spring (Egan)	38.59947	-114.91624	14.0	5.4	6.79	-13.85	-106.0	34.00	5.80	13.00		4.20	156.00	7.20	50.00	0.1	408	GS187	Spring	206	08/03/85
Big Spring (Egan)	38.59947	-114.91624	13.0	5.8	6.50	-13.92	-104.2	--	--	--	--	--	--	--	--	--	--	--	Spring	206	10/14/03
Big Spring (Egan)	38.59947	-114.91624	12.9	5.2	6.11	-13.98	-106.1	34.70	5.78	12.40	2.36	3.80	152.00	7.10	51.70		62980	ER-4	Spring	206	07/31/05
Big Spring (Egan)	38.59947	-114.91624	12.8	5.4	6.76	-13.86	-105.8	34.10	5.83	12.60	2.38	3.90	146.00	7.00	52.10	0.1	65050	ER-24	Spring	441	07/13/06
Big Spring (Grant)	38.37056	-115.48111	12.5	--	8.10	-15.20	-112.0	78.00	7.00	4.90	--	2.10	268.00	13.00	9.50	<.1	366	GS151	Spring	194	07/24/85
Big Spring Snake Valley	38.69892	-114.13223	17.2	5.3	7.54	-15.14	-112.2	47.80	20.30	5.50	1.51	5.10	228.00	8.50	12.60	--	61964	--	Spring	325	01/22/05
Big Spring Snake Valley	38.69892	-114.13223	--	--	--	-15.22	-112.2	48.30	19.50	5.28	1.54	5.50	8.50	234.00	12.70	0.1	63226	SU-2	Spring	325	08/13/05
Big Spring Snake Valley	38.69892	-114.13223	17.2	4.9	7.50	-15.10	-110.3	42.90	20.20	5.34	1.51	5.80	229.00	8.50	12.70	0.1	63569	--	Spring	--	11/08/05
Big Spring Snake Valley	38.69892	-114.13223	16.8	5.2	7.61	-15.17	-111.6	47.50	19.60	5.32	1.50	5.50	229.00	8.60	12.50	0.1	64238	SU-2	Spring	325	02/25/06
Big Spring Snake Valley	38.69892	-114.13223	17.2	5.3	7.43	-15.10	-112.6	49.00	20.30	6.18	2.61	7.30	232.00	9.30	12.80	0.1	64741	SU-2	Spring	325	05/21/06
Big Spring Snake Valley	38.69892	-114.13223	17.3	5.4	7.49	-15.15	-111.8	47.70	20.40	5.20	1.42	5.33	232.00	8.84	12.70	0.1	65291	SU-2	Spring	325	08/24/06
Big Spring Snake Valley	38.69892	-114.13223	17.0	4.8	7.44	-15.20	-111.1	49.70	20.30	5.93	1.45	6.10	232.00	8.50	12.90	0.1	65659	SU-2	Spring	325	10/29/06
Big Spring North	38.65611	-114.63306	20.5	--	7.60	-15.10	-112.0	49.00	19.00	5.30	2.10	6.00	240.00	12.00	21.00	0.2	416	GS193	Spring	211	04/04/85
Big Spring South	38.65417	-114.63306	18.5	--	7.50	-14.80	-111.0	45.00	18.00	5.40	1.90	5.60	200.00	12.00	18.00	0.2	415	GS192	Spring	210	04/04/85
Bishop Spring	37.41854	-114.64169	--	--	--	-11.70	-85.5	--	--	--	--	--	--	--	--	--	208	GS80	Spring	107	02/02/84
Bishop Spring	37.41854	-114.64169	17.5	6.3	7.04	-11.67	-88.0	68.00	24.10	17.10	0.92	13.40	332.00	14.50	54.80	--	58493	--	Spring	107	01/14/04
Bishop Spring	37.41854	-114.64169	18.4	4.6	6.93	-11.78	-88.1	--	--	--	--	--	--	--	--	--	62618	DRI-DR-6	Spring	107	05/20/05
Bitter Spring	36.28500	-114.51417	17.2	4.8	7.58	-9.90	-77.0	--	--	--	--	--	--	--	--	--	22	PL15	Spring	14	02/06/96
Black Rock Spring	37.91204	-114.91906	--	--	--	-12.25	-94.0	--	--	--	--	--	--	--	--	--	313	GS117	Spring	158	03/22/88
Black Rock Spring	37.91204	-114.91906	12.1	8.3	7.60	-12.36	-93.6	36.70	7.98	16.10	4.62	13.90	146.00	15.90	63.60	--	59687	--	Spring	158	03/23/04
Blue Point Spring	36.39000	-114.43306	--	--	--	-12.40	-93.0	--	--	--	--	--	--	--	--	--	49	PL8	Spring	26	06/24/85
Blue Point Spring	36.39000	-114.43306	--	--	--	-12.35	-92.5	--	--	--	--	--	--	--	--	--	47.5	USGS	Spring	26	07/01/85
Blue Point Spring	36.39000	-114.43306	30.0	--	7.80	-12.50	-93.5	470.00	160.00	330.00	23.00	400.00	160.00	1900.00	16.00	1.5	48	GS15	Spring	26	07/01/85
Blue Point Spring	36.39000	-114.43306	29.6	2.7	7.05	-12.30	-91.0	--	--	--	--	--	--	--	--	--	47	PL8	Spring	26	02/08/96
Blue Point Springs	36.39000	-114.43306	--	--	--	-12.47	-93.0	--	--	--	--	--	--	--	--	--	USGS	--	spring	--	06/05/03
Blue Rock Spring	38.15344	-114.35401	--	--	--	-12.68	-93.4	--	--	--	--	--	--	--	--	--	--	--	Spring	311	04/28/04
Boulder Spring (KSV-4)	37.31436	-114.67261	--	--	--	-12.00	-87.5	--	--	--	--	--	--	--	--	--	196	Kirk1027	Spring	98	--
Boulder Spring (KSV-4)	37.31436	-114.67261	16.8	--	7.90	-12.60	-87.0	21.00	4.90	12.00	2.30	7.80	100.00	6.00	41.00	1.7	198	GS74	Spring	98	02/02/84
Boulder Spring (KSV-4)	37.31436	-114.67261	5.0	8.8	7.36	-12.60	-91.0	19.40	4.46	11.40	0.26	6.60	88.90	5.70	42.80	--	58491		Spring	98	01/13/04
Boulder Spring (KSV-4)	37.31436	-114.67261	13.6	7.7	7.59	-12.66	-91.3	21.20	3.78	55.20	4.08	25.00	138.00	34.80	65.30	--	62394	DRI-DR-3	Spring	98	04/27/05
Big Tom Plain Spring	39.08701	-115.37737	7.4	6.1	6.70	-15.92	-121.1	--	--	--	--	--	--	--	--	--	62713	DRI-WP-8	Spring	326	06/06/05
Bradshaw Well	37.34917	-114.54389	14.8	--	7.30	-11.40	-88.5	85.00	28.00	120.00	11.00	52.00	550.00	76.00	63.00	2.3	202	GS76	Well	102	02/01/84
Brady Spring	38.32746	-115.47509	10.3	--	--	-15.38	-108.5	82.80	8.45	2.90	1.01	0.80	292.00	2.90	13.80	--	57754	--	Spring	282	10/28/03
Brady Spring (duplicate sample)	38.32746	-115.47509	--	--	--	-15.38	-110.4	--	--	--	--	--	--	--	--	--	57754	--	Spring	282	10/28/03
Buckboard Spring	37.58886	-114.63111	14.7	7.1	7.70	-11.71	-88.2	45.10	8.31	17.30	2.05	13.90	182.00	10.60	45.50	--	59697	--	Spring	264	03/26/04
Burnt Canyon Spring (Unnamed Spring in Burnt Canyon)	38.28944	-114.20889	11.0	--	7.60	-12.30	-93.0	35.00	7.70	8.10	0.50	5.20	140.00	8.20	38.00	0.1	356	GS140	Spring	187	06/05/85

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Butcher Spring	38.03035	-114.01531	10.1	7.6	7.10	-14.22	-103.2	25.50	5.44	10.80	1.01	18.10	78.30	10.90	26.90	0.2	64910	MG-7	Spring	424	06/23/06
Butte Spring	39.75816	-115.24246	13.7	7.4	6.89	-15.79	-120.4	--	--	--	--	--	--	--	--	--	62619	DRI-BT-1	Spring	327	05/24/05
Byron Well	36.58368	-114.64163	--	--	--	-13.27	-97.1	--	--	--	--	--	--	--	--	--	108503	SNWA	Well	623	01/28/05
Butterfield Spring	38.43972	-115.01083	16.5	6.1	7.31	-14.20	-105.0	47.00	22.00	6.00	2.50	4.70	260.00	8.00	23.00	0.1	384	GS163	Spring	202	07/19/81
Caliente City Well	37.61583	-114.51333	14.3	--	--	-12.40	-89.0	--	--	--	--	--	--	--	--	--	263	GS95	Well	124	01/31/84
Cabin Spring	39.75790	-115.27245	11.0	8.7	7.00	-15.89	-124.4	--	--	--	--	--	--	--	--	--	62708	DRI-BT-7	Spring	328	06/05/05
Cain Springs	39.54258	-114.22588	14.9	4.5	6.92	-10.85	-98.4	191.00	53.60	117.00	0.85	352.00	322.00	162.00	34.70	0.3	63282	--	Spring	400	08/26/05
Caliente Hot Springs (Hotel)	37.62111	-114.51042	45.0	--	7.80	-14.50	-109.0	37.00	7.30	49.00	19.00	13.00	222.00	34.00	130.00	1.4	270	GS99	Spring	129	04/10/85
Caliente Hot Springs (Hotel)	37.62111	-114.51042	40.7	4.4	8.17	-14.52	-106.4	35.00	7.34	50.10	18.70	14.50	213.00	37.20	128.00	--	61621	--	Spring	129	10/20/04
Caliente Hot Springs (Hotel)	37.62111	-114.51042	40.4	4.1	8.06	-14.29	-109.3	35.60	7.17	51.80	19.00	14.50	208.00	44.80	119.00	--	61970	--	Spring	129	01/24/05
Caliente Hot Springs (Hotel)	37.62111	-114.51042	41.0	4.0	7.52	-14.43	-107.0	--	--	--	--	--	--	--	--	--	62620	DRI-MW-2	Spring	129	05/19/05
Caliente Hot Springs (Hotel)	37.62111	-114.51042	40.1	2.8	7.62	-14.47	-109.0	--	--	--	--	--	--	--	--	--	63230	DRI-MW-2	Spring	129	08/16/05
Caliente Hot Springs (Hotel)	37.62111	-114.51042	41.5	3.1	7.71	-14.47	-107.2	35.00	7.36	51.20	18.80	13.70	214.00	39.10	122.00	1.5	63572		Spring	129	11/09/05
Caliente Hot Springs (Hotel)	37.62111	-114.51042	39.7	4.5	7.91	-14.42	-107.7	38.40	7.61	52.20	18.90	17.30	215.00	43.60	119.00	1.4	64170	MW-2	Spring	129	02/17/06
Caliente Hot Springs (Hotel)	37.62111	-114.51042	39.9	3.3	7.98	-14.38	-107.3	39.00	7.93	53.60	21.10	18.50	224.00	46.50	118.00	1.4	64744	MW-2	Spring	129	05/22/06
Calpine Test Well 1a	36.54611	-114.80194	30.5	--	--	-13.50	-99.0	--	--	--	--	--	--	--	--	--	999	ECP-1a	Well	43	04/07/00
Camp Creek	38.24361	-114.25222	9.0	--	7.90	-14.00	-102.0	--	--	--	--	--	--	--	--	--	349	E3	Surface	184	04/09/85
Carpenter Spring	38.05000	-115.61167	16.0	--	--	-11.85	-95.0	--	--	--	--	--	--	--	--	--	332	GS126	Spring	171	07/31/85
Cave Spring (Cave Valley)	38.64111	-114.79583	12.0	8.4	7.41	-13.85	-100.0	16.00	2.20	3.10		1.00	62.00	4.50	14.00	<.1	414	GS191	Spring	209	08/02/85
Cave Spring (Cave Valley)	38.64111	-114.79583	--	--	--	-14.16	-104.9	--	--	--	--	--	--	--	--	--	68110	SNWA	Spring	209	08/06/03
Cave Spring (Cave Valley)	38.64111	-114.79583	--	--	--	-13.54	-102.7	--	--	--	--	--	--	--	--	--	88485	SNWA	Spring	209	06/21/04
Cave Spring (Cave Valley)	38.64111	-114.79583	11.7	7.6	7.20	-14.20	-102.2	15.40	2.04	2.57	0.68	1.00	55.40	2.60	16.00	0.1	65057	SC-8	Spring	209	07/14/06
Cave Spring (Clover)	37.52979	-114.24092	18.7	4.7	7.00	-12.21	-90.8	47.80	9.12	26.40	8.41	20.00	219.00	10.80	57.40	--	61101	--	Spring	247	07/31/04
Cave Spring (Clover)	37.52979	-114.24092	18.7	4.7	7.00	-12.53	-94.7	--	--	--	--	--	--	--	--	--	61101B	--	Spring	247	07/31/04
Cave Valley MX	38.46859	-114.86944	--	--	--	-13.94	-105.0	--	--	--	--	--	--	--	--	--	--	USGS	Deep Well	620	07/10/03
Cave Valley Seedling Well	38.58298	-114.79334	--	--	--	-13.75	-104.7	--	--	--	--	--	--	--	--	--	112271	SNWA	Well	625	07/25/05
Cedar Spring	39.77309	-114.21140	14.4	2.8	7.20	-15.52	-121.5	104.00	50.60	16.50	1.60	42.90	208.00	262.00	14.60	0.5	63275	--	Spring	393	08/23/05
Cedar Cabin Spring	38.79689	-114.22339	9.6	9.0	7.55	-14.10	-106.0	62.30	20.20	5.45	1.04	5.00	5.70	272.00	12.00	<.04	62913	SN-4	Spring	380	07/13/05

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
The Cedars	38.93537	-114.41800	18.7	8.0	8.03	-15.02	-110.3	20.00	1.70	5.88	0.85	2.00	74.90	3.20	20.70	--	61965	--	Spring	329	01/22/05
The Cedars	38.93537	-114.41800	18.9	8.4	7.97	-15.03	-108.1	--	--	--	--	--	--	--	--	--	62621	DRI-SV-1	Spring	329	05/20/05
The Cedars	38.93537	-114.41800	--	--	--	-15.00	-108.6	19.80	1.68	5.85	0.86	2.00	3.30	74.20	20.60	0.3	63225	SV-1	Spring	329	08/12/05
The Cedars	38.93537	-114.41800	18.3	7.3	7.95	-15.00	-108.2	20.10	1.69	5.71	0.82	2.00	73.10	3.30	20.70	0.2	63570		Spring	329	11/08/05
The Cedars	38.93537	-114.41800	18.2	7.7	8.10	-15.02	-108.4	20.10	1.59	5.60	0.84	2.10	74.80	3.40	20.50	0.2	64240	SV-1	Spring	329	02/26/06
The Cedars	38.93537	-114.41800	18.8	8.5	7.90	-15.03	-108.3	20.10	1.67	5.85	1.84	2.10	74.10	3.50	20.80	0.2	64742	SV-1	Spring	329	05/21/06
The Cedars	38.93537	-114.41800	19.9	7.6	8.00	-14.97	-109.4	20.10	1.78	5.43	0.75	2.07	72.10	3.55	20.80	0.2	65369	SV-1	Spring	329	08/30/06
The Cedars	38.93537	-114.41800	18.4	8.3	7.83	-15.05	-109.9	20.00	1.68	5.67	0.82	2.00	72.90	3.40	20.60	0.2	65660	SV-1	Spring	329	10/29/06
CE-DT-4	36.79556	-114.89222	34.0	3.5	7.35	-13.00	-102.5	46.00	19.00	84.00	11.00	35.00	294.00	110.00	33.00	1.9	138	GS52	Well	78	12/23/80
CE-DT-6 Well	36.76778	-114.78694	--	--	--	-13.10	-99.0	--	--	--	--	--	--	--	--	--	130.2	DRI	Well	72	09/28/86
CE-DT-6 Well	36.76778	-114.78694	33.5	3.7	7.16	-12.95	-97.0	58.00	25.00	88.00	11.00	53.00	272.00	160.00	30.00	2.1	130	GS47	Well	72	09/28/86
CE-VF-2 Well	36.87500	-114.94556	--	--	--	-12.95	-101.0	--	--	--	--	--	--	--	--	--	155	USGS	Well	81	02/05/86
CE-VF-2 Well	36.87500	-114.94556	34.0	2.9	7.40	-13.10	-101.0	47.00	21.00	81.00	11.00	34.00	303.00	90.00	34.00	1.7	156	USGS	Well	81	01/06/88
Chicken Spring	39.23885	-115.38886	8.3	5.7	6.60	-16.17	-122.0	--	--	--	--	--	--	--	--	--	62715	DRI-WP-10	Spring	330	06/07/05
Chimney Rock Spring	38.83528	-114.88417	13.0	1.4	6.78	-14.30	-109.0	56.00	6.80	12.00		5.40	207.00	21.00	56.00	0.2	425	GS205	Spring	219	08/01/85
Chimney Rock Spring	38.83528	-114.88417	12.8	0.9	6.73	-14.74	-112.0	39.30	5.51	14.00	8.38	3.30	171.00	10.70	61.10	0.2	65052	ER-26	Spring	219	07/13/06
Circle Wash Spring	39.12170	-115.36929	7.6	7.1	6.20	-15.30	-114.5	--	--	--	--	--	--	--	--	--	62710	DRI-WP-5	Spring	331	06/06/05
Clover Creek Valley Well 232	37.50500	-114.27600	21.5	--	7.80	-11.70	-84.0	60.00	6.00	8.00	3.00	26.00	180.00	13.00	--	0.4	232	E29	Well	114	07/18/75
Clover Creek Valley Well 246	37.58470	-114.25980	26.0	--	7.80	-12.40	-89.0	41.00	6.00	10.00	5.00	17.00	166.00	4.00	--	--	246	E28	Well	120	07/18/75
Cold Spring	37.71370	-115.41016	--	--	--	-12.98	-98.9	49.70	12.10	22.80	1.50	19.40	208.00	22.60	50.70	--	60841	--	Spring	288	06/25/04
Cold Spring, Preston	38.91800	-115.06680	22.0	3.0	7.20	-15.80	-121.0	39.00	19.00	12.00	3.10	13.00	190.00	39.00	20.00	0.3	446	GS221	Spring	230	07/16/81
Cold Spring, Preston	38.91800	-115.06680	21.5	3.0	7.80	-15.80	-126.0	43.00	20.00	13.00	2.90	14.00	190.00	37.00	20.00	0.4	447	GS222	Spring	230	06/16/83
Connor Spring	37.90165	-114.56023	8.4	7.7	7.68	-13.84	-100.6	72.30	25.80	1.48	0.59	2.00	348.00	3.80	8.70	--	60838	--	Spring	283	06/24/04
Corn Creek Spring South	36.43890	-115.35775	21.4	4.0	7.44	-12.88	-95.0	51.00	48.20	9.81	3.02	9.10	401.00	25.10	28.70	--	58503	--	Spring	307	01/17/04
Corn Creek Spring South	36.43890	-115.35775	21.1	3.3	7.26	-12.89	-95.0	47.40	33.70	6.44	2.11	6.90	288.00	18.50	19.50	--	60852	--	Spring	307	06/30/04
Corral Spring (Unnamed Spring)	36.37056	-114.46000	17.0	6.2	7.31	-12.10	-91.5	--	--	--	--	--	--	--	--	--	28	PL13	Spring	19	02/07/96
Cottonwood Spring (Fairview)	38.31204	-114.63476	13.1	4.6	--	-13.40	-102.2	33.80	4.87	17.80	0.80	6.10	161.00	4.70	38.00	--	60848	--	Spring	274	06/29/04
Cottonwood Spring (Black Mtns.)	36.20333	-114.64361	12.6	6.5	7.81	-10.80	-80.0	524.00	220.00	209.00	10.70	63.60	205.00	2410.00	17.40	--	13	PL17	Spring	8	02/06/96
Cottonwood Spring (Delamar)	37.53418	-114.74636	15.5	2.3	7.10	-12.87	-96.9	80.00	9.32	29.50	0.70	17.30	311.00	18.70	48.70	--	59698	--	Spring	265	03/26/04
Cow Camp Spring	36.58361	-115.30722	14.5	--	7.60	-12.60	-90.5	48.00	31.00	21.00	0.70	28.00	290.00	23.00	16.00	0.2	75	GS19	Spring	47	10/28/81
Cow Camp Spring	36.58361	-115.30722	10.0	5.9	7.60	-12.60	-93.0	50.00	35.00	25.00	0.60	29.00	--	29.00	15.00	0.2	77	GS21	Spring	47	05/10/83
Cow Camp Spring	36.58361	-115.30722	16.8	5.1	7.26	-12.46	-92.0	48.90	35.60	26.90	0.55	23.50	312.00	24.60	17.60	--	61105		Spring	47	07/27/04
Cow Camp Spring	36.58361	-115.30722	10.1	8.4	6.96	-12.47	-91.9	52.00	38.00	38.90	0.29	39.90	298.00	48.60	15.10	--	62399	DRI-SR-4	Spring	47	04/28/05

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Coyote Spring	38.03186	-114.86219	--	--	--	-12.04	-97.2	--	--	--	--	--	--	--	--	--	88474	SNWA	Spring	169	06/21/04
Coyote Spring	38.03186	-114.86219	13.3	4.7	6.76	-12.26	-95.2	75.10	11.40	55.50	10.70	31.70	246.00	105.00	82.70	--	62409	DRI-DL-1	Spring	169	05/01/05
Coyote Spring	38.03186	-114.86219	--	--	--	-12.80	-95.0	--	--	--	--	--	--	--	--	--	330	Kirk1017	Spring	169	--
Crystal Springs	37.53144	-115.23364	--	--	--	--	-109.0	--	--	--	--	--	--	--	--	--	--	Win	Spring	116	08/01/68
Crystal Springs	37.53144	-115.23364	--	--	--	--	-110.0	--	--	--	--	--	--	--	--	--	--	Win	Spring	116	01/01/69
Crystal Springs	37.53144	-115.23364	--	--	--	--	-109.0	--	--	--	--	--	--	--	--	--	--	Win	Spring	116	03/01/70
Crystal Springs	37.53144	-115.23364	27.5	1.8	7.34	-14.30	-109.0	43.00	21.00	22.00	5.00	8.90	260.00	34.00	25.00	0.3	235	GS87	Spring	116	07/20/81
Crystal Springs	37.53144	-115.23364	26.5	--	7.40	-14.38	-108.4	44.00	22.00	24.00	5.40	8.60	248.00	32.00	24.00	0.3	238	GS90	Spring	116	08/16/94
Crystal Springs	37.53144	-115.23364	28.0	--	7.74	-14.39	-106.9	44.16	22.56	23.84	4.83	9.60	255.00	34.70	24.74	0.4	239	IT120	Spring	116	08/07/95
Crystal Springs	37.53162	-115.23363	--	--	--	-14.32	-108.0	--	--	--	--	--	--	--	--	--	USGS	--	Spring	116	06/03/03
Crystal Springs	37.53144	-115.23364	--	--	--	-14.23	-111.0	--	--	--	--	--	--	--	--	--	84392	SNWA	Spring	116	05/24/04
Crystal Springs	37.53144	-115.23364	27.3	5.1	7.25	-14.36	-109.2	43.10	22.20	23.60	5.26	8.70	255.00	32.30	26.40	--	61106	--	Spring	116	07/30/04
Crystal Springs	37.53144	-115.23364	27.3	1.3	7.59	-14.41	-109.0	45.30	22.40	24.20	5.28	9.10	240.00	33.60	26.60	--	61618	--	Spring	116	10/20/04
Crystal Springs	37.53144	-115.23364	27.2	1.3	7.50	-14.35	-109.4	45.60	22.00	24.10	5.18	8.80	247.00	33.20	25.20	--	61971	--	Spring	116	01/24/05
Crystal Springs	37.53144	-115.23364	27.1	1.3	7.26	-14.44	-107.3	--	--	--	--	--	--	--	--	--	62622	DRI-PV-2	Spring	116	05/18/05
Crystal Springs	37.53144	-115.23364	27.0	1.3	6.92	-14.46	-109.3	--	--	--	--	--	--	--	--	--	63229	DRI-PV-2	Spring	116	08/14/05
Crystal Spring	37.53144	-115.23364	27.1	1.3	7.38	-14.42	-110.1	45.70	22.20	23.80	5.10	9.30	248.00	33.10	25.00	0.3	63574	--	Spring	116	11/09/05
Crystal Spring	37.53181	-115.23383	27.1	1.4	7.43	-14.47	-108.5	45.10	22.10	23.60	5.13	9.30	245.00	33.90	24.70	0.3	65655	PV-2	Spring	116	10/28/06
Crystal Springs	37.53181	-115.23383	27.1	1.3	7.44	-14.53	-108.8	46.30	22.50	24.20	5.35	9.50	247.00	33.80	24.70	0.4	64168	PV-2	Spring	116	02/17/06
Crystal Springs	37.53181	-115.23383	27.2	1.2	7.51	-14.47	-109.5	45.50	21.90	24.00	5.72	9.50	247.00	35.10	25.40	0.4	64746	PV-2	Spring	116	05/22/06
Crystal Springs	37.53181	-115.23383	27.1	1.3	7.42	-14.49	-108.8	45.90	22.60	21.20	4.36	9.07	239.00	34.80	25.00	0.3	65290	PV-2	Spring	116	08/23/06
CSV-2 Well	36.78056	-114.72222	27.0	4.0	7.40	-12.85	-98.0	60.00	27.00	100.00	10.00	61.00	276.00	160.00	30.00	2.3	135	GS51	Well	76	01/26/86
CSV-2 Well	36.78056	-114.72222	--	--	--	-12.99	-97.7	--	--	--	--	--	--	--	--	--	USGS	--	Well	76	07/08/03
CSV-3 Well	36.69083	-114.92500	41.0	--	7.35	-10.35	-75.0	51.00	25.00	38.00	10.00	26.00	239.00	54.00	24.00	1.2	104	GS38	Well	60	10/07/87
CSV-3 Well	36.69083	-114.92500	--	--	--	-10.30	-75.8	--	--	--	--	--	--	--	--	--	121722	SNWA	Well	60	01/26/06
Davies Spring	36.96556	-114.50194	14.3	--	--	-12.50	-89.0	--	--	--	--	--	--	--	--	--	177	GS64	Spring	90	02/06/84
Deadman Spring (Highland)	37.91861	-114.54139	9.5	--	7.10	-13.30	-99.0	98.00	41.00	5.00	0.90	4.20	506.00	8.30	19.00	0.1	319	GS119	Spring	162	04/07/85
Deadman Spring (Highland)	37.91861	-114.54139	27.9	4.9	9.68	-10.83	-90.9	12.20	40.10	4.11	0.43	2.50	143.00	5.40	2.10	--	60837	--	Spring	162	06/24/04
Decathon Spring	38.80738	-114.27884	7.6	7.1	6.89	-14.60	-107.0	111.00	7.58	2.88	0.54	3.40	11.40	325.00	11.30	0.1	62914	SN-5	Spring	381	07/14/05
Deer Spring (White Pine)	38.99498	-115.39136	--	--	--	-15.87	-118.9	--	--	--	--	--	--	--	--	--	JThomas-032304-4	WP-4	Spring	322	10/12/03
Deer Spring (White Pine)	38.99498	-115.39136	9.4	6.3	6.90	-15.87	-119.6	--	--	--	--	--	--	--	--	--	62822	WP-4	Spring	322	06/28/05
Deer Spring (Butte)	39.48683	-115.27559	12.3	6.4	6.30	-14.74	-114.1	--	--	--	--	--	--	--	--	--	62704	DRI-BT-6	Spring	332	06/04/05
Delmues Spring (Unnamed Spring)	37.86000	-114.32222	18.0	--	7.70	-13.40	-104.0	47.00	6.70	30.00	6.30	24.00	180.00	18.00	64.00	0.6	302	GS111	Spring	149	04/08/85
Desert Valley (Dry Lake) Well #1	36.95306	-115.19750	19.0	2.8	7.97	-13.10	-98.0	22.00	27.00	35.00	5.70	8.90	413.00	48.00	49.00	0.6	171	GS61	Well	87	03/18/87
Dipping Tank Spring	39.77522	-114.47512	12.0	7.8	6.83	-15.74	-119.8	47.50	8.37	16.20	2.01	18.00	167.00	14.60	30.70	0.1	63280	--	Spring	398	08/25/05
DLLLC Hidden Valley	36.49340	-114.92657	--	--	--	-12.90	-97.0	--	--	--	--	--	--	--	--	--	999	HV-1	Well	37	06/05/00
Dodge Well	38.24444	-114.54250	17.0	--	--	-14.20	-107.0	--	--	--	--	--	--	--	--	--	350	GS137	Well	185	06/07/85
Douglas Spring	38.85003	-115.14867	--	--	--	-13.01	-106.4	--	--	--	--	--	--	--	--	--	112274	SNWA	Spring	626	07/26/05
Dry Lake Valley Well	36.45500	-114.84389	29.0	2.0	7.27	-13.30	-97.5	110.00	48.00	120.00	13.00	170.00	210.00	360.00	21.00	2.1	64	GS17	Well	34	07/01/85

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
East Settling Spring	37.37315	-114.23282	--	--	--	-12.76	-92.2	--	--	--	--	--	--	--	--	--	61100B	--	Spring	248	07/31/04
Easter Spring	39.04120	-115.34883	11.1	6.7	7.30	-15.56	-119.4	--	--	--	--	--	--	--	--	--	62823	WP-23	Spring	365	06/29/05
EH-3 Weiser Wash	36.69222	-114.52556	24.1	--	7.80	-12.70	-91.0	511.00	201.00	170.00	22.00	194.00	123.00	2100.00	15.00	--	--	4	Well	61	averages
EH-4 Weiser Wash	36.70639	-114.71611	22.8	0.0	8.30	-13.00	-98.0	49.00	30.00	90.00	12.00	57.00	245.00	171.00	28.00	0.0	AVG	--	Well	63	averages
EH-6 Weiser Wash	36.68167	-114.57000	24.8	0.0	7.70	-13.90	-99.5	341.00	131.00	274.00	31.00	41.00	178.00	1800.00	13.00	0.0	AVG	--	Well	59	averages
EH-7	36.67056	-114.53139	21.0	--	7.33	-12.45	-91.0	470.00	190.00	170.00	20.00	65.00	--	2000.00	15.00	0.9	99	GS35	Well	56	03/19/87
EH-8 Weiser Wash	36.67389	-114.57583	0.0	0.0	7.60	-13.70	-96.5	375.00	104.00	416.00	22.00	233.00	162.00	1780.00	26.00	0.0	AVG	--	Well	57	averages
Eightmile Spring	37.46466	-115.06440	17.9	6.7	7.23	-13.12	-96.7	45.00	9.15	13.20	1.49	10.60	189.00	8.90	43.20	0.0	61103	--	Spring	295	07/30/04
Eightmile Spring	37.46466	-115.06440	14.4	6.7	7.35	-13.06	-94.4	52.20	9.90	17.80	1.07	16.20	195.00	14.80	37.60	0.0	61106C	DRI-PR-11	Spring	295	04/30/05
Eight Mile Spring (Snake Range)	39.38830	-114.28433	11.1	7.7	7.02	-15.53	-116.3	77.80	18.30	5.74	0.86	4.70	307.00	9.50	12.60	<.05	63284	SN-32	Spring	402	08/26/05
Eight Mile Spring (Snake Range)	39.38830	-114.28433	11.0	7.1	7.31	-15.38	-114.8	79.70	18.50	5.28	0.76	4.86	306.00	9.59	12.40	0.1	65421	SN-32	Spring	402	09/17/06
Eight Mile Spring (Snake Range)	39.38830	-114.28433	11.5	7.5	7.36	-15.40	-114.3	80.20	18.70	5.79	0.81	4.81	333.00	8.96	11.40	0.1	68482	SN-32	Spring	496	06/02/08
Eight Mile Spring (Snake Range)	39.38830	-114.28433	11.4	6.9	7.39	-15.46	-112.0	78.40	18.70	5.76	0.83	4.61	330.00	9.02	12.00	0.0	68915	SN-32	Spring	496	09/12/08
Eight Mile Spring (Snake Range)	39.38830	-114.28433	11.4	7.5	7.31	-15.39	-115.7	78.90	18.80	5.78	0.84	4.65	322.00	8.87	11.60	0.1	69146	SN-32	Spring	496	11/01/08
Eight Mile Spring (Snake Range)	39.38830	-114.28433	--	--	--	-15.30	-114.8	79.70	18.50	5.58	0.73	4.74	316.00	8.43	12.20	0.1	69867	SN-32	Spring	496	08/15/09
Eight Mile Spring (Snake Range)	39.38830	-114.28433	--	--	--	-15.45	-115.6	77.90	17.70	5.79	0.82	4.93	329.00	9.01	11.50	0.0	70617	SN-32	Spring	496	11/17/09
Ella Spring	37.49072	-114.44835	7.5	3.6	7.70	-12.56	-95.8	44.20	8.55	11.10	1.84	7.00	170.00	8.80	27.10	--	59702	--	Spring	251	03/27/04
Emigrant Spring	38.62500	-115.04778	19.5	5.2	7.14	-14.50	-108.0	67.00	24.00	5.30	1.60	2.90	300.00	14.00	13.00	0.2	410	GS188	Spring	207	07/18/81
Emigrant Spring	38.62500	-115.04778	20.1	--	--	--	-107.5	--	--	--	--	--	--	--	--	--	411	GS189	Spring	207	01/17/84
Fence Spring	38.17978	-114.71593	--	--	--	-12.55	-97.4	--	--	--	--	--	--	--	--	--	--	--	Spring	278	06/29/04
Flag Spring #3	38.42139	-115.02222	22.8	-	7.50	-14.30	-105.0	50.00	21.00	10.00	3.40	6.60	270.00	12.00	26.00	0.2	380	GS161	Spring	201	01/17/84
Flatnose Spring (Unnamed Spring)	37.89611	-114.22583	25.0	--	8.00	-13.40	-101.0	26.00	3.50	34.00	5.60	10.00	146.00	18.00	55.00	1.3	306	GS113	Spring	153	04/08/85
Forest Home Spring (Unnamed Spring)	38.37750	-115.37528	14.0	5.3	7.63	-14.50	-108.5	62.00	26.00	9.90	--	6.90	309.00	19.00	14.00	<.1	368	GS152	Spring	195	07/24/85
Four Mile Spring	39.30724	-114.29803	9.4	6.5	7.23	-14.75	-112.5	85.50	33.70	8.88	1.18	7.49	375.00	40.20	15.80	0.1	65413	SN-25	Spring	488	09/16/06
Fox Cabin	38.16267	-114.65034	--	--	--	-13.59	-103.5	--	--	--	--	--	--	--	--	--	--	--	Spring	273	06/29/04
Fugro CV Deep Well CE-DT-5	36.79556	-114.89222	35.5	2.3	7.15	-12.90	-99.5	46.00	20.00	78.00	11.00	34.00	300.00	100.00	33.00	1.9	139	GS53	Well	77	07/22/81
Fugro CV Deep Well CE-DT-6	36.79556	-114.89222	--	--	--	-13.16	-100.1	--	--	--	--	--	--	--	--	--	65461	SNWA	Well	77	04/08/03
Fugro CV Deep Well CE-DT-5	36.79556	-114.89222	--	--	--	-12.99	-99.6	--	--	--	--	--	--	--	--	--	USGS	--	Well	77	05/28/03
Fugro CV Deep Well CE-DT-5	36.79556	-114.89222	--	--	--	-12.99	-99.6	--	--	--	--	--	--	--	--	--	USGS	--	Deep Well	77	02/16/05

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Fugro Dry Lake V Deep Well	38.14583	-114.89333	27.5	3.2	7.08	-14.20	-108.0	73.00	29.00	20.00	6.90	6.20	--	27.00	25.00	0.5	343	GS133	Well	179	12/10/80
Fugro Dry Lake V Deep Well	38.14583	-114.89333	--	--	--	-14.11	-107.0	--	--	--	--	--	--	--	--	--	USGS	--	Well	179	06/19/03
Fugro Steptoe V Deep Well	38.92000	-114.84528	11.0	5.5	7.50	-14.90	-117.0	66.00	14.00	15.00	4.40	12.00	--	57.00	28.00	0.4	443	GS218	Well	228	01/19/81
Garden Spring	37.26425	-114.28869	8.8	6.5	7.06	-11.54	-87.0	--	--	--	--	--	--	--	--	--	58500	--	Spring	246	01/15/04
Geyser Spring	38.68000	-114.66556	12.5	--	7.80	-14.50	-105.0	--	--	--	--	--	--	--	--	--	419	E1	Spring	213	04/03/85
Gourd Spring	36.95861	-114.29167	E16.	--	--	-10.60	-77.5	--	--	--	--	--	--	--	--	--	175	GS63	Spring	89	02/06/84
GP Apex Well	36.34111	-114.92667	--	--	--	-13.35	-97.5	--	--	--	--	--	--	--	--	--	999	Jim	Well	17	09/29/86
GP Apex Well	36.34111	-114.92667	31.0	5.5	6.96	-13.45	-98.0	120.00	47.00	130.00	13.00	200.00		380.00	23.00	1.4	24	PLC23	Well	17	09/30/86
GP Apex Well	36.34111	-114.92667	--	--	--	-13.80	-96.0	--	--	--	--	--	226.00	--	--	--	25	GS8	Well	17	09/30/86
Gandy Warm Spring (Warm Spring Near Gandy)	39.46000	-114.03707	27.0	492.0	7.23	-15.83	-119.6	49.80	16.80	29.30	3.94	23.90	245.00	22.10	23.10	--	61482	--	Spring	333	09/24/04
Gandy Warm Spring (Warm Spring Near Gandy)	39.46000	-114.03707	26.9	6.3	7.71	-15.88	-120.0	50.70	17.10	29.10	3.92	23.60	236.00	22.60	22.80	--	61963	--	Spring	333	01/22/05
Gandy Warm Spring (Warm Spring Near Gandy)	39.46000	-114.03707	--	--	--	-15.83	-119.4	--	--	--	--	--	--	--	--	--	62623	--	Spring	333	05/23/05
Gandy Warm Spring (Warm Spring Near Gandy)	39.46000	-114.03707	--	--	--	-15.93	-119.8	49.90	16.40	28.40	3.86	23.60	22.20	240.00	22.30	0.2	63224	SU-1	Spring	333	08/12/05
Gandy Warm Spring (Warm Spring Near Gandy)	39.46000	-114.03707	26.6	4.9	7.52	-15.90	-122.8	47.30	17.00	28.50	3.91	22.80	235.00	22.50	22.70	0.6	63568	--	Spring	333	11/08/05
Gandy Warm Spring (Warm Spring Near Gandy)	39.46000	-114.03707	26.8	5.5	7.58	-15.96	-119.5	50.80	16.20	28.20	3.89	23.70	236.00	22.80	22.50	0.7	64237	SU-1	Spring	333	02/25/06
Gandy Warm Spring (Warm Spring Near Gandy)	39.46000	-114.03707	27.3	5.8	7.55	-16.00	-121.2	50.40	16.60	28.80	4.92	24.20	236.00	23.50	23.00	0.6	64740	SU-1	Spring	333	05/21/06
Gandy Warm Spring (Warm Spring Near Gandy)	39.46000	-114.03707	26.7	5.8	7.59	-15.88	-120.4	51.20	17.00	24.10	3.01	24.40	247.00	22.80	21.80	0.6	65292	SU-1	Spring	333	08/25/06
Gandy Warm Spring (Warm Spring Near Gandy)	39.46000	-114.03707	26.9	5.7	7.56	-15.91	-120.3	51.10	17.10	28.60	3.85	24.10	233.00	22.70	22.40	0.6	65658	SU-1	Spring	333	10/29/06
Granite Spring	38.56271	-114.91658	11.8	5.8	6.83	-13.32	-103.4	44.60	10.90	16.60	2.92	12.60	186.00	17.20	57.30	0.2	65049	ER-23	Spring	440	07/13/06
Grapevine Spring (KSV-2)	37.12988	-114.70972	--	--	--	-11.60	-88.0	--	--	--	--	--	--	--	--	--	183	Kirk1028	Spring	93	--
Grapevine Spring (KSV-2)	37.12988	-114.70972	18.5	--	7.30	-12.00	-87.5	75.00	22.00	17.00	2.30	27.00	280.00	40.00	22.00	0.9	185	GS69	Spring	93	02/03/84
Grapevine Spring (KSV-2)	37.12988	-114.70972	18.2	2.4	7.56	-11.90	-88.6	77.20	17.30	20.20	2.90	31.40	236.00	44.50	28.30	--	62396	DRI-MM-1	Spring	93	04/27/05
Grapevine Spring (KSV-2)	37.12988	-114.70972	--	--	--	-11.95	-85.2	77.50	17.90	18.70	2.38	32.70	245.00	46.70	27.30	0.3	63223	DRI-MM-1	Spring	93	08/16/05
Grapevine Spring (KSV-2)	37.12988	-114.70972	18.3	5.7	7.71	-11.89	-87.7	79.20	17.60	18.10	2.62	30.10	244.00	42.80	26.80	0.7	63573	--	Spring	93	11/09/05
Grapevine Spring WR7	37.12988	-114.70972	12.1	4.9	7.50	-12.00	-87.3	76.30	18.00	18.00	1.95	32.10	228.00	44.80	24.20	0.7	64171	MM-1	Spring	93	02/16/06
Grapevine Spring WR7	37.12988	-114.70972	18.8	1.3	7.30	-11.92	-87.3	76.70	17.70	16.80	2.55	28.00	248.00	40.00	26.70	0.7	64745	MM-1	Spring	93	05/22/06
Grapevine Spring WR7	37.12988	-114.70972	20.7	2.6	7.14	-12.00	-87.4	73.40	18.50	16.70	1.96	31.00	233.00	45.60	24.80	0.7	65288	MM-1	Spring	93	08/23/06
Grapevine Spring WR7	37.12988	-114.70972	17.3	2.9	7.28	-11.93	-87.2	74.00	18.50	18.10	2.05	29.60	228.00	44.70	24.10	0.7	65665	MM-1	Spring	93	10/30/06
Grapevine Spring WR7	37.12988	-114.70972	--	--	--	-12.03	-87.5	--	--	--	--	--	--	--	--	--	--	MM-1	Spring	93	05/09/07
Grass Valley Springs	39.71321	-114.23300	9.2	6.0	6.35	-16.72	-124.7	18.00	3.26	12.30	0.94	5.90	81.00	5.10	26.60	0.1	63274		Spring	392	08/23/05

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Gubler Canyon Creek Spring (Unnamed Spring in Gubler Canyon)	39.13389	-114.96139	12.5	--	--	-14.90	-111.0	--	--	--	--	2.40	--	--	--	--	457	GS243	Spring	235	06/16/83
Hackberry Spring	36.91778	-114.43778	10.0	--	--	-12.30	-87.0	--	--	--	--	--	--	--	--	--	162	GS58	Spring	84	02/05/84
Haggerty Spring	38.66930	-114.90482	11.9	6.0	6.85	-14.78	-109.6	69.70	13.00	3.94	0.76	2.80	259.00	7.00	10.60	--	62979	ER-9	Spring	387	07/31/05
Headwaters Spring WR5	38.36575	-114.31935	9.6	6.5	7.00	-14.65	-106.9	10.40	2.41	4.47	1.31	4.50	37.10	4.70	19.10	--	60311	--	Spring	309	05/19/04
Headwaters Spring WR5	38.36575	-114.31935	--	--	--	-14.67	-108.7	--	--	--	--	--	--	--	--	--	60311B	--	Spring	309	07/18/04
Headwaters Spring WR5	38.36575	-114.31935	8.2	7.1	6.85	-14.67	-108.8	11.20	2.51	4.79	1.21	4.20	37.20	4.40	20.40	--	61481	--	Spring	309	09/23/04
Headwaters Spring WR5	38.36575	-114.31935	--	--	--	-15.01	-110.4	--	--	--	--	--	--	--	--	--	62970	--	Spring	309	07/27/05
Headwaters Spring WR5	38.36575	-114.31935	--	--	--	-14.99	-109.6	11.80	2.54	4.88	1.21	4.70	3.40	44.30	21.10	0.2	63221	WC-1	Spring	309	08/13/05
Headwaters Spring WR5	38.36575	-114.31935	9.5	6.0	6.36	-14.71	-107.8	13.80	3.00	5.43	1.34	6.20	46.90	4.40	21.40	0.1	63565		Spring	309	11/07/05
Headwaters Spring WR5	38.36575	-114.31935	9.3	6.3	6.54	-14.52	-106.3	11.40	2.57	5.21	1.27	3.70	45.00	3.70	22.00	0.1	64737	WC-1	Spring	309	05/23/06
Headwaters Spring WR5	38.36575	-114.31935	12.1	6.1	6.37	-14.59	-107.7	10.70	2.46	5.04	1.29	4.48	43.20	4.08	21.20	0.1	65370	WC-1	Spring	309	08/31/06
Headwaters Spring WR5	38.36575	-114.31935	8.9	7.1	6.50	-14.47	-107.3	11.50	2.68	5.28	1.30	4.41	41.10	4.03	21.50	0.1	65744	WC-1	Spring	309	11/16/06
WR 5 Autosampler	38.36575	-114.31935	--	--	--	-14.61	-107.6	--	--	--	--	--	--	--	--	--	DRI-65370-9	WC-1	Spring	309	12/01/05
WR 5 Autosampler	38.36575	-114.31935	--	--	--	-14.70	-108.6	--	--	--	--	--	--	--	--	--	DRI-65370-12	WC-1	Spring	309	01/01/06
WR 5 Autosampler	38.36575	-114.31935	--	--	--	-14.52	-107.7	--	--	--	--	--	--	--	--	--	DRI-65370-14	WC-1	Spring	309	02/01/06
WR 5 Autosampler	38.36575	-114.31935	--	--	--	-14.34	-105.7	--	--	--	--	--	--	--	--	--	DRI-65370-16	WC-1	Spring	309	03/01/06
WR 5 Autosampler	38.36575	-114.31935	--	--	--	-14.36	-105.5	--	--	--	--	--	--	--	--	--	DRI-65370-20	WC-1	Spring	309	05/01/06
WR5 Autosample 1	38.36575	-114.31935	--	--	--	-14.53	-105.7	--	--	--	--	--	--	--	--	--	65744 Auto1	WC-1	Spring	309	09/01/06
WR5 Autosample 5	38.36575	-114.31935	--	--	--	-14.10	-105.4	--	--	--	--	--	--	--	--	--	65744 Auto5	WC-1	Spring	309	11/01/06
Headwaters Spring WR5	38.36575	-114.31935	8.5	NA	6.24	-14.24	-105.0	10.60	2.41	4.62	1.24	3.10	41.80	3.50	19.40	0.1	65744	WC-1	Spring	309	05/07/07
Headwaters Spring WR5	38.36575	-114.31935	--	--	--	-14.33	-105.2	--	--	--	--	--	--	--	--	--	67249A	WC-1	Spring	309	06/01/07
Headwaters Spring WR5	38.36575	-114.31935	--	--	--	-14.21	-104.5	--	--	--	--	--	--	--	--	--	67249B	WC-1	Spring	309	07/01/07
Headwaters Spring WR5	38.36575	-114.31935	12.8	4.3	6.30	-14.32	-106.4	10.30	2.35	5.37	1.39	3.64	43.80	3.71	19.60	<.1	67249	WC-1	Spring	309	08/20/07
Headwaters Spring WR5	38.36575	-114.31935	10.1	5.5	6.40	-14.32	-105.3	10.30	2.33	4.81	1.18	3.80	40.80	3.60	18.90	0.1	67507	WC-1	Spring	309	11/02/07
Headwaters Spring WR5	38.36575	-114.31935	9.2	5.5	6.29	-14.30	-105.4	9.72	2.28	4.46	1.16	3.40	38.20	3.58	19.40	0.1	68475	WC-1	Spring	309	05/30/08
Headwaters Spring WR5	38.36575	-114.31935	11.5	6.4	6.32	-14.44	-104.9	9.94	2.40	4.53	1.26	3.72	38.70	3.72	20.30	0.1	68912	WC-1	Spring	309	09/11/08
Headwaters Spring WR5	38.36575	-114.31935	10.1	6.8	6.24	-14.44	-106.4	10.10	2.38	4.48	1.32	3.75	47.00	3.61	19.20	0.1	69143	WC-1	Spring	309	10/30/08
Headwaters Spring WR5	38.36575	-114.31935	9.0	7.3	6.17	-13.98	-103.4	10.10	2.42	4.51	1.29	3.47	40.30	3.70	19.00	0.1	69859	WC-1	Spring	309	05/18/09
Headwaters Spring WR5	38.36575	-114.31935	--	--	--	-14.14	-103.8	10.20	2.36	4.54	1.29	3.85	39.60	3.72	20.30	0.1	69859	WC-1	Spring	309	08/17/09
Headwaters Spring WR5	38.36575	-114.31935	--	--	--	-14.27	-104.7	9.70	2.25	4.52	1.20	4.08	38.20	3.75	18.60	0.1	70611	WC-1	Spring	309	11/14/09
Hells Acres Gulch Spring (Unnamed Spring in Hells Acres Gulch)	37.46028	-115.12472	13.0	--	8.30	-12.30	-93.0	45.20	9.03	20.70	2.38	8.20	198.00	19.90	39.00	--	211	K9	Spring	109	01/14/85
Henry Spring	37.68990	-115.37391	--	--	--	-12.77	-97.4	--	--	--	--	--	--	--	--	--	--	--	Spring	287	06/25/04
High Springs	39.13012	-114.95041	7.4	6.5	7.50	-15.43	-113.4	66.20	10.10	3.65	0.91	0.80	232.00	17.90	10.40	0.1	65042	ER-16	Spring	433	07/12/06
Highland Spring	37.92110	-114.54923	10.0	--	7.20	-13.30	-98.5	86.00	36.00	4.70	1.00	4.40	474.00	8.10	15.00	0.1	320	GS120	Spring	163	04/07/85
Highland Spring	37.92110	-114.54923	11.6	5.8	7.35	-13.49	-99.6	77.10	35.90	3.71	0.71	3.70	413.00	6.20	15.30	--	60839	--	Spring	163	06/24/04
Highland Spring	37.92110	-114.54923	10.2	7.3	6.79	-13.30	-99.3	82.90	35.10	4.34	0.64	3.40	403.00	5.90	16.10	--	62408	DRI-HR-1	Spring	163	05/01/05

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Hiko Spring	37.59833	-115.21444	--	--	--	-13.80	-109.0	--	--	--	--	--	--	--	--	--	249	PLC12	Spring	122	--
Hiko Spring	37.59833	-115.21444	--	--	--	--	-110.5	--	--	--	--	--	--	--	--	--	254	IT127	Spring	122	08/01/68
Hiko Spring	37.59833	-115.21444	--	--	--	--	-109.5	--	--	--	--	--	--	--	--	--	255	IT128	Spring	122	01/01/69
Hiko Spring	37.59833	-115.21444	--	--	--	--	-109.5	--	--	--	--	--	--	--	--	--	256	IT129	Spring	122	03/01/70
Hiko Spring	37.59833	-115.21444	26.0	--	7.40	-15.30	-110.0	49.0	23.00	26.00	7.40	11.00	282.00	37.00	30.00	0.6	251	IT124	Spring	122	01/14/85
Hiko Spring	37.59833	-115.21444	--	--	--	-14.00	-105.0	--	--	--	--	--	--	--	--	--	257	IT130	Spring	122	01/14/85
Hiko Spring	37.59833	-115.21444	26.5	--	7.73	-14.45	-107.7	46.40	23.33	25.57	6.63	11.00	273.00	38.10	33.08	0.5	252	IT125	Spring	122	08/07/95
Hole in the Bank Spring	38.84915	-114.89566	6.9	7.9	6.64	-15.37	-114.9	43.70	11.00	12.40	2.95	5.10	195.00	10.50	50.60	0.1	62977	ER-8	Spring	386	07/31/05
Horse Spring (Morman)	36.94139	-114.44639	--	--	--	-12.70	-89.0	--	--	--	--	--	--	--	--	--	167	GS59	Spring	85	02/05/84
Horse Spring (Grant)	38.32951	-115.38580	14.7	7.2	7.10	-12.86	-99.5	--	--	--	--	--	--	--	--	--	62829	GR-3	Spring	370	06/30/05
Horsethief Spring	38.02649	-114.24511	11.7	1.6	6.92	-12.73	-96.3	56.60	7.96	16.50	1.22	18.60	206.00	13.00	50.10	--	60314	--	Spring	314	05/20/04
Horsethief Spring	38.02649	-114.24511	9.7	1.9	6.39	-12.62	-97.6	76.50	10.60	27.60	0.50	19.50	293.00	13.50	60.30	--	62406	DRI-WC-6	Spring	314	05/01/05
Hot Creek Campground Well	38.38833	-115.13278	19.0	--	--	-15.30	-118.0	--	--	--	--	--	--	--	--	--	374	GS155	Well	198	07/19/81
Hot Creek Springs	38.38251	-115.15451	32.5	1.0	7.22	-15.50	-118.0	59.00	21.00	24.00	5.50	10.00	--	46.00	28.00	0.9	372	GS153	Spring	197	07/19/81
Hot Creek Springs	38.38251	-115.15451	--	--	--	-15.82	-120.0	--	--	--	--	--	--	--	--	--	68113	SNWA	Spring	197	08/08/03
Hot Creek Springs	38.38251	-115.15451	--	--	--	-15.51	-120.1	--	--	--	--	--	--	--	--	--	88477	SNWA	Spring	197	06/23/04
Hot Creek Springs	38.38251	-115.15451	31.8	1.3	7.17	-15.71	-120.5	57.90	22.10	24.90	4.82	10.10	282.00	43.90	28.20	--	61484	--	Spring	197	09/25/04
Hot Creek Springs	38.38251	-115.15451	31.3	1.4	7.33	-15.66	-119.0	59.00	22.20	25.00	5.28	10.00	272.00	45.50	27.80	--	61972	--	Spring	197	01/24/05
Hot Creek Springs	38.38251	-115.15451	31.2	1.6	7.05	-15.66	-118.6	--	--	--	--	--	--	--	--	--	62624	DRI-WV-2	Spring	197	05/18/05
Hot Creek Springs	38.38251	-115.15451	31.3	1.6	6.77	-15.70	-117.4	--	--	--	--	--	--	--	--		63228	DRI-WV-2	Spring	197	08/14/05
Hot Creek Spring	38.38251	-115.15451	30.9	1.5	7.33	-15.73	-119.1	59.70	22.40	24.30	5.03	10.00	273.00	45.10	27.70	1.0	63564	--	Spring	197	11/06/05
Hot Creek Spring	38.38251	-115.15451	31.3	1.9	7.32	-15.77	-119.2	58.70	22.10	24.50	5.22	10.20	269.00	45.40	27.80	1.0	65656	WV-2	Spring	197	10/28/06
Hot Creek Springs	38.38251	-115.15451	31.3	1.1	7.29	-15.75	-118.4	59.50	21.50	24.30	5.14	10.10	271.00	45.20	28.80	1.0	64234	WV-2	Spring	197	02/17/06
Hot Creek Springs	38.38251	-115.15451	31.7	1.5	7.36	-15.67	-120.1	59.60	21.60	25.20	5.15	10.60	269.00	47.00	28.40	1.0	64736	WV-2	Spring	197	05/22/06
Hot Creek Springs	38.38251	-115.15451	31.4	1.3	7.30	-15.75	-119.0	59.30	22.30	22.30	4.53	10.10	268.00	46.00	27.70	1.0	65367	WV-2	Spring	197	08/29/06
Indian Spring (N Jakes V)	39.44040	-115.31884	--	--	--	-15.25	-118.4	--	--	--	--	--	--	--	--	--	92573	SNWA	Spring	334	07/27/04
Indian Spring (N Jakes V)	39.44040	-115.31884	11.3	7.9	7.10	-15.31	-119.1	--	--	--	--	--	--	--	--	--	62709	DRI-BT-8	Spring	334	06/05/05
Indian Springs (S Springs V)	38.64160	-114.44957	--	--	--	-14.16	-106.3	26.30	4.10	12.70	4.56	9.40	114.00	6.70	72.80	0.1	62974	FO-1	Spring	375	07/29/05
Iverson's Spring	36.71028	-114.71194	--	--	--	--	-97.0	--	--	--	--	--	--	--	--	--	111	PLC18	Spring	65	--
Jenson Well	37.18417	-114.46444	18.0	--	7.70	-11.60	-88.5	55.00	14.00	100.00	7.20	45.00	340.00	80.00	56.00	2.1	187	GS70	Well	95	04/10/85
John Wadsworth	37.76861	-114.40694	14.5	--	7.50	-12.90	-101.0	120.00	47.00	150.00	9.50	88.00	601.00	200.00	76.00	6.5	286	GS101	Well	140	06/04/85
Johnson Spring	39.92319	-114.98923	10.2	9.0	7.54	-15.94	-123.4	--	--	--	--	--	--	--	--	--	62625	DRI-CC-1	Spring	335	05/24/05
Jones Spring Pumphouse	36.71116	-114.71694	27.2	5.3	7.44	-12.99	-98.9	63.40	27.40	95.70	11.10	63.10	252.00	178.00	29.50	--	62033		Spring	293	02/10/05
Jones Spring Pumphouse	36.71116	-114.71694	32.0	3.9	7.00	-12.99	-97.8	63.70	27.30	96.00	11.20	61.90	256.00	174.00	31.40	2.2	62034	DRI-MV-6	Spring	293	06/08/05
Jones Spring Pumphouse	36.71116	-114.71694	31.7	3.7	7.36	-13.07	-97.7	63.80	27.40	96.30	10.90	61.80	254.00	178.00	29.40	2.2	64175	MV-5	Spring	292	02/16/06
Jones Spring Pumphouse	36.71116	-114.71694	32.2	4.4	7.27	-13.07	-97.9	62.60	27.10	93.10	11.20	62.60	254.00	181.00	29.70	2.2	64902	MV-5	Spring	292	06/21/06
Jones Spring Pumphouse	36.71116	-114.71694	32.2	4.1	7.30	-13.10	-97.3	63.70	27.80	84.50	9.32	62.20	269.00	179.00	29.30	2.1	65285	MV-5	Spring	292	08/23/06
Jones Spring Pumphouse	36.71116	-114.71694	31.2	4.1	7.29	-13.05	-97.9	63.63	27.37	93.43	10.80	62.05	256.17	177.67	29.75	2.2	--	--	Spring	292	--

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Juanita Spring	36.63694	-114.24750	26.0	--	7.30	-11.65	-87.0	130.00	43.00	25.00	5.30	15.00	--	370.00	29.00	1.0	90	GS30	Spring	50	01/25/86
Kalamazoo Spring WR6	39.56648	-114.59594	12.1	6.8	7.33	-16.22	-121.6	47.20	15.50	2.46	0.71	2.10	208.00	10.60	10.50	--	60962	SC-3	Spring	336	07/20/04
Kalamazoo Spring WR6	39.56648	-114.59594	12.3	6.7	7.32	-16.22	-118.5	46.80	16.00	3.20	0.87	1.90	196.00	11.00	11.70	--	61348A	SC-3	Spring	336	09/21/04
Kalamazoo Spring WR6	39.56648	-114.59594	11.9	6.9	7.42	-16.28	-121.6	48.60	16.50	3.49	0.79	1.80	209.00	12.10	11.40	--	61966	SC-3	Spring	336	01/23/05
Kalamazoo Spring WR6	39.56648	-114.59594	--	--	--	-16.13	-118.6	--	--	--	--	--	--	--	--	--	62636	SC-3	Spring	336	05/23/05
Kalamazoo Spring WR6	39.56648	-114.59594	--	--	--	-16.18	-119.2	49.60	15.20	3.03	0.71	1.80	214.00	11.40	11.50	0.1	63222A	SC-3	Spring	336	08/12/05
Kalamazoo Spring WR6	39.56648	-114.59594	11.9	7.3	7.47	-16.17	-121.0	49.10	17.50	3.46	0.74	1.90	219.00	12.80	12.40	<.05	63567	SC-3	Spring	336	11/08/05
Kalamazoo Spring WR6	39.56648	-114.59594	11.7	7.1	7.60	-16.22	-119.3	49.30	16.60	3.42	0.79	2.00	213.00	12.80	12.10	<.1	64236	SC-3	Spring	336	02/25/06
Kalamazoo Spring WR6	39.56648	-114.59594	9.8	8.1	7.51	-16.06	-118.0	50.00	11.00	2.65	0.55	1.40	191.00	7.40	9.60	<.05	64739	SC-3	Spring	336	05/21/06
Kalamazoo Spring WR6	39.56648	-114.59594	--	--	--	-16.16	-120.1	--	--	--	--	--	--	--	--	--	--	SC-3	Spring	336	08/02/06
Kalamazoo Spring WR6	39.56648	-114.59594	11.9	7.3	7.55	-16.24	-119.7	50.00	17.10	2.87	0.60	2.02	230.00	12.40	12.00	<.05	65368	SC-3	Spring	336	08/30/06
Kalamazoo Spring WR6	39.56648	-114.59594	12.0	6.5	7.52	-16.11	-120.5	50.20	17.30	3.51	0.82	1.50	216.00	12.50	12.40	<.05	65657	SC-3	Spring	336	10/29/06
Kalamazoo Spring WR6	39.56648	-114.59594	11.3		7.60	-16.19	-120.4	48.70	16.30	3.67	0.76	1.45	220.00	11.70	12.40	0.1	65657	SC-3	Spring	336	05/08/07
Kalamazoo Spring WR7	39.56648	-114.59594	12.4	5.7	7.51	-16.22	-120.4	47.90	16.40	3.21	0.72	1.26	225.00	12.00	10.90	<.1	67250	SC-3	Spring	336	08/21/07
Kalamazoo Spring WR8	39.56648	-114.59594	12.0	4.2	7.67	-16.28	-120.7	50.10	17.40	3.35	0.77	1.40	227.00	12.30	11.30	<.05	67513	SC-3	Spring	336	11/04/07
Kalamazoo Spring WR9	39.56648	-114.59594	11.8	6.9	7.50	-16.30	-121.3	45.70	16.20	3.15	0.68	1.79	225.00	12.60	11.40	0.1	67947	SC-3	Spring	336	03/02/08
Kalamazoo Spring WR10	39.56648	-114.59594	11.7	6.9	7.67	-16.20	-120.4	48.20	16.40	3.44	0.78	1.79	220.00	12.10	11.50	0.0	68478	SC-3	Spring	336	05/31/08
Kalamazoo Spring WR11	39.56648	-114.59594	12.4	7.3	7.52	-16.37	-120.0	48.20	17.20	3.17	0.74	1.84	222.00	12.00	11.10	0.0	68917	SC-3	Spring	336	09/13/08
Kalamazoo Spring WR12	39.56648	-114.59594	12.3	7.0	7.55	-16.32	-121.4	47.90	17.30	3.38	0.92	1.80	218.00	12.00	11.00	0.1	69148	SC-3	Spring	336	11/01/08
Kalamazoo Spring WR13	39.56648	-114.59594	11.9	6.9	7.58	-16.36	-121.6	48.50	16.90	3.25	0.76	1.70	213.00	11.60	11.50	0.0	69427	SC-3	Spring	336	01/16/09
Kalamazoo Spring WR14	39.56648	-114.59594	10.3	7.6	7.57	-16.23	-118.9	46.90	12.00	3.27	0.70	1.46	195.00	8.91	11.30	0.0	69866	SC-3	Spring	336	05/21/09
Kalamazoo Spring WR15	39.56648	-114.59594	--	--	--	-16.21	-120.3	47.90	15.80	3.11	0.69	1.90	209.00	10.70	11.40	0.0	69866	SC-3	Spring	336	08/15/09
Kalamazoo Spring WR16	39.56648	-114.59594	--	--	--	-16.32	-121.1	48.00	16.50	3.28	0.82	1.97	225.00	11.50	10.80	0.0	70615	SC-3	Spring	336	11/15/09
Kane Springs (KSV-3)	37.24611	-114.70584	--	--	--	-12.60	-87.0	--	--	--	--	--	--	--	--	--	193	Kirk1025	Spring	97	--
Kane Springs (KSV-3)	37.24611	-114.70584	16.4	--	7.20	-11.90	-86.5	44.00	13.00	20.00	5.90	17.00	210.00	14.00	60.00	2.8	195	GS72	Spring	97	02/02/84
Kane Springs (KSV-3)	37.24611	-114.70584	14.8	5.2	7.04	-11.88	-87.0	49.00	13.60	20.30	1.36	17.60	214.00	15.10	64.50	--	58490	--	Spring	97	01/13/04
Kershaw-Ryan Spring #1	37.59028	-114.52010	20.0	6.5	8.40	-13.11	-95.1	24.20	2.66	26.50	4.38	6.30	140.00	4.40	46.10	--	59701	--	Spring	250	03/27/04
Kiln Spring	37.80510	-114.16423	11.5	2.4	7.11	-12.34	-91.9	93.50	22.90	34.80	0.53	51.20	320.00	56.90	27.40	0.2	64904	MG-1	Spring	418	06/21/06
Lake Mead Base Well #3	36.23917	-115.00444	--	--	--	-13.80	-101.5	--	--	--	--	--	--	--	--	--	19	PLC35	Well	12	--
Lake Valley Well	38.35556	-114.58917	18.0	--	8.10	-14.70	-111.0	61.00	9.70	22.00	2.10	68.00	121.00	25.00	25.00	0.2	365	GS147	Well	193	06/07/85
Lamb Spring	36.94500	-115.10583	13.5	--	--	-13.15	-92.5	37.00	41.00	8.70	0.60	8.60	--	24.00	12.00	0.2	168	--	Spring	86	05/19/88
Lester Mathews Well	37.79361	-114.39972	20.0	--	8.10	-13.30	-103.0	73.00	21.00	140.00	10.00	44.00	--	170.00	64.00	3.1	289	GS104	Well	142	06/04/85
Lime Spring	37.91467	-114.54022	21.0	--	8.30	-12.90	-97.0	55.00	31.00	3.80	0.90	4.10	290.00	8.90	14.00	0.1	315	GS118	Spring	160	04/07/85
Lime Spring	37.91467	-114.54022	15.1	0.4	7.35	-13.41	-99.9	76.10	40.60	3.27	1.09	3.60	433.00	6.40	14.10	--	60840	--	Spring	160	06/24/04
Lion Spring	38.25863	-114.13032	9.8	8.2	7.77	-14.11	-103.4	37.00	7.04	17.20	3.84	36.10	124.00	15.30	56.60	--	60317	--	Spring	318	05/21/04
Lion Spring (Egan Range)	39.18037	-114.98444	12.5	5.1	7.28	-15.34	-114.8	64.50	13.20	13.70	4.61	15.40	237.00	28.70	42.30	0.1	65039	ER-13	Spring	430	07/12/06
Little Ash Spring (Ash Spring)	37.46389	-115.19167	37.0	--	7.36	-14.20	-107.2	45.27	15.40	29.80	7.30	9.50	250.00	35.00	31.54	0.8	229	IT33	Spring	111	08/08/95
Little Boulder Spring	37.71330	-114.95217	12.0	6.4	7.10	-13.06	-97.2	21.80	5.88	7.99	2.91	4.90	101.00	7.80	44.80	--	59690	--	Spring	301	03/24/04
Little Currant Creek	38.83444	-115.35806	10.5	--	--	-15.00	-113.0	--	--	--	--	--	--	--	--	--	--	--	Surface	217	08/23/83

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Little Spring (Grant Range)	38.33197	-115.36050	14.7	1.7	6.90	-12.48	-99.4	--	--	--	--	--	--	--	--	--	62828	--	Spring	369	06/30/05
Little Springs (Clover Mts)	37.53418	-114.35607	18.5	5.3	7.56	-12.78	-93.0	30.20	5.11	11.20	2.77	9.70	137.00	4.80	56.50	--	61096	--	Spring	254	07/31/04
Little Springs (Clover Mts)	37.53418	-114.35607	17.1	6.7	6.81	-12.84	-93.5	29.60	4.73	10.80	2.45	8.60	112.00	5.00	46.60	--	62403	DRI-CR-7	Spring	254	04/30/05
Little Cut Spring	37.69653	-115.37810	--	--	--	-12.93	-98.4	68.80	19.70	21.10	2.57	22.20	295.00	30.60	55.90	--	60844		Spring	286	06/25/04
Little Cut Spring	37.69653	-115.37810	10.4	4.8	6.77	-12.76	-98.2	75.00	21.00	22.80	2.30	21.10	302.00	33.10	52.20	--	62410	DRI-MI-1	Spring	286	05/02/05
Little Tom Plain Spring	39.08092	-115.37152	8.0	7.2	6.70	-15.87	-121.8	--	--	--	--	--	--	--	--	--	62712	DRI-WP-7	Spring	337	06/06/05
Little Tom Plain Spring (RS)	39.08103	-115.37172	8.9	5.7	7.13	-15.85	-120.1	66.80	5.61	19.30	2.63	14.70	231.00	19.80	47.30	0.3	65037	WP-12	Spring	337	07/11/06
Littlefield Spring	38.23125	-114.70223	14.9	5.0	7.02	-12.73	-98.5	67.10	13.30	16.30	2.75	22.50	254.00	20.90	47.50	--	60847	--	Spring	275	06/26/04
Littlefield Spring	38.23125	-114.70223	--	--	--	-12.40	-98.0	--	--	--	--	--	--	--	--	--	112272	SNWA	Spring	275	07/25/05
Lone Pine Spring	38.89556	-114.89944	--	--	--	-14.98	-109.2	--	--	--	--	--	--	--	--	--	--	--	Spring	223	10/13/03
Lone Pine Spring	38.89556	-114.89944	8.0	7.4	7.50	-14.95	-111.5	67.00	4.20	3.50		1.60	224.00	3.70	17.00	<.1	434	GS214	Spring	223	08/01/85
Lone Pine Spring	38.89556	-114.89944	7.0	7.1	7.44	-14.77	-110.0	72.50	3.80	4.35	1.27	2.30	220.00	6.00	27.60	0.1	65053	ER-27	Spring	223	07/13/06
Lower Chokecherry Spring	37.53721	-114.69709	6.4	7.3	7.70	-12.98	-98.4	73.20	15.20	26.70	1.55	19.40	296.00	25.00	53.40	--	59694	--	Spring	261	03/25/04
Lower Fairview	38.17573	-114.65551	--	--	--	-12.39	-97.5	--	--	--	--	--	--	--	--	--	--	--	Spring	281	06/29/04
Lower Indian Spring	37.45006	-114.65730	21.4	3.6	8.30	-12.62	-96.0	1.90	0.17	95.10	0.80	12.10	221.00	10.40	56.20	--	58498	--	Spring	267	01/14/04
Lower Little Cherry Cr Spring	38.16722	-115.65333	--	8.0	7.55	-13.90	-103.0	--	--	--	--	--	268.00	--	--	--	346	GS135	Spring	182	07/31/85
Lower Pony Spring	38.31972	-114.60722	20.0	--	--	-13.20	-101.0	--	--	--	--	--	--	--	--	--	359	GS142	Spring	190	07/23/81
Lower Pony Spring	38.31972	-114.60722	14.0	--	7.90	-13.30	-101.0	45.00	2.00	36.00	1.10	10.00	202.00	8.20	47.00	0.1	360	GS143	Spring	190	04/05/85
Unnamed Spring in Snow Creek	40.07837	-114.91138	--	--	--	-16.24	-120.9	--	--	--	--	--	--	--	--	--	62629B	DRI-CC-3	Spring	338	05/24/05
Lund Spring	38.85000	-115.00250	19.0	5.7	7.49	-15.40	-113.0	56.00	23.00	3.80	0.90	2.80	270.00	11.00	11.00	0.1	429	GS210	Spring	221	04/27/82
Lund Spring	38.85000	-115.00250	--	--	--	-15.37	-117.1	--	--	--	--	--	--	--	--	--	68109	SNWA	Spring	221	08/06/03
Lund Spring	38.85000	-115.00250	--	--	--	-14.97	-115.3	--	--	--	--	--	--	--	--	--	88478	SNWA	Spring	221	06/24/04
M-8 Spring (Unnamed Spring)	36.72083	-114.72750	--	--	--	-12.75	-99.0	--	--	--	--	--	--	--	--	--	119	PLC15	Spring	68	10/30/85
M-9 Spring (Unnamed Spring)	36.72583	-114.72722	--	--	--	-12.45	-96.5	--	--	--	--	--	--	--	--	--	126	PLC16	Spring	70	10/30/85
Maynard Lake Spring (Unnamed Spring)	37.19167	-115.03389	9.6	--	7.90	-12.30	-94.0	43.00	23.00	114.00	14.00	30.00	405.00	88.00	--	--	186	IT136	Spring	94	01/14/85
McDermitt Spring	38.25914	-114.63164	--	--	--	-11.21	-94.3	--	--	--	--	--	--	--	--	--	--	--	Spring	323	06/26/04
Meadow Valley Wash, Cal.	37.63581	-114.51357	5.0	--	7.80	-13.10	-97.0	58.00	25.00	94.60	15.40	59.10	387.00	66.20	59.00	2.0	271	E27	Surface	130	12/00/79
Meloy Spring	38.25181	-114.70497	14.4	6.9	7.15	-12.75	-99.8	68.10	12.20	16.40	4.40	24.90	248.00	18.10	54.20	--	60845	--	Spring	276	06/26/04
Merril's Camp #39	38.18825	-113.86636	8.4	6.3	7.21	-14.13	-102.1	41.80	5.69	8.36	0.38	6.50	156.00	5.40	15.50	0.1	63597	--	Spring	410	11/19/05

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APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Mesquite Wtr Bunkerville 1	36.77528	-114.11806	23.0	--	7.50	-13.51	-102.5	54.00	28.00	39.00	8.10	31.00	198.00	120.00	25.00	0.9	132	GS49	Well	74	08/17/94
Mesquite Wtr Bunkerville 2	36.77417	-114.12889	23.0	--	7.60	-13.51	-102.1	38.00	20.00	50.00	7.50	13.00	220.00	89.00	21.00	1.4	131	GS48	Well	73	08/18/94
Mesquite Wtr Virgin Vly 5	36.77806	-114.08417	26.5	--	7.40	-13.78	-103.3	110.00	54.00	100.00	7.60	100.00	145.00	440.00	22.00	0.3	133	GS50	Well	75	08/17/94
Mesquite Wtr Virgin Vly 25	36.80833	-114.07250	23.0	--	7.60	-12.85	-98.9	55.00	34.00	210.00	9.30	160.00	210.00	300.00	28.00	1.2	152	GS54	Well	79	08/18/94
Moapa Well	36.53139	-114.79667	--	--	--	-13.40	-99.0	--	--	--	--	--	--	--	--	--	999	TH-1	Well	41	04/07/00
Mike's Spring	39.64370	-114.20490	10.7	6.4	6.77	-15.89	-121.1	61.90	18.90	31.80	1.81	29.20	246.00	34.80	27.50	0.4	63272	--	Spring	390	08/23/05
Mirant	36.41861	-114.95750	--	--	--	-13.23	-96.8	--	--	--	--	--	--	--	--	--	USGS	618	Well	622	06/04/03
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	5.7	8.7	7.50	-15.58	-111.2	56.70	10.00	2.48	0.61	1.10	229.00	4.30	7.40	--	57694	WP-1	Spring	320	10/12/03
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	6.0	8.5	7.46	-15.32	-113.3	76.00	7.73	2.68	0.70	1.10	259.00	3.30	9.00	--	59578	WP-1	Spring	320	03/23/04
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	6.7	9.7	8.00	-15.62	-114.0	60.50	9.88	2.09	0.54	1.00	219.00	3.80	7.80	--	60784	WP-1	Spring	320	06/21/04
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	7.3	10.1	7.41	-15.51	-115.7	60.80	10.90	3.17	1.00	1.20	231.00	4.20	7.50	--	61478	WP-1	Spring	320	09/22/04
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	5.0	8.6	8.14	-15.58	-115.1	62.00	10.70	2.83	0.77	1.30	227.00	4.50	7.40	--	61962	WP-1	Spring	320	01/21/05
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	6.4	9.4	6.61	-15.55	-112.3	--	--	--	--	--	--	--	--	--	62632A	WP-1	Spring	320	05/21/05
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	5.9	9.4	6.80	-15.63	-113.2	59.10	9.81	2.38	0.63	1.10	224.00	4.30	7.60	0.5	63218	WP-1	Spring	320	08/14/05
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	5.7	9.8	7.20	-15.65	-113.8	57.20	10.10	2.34	0.58	1.20	211.00	4.50	7.40	0.1	63561	WP-1	Spring	320	11/05/05
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	5.7	8.1	7.51	-15.69	-113.8	55.70	9.83	2.45	0.64	1.20	208.00	4.70	7.30	<.1	64235	WP-1	Spring	320	02/24/06
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	5.9	9.2	7.38	-15.38	-111.8	59.10	6.32	1.89	0.49	1.00	199.00	2.40	7.80	0.1	64733	WP-1	Spring	320	05/20/06
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	--	--	--	-15.63	-114.1	--	--	--	--	--	--	--	--	--	--	WP-1	Spring	320	07/11/06
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	5.7	8.4	7.12	-15.64	-114.7	56.20	10.10	2.41	0.58	1.28	217.00	4.77	7.39	0.1	65365	WP-1	Spring	320	08/29/06
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	5.6	8.3	7.20	-15.67	-114.5	56.00	10.20	2.48	0.62	1.21	209.00	4.55	7.28	0.1	65743	WP-1	Spring	320	11/15/06
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	5.9	--	7.24	-15.61	-114.6	64.90	8.57	2.36	0.61	0.88	244.00	3.57	7.10	0.1	65743	WP-1	Spring	320	05/06/07
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	6.0	6.3	7.19	-15.64	-114.1	56.40	10.30	2.46	0.60	0.80	228.00	4.71	6.97	<.1	67246	WP-1	Spring	320	08/19/07
Monitoring Spring WR1 (White Pine Range)	38.94951	115.40898	5.7	6.11	7.27	-15.68	-113.8	59.4	10.6	2.31	0.56	1	231	4.6	6.76	0.06	67509	WP-1	Spring	320	11/03/07
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	5.8	8.1	6.67	-15.70	-114.2	54.10	9.74	2.43	0.61	1.10	224.00	4.85	6.86	0.1	67950	WP-1	Spring	320	03/03/08
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	5.9	7.3	7.40	-15.59	-113.0	65.10	9.03	2.42	0.63	1.09	244.00	3.74	7.20	0.1	68483	WP-1	Spring	320	05/29/08
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	6.6	9.7	7.48	-15.69	-113.2	59.80	10.80	2.42	0.58	1.16	235.00	4.66	7.19	0.1	68918	WP-1	Spring	320	09/14/08
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	6.0	8.6	7.22	-15.68	-114.7	60.20	10.90	2.54	0.68	1.04	235.00	4.64	7.00	0.0	69149	WP-1	Spring	320	10/31/08
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	5.9	8.6	7.39	-15.66	-114.2	61.00	10.70	2.55	0.66	1.00	228.00	4.50	7.00	0.1	69428	WP-1	Spring	320	01/15/09
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	5.9	9.2	7.23	-15.90	-116.2	62.60	3.09	1.78	0.54	0.85	217.00	2.09	6.15	0.0	69861	WP-1	Spring	320	05/19/09
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	--	--	--	-15.69	-113.9	59.70	10.40	2.04	0.52	1.06	222.00	4.10	7.41	0.0	69861	WP-1	Spring	320	08/16/09
Monitoring Spring WR1 (White Pine Range)	38.94903	-115.41008	--	--	--	-15.71	-114.6	58.90	10.40	2.39	0.64	1.14	236.00	4.33	6.85	0.1	70616	WP-1	Spring	320	11/16/09
Monitoring Spring WR1 (White Pine Range)	38.94951	115.40898	--	--	--	-15.69	-114.9	63.5	9.16	2.37	0.54	1.2	235	3.4	7.3	0.06	70616	WP-1	Spring	320	06/18/10

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Moon River Spring	38.35167	-115.18083	32.5	2.3	7.38	-15.80	-120.0	55.00	22.00	22.00	4.40	9.30	260.00	44.00	25.00	1.2	362	GS145	Spring	192	04/27/82
Moorman Spring	38.59472	-115.13833	37.0	1.7	7.03	-15.70	-119.0	58.00	19.00	24.00	5.90	9.90	--	47.00	27.00	1.3	405	GS185	Spring	205	07/18/81
Moorman Spring	38.59472	-115.13833	--	--		-15.54	-120.2	--	--	--	--	--	--	--	--	--	88479	SNWA	Spring	205	06/23/04
Mormon Well Spring	36.64389	-115.09778	11.5	--	7.26	-12.90	-92.5	81.00	40.00	11.00	0.40	24.00	--	--	16.00	0.1	94	GS32	Spring	53	10/27/81
Mormon Well Spring	36.64389	-115.09778	10.0	5.1	7.60	-12.50	-91.0	65.00	41.00	12.00	1.00	12.00	395.00	21.00	16.00	0.1	95	GS33	Spring	53	05/09/83
Mormon Well Spring	36.64389	-115.09778	12.0	--	7.36	-12.60	-92.0	84.00	44.00	13.00	0.50	12.00	--	23.00	17.00	0.2	96	GS34	Spring	53	10/07/87
Mud Spring (Buck Mts)	39.73587	-115.57036	11.6	9.4	6.90	-15.21	-117.6	--	--	--	--	--	--	--	--	--	62705	DRI-BK-1	Spring	339	06/05/05
Mud Sp Barcass 34 (Snake Range)	39.32571	-114.26714	6.9	7.5	7.13	-15.43	-117.1	73.40	14.50	3.02	0.64	2.50	287.00	5.40	10.00	<.05	63528	--	Spring	404	10/25/05
Mud Spring	39.08160	-114.97241	12.4	5.0	7.31	-14.53	-111.0	62.40	11.20	14.10	0.57	8.60	235.00	18.40	15.20	0.1	65055	ER-29	Spring	446	07/13/06
Murphy Spring	38.33973	-115.44937	10.6	8.7	6.70	-15.40	-114.5	--	--	--	--	--	--	--	--	--	62833	--	Spring	373	07/02/05
Mustang Spring	37.73553	-114.92166	10.0	3.4	7.00	-12.60	-91.0	111.00	7.98	17.30	6.49	11.40	346.00	58.00	58.00	--	277	K6	Spring	135	01/14/85
Mustang Spring	37.73553	-114.92166	13.4	6.2	6.80	-12.37	-90.0	105.00	7.77	18.40	6.77	9.90	319.00	61.60	62.10	--	59691	--	Spring	135	03/24/04
Mustang Spring (Snake)	38.86257	-114.27179	4.3	8.4	7.09	-15.30	-111.0	68.00	4.58	1.32	0.36	0.80	5.50	218.00	5.70	2.2	62915	SN-6	Spring	382	07/14/05
MVW above Eagle Canyon	38.02778	-114.18583	19.0	--	8.20	-12.00	-93.0	--	--	--	--	--	--	--	--	--	328	E6	Surface	168	04/09/85
Narrow Canyon Spring	37.36729	-114.67807	9.9	5.8	7.20	-12.47	-92.5	61.90	12.70	17.70	1.87	17.90	228.00	20.80	47.20	--	59683		Spring	257	03/22/04
Nellis AFB #4	36.24889	-115.00417	--	--	--	-13.20	-95.0	--	--	--	--	--	--	--	--	--	20	PLC36	Well	13	--
Nellis AFB Well #13	36.21222	-115.05000	--	--	--	-13.80	-98.0	--	--	--	--	--	--	--	--	--	18	PLC34	Well	11	--
Newels Spring	37.90248	-114.03202	21.5	7.2	7.74	-12.48	-96.0	88.00	16.90	22.60	2.39	39.00	289.00	36.50	36.10	0.5	64909	MG-6	Spring	423	06/22/06
Nicholas Spring	38.91062	-115.06142	22.0	3.4	7.75	-16.10	-124.0	42.00	19.00	13.00	3.30	24.00	180.00	40.00	20.00	0.6	440	GS219	Spring	227	04/27/82
North Creek Spring	38.71056	-114.73056	8.5	--	6.90	-14.60	-105.0	9.10	1.60	2.20	0.90	1.30	25.00	3.80	12.00	0.4	420	GS198	Spring	214	04/03/85
North Lee Well	37.82444	-114.38444	22.0	--3	8.00	-13.30	-101.0	59.00	12.00	44.00	9.90	48.00	220.00	33.00	54.00	1.0	299	GS109	Well	147	06/04/85
North Spring	39.15611	-114.96306	5.5	--	--	-15.00	-113.0	--	--	--	--	4.20	--	--	--	--	459	GS245	Spring	237	06/17/83
North Springs	39.15490	-114.96278	6.3	7.1	7.42	-15.21	-111.7	54.30	9.63	3.44	0.52	1.40	201.00	10.70	9.30	0.1	65041	ER-15	Spring	237	07/12/06
Oak Spring	37.60547	-114.71015	10.5	7.1	7.05	-11.87	-90.0	84.90	16.50	64.10	1.97	41.10	355.00	34.20	56.50	--	58502	--	Spring	269	01/16/04
Ox Valley Spring	37.97053	-114.05966	8.8	6.0	7.02	-13.95	-100.0	37.50	6.97	5.23	0.50	4.60	118.00	25.00	12.40	0.6	64908	MG-5	Spring	422	06/22/06
Oxborrow Well	37.88611	-114.30472	11.5	--	7.90	-11.80	-92.0	130.00	22.00	65.00	11.00	140.00	351.00	63.00	58.00	0.8	303	GS112	Well	150	06/05/85
Pahroc Spring	37.66466	-114.98065	16.0	0.8	7.60	-12.50	-89.0	30.90	8.28	12.30	5.63	11.70	135.00	11.40	59.00	--	272	K5	Spring	131	01/14/85
Pahroc Spring	37.66466	-114.98065	14.4	5.7	7.40	-12.65	-94.0	25.60	6.69	40.10	5.72	13.10	169.00	12.90	66.80	--	58494		Spring	131	01/16/04
Pahroc Spring	37.66466	-114.98065	--	--	--	-12.55	-93.9	--	--	--	--	--	--	--	--	--	111191/12 0746	SNWA	Spring	131	04/05/05
Pahroc Spring	37.66466	-114.98065	16.0	7.3	6.61	-12.79	-93.5	31.30	8.33	12.70	5.16	12.60	134.00	12.80	62.10	--	61106C	DRI-PR-1	Spring	131	04/30/05

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Panaca Spring	37.80754	-114.38086	29.0	5.6	7.80	-13.90	-106.0	32.00	9.80	36.00	6.80	15.00	--	29.00	45.00	1.6	294	GS107	Spring	144	04/26/84
Panaca Spring	37.80754	-114.38086	29.5	--	7.90	-14.00	-108.0	34.00	10.00	38.00	7.10	16.00	--	25.00	50.00	1.5	292	GS105	Spring	144	04/08/85
Panaca Spring	37.80754	-114.38086	28.5	6.2	7.79	-14.20	-106.5	33.00	10.00	37.00	6.70	17.00	--	27.00	48.00	1.4	293	GS106	Spring	144	11/11/86
Panaca Spring	37.80754	-114.38086	--	--	--	--	-107.0	--	--	--	--	--	--	--	--	--	293	DRI	Spring	144	11/11/86
Panaca Spring	37.80754	-114.38086	28.4	4.0	7.83	-14.11	-107.4	32.40	10.40	38.00	7.43	17.80	176.00	30.40	52.40	--	61619	--	Spring	144	10/20/04
Panaca Spring	37.80754	-114.38086	28.6	5.4	7.68	-14.25	-107.9	32.60	10.30	37.90	7.19	17.30	177.00	29.30	49.70	--	61969	--	Spring	144	01/24/05
Panaca Spring	37.80754	-114.38086	28.3	4.7	7.04	-14.15	-107.1	--	--	--	--	--	--	--	--	--	62626	DRI-MW-1	Spring	144	05/20/05
Panaca Spring	37.80754	-114.38086	28.9	4.4	7.04	-14.17	-106.4	--	--	--	--	--	--	--	--	--	63231	DRI-MW-1	Spring	144	08/16/05
Panaca Spring	37.80754	-114.38086	28.7	4.6	7.60	-14.18	-106.8	30.00	10.30	37.60	7.00	17.40	179.00	29.10	49.00	1.4	63571	--	Spring	144	11/09/05
Panaca Spring	37.80754	-114.38086	28.8	4.2	7.71	-14.20	-105.8	34.20	10.20	37.90	6.97	17.90	178.00	29.70	48.80	1.5	64169	MW-1	Spring	144	02/17/06
Panaca Spring	37.80754	-114.38086	28.8	5.9	7.80	-14.17	-107.1	32.60	9.97	37.00	9.66	18.20	180.00	30.70	50.20	1.5	64743	MW-1	Spring	144	05/22/06
Panaca Spring	37.80754	-114.38086	29.1	5.9	7.67	-14.24	-107.0	32.60	10.20	34.60	6.06	17.80	184.00	30.50	49.80	1.5	65289	MW-1	Spring	144	08/23/06
Panaca Spring	37.80754	-114.38086	28.9	4.4	7.62	-14.14	-106.9	32.70	10.00	37.00	1.74	17.30	175.00	29.80	49.90	1.5	65654	MW-1	Spring	144	10/28/06
Panaca Town Well	37.79722	-114.39917	29.5	--	7.90	-14.00	-106.0	45.00	1.00	47.00	8.30	19.00	203.00	68.00	58.00	1.8	291	E16	Well	143	06/04/85
Parsnip Spring	38.14944	-114.26250	19.0	--	7.70	-12.80	-93.5	16.00	3.00	12.00	2.20	7.50	70.00	9.10	41.00	0.1	344	GS134	Spring	180	06/05/85
Patterson Pass Spring WR3	38.60280	-114.71481	12.0	6.0	6.60	-14.91	-106.5	--	--	--	--	--	--	--	--	--	57755	SC-2	Spring	305	10/30/03
Patterson Pass Spring WR3 (duplicate sample)	38.60280	-114.71481	--	--	--	-14.94	-109.2	--	--	--	--	--	--	--	--	--	57755	SC-2	Spring	305	10/30/03
Patterson Pass Spring WR3	38.60280	-114.71481	11.8	3.6	6.07	-14.75	-106.2	19.50	3.83	1.99	1.42	0.90	68.60	9.60	10.80	--	59579	SC-2	Spring	305	03/24/04
Patterson Pass Spring WR3	38.60280	-114.71481	11.5	6.2	7.10	-14.84	-109.1	19.80	4.62	3.00	1.46	1.20	67.00	9.80	11.10	--	60786	SC-2	Spring	305	06/23/04
Patterson Pass Spring WR3	38.60280	-114.71481	12.0	5.9	7.45	-14.79	-107.9	18.50	3.86	1.94	1.39	0.90	66.50	9.40	10.20	--	61480	SC-2	Spring	305	09/23/04
Patterson Pass Spring WR3	38.60280	-114.71481	11.7	5.5	6.82	-14.77	-108.3	20.50	4.14	2.20	1.46	1.20	71.60	9.80	10.50	--	61967	SC-2	Spring	305	01/23/05
Patterson Pass Spring WR3	38.60280	-114.71481	11.4	6.0	6.66	-14.71	-106.8	--	--	--	--	--	--	--	--	--	61481	SC-2	Spring	305	05/20/05
Patterson Pass Spring WR3	38.60280	-114.71481	--	--	--	-14.83	-107.6	18.80	3.66	1.89	1.41	1.00	65.50	8.70	10.10	0.7	63220	SC-2	Spring	305	08/15/05
Patterson Pass Spring WR3	38.60280	-114.71481	12.1	6.1	6.97	-14.87	-107.5	19.30	3.74	1.90	1.35	1.10	63.80	8.70	10.00	0.4	63566	SC-2	Spring	305	11/07/05
Patterson Pass Spring WR3	38.60280	-114.71481	11.8	7.1	6.78	-14.91	-108.1	19.60	3.82	1.86	1.23	1.12	65.90	9.10	10.20	0.5	65371	SC-2	Spring	305	08/31/06
Patterson Pass Spring WR3	38.60280	-114.71481	12.2	6.8	6.87	-14.89	-108.4	19.20	3.81	2.07	1.43	1.00	66.30	8.80	10.10	0.5	65653	SC-2	Spring	305	10/28/06
Patterson Pass Spring WR3	38.60280	-114.71481	11.9	6.4	6.52	-14.90	-106.9	19.40	3.68	1.86	1.42	1.20	65.00	8.80	10.10	0.5	64239	SC-2	Spring	305	02/26/06
Patterson Pass Spring WR3	38.60280	-114.71481	11.7	7.5	6.95	-14.86	-108.5	19.20	3.80	2.20	1.20	1.20	67.20	9.10	10.20	0.5	64738	SC-2	Spring	305	05/23/06
Patterson Pass Spring WR3	38.60280	-114.71481	--	--	--	-14.86	-107.9	--	--	--	--	--	--	--	--	--	--	SC-2	Spring	305	07/14/06
Patterson Pass Spring WR3	38.60280	-114.71481	11.7	--	6.60	-14.96	-108.5	19.90	3.82	1.99	1.40	0.95	69.00	8.37	9.59	0.5	65653	SC-2	Spring	305	05/07/07
Patterson Pass Spring WR3	38.60280	-114.71481	12.0	5.1	6.80	-14.87	-108.2	19.30	3.81	1.97	1.38	0.97	71.00	9.16	9.72	0.1	67248	SC-2	Spring	305	08/20/07
Patterson Pass Spring WR3	38.60280	-114.71481	12.2	3.3	6.79	-14.90	-107.3	20.10	3.93	2.09	1.39	1.00	70.00	9.10	9.50	0.5	67508	SC-2	Spring	305	11/02/07
Patterson Pass Spring WR3	38.60280	-114.71481	11.8	5.2	6.39	-14.94	-107.7	18.20	3.67	2.03	1.40	1.00	71.50	9.16	9.34	0.5	67951	SC-2	Spring	305	03/04/08
Patterson Pass Spring WR3	38.60280	-114.71481	11.7	5.1	6.83	-14.93	-106.9	18.70	3.91	2.05	1.37	1.04	69.50	9.22	9.40	0.5	68476	SC-2	Spring	305	05/30/08
Patterson Pass Spring WR3	38.60280	-114.71481	12.0	6.2	6.90	-14.95	-106.6	18.80	3.91	1.90	1.30	1.03	71.70	9.44	9.92	0.5	68911	SC-2	Spring	305	09/11/08
Patterson Pass Spring WR3	38.60280	-114.71481	12.2	5.7	6.51	-14.95	-107.8	19.40	3.95	2.03	1.47	0.93	72.70	9.45	9.52	0.5	69142	SC-2	Spring	305	10/31/08
Patterson Pass Spring WR3	38.60280	-114.71481	12.1	6.1	6.82	-14.96	-107.2	19.80	3.94	2.06	1.45	0.90	77.50	9.00	9.80	0.5	69423	SC-2	Spring	305	01/14/09
Patterson Pass Spring WR3	38.60280	-114.71481	11.6	5.9	6.76	-14.87	-106.1	19.30	3.90	2.05	1.36	0.90	69.10	9.41	9.54	0.5	69860	SC-2	Spring	305	05/18/09
Patterson Pass Spring WR3	38.60280	-114.71481	--	--	--	-14.93	-107.7	17.90	3.83	1.85	1.36	0.86	68.60	9.19	10.00	0.5	69860	SC-2	Spring	305	08/17/09
Patterson Pass Spring WR3	38.60280	-114.71481	--	--	--	-14.95	-108.1	19.50	3.91	2.00	1.75	1.04	72.30	9.52	9.47	0.5	70613	SC-2	Spring	305	11/15/09

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Peach Spring	36.95444	-114.28972	15.1	--	--	-10.40	-76.5	--	--	--	--	--	--	--	--	--	173	GS62	Spring	88	02/06/84
Pederson's East	36.70933	-114.71556	32.0	2.4	7.31	-12.92	-97.0	64.30	28.50	96.40	11.60	66.10	255.00	178.00	30.30	--	58497	DRI-MV-2	Spring	290	01/12/04
Pederson's East	36.70933	-114.71556	31.9	2.7	7.38	-12.92	-97.0	64.60	27.60	94.20	11.10	61.40	264.00	181.00	29.10	--	60307	DRI-MV-2	Spring	290	05/18/04
Pederson's East	36.70933	-114.71556	--	--	--	-12.98	-98.4	68.20	28.30	94.00	11.30	61.50	257.00	178.00	31.20	--	61613	DRI-MV-2	Spring	290	10/19/04
Pederson's East	36.70933	-114.71556	31.2	3.2	7.37	-12.89	-98.3	64.40	27.70	95.60	11.20	62.00	253.00	181.00	29.50	--	62032	DRI-MV-2	Spring	290	02/10/05
Pederson's East	36.70933	-114.71556	32.0	3.0	6.80	-12.96	-98.3	--	--	--	--	--	--	--	--	--	62033	DRI-MV-2	Spring	290	06/08/05
Pederson East	36.70933	-114.71556	31.6	2.7	7.32	-13.00	-97.5	64.80	27.70	95.70	10.10	61.00	254.00	180.00	29.10	2.2	64173	MV-2	Spring	290	02/16/06
Pederson East	36.70933	-114.71556	31.7	2.7	7.28	-13.02	-97.7	63.40	27.30	92.70	11.10	61.70	253.00	182.00	29.40	2.2	64901	MV-2	Spring	290	06/21/06
Pederson East	36.70933	-114.71556	32.0	2.8	7.25	-13.06	-97.4	64.80	28.10	86.00	9.64	61.80	257.00	183.00	29.10	2.2	65287	MV-2	Spring	290	08/23/06
Pederson East	36.70933	-114.71556	31.9	2.6	7.30	-13.03	-98.7	63.90	27.80	93.30	11.00	59.30	253.00	179.00	29.00	2.2	65663	MV-2	Spring	290	10/30/06
Pederson's Warm Spring (M-13)	36.70958	-114.71594	--	--	--	--	-98.0	--	--	--	--	--	--	--	--	--	113.2	jim	Spring	67	1/00/69
Pederson's Warm Spring (M-13)	36.70958	-114.71594	--	--	--	--	-97.0	--	--	--	--	--	--	--	--	--	113.2	jim	Spring	67	3/00/70
Pederson's Warm Spring (M-13)	36.70958	-114.71594	32.5	--	7.20	-12.90	-96.5	66.00	26.00	96.00	10.00	61.00	270.00	190.00	62.06	2.1	113	IT249	Spring	67	07/22/81
Pederson's Warm Spring (M-13)	36.70958	-114.71594	--	--	--	-12.75	-97.0	--	--	--	--	--	--	--	--	--	118	PLC17	Spring	67	10/30/85
Pederson's Warm Spring (M-13)	36.70958	-114.71594	--	--	--	-13.05	-99.0	--	--	--	--	--	--	--	--	--	115	IT251	Spring	67	01/07/88
Pederson's Warm Spring (M-13)	36.70958	-114.71594	--	--	--	-12.85	-96.9	--	--	--	--	--	--	--	--	--	USGS	--	spring	67	07/30/03
Pederson's Warm Spring (M-13)	36.70958	-114.71594	31.6	2.2	7.29	-12.91	-97.2	65.30	28.40	99.20	11.40	67.70	261.00	189.00	28.40	--	58488	DRI-MV-1	Spring	67	01/12/04
Pederson's Warm Spring (M-13)	36.70958	-114.71594	31.1	3.8	7.42	-12.85	-97.5	65.40	27.80	97.20	10.90	65.90	265.00	184.00	29.20	--	60306	DRI-MV-1	Spring	67	05/18/04
Pederson's Warm Spring (M-13)	36.70958	-114.71594	--	--	--	-12.92	-97.4	64.50	27.80	97.20	11.00	63.00	257.00	183.00	30.60	--	61617	DRI-MV-1	Spring	67	10/19/04
Pederson's Warm Spring (M-13)	36.70958	-114.71594	31.2	3.0	7.31	-12.91	-98.0	64.80	27.40	98.80	10.90	63.20	256.00	186.00	29.80	--	62031	DRI-MV-1	Spring	67	02/10/05
Pederson's Warm Spring (M-13)	36.70958	-114.71594	31.9	3.6	7.00	-12.91	-97.6	--	--	--	--	--	--	--	--	--	62032	DRI-MV-1	Spring	67	06/08/05
Pederson's Warm Spring (M-13)	36.70958	-114.71594	31.3	2.7	7.34	-13.02	-97.2	66.60	27.70	99.20	10.60	62.40	255.00	185.00	29.40	2.2	64172	MV-1	Spring	67	02/16/06
Pederson's Warm Spring (M-13)	36.70958	-114.71594	31.6	4.3	7.39	-12.98	-98.1	64.10	27.20	95.20	10.90	62.90	255.00	186.00	29.10	2.2	64900	MV-1	Spring	67	06/21/06
Pederson's Warm Spring (M-13)	36.70958	-114.71594	31.8	2.9	7.24	-13.01	-97.7	65.30	28.20	90.00	9.30	63.70	251.00	187.00	29.20	2.2	65286	MV-1	Spring	67	08/23/06
Pederson's Warm Spring (M-13)	36.70958	-114.71594	31.5	2.3	7.35	-13.04	-97.3	64.80	27.80	97.00	10.90	61.30	254.00	184.00	28.80	2.2	65664	MV-1	Spring	67	10/30/06
Perry Sp Barcass 37	38.33285	-114.97586	12.1	4.8	7.06	-15.04	-107.7	78.90	20.90	24.10	2.64	19.10	333.00	25.10	27.90	0.2	63531	--	Spring	408	10/27/05
Pine Spring	37.90800	-114.55132	4.5	--	--	-13.40	-99.0	--	--	--	--	--	--	--	--	--	312	GS116	Spring	157	04/07/85
Pine Spring	37.90800	-114.55132	--	--	--	-13.33	-99.0	--	--	--	--	--	--	--	--	--	--	--	Spring	157	06/24/04
Pine Springs (Egan Range)	39.11755	-114.94425	8.7	7.9	7.90	-15.71	-116.0	71.10	9.58	3.69	0.46	0.70	246.00	13.90	10.90	0.1	65043	ER-17	Spring	434	07/12/06
Preston Big Spring	38.93331	-115.08222	21.0	3.1	7.70	-15.60	-126.0	44.00	20.00	13.00	2.90	14.00	185.00	36.00	20.00	0.4	450	GS224	Spring	231	06/16/83
Preston Big Spring	38.93331	-115.08222	22.0	3.1	7.65	-15.90	-123.0	45.00	20.00	13.00	3.00	15.00	--	38.00	19.00	0.4	452	GS226	Spring	231	06/26/84
Preston Big Spring	38.93331	-115.08222	--	--	--	-15.99	-121.8	--	--	--	--	--	--	--	--	--	68111	SNWA	Spring	231	08/06/03
Preston Big Spring	38.93331	-115.08222	--	--	--	-15.66	-123.1	--	--	--	--	--	--	--	--	--	88482	SNWA	Spring	231	06/24/04
Preston Big Spring	38.93331	-115.08222	21.2	2.6	7.32	-15.87	-122.6	40.70	19.40	13.60	3.11	15.90	182.00	37.70	19.90	--	61483	DRI-WV-1	Spring	231	09/25/04
Preston Big Spring	38.93331	-115.08222	20.8	3.1	7.64	-15.89	-122.4	41.90	19.80	13.00	3.23	16.00	176.00	38.10	19.90	--	61968	DRI-WV-1	Spring	231	01/24/05
Preston Big Spring	38.93331	-115.08222	21.1	3.1	7.52	-15.86	-120.0	--	--	--	--	--	--	--	--	--	62627	DRI-WV-1	Spring	231	05/21/05
Preston Big Spring	38.93331	-115.08222	21.1	3.0	7.04	-15.88	-121.2	--	--	--	--	--	--	--	--	--	63227	DRI-WV-1	Spring	231	08/14/05
Preston Big Spring	38.93331	-115.08222	20.9	2.6	7.77	-15.86	-120.4	41.90	19.60	12.60	3.08	15.80	174.00	38.10	20.00	0.3	63563	--	Spring	231	11/06/05
Preston Big Spring	38.93331	-115.08222	21.3	3.8	7.66	-15.95	-121.8	41.60	19.20	13.20	3.16	16.50	175.00	39.90	20.40	0.4	64735	WV-1	Spring	231	05/20/06
Preston Big Spring	38.93331	-115.08222	-	-	-	-15.98	-121.7	-	-	-	-	-	-	-	-	-	--	WV-1	Spring	231	07/12/06
Preston Big Spring	38.93331	-115.08222	21.0	2.7	7.54	-15.96	-121.6	42.00	19.70	12.50	2.94	16.10	183.00	39.60	19.90	0.4	65366	WV-1	Spring	231	08/29/06
Preston Big Spring	38.93331	-115.08222	21.0	3.0	7.66	-15.88	-120.9	41.80	19.60	12.70	3.16	15.60	174.00	39.00	19.80	0.4	65652	WV-1	Spring	231	10/27/06

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Quaking Aspen Spring	37.37563	-114.24255	9.6	3.2	6.18	-12.98	-93.6	13.80	3.68	11.40	1.48	4.10	83.30	2.10	49.60	--	61100	--	Spring	255	07/31/04
Rabbit Brush	39.18383	-114.27363	--	--	--	-15.50	-117.1	--	--	--	--	--	--	--	--	--	--	--	Spring	412	10/26/05
Railroad Well	37.35111	-114.53389	16.0	--	7.60	-11.60	-86.0	42.00	14.00	98.00	8.80	42.00	300.00	60.00	51.00	2.3	204	GS77	Well	103	01/31/84
Railroad Well (Farrier, NV)	36.81361	-114.65389	22.8	--	8.00	-12.50	-97.5	84.00	31.00	150.00	19.00	52.00	64.00	550.00	23.00	1.6	154	USGS	Well	80	02/04/84
Raised Sp Barcass 36	38.97259	-114.37041	10.8	7.6	6.07	-13.54	-103.7	7.01	1.77	2.38	0.66	1.00	31.20	2.40	11.40	0.1	63532	--	Spring	407	10/27/05
Ram. Res. Wtr Supply Well	39.74333	-115.45111	11.9	50.0	8.02	-16.75	-129.5	--	--	--	--	--	155.00	--	--	--	470	GS261	Well	244	07/19/85
Ramone Mathews Well	37.52667	-114.24417	18.5	--	7.80	-12.30	-92.0	42.00	6.30	20.00	5.90	15.00	171.00	12.00	61.00	0.3	233	GS86	Well	115	06/03/85
Randono Well	37.32389	-114.50222	17.2	--	7.60	-11.70	-87.5	46.00	14.00	100.00	8.40	44.00	350.00	63.00	54.00	2.3	200	GS75	Well	100	02/03/84
Rattlesnake Spring	37.82624	-114.93012	14.1	7.4	7.80	-12.65	-97.3	47.60	7.50	27.60	5.16	16.50	199.00	19.30	52.50	--	59692	--	Spring	302	03/24/04
Red Rock Spring	37.56698	-114.75320	10.0	--	7.32	-12.30	-95.0	85.40	13.30	28.40	2.40	15.70	332.00	16.30	41.10	--	58495	--	Spring	256	01/10/04
Reed Spring	37.55731	-115.41800	--	--	--	-14.24	-98.4	49.60	14.20	13.70	2.78	17.30	199.00	18.90	43.90	--	60843	--	Spring	289	06/25/04
Ripgut Sp #40	38.24802	-114.03920	18.7	5.7	6.95	-14.38	-106.4	25.20	4.58	18.20	8.17	17.00	116.00	6.40	63.50	0.2	63598	--	Spring	411	11/19/05
Robison Spring	38.21273	-114.70636	--	--	--	-12.34	-97.9	--	--	--	--	--	--	--	--	--	--	--	Spring	279	06/29/04
Robbers Roost #2 Spring (Butte)	39.49596	-115.28046	12.7	1.3	6.20	-14.39	-112.0	--	--	--	--	--	--	--	--	--	62703	DRI-BT-5	Spring	340	06/04/05
Robbers Roost Spring (Schell Ck)	38.77051	-114.78331	--	--	--	-14.75	-109.7	58.80	27.90	11.20	0.56	7.20	304.00	21.70	14.30	0.1	62978	SC-5	Spring	389	07/31/01
Robbers Roost Spring (Schell Ck)	38.77051	-114.78331	--	--	--	-14.15	-109.2	--	--	--	--	--	--	--	--	--	68116	SNWA	Spring	389	08/06/03
Rock Springs	39.85979	-114.47277	9.4	5.1	6.05	-15.17	-118.4	50.00	8.01	12.50	0.91	5.80	188.00	15.70	38.20	0.1	63281	--	Spring	399	08/25/05
Rogers Spring	36.37750	-114.44389	30.5	2.3	7.02	-12.20	-92.0	410.00	140.00	280.00	21.00	330.00	--	1600.00	18.00	1.3	35	GS10	Spring	21	07/21/81
Rogers Spring	36.37750	-114.44389	30.0	--	7.48	-12.40	-92.0	423.00	143.00	291.00	22.70	327.00	161.00	1620.00	16.80	1.4	33	PL11	Spring	21	03/19/92
Rogers Spring	36.37750	-114.44389	30.0	2.6	7.03	-12.40	-91.0	--	--	--	--	--	--	--	--	--	32	PL11	Spring	21	02/08/96
Ryans Spring D 38	38.33121	-113.92855	8.0	2.2	7.07	-13.68	-103.5	80.80	8.31	24.90	0.91	41.50	264.00	22.80	33.30	0.1	63596	--	Spring	409	11/19/05
Rye Patch Spring	36.57967	-115.30586	9.7	8.1	7.54	-12.31	-89.3	49.50	24.20	16.00	1.98	17.50	218.00	22.00	13.70	--	62397	DRI-SR-5	Spring	341	04/28/05
Saddle Spring (White Pine)	38.97541	-115.40023	--	--	--	-15.00	-116.0	--	--	--	--	3.10	--	--	--	--	438	GS217	Spring	357	06/15/83
Saddle Spring (White Pine)	38.97541	-115.40023	7.6	6.9	6.20	-15.66	-118.6	--	--	--	--	--	--	--	--	--	62820	WP-2	Spring	357	06/28/05
Saddle Spring (White Pine)	38.97541	-115.40023	--	--	--	-15.70	-115.7	--	--	--	--	--	--	--	--	--	--	WP-2	Spring	357	10/12/03
Sage Hen Spring	39.11533	-115.39212	7.7	7.0	6.20	-14.76	-112.4	--	--	--	--	--	--	--	--	--	62714	DRI-WP-9	Spring	342	06/06/05
Sand Spring	39.33056	-115.45500	13.0	--	--	-16.20	-123.0	--	--	--	--	--	--	--	--	--	465	GS250	Spring	239	07/14/81
Sammy Spring	39.43597	-115.32453	11.6	6.9	6.93	-15.30	-117.6	--	--	--	--	--	--	--	--	--	62628	DRI-BT-2	Spring	343	05/24/05

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Sandstone Spring	36.21111	-114.55667	11.0	2.0	7.03	-10.50	-79.0	209.00	79.20	21.90	4.96	16.90	249.00	725.00	13.80	--	17	PL16	Spring	10	02/07/96
Sawmill Spring (Sheep)	36.68056	-115.17611	--	--	--	-12.85	-92.0	12.00	29.00	1.80	0.60	2.10	--	5.90	6.10	0.2	101	GS36	Spring	58	05/19/88
Sawmill Spring (Delamar Range)	37.36762	-114.69708	10.3	10.3	6.90	-12.58	-88.7	56.20	10.40	18.90	2.18	16.60	220.00	19.00	41.70	--	59685	--	Spring	259	03/22/04
Sawmill Spring West	37.36734	-114.69749	9.7	6.6	6.50	-12.86	-91.8	33.90	4.55	12.10	2.00	7.40	146.00	7.00	36.80	--	59684	--	Spring	258	03/22/04
Scirpus Spring (No spring on Map)	36.37694	-114.44917	17.0	0.7	7.13	-12.00	-90.0	513.00	186.00	350.00	25.30	386.00	266.00	2040.00	20.40	--	30	PL12	Spring	20	02/07/96
Scotty Spring	38.16479	-114.68374	14.2	1.9	7.07	-12.73	-98.9	67.30	12.60	23.00	1.36	30.70	254.00	21.10	44.60	--	60846		Spring	272	06/26/04
Seaman Spring	37.86120	-115.19877	--	--	--	-13.13	-99.0	--	--	--	--	--	--	--	--	--	--	--	Spring	306	06/25/04
Second Sawmill Spring	38.87583	-114.89861	6.5	--	--	-14.70	-110.0	--	--	--	--	--	--	--	--	--	431	GS212	Spring	222	08/01/85
Secret Spring	38.83889	-115.28972	--	--	--	-14.00	-110.0	--	--	--	--	11.00	--	--	--	--	427	GS208	Spring	220	06/16/83
Sheep Spring (Clover)	37.40063	-114.27779	10.0	--	6.80	-12.00	-87.0	24.00	5.00	9.80	1.30	7.90	96.00	7.00	33.00	0.7	209.5	Jim	Spring	108	06/03/85
Sheep Spring (Clover)	37.40063	-114.27779	18.5	1.1	6.90	-12.06	-90.5	32.70	6.46	11.80	2.01	9.80	143.00	5.10	45.50	--	61097	DRI-CR-9	Spring	108	07/31/04
Sheep Spring (Schell Ck)	38.67611	-114.77667	14.0	6.7	6.63	-13.70	-99.5	8.00	2.10	2.80	--	1.50	46.00	4.10	14.00	<.1	418	GS194	Spring	212	08/02/85
Sheep Spring (Sheep Range)	36.89500	-115.11472	15.0	6.5	7.75	-13.35	-96.0	31.00	40.00	7.90	1.10	7.10	--	13.00	13.00	0.2	159	GS57	Spring	83	05/19/88
Shellback Spring	39.13197	-115.38436	7.7	8.8	6.50	-16.54	-123.6	--	--	--	--	--	--	--	--	--	62719	DRI-WP-14	Spring	344	06/07/05
Shingle Spring	38.53972	-114.93472	15.0	--	--	-13.25	-103.5	--	--	--	--	--	--	--	--	--	388	GS168	Spring	203	08/03/85
Shingle Spring	38.53958	-114.93553	15.2	4.3	7.15	-13.41	-103.8	61.70	18.80	15.60	2.51	16.20	260.00	23.30	44.80	0.2	65048	ER-22	Spring	203	07/13/06
Sidehill Spring	38.41596	-114.79613	13.0	--	--	-13.05	-100.0	--	--	--	--	--	--	--	--	--	377	GS160	Spring	200	08/02/85
Sidehill Spring	38.41596	-114.79613	--	--	--	-13.10	-101.8	--	--	--	--	--	--	--	--	--	88483	SNWA	Spring	200	06/21/04
Sidehill Spring	38.41596	-114.79613	12.6	6.3	6.76	-13.37	-100.8	50.90	16.60	12.50	1.14	6.90	242.00	11.90	51.40	0.1	62981	--	Spring	200	08/01/05
Silver Spring	38.81085	-114.88121	9.3	7.8	6.72	-14.74	-111.9	80.60	5.42	5.40	0.66	3.50	261.00	10.30	12.50	0.1	62975	ER-7	Spring	385	07/29/05
Silver Spring (RS)	38.81061	-114.88117	9.0	8.3	7.43	-14.68	-110.8	79.90	5.50	5.45	0.59	3.10	255.00	10.70	12.60	0.1	65051	ER-25	Spring	385	07/13/06
Sixmile Spring	37.49222	-115.08806	22.0	--	7.85	-13.06	-93.4	45.19	10.58	16.90	1.30	3.20	207.00	11.70	49.58	0.1	230	IT151	Spring	112	08/08/95
SK-10	38.75000	-115.17000	--	--	--	--	-119.0	--	--	--	--	16.30	--	--	--	--	423	Kirk110	Well	218	--
SK-18	37.71000	-114.80000	--	--	--	--	-95.0	--	--	--	--	11.30	--	--	--	--	276	Kirk130	Well	134	--
Snow Creek Spring (Unnamed Spring in Snow Creek)	40.07837	-114.91138	7.9	9.3	7.21	-16.22	-120.7	--	--	--	--	--	--	--	--	--	62629A	DRI-CC-2	Spring	345	05/24/05
Snowmelt Below Duckwater Peak	38.90056	-115.38250	10.0	--		-14.10	-105.0	--	--	--	--	0.60	--	--	--	--	437	GS216	Surface	224	06/15/83
South Monument Spring	38.25586	-114.11651	9.1	5.8	7.10	-14.23	-102.3	25.50	5.59	12.60	5.78	22.50	101.00	8.60	55.50	--	60318	--	Spring	319	05/21/04
South Spring (Egan)	39.14556	-114.97000	7.0	--	---	-15.00	-111.0	--	--	--	--	3.00	--	--	--	--	458	GS244	Spring	236	06/17/83

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
South Springs (Egan)	39.14526	-114.97287	6.8	8.8	7.80	-15.23	-111.9	46.60	10.90	5.15	0.53	2.30	190.00	11.20	9.50	0.1	65040	ER-14	Spring	236	07/12/06
South Spring (Snake)	38.80405	-114.17588	9.7	5.7	6.87	-14.70	-108.0	66.30	28.80	2.23	0.54	2.60	3.40	343.00	7.60	0.2	62917	SN-7	Spring	383	07/14/05
Spencer Well	37.39500	-115.18028	19.0	--	7.69	-13.68	-104.1	53.76	43.97	119.40	14.50	45.90	466.00	158.00	59.81	1.6	206	IT155	Well	106	08/06/95
Spring Creek Spring	38.90935	-114.11295	12.9	8.1	7.26	-15.40	-113.0	64.20	7.85	6.94	1.22	6.70	12.50	227.00	11.50	1.5	62916	SN-8	Spring	384	07/16/05
Unnamed Spring nr Redd's Cabin Summit	38.12512	-114.06920	8.0	--	7.90	-12.50	-95.0	92.00	19.00	26.00	2.40	23.00	--	25.00	23.00	0.3	334	GS128	Spring	173	04/09/85
Unnamed Spring nr Redd's Cabin Summit	38.12512	-114.06920	15.9	7.7	7.85	-12.37	-93.7	93.10	21.30	30.90	1.32	26.90	374.00	31.60	25.50	--	60315	WM-3	Spring	173	05/21/04
Unnamed Spring in Schell Creek Range	38.51851	-114.74229	--	--	--	-14.40	-108.1	17.60	3.77	1.87	1.16	0.90	67.90	9.50	10.80	--	57756	--	Spring	304	10/29/03
Unnamed Spring in Schell Creek Range	38.51851	-114.74229	--	--	--	-14.46	-105.8	--	--	--	--	--	--	--	--	--	57756	--	Spring	304	10/29/03
Unnamed Spring in Schell Creek Range	38.51851	-114.74229	10.7	6.5	7.22	-14.61	-106.9	56.00	8.70	23.20	0.34	11.80	210.00	26.20	16.20	0.2	62976	SC-4	Spring	304	07/30/05
Unnamed Spring in Schell Creek Range	38.51851	-114.74229	11.0	3.8	7.41	-14.45	-108.3	55.60	8.58	21.40	<.1	11.50	210.00	25.00	15.40	0.1	65058	SC-9	Spring	304	07/14/06
Indian Spring near Steward Ranch	38.31056	-114.65028	8.0	--	7.00	-13.60	-102.0	38.00	5.90	17.00	0.60	7.90	161.00	12.00	46.00	0.2	357	GS141	Spring	188	04/05/85
Stock Well (Delamar Wash)	37.34944	-114.75833	--	--	--	--	-88.0	--	--	--	--	--	--	--	--	--	1000	GS999	Well	101	--
Stove Spring	39.09486	-115.36359	9.1	7.1	6.40	-15.71	-114.5	--	--	--	--	--	--	--	--	--	62711	DRI-WP-6	Spring	347	06/06/05
Summit Spring	39.55109	-115.23000	7.7	6.4	6.50	-15.94	-120.8	--	--	--	--	--	--	--	--	--	62702	DRI-BT-4	Spring	348	06/04/05
Summit Spring (Mahogany Mts.)	37.74984	-114.15359	13.2	2.1	7.07	-12.04	-92.1	107.00	24.40	57.10	2.74	59.40	422.00	40.80	55.00	0.4	64905	MG-2	Spring	419	06/21/06
Teaspoon Spring	38.34509	-115.41189	11.9	4.8	7.00	-13.26	-100.0	--	--	--	--	--	--	--	--	--	62830	--	Spring	371	06/30/05
The Seeps (Spring)	37.73944	-115.57556	9.0	--	7.50	-13.30	-98.0	110.00	25.90	53.00	3.88	41.70	455.00	53.40	55.00	--	281	K10	Spring	136	01/15/85
Thirty Mile Spring	39.55556	-115.21806	8.5	--	8.00	-16.40	-126.0	29.00	4.60	13.00	2.80	5.50	140.00	7.90	43.00	0.2	468	GS256	Spring	242	08/23/83
Tippet Spring	39.87691	-114.37348	21.4	2.8	6.80	-16.24	-121.9	54.80	30.20	7.65	1.08	7.10	279.00	26.00	12.00	0.1	63276	--	Spring	394	08/24/05
Tobe Spring	38.00609	-114.08980	19.8	8.0	8.70	-13.04	-100.0	49.60	7.84	25.30	3.21	20.90	89.10	20.50	45.60	--	60312	--	Spring	315	05/20/04
Tobe Spring 2	38.00675	-114.08969	13.7	4.0	7.20	-12.09	-93.6	38.20	5.72	17.10	3.44	14.80	157.00	7.00	47.00	--	60313	--	Spring	316	05/20/04
Trough Spring	38.36971	-114.96316	--	--	--	-13.56	-103.6	--	--	--	--	--	--	--	--	--	--	--	Spring	413	28-Oct_05
Tunnel Spring	39.35142	-115.44964	10.4	5.5	7.00	-15.02	-118.3	--	--	--	--	--	--	--	--	--	62832	--	Spring	366	07/01/05
Twin Spring	37.46996	-115.02371	16.9	7.0	7.23	-13.24	-97.4	40.90	9.48	17.20	2.15	10.40	190.00	8.80	48.60	--	61104	--	Spring	294	07/30/04
Unnamed Chokecherry Spring	37.53905	-114.70312	11.8	6.2	7.20	-12.54	-98.1	23.90	5.86	9.31	1.43	3.50	109.00	7.90	48.60	--	59696	--	Spring	263	03/25/04

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Unnamed Hayden Canyon Spring	39.15147	-115.39264	6.9	6.0	7.00	-15.69	-120.9	--	--	--	--	--	--	--	--	--	62718	DRI-WP-13	Spring	350	06/07/05
Unnamed Near Little Willow Spring	39.72235	-115.60986	9.4	8.4	7.20	-17.04	-125.9	--	--	--	--	--	--	--	--	--	62707	DRI-BK-3	Spring	351	06/05/05
Unnamed Shellback Ridge Spring	39.14038	-115.38952	7.0	0.3	4.90	-16.18	-123.6	--	--	--	--	--	--	--	--	--	62720	DRI-WP-15	Spring	352	06/07/05
Unnamed Spring (Unnamed Combs Creek Spring)	39.50919	-114.99298	--	--	--	-15.63	-118.9	--	--	--	--	--	--	--	--	--	62630	DRI-ER-6	Spring	353	05/24/05
Unnamed Spring #3 (Snake)	38.73321	-114.33335	11.7	6.5	6.78	-14.10	-109.0	104.00	21.40	44.70	1.70	90.10	70.00	283.00	114.00	0.2	62920	SN-3	Spring	379	07/13/05
Unnamed Spring #4 (Snake)	38.83515	-114.19643	6.1	5.0	6.43	-14.65	-107.2	131.00	22.30	6.06	1.02	6.60	474.00	17.90	11.00	0.1	62972	SN-1	Spring	376	07/28/05
Unnamed Spring #5 (Snake)	38.85148	-114.17036	11.9	5.8	6.97	-14.04	-106.7	58.40	30.80	9.34	1.22	9.20	322.00	9.20	10.90	0.1	62973	SN-2	Spring	377	07/28/05
Unnamed Spring #1 (White Pine)	38.96778	-115.39900	8.3	8.9	6.50	-15.36	-114.8	--	--	--	--	--	--	--	--	--	62818	--	Spring	359	06/28/05
Unnamed Spring #2 (Mahogany Mts)	37.94321	-114.06842	13.4	6.3	7.35	-13.47	-100.7	64.10	8.94	12.10	0.89	10.20	210.00	23.60	21.60	0.7	64907	MG-4	Spring	421	06/22/06
Unnamed Spring #1(White Rock Mts)	38.30341	-114.16038	10.4	8.0	7.35	-15.05	-109.6	47.20	8.85	15.90	0.98	45.50	128.00	14.00	35.50	0.1	64897	WM-8	Spring	415	06/19/06
Unnamed Spring #2 (White Rock Mts)	38.19539	-114.10582	11.1	2.8	6.67	-13.00	-97.0	29.10	7.85	10.40	0.52	3.30	130.00	8.30	40.70	0.2	64899	WM-10	Spring	417	06/19/06
Unnamed Spring #1(Egan)	39.06895	-114.91885	7.0	6.9	7.11	-15.14	-112.2	82.60	9.14	4.46	0.94	1.60	277.00	20.90	11.20	0.1	65044	ER-18	Spring	435	07/12/06
Unnamed Spring #2 (White Pine)	38.97696	-115.40065	8.7	5.9	5.70	-15.66	-114.9	--	--	--	--	--	--	--	--	--	62819	--	Spring	360	06/28/05
Unnamed Spring #2 (Egan Range)	39.04577	-114.92458	4.1	7.6	7.50	-15.14	-110.0	50.70	5.87	3.95	0.68	1.00	182.00	5.80	9.20	0.1	65045	ER-19	Spring	436	07/12/06
Unnamed Spring #3 (White Pine)	38.98418	-115.39037	9.8	2.9	6.10	-14.96	-113.1	--	--	--	--	--	--	--	--	--	62821		Spring	361	06/28/05
Unnamed Spring #3 (Egan Range)	39.05677	-114.92678	4.8	8.8	7.50	-15.07	-110.2	66.90	4.69	3.98	0.69	0.90	221.00	5.50	10.20	0.1	65046	ER-20	Spring	437	07/12/06
Unnamed Spring #4 (White Pine)	39.03633	-115.39347	8.1	3.7	6.90	-15.01	-116.3	--	--	--	--	--	--	--	--	--	62824	--	Spring	362	06/29/05
Unnamed Spring #4 (Egan Range)	39.08531	-114.92188	6.7	8.7	7.43	-15.37	-114.0	65.10	10.10	3.38	0.78	1.30	229.00	11.90	11.50	0.1	65047	ER-21	Spring	438	07/12/06
Unnamed Spring #5 (White Pine)	39.00631	-115.39043	9.0	7.0	7.00	-16.01	-120.4	--	--	--	--	--	--	--	--	--	62825	WP-13	Spring	363	06/29/05
Unnamed Spring #5 (White Pine)	39.00631	-115.39043	--	--	--	-14.04	-106.7	--	--	--	--	--	--	--	--	--	62973	WP-13	Spring	363	07/28/01
Unnamed Spring #5 (RS, White Pine)	39.00630	-115.39043	8.9	6.8	7.12	-16.02	-120.8	62.50	5.30	14.80	1.16	6.90	224.00	10.60	30.50	0.2	65038	WP-13	Spring	363	07/11/06
Unnamed Spring #5 (Egan Range)	38.90310	-114.92343	7.3	7.1	7.04	-14.72	-109.6	93.10	18.30	4.39	0.92	3.30	331.00	32.40	14.00	0.1	65054	ER-28	Spring	445	07/13/06

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Unnamed Spring #6 (White Pine)	38.99300	-115.37519	9.1	0.5	6.80	-14.98	-115.1	--	--	--	--	--	--	--	--	--	62826	--	Spring	364	06/29/05
Unnamed Spring #7 (Quinn)	38.16152	-115.64159	7.4	6.1	6.70	-14.23	-105.9	--	--	--	--	--	--	--	--	--	62834	--	Spring	367	07/02/05
Unnamed Spring #8 (Quinn)	38.05659	-115.66484	11.5	0.3	6.50	-14.18	-104.4	--	--	--	--	--	--	--	--	--	62835	--	Spring	368	07/02/05
Unnamed Spring #7 (Kern MTS)	39.68072	-114.19089	10.2	0.1	6.32	-15.80	-116.3	51.50	11.00	25.70	0.82	14.90	232.00	14.10	36.00	0.4	63273	--	Spring	391	08/23/05
Unnamed Spring #8 (Antelope Range)	39.98778	-114.43341	9.2	2.9	6.13	-15.85	-121.4	35.90	6.98	12.80	1.89	11.10	130.00	22.10	44.90	0.1	63277	--	Spring	395	08/24/05
Unnamed Spring #9 (Antelope Range)	39.99364	-114.42071	8.3	5.6	6.16	-16.41	-123.0	32.80	6.25	8.86	3.03	14.80	109.00	14.90	44.40	0.1	63278	--	Spring	396	08/25/05
Unnamed Spring #10 (Antelope Range)	39.93797	-114.36074	12.9	1.3	6.59	-15.95	-122.0	92.00	49.20	34.10	1.19	35.50	329.00	175.00	19.30	0.2	63279	--	Spring	397	08/25/05
Unnamed Springs #11(Snake Range)	39.48477	-114.31032	8.9	7.9	6.71	-15.65	-117.1	60.10	11.40	11.40	1.56	8.30	231.00	11.10	19.10	0.1	63283	--	Spring	401	08/26/05
Unnamed Spring #12 (Snake Range)	39.30746	-114.21610	7.6	6.5	7.24	-15.89	-116.6	39.10	3.53	4.78	0.64	2.40	130.00	4.20	11.90	0.1	63527	--	Spring	403	10/25/05
Unnamed Sp Silver Cr Canyon	39.22899	-114.26075	9.2	3.1	7.39	-15.38	-115.7	71.30	30.40	8.93	0.75	6.60	322.00	35.40	12.60	0.1	63529	--	Spring	405	10/26/05
Unnamed Spring 13 (Snake Range)	39.17779	-114.28686	9.9	6.2	7.48	-14.76	-114.3	79.10	94.70	67.80	1.14	83.60	437.00	234.00	19.60	0.2	63530	--	Spring	406	10/26/05
Unnamed Stone Cabin Spring	39.15911	-115.39892	8.5	8.2	6.80	-15.31	-114.2	--	--	--	--	--	--	--	--	--	62717	DRI-WP-12	Spring	354	06/07/05
Unnamed Stone Cabin Spring	39.15911	-115.39892	9.2	7.2	7.31	-15.47	-118.2	66.70	11.70	14.30	0.92	7.90	248.00	13.00	16.80	0.2	65036	WP-11	Spring	354	07/11/06
Unnamed Spring (Clover)	37.27654	-114.30744	3.3	4.9	7.09	-12.20	-88.0	126.00	22.60	56.60	1.51	14.80	401.00	157.00	35.40	--	58501	--	Spring	249	01/15/04
Unnamed Spring	37.49917	-114.45250	10.0	--	--	-11.60	-86.5	--	--	--	--	--	--	--	--	--	231	GS85	Spring	113	06/03/85
Unnamed Spring in dry creek bed (White Pine Range)	38.89546	-115.38372	--	--	--	-15.31	-113.6	--	--	--	--	--	--	--	--	--	--		Spring	321	10/12/03
Unnamed Spring in Miller Canyon	38.32738	-114.24383	--	--	--	-14.27	-103.7	--	--	--	--	--	--	--	--	--	--		Spring	313	05/19/04
Unnamed Spring in Road (South Pahroc Range)	37.53638	-115.10651	28.4	4.5	6.37	-13.07	-96.7	42.60	10.00	16.10	1.53	8.80	193.00	8.70	49.70	--	61098	--	Spring	303	07/30/04
Unnamed Spring nr Clover Creek	37.61461	-114.45061	16.2	0.9	6.99	-11.96	-89.7	67.40	9.05	29.90	6.83	20.30	299.00	11.10	55.60	--	61102	--	Spring	252	07/31/04
Unnamed Spring nr Six Mile seep	37.49680	-115.09102	--	--	--	-12.62	-94.5	--	--	--	--	--	--	--	--	--	61106A	--	Spring	296	07/30/04
Unnamed Spring--nr Blackrock	37.91689	-114.91859	9.2	7.1	7.40	-11.90	-94.3	45.90	9.28	25.80	6.14	23.70	184.00	23.10	69.20	--	59688	--	Spring	299	03/23/04
Unnamed Well (Longdale)	36.59000	-114.48000	--	--	7.80	-13.20	-103.0	29.00	2.20	35.00	5.20	6.00	135.00	26.00	132.68	1.0	78	IT174	Well	48	03/04/74

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Unnamed Well (Near Dry Lake Range)	36.38278	-114.91667	26.5	0.5	7.33	-13.70	-96.0	123.00	46.00	140.00	16.00	190.00	230.00	360.00	21.00	1.6	41	GS12	Well	24	04/26/82
South Fox Well	38.77222	-114.52667	12.0	3.3	7.80	-15.00	-113.0	34.00	21.00	7.10	1.60	6.00	--	8.00	15.00	0.3	422	GS201	Well	216	07/06/83
Unnamed, Kaolin Wash	36.48722	-114.46667	14.1	6.0	8.46	-11.30	-88.0	48.90	25.90	77.60	21.30	46.50	213.00	168.00	19.10	--	67	PL3	Spring	35	02/09/96
Upper Burnt Canyon Spring	38.28729	-114.20049	14.8	3.0	6.80	-12.83	-97.6	65.90	15.30	11.50	0.57	17.30	251.00	6.70	50.40	0.2	64898	WM-9	Spring	416	06/19/06
Upper Burnt Canyon Spring #2	38.28729	-114.20049	--	--	--	-13.66	-103.6	--	--	--	--	--	--	--	--	--	--	WM-9b	Spring	416	06/19/06
Upper Chokecherry Spring	37.53746	-114.69833	9.3	7.3	8.00	-12.96	-98.9	53.00	10.60	23.20	1.23	13.60	219.00	16.70	50.00	--	59695	--	Spring	262	03/25/04
Upper Conner Spring	37.90278	-114.56056	8.0	8.2	7.43	-13.85	-100.0	73.00	26.00	2.20	0.50	2.10	351.00	5.40	8.50	<.1	310	GS115	Spring	156	11/11/86
Upper Conner Spring	37.90278	-114.56056	9.2	8.1	7.74	-13.88	-102.3	76.90	27.60	1.58	0.59	1.90	368.00	3.60	8.50	--	60836	--	Spring	156	06/24/04
Upper Fairview	38.18657	-114.66620	18.0	1.8	7.23	-12.66	-97.7	60.20	10.60	28.10	2.64	23.60	259.00	14.50	48.40	--	60850	--	Spring	280	06/29/04
Upper Illipah Crk	39.28167	-115.39000	--	--	--	-16.00	-124.0	--	--	--	--	--	--	--	--	--	--	GS999	Surface	238	06/13/83
Upper Illipah Crk	39.28167	-115.39000	--	--	--	-16.20	-123.0	--	--	--	--	--	--	--	--	--	--	GS999	Surface	238	08/23/83
Upper Illipah Crk	39.28167	-115.39000	--	--	--	-15.95	-120.9	--	--	--	--	--	--	--	--	--	68119	SNWA	Surface	238	08/05/03
Upper Indian Spring	37.45202	-114.65831	11.7	3.6	7.31	-11.46	-88.0	68.00	19.30	23.90	0.34	9.10	319.00	13.00	53.40	--	58499		Spring	268	01/14/04
Unnamed Spring near Pony Spring	38.32139	-114.64222	11.5	--	--	-12.90	-99.0	--	--	--	--	--	--	--	--	--	361	GS144	Spring	191	07/23/81
Upper Riggs Spring WR4	37.36833	-114.64778	10.8	--	--	-11.90	-88.0	--	--	--	--	--	--	--	--	--	207	GS78	Spring	105	02/02/84
Upper Riggs Spring WR4	37.36833	-114.64778	10.1	4.4	7.30	-11.90	-87.0	64.70	15.90	19.40	0.02	17.50	274.00	12.00	57.80	--	58492	--	Spring	105	01/13/04
Upper Riggs Spring WR4	37.36833	-114.64778	16.9	10.9	7.99	-11.95	-86.6	57.60	15.90	17.60	3.36	16.50	256.00	12.70	48.80	--	60082	--	Spring	105	04/29/04
Upper Riggs Spring WR4	37.36833	-114.64778	13.2	0.7	7.37	-11.55	-86.2	63.40	16.60	18.80	4.16	16.40	277.00	8.70	57.20	--	61614	--	Spring	105	10/19/04
Upper Riggs Spring WR4	37.36833	-114.64778	6.0	6.8	7.08	-12.46	-87.0	35.50	8.79	11.60	2.04	7.20	153.00	8.10	42.00	--	62035	--	Spring	105	02/10/05
Upper Terrace Spring WR2	39.08664	-114.92565	--	--	--	--	--	39.70	10.90	4.09	0.72	2.10	173.00	7.30	11.90	--	57696	ER-1	Spring	270	10/13/03
Upper Terrace Spring WR2	39.08664	-114.92565	8.2	5.1	7.10	-15.43	-114.9	39.80	11.00	4.07	0.72	2.10	172.00	7.30	12.10	--	57697	ER-1	Spring	270	10/15/03
Upper Terrace Spring WR2	39.08664	-114.92565	7.6	--	7.90	-15.44	-111.8	40.50	10.80	4.25	0.80	2.10	172.00	7.10	9.20	--	60080	ER-1	Spring	270	04/26/04
Upper Terrace Spring WR2	39.08664	-114.92565	8.0	8.0	7.51	-15.40	-115.6	40.40	10.70	3.60	0.71	2.40	169.00	7.40	11.80	--	60785	ER-1	Spring	270	06/23/04
Upper Terrace Spring WR2	39.08664	-114.92565	8.2	7.1	6.85	-15.35	-114.4	41.60	11.30	4.29	0.75	2.40	177.00	7.30	11.80	--	61479	ER-1	Spring	270	09/22/04
Upper Terrace Spring WR2	39.08664	-114.92565	7.2	8.3	7.82	-15.41	-114.6	40.30	10.70	4.24	0.81	2.30	168.00	7.70	11.10	--	62030	ER-1	Spring	270	02/09/05
Upper Terrace Spring WR2	39.08664	-114.92565	--	--	--	-15.24	-113.7	--	--	--	--	--	--	--	--	--	62633A	ER-1	Spring	270	05/21/05
Upper Terrace Spring WR2	39.08664	-114.92565	--	--	--	-15.43	-113.4	41.80	10.50	4.14	0.76	2.30	173.00	7.90	11.20	<.05	63219	ER-1	Spring	270	08/14/05
Upper Terrace Spring WR2	39.08664	-114.92565	7.7	8.1	7.77	-15.41	-113.7	41.30	10.80	4.06	0.74	2.20	167.00	7.50	11.30	0.1	63562	ER-1	Spring	270	11/06/05
Upper Terrace Spring WR2	39.08664	-114.92565	7.5	8.3	7.87	-15.41	-114.5	40.50	10.70	4.23	1.10	2.30	164.00	7.70	11.50	0.1	64734	ER-1	Spring	270	05/24/06
Upper Terrace Spring WR2	39.08664	-114.92565	--	--	--	-15.43	-114.1	--	--	--	--	--	--	--	--	--	--	ER-1	Spring	270	07/12/06
Upper Terrace Spring WR2	39.08664	-114.92565	7.9	7.6	7.68	-15.48	-114.1	41.40	10.90	3.65	0.61	2.13	166.00	7.61	11.20	0.1	65364	ER-1	Spring	270	08/29/06
Upper Terrace Spring WR2	39.08664	-114.92565	7.7	7.1	7.80	-15.50	-115.2	41.10	10.90	4.34	0.92	1.40	169.00	7.20	11.20	0.1	65651	ER-1	Spring	270	10/27/06
Upper Terrace Spring WR2	39.08664	-114.92565	7.5		7.87	-15.46	-114.2	40.30	10.70	4.07	0.76	1.89	173.00	6.47	10.60	0.1	65651	ER-1	Spring	270	05/08/07

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
Upper Terrace Spring WR2	39.08664	-114.92565	8.2	6.2	7.70	-15.46	-114.7	39.80	10.70	4.07	0.82	1.25	178.00	6.92	10.80	--	67247	ER-1	Spring	270	08/23/07
Upper Terrace Spring WR2	39.08664	-114.92565	8.0	5.9	7.83	-15.46	-113.6	41.70	11.20	4.00	0.75	1.90	176.00	6.70	10.50	0.1	67510	ER-1	Spring	270	11/03/07
Upper Terrace Spring WR2	39.08664	-114.92565	7.8	8.2	7.84	-15.48	-113.7	39.90	11.00	4.08	0.77	2.00	176.00	6.66	10.40	0.1	68479	ER-1	Spring	270	06/01/08
Upper Terrace Spring WR2	39.08664	-114.92565	8.4	8.2	7.78	-15.54	-113.3	38.80	10.70	3.95	0.67	2.07	178.00	6.82	11.00	0.1	68910	ER-1	Spring	270	09/10/08
Upper Terrace Spring WR2	39.08664	-114.92565	8.3	7.9	7.86	-15.50	-114.8	40.10	11.00	4.11	0.88	1.95	184.00	6.75	10.50	0.1	69141	ER-1	Spring	270	10/29/08
Upper Terrace Spring WR2	39.08664	-114.92565	7.9	8.1	7.85	-15.55	-114.3	39.60	10.80	4.00	0.75	1.97	168.00	6.61	10.40	0.1	69862	ER-1	Spring	270	05/19/09
Upper Terrace Spring WR2	39.08664	-114.92565	--	--	--	-15.47	-114.9	40.80	10.90	4.08	0.69	2.04	172.00	6.42	11.20	0.1	69862	ER-1	Spring	270	08/15/09
Upper Terrace Spring WR2	39.08664	-114.92565	--	--	--	-15.64	-114.9	40.80	11.00	4.12	0.77	2.07	182.00	6.58	10.50	0.1	70610	ER-1	Spring	270	11/13/09
Upper Tower Spring	38.12049	-114.33344	--	--	--	-12.30	-93.3	20.20	3.33	16.30	6.15	7.60	104.00	7.20	45.80	--	60081	--	Spring	312	04/28/04
US Lime Well (Genstar)	36.39139	-114.90389	24.0	4.8	7.40	-12.75	-97.0	120.00	47.00	140.00	1.30	180.00	226.00	370.00	23.00	1.6	52	GS16	Well	27	03/31/86
USGS CSV-1	36.76694	-114.86194	29.5	--	--	-13.55	-103.0	260.00	93.00	160.00	30.00	39.00	--	1300.00	19.00	1.2	127	GS45	Well	71	05/18/88
USGS-MX C.V. Well (CV-DT-1)	38.13778	-115.33861	23.0	3.4	7.20	-14.60	-110.0	37.00	19.00	20.00	4.60	5.70	253.00	26.00	36.00	0.4	338	GS130	Well	176	10/15/81
USGS-MX C.V. Well (CV-DT-1)	38.13778	-115.33861	--	--		-14.52	-108.0	--	--	--	--	--	--	--	--	--	USGS	--	Well	--	06/25/03
USGS-MX CE, VF-1	36.87528	-114.94528	28.0	--	7.03	-12.65	-94.0	41.00	7.50	34.00	1.20	42.00	156.00	20.00	14.00	0.5	157	GS56	Well	82	01/06/88
Valley of Fire Well	36.42250	-114.54778	28.0	--	7.40	-10.60	-82.0	118.00	53.00	39.00	8.20	21.00	164.00	449.00	8.30	0.2	58	PLC33	Well	31	06/24/85
VF Spring 1	36.40139	-114.40194	23.0	5.0	7.10	-11.20	-88.0	--	--	--	--	--	--	--	--	--	53	PL7	Spring	28	02/09/96
VF Spring 2	36.40528	-114.43056	13.5	3.9	7.76	-11.80	-92.0	--	--	--	--	--	--	--	--	--	55	PL6	Spring	29	03/07/96
VF Spring 3	36.40583	-114.44389	15.0	5.3	7.61	-12.20	-93.0	537.00	208.00	295.00	51.10	278.00	169.00	2290.00	12.40	--	57	PL5	Spring	30	03/07/96
Wamp Spring	36.64167	-115.07000	7.0	--	8.15	-10.60	-81.0	71.00	13.00	10.00	2.10	4.90	585.00	8.40	24.00	0.2	91	GS31	Spring	52	03/20/87
Water Canyon	38.98816	-114.96032	11.0	--	--	-15.00	-115.0	--	--	--	--	--	--	--	--	--	1033	GS999	Surface	233	06/14/83
Water Canyon	38.98816	-114.96032	9.0	--	--	-15.50	-117.0	--	--	--	--	--	--	--	--	--	1033	GS999	Surface	233	08/23/83
																					--
Water Canyon at USGS gage	38.98700	-114.95500	--	--	--	-15.41	-109.5	--	--	--	--	--	--	--	--	--	--	--	Spring	271	10/24/03
Water Canyon at USGS gage (duplicate sample)	38.98700	-114.95500	--	--	--	-15.43	-112.7	--	--	--	--	--	--	--	--	--	--	--	Spring	271	10/24/03
Water Canyon Spring	39.00691	-114.91063	8.9	7.9	7.30	-15.60	-114.4	40.10	11.00	4.04	0.72	7.30	180.00	1.64	12.00	--	57695	--	Spring	358	10/14/03
Water Canyon Spring (Mahogany)	37.95662	-114.06494	11.1	2.2	7.11	-13.68	-100.4	81.90	11.80	9.44	1.12	5.10	210.00	84.10	17.20	1.6	64906	MG-3	Spring	420	06/22/06
Water Tank 0.4mi West of Sixmile	37.49119	-115.09605	--	--	--	-12.44	-93.8	--	--	--	--	--	--	--	--	--	61106C	--	Spring	297	07/30/04
Weaver Well	37.74472	-114.43070	17.0	--	7.70	-13.10	-101.0	100.00	42.00	110.00	14.00	110.00	430.00	180.00	73.00	2.9	283	GS100	Well	137	06/04/85
Well at Alligator Ridge	39.73735	-115.51432	34.0	4.1	7.20	-16.60	-127.0	60.00	23.00	19.00	6.50	6.70	--	52.00	26.00	1.0	469	GS260	Well	243	04/24/84
White Rock Spring (Sheep)	36.70791	-115.23942	19.9	1.7	7.02	-9.96	-84.8	41.80	35.10	18.20	11.90	10.80	326.00	12.70	57.70	--	61095	--	Spring	64	07/27/04
White Rock Spring (Sheep)	36.70791	-115.23942	10.2	3.8	6.51	-10.38	-86.1	39.80	35.20	16.80	10.50	10.30	303.00	12.50	46.50	--	62398	DRI-SR-3	Spring	64	04/28/05

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
White Rock Spring (Butte)	40.06079	-115.16385	9.4	6.0	6.38	-15.36	-119.2	--	--	--	--	--	--	--	--	--	62631	DRI-BT-3	Spring	355	05/24/05
White Rock Well	38.12557	-114.17027	14.5	--	7.90	-13.10	-101.0	68.00	10.00	11.00	4.00	51.00	168.00	20.00	61.00	0.6	336	E4	Well	175	07/24/75
White Rock Spring (Seaman Range)	37.89630	-115.01970	--	--	--	-12.10	-90.0	--	--	--	--	--	--	--	--	--	308	Kirk1019	Spring	154	01/13/85
								--	--	--	--	--	--	--	--	--					
Wildhorse Spring (Fairview)	38.19722	-114.60861	8.0	--	7.60	-11.70	-92.5	--	--	--	--	--	--	--	--	--	348	GS136	Spring	183	04/06/85
Wild Horse Spring (White Pine)	39.33361	-115.44333	17.5	--	--	-16.80	-129.0	--	--	--	--	--	--	--	--	--	466	GS251	Spring	240	07/14/81
Warm Spring (White Pine Range)	38.94778	-115.22806	53.0	1.0	9.25	-15.80	-118.0	1.60	<.12	61.00	0.60	9.40	--	16.00	56.00	13.0	453	GS204	Spring	232	04/29/82
Warm Spring (White Pine Range)	38.94778	-115.22806	--	--	--	-14.37	-114.8	--	--	--	--	--	--	--	--	--	112273	SNWA	Spring	232	07/26/05
Willow Spring (KSV-1)	37.09483	-114.83096	--	--	--	-11.90	-86.5	--	--	--	--	--	--	--	--	--	180	Kirk1026	Spring	92	--
Willow Spring (KSV-1)	37.09483	-114.83096	17.4	--	7.50	-11.60	-88.0	20.00	2.70	56.00	4.60	22.00	140.00	34.00	65.00	1.1	182	GS67	Spring	92	02/03/84
Willow Spring (KSV-1)	37.09483	-114.83096	9.3	8.3	7.52	-11.57	-88.0	18.20	3.17	55.90	2.24	21.30	131.00	33.50	67.30	--	58489		Spring	92	01/12/04
Willow Spring (KSV-1)	37.09483	-114.83096	16.7	1.6	7.44	-11.63	-89.1	19.90	4.25	9.85	1.74	6.50	84.90	6.30	37.20	--	62395	DRI-DR-2	Spring	92	04/27/05
Willow Spring 2 (So.of Oak Sps.summit)	37.55653	-114.69773	13.7	2.5	7.40	-11.69	-91.2	59.40	14.70	25.50	1.79	13.60	274.00	15.20	55.70	--	59693	--	Spring	260	03/25/04
Wilson Creek	38.31806	-114.40333	17.0	--	8.00	-13.20	-97.5	21.00	3.30	11.00	2.90	7.00	77.00	11.00	39.00	0.3	358	E2	Surface	189	04/05/85
Wiregrass Spring (Sheep)	36.63325	-115.20842	9.5	--	7.30	-12.80	-94.0	69.00	32.00	2.70	1.10	3.00	--	5.00	12.00	0.1	82	GS22	Spring	49	10/28/81
Wiregrass Spring (Sheep)	36.63325	-115.20842	6.5	6.1	7.30	-12.70	-96.0	68.00	32.00	3.20	1.10	3.20	--	9.00	12.00	0.1	83	GS23	Spring	49	05/11/83
Wiregrass Spring (Sheep)	36.63325	-115.20842	--	--	--	-12.85	-94.0	--	--	--	--	--	--	--	--	--	83.5	JIM	Spring	49	10/09/86
Wiregrass Spring (Sheep)	36.63325	-115.20842	4.0	--	7.32	-12.80	-91.5	71.00	34.00	2.80	1.10	3.40	374.00	6.90	12.00	0.1	84	GS24	Spring	49	03/20/87
Wiregrass Spring (Sheep)	36.63325	-115.20842	13.0	--	--	-12.55	-92.0	70.00	33.00	2.80	1.50	2.90	--	7.10	12.00	0.2	85	GS25	Spring	49	06/17/87
Wiregrass Spring (Sheep)	36.63325	-115.20842	14.0	5.4	7.34	-12.75	-94.0	68.00	33.00	3.10	1.00	2.90	372.00	7.30	12.00	0.2	86	GS26	Spring	49	08/04/87
Wiregrass Spring (Sheep)	36.63325	-115.20842	4.0	5.0	7.32	-12.85	-97.0	72.00	34.00	3.10	5.70	3.80	--	7.70	12.00	0.2	87	GS27	Spring	49	01/05/88
Wiregrass Spring (Sheep)	36.63325	-115.20842	8.0	5.0	7.41	-12.95	-95.5	72.00	34.00	2.80	1.00	2.60	--	7.30	12.00	0.2	88	GS28	Spring	49	04/06/88
Wiregrass Spring (Sheep)	36.63325	-115.20842	7.0	--	7.30	-12.85	-94.5	69.00	36.00	3.10	1.10	2.70	--	7.30	12.00	0.1	89	GS29	Spring	49	12/12/88
Wiregrass Spring (Sheep)	36.63325	-115.20842	8.2	2.3	7.34	-12.87	-94.0	--	--	--	--	--	--	--	--	--	58487	--	Spring	49	01/17/04
Wiregrass Spring (Sheep)	36.63325	-115.20842	9.9	2.5	6.89	-13.12	-96.8	67.80	33.20	2.48	0.98	3.70	367.00	6.00	14.40	--	60851	--	Spring	49	06/30/04
Wiregrass Spring (Sheep)	36.63325	-115.20842	8.3	4.0	6.55	-13.76	-101.2	74.40	40.60	3.92	1.27	3.90	404.00	5.40	14.80	--	62400	DRI-SR-2	Spring	49	04/29/05
Wiregrass Spring (Sheep)	36.63325	-115.20842	--	--	--	-13.19	-95.6	--	--	--	--	--	--	--	--	--	--	SH-2	Spring	49	04/29/06
Wiregrass Spring (Grant)	38.35211	-115.42693	14.3	4.3	7.50	-13.29	-101.4	--	--	--	--	--	--	--	--	--	62831	--	Spring	372	06/30/05
Woodchuck Spring	39.72453	-115.57297	7.5	6.9	6.80	-15.55	-119.6	--	--	--	--	--	--	--	--	--	62706	DRI-BK-2	Spring	356	06/05/05
180W501	38.59201	-114.84080	--	--	--	-14.12	-105.6	--	--	--	--	--	--	--	--	--	--	SNWA	Well	600	05/17/06
180W902M	38.36331	-114.82750	--	--	--	-13.99	-107.1	--	--	--	--	--	--	--	--	--	120738	SNWA	Well	601	10/19/05
180W902M	38.36331	-114.82750	--	--	--	-14.12	-104.7	--	--	--	--	--	--	--	--	--	--	SNWA	Well	601	05/18/06
181M1	37.91163	-114.85528	--	--	--	-13.57	-104.9	--	--	--	--	--	--	--	--	--	120739	SNWA	Well	603	08/30/05
181M1	37.91163	-114.85528	--	--	--	-13.67	-105.0	--	--	--	--	--	--	--	--	--	--	SNWA	Well	603	05/31/06
181W909M	37.69600	-114.74639	--	--	--	-13.70	-106.4	--	--	--	--	--	--	--	--	--	120737	SNWA	Well	604	04/27/05
181W909M	37.69600	-114.74639	--	--	--	-13.50	-104.6	--	--	--	--	--	--	--	--	--	--	SNWA	Well	604	06/05/06
182M-1	37.34683	-114.95796	--	--	--	-14.07	-109.6	--	--	--	--	--	--	--	--	--	--	SNWA	Well	606	05/23/06

APPENDIX 1. ISOTOPIC, FIELD PARAMETER, AND WATER CHEMISTRY DATA FOR ALL SITES USED IN THIS STUDY AND SOME ADDITIONAL SITES IN EASTERN AND SOUTHERN NEVADA (CONTINUED).

Name	Latitude Degrees	Longitude Degrees	Water Temp. (°C)	DO (mg/L)	pH	$\delta^{18}O$ (‰)	δD (‰)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	F (mg/L)	Sample #	REF_ID	Site Type	Site #	Date
182W906M	37.32691	-114.85463	--	--	--	-12.89	-103.6	--	--	--	--	--	--	--	--	--	120743	SNWA	Well	607	03/19/05
182W906M	37.32691	-114.85463	--	--	--	-13.40	-100.7	--	--	--	--	--	--	--	--	--	120741	SNWA	Well	607	09/02/05
209M-1	37.64351	-114.98950	--	--	--	-13.00	-99.7	--	--	--	--	--	--	--	--	--	120742	SNWA	Well	608	08/04/05
209M-1	37.64351	-114.98950	--	--	--	-13.53	-104.7	--	--	--	--	--	--	--	--	--	--	SNWA	Well	608	06/14/06
CSI-1	36.79768	-114.91471	--	--	--	-13.08	-102.6	--	--	--	--	--	--	--	--	--	--	SNWA	Well	609	05/31/05
CSI-2	36.79768	-114.91471	--	--	--	-12.90	-100.2	--	--	--	--	--	--	--	--	--	--	SNWA	Well	610	09/30/05
CSI-3	36.82554	-114.91667	--	--	--	-13.03	-99.6	--	--	--	--	--	--	--	--	--	--	SNWA	Well	611	09/13/06
CSI-4	36.84998	-114.95452	--	--	--	-12.68	-98.6	--	--	--	--	--	--	--	--	--	174086	SNWA	Well	628	12/05/07
CSVM-1	36.79118	-114.88621	--	--	--	-13.13	-99.3	--	--	--	--	--	--	--	--	--	65462	SNWA	Well	632	02/27/03
CSVM-2	36.66182	-114.92305	--	--	--	-13.13	-96.3	--	--	--	--	--	--	--	--	--	65453	SNWA	Well	612	02/23/03
CSVM-2	36.66182	-114.92305	--	--	--	-13.14	-97.7	--	--	--	--	--	--	--	--	--	--	SNWA	Well	612	01/10/06
CSVM-3	37.05250	-114.98336	--	--	--	-12.86	-98.4	--	--	--	--	--	--	--	--	--	65456	SNWA	Well	613	05/19/03
CSVM-3	37.05250	-114.98336	--	--	--	-13.10	-98.0	--	--	--	--	--	--	--	--	--	--	SNWA	Well	613	01/06/06
CSVM-4	36.99106	-114.88648	--	--	--	-13.37	-102.7	--	--	--	--	--	--	--	--	--	65455	SNWA	Well	614	03/26/03
CSVM-4	36.99106	-114.88648	--	--	--	-13.41	-102.5	--	--	--	--	--	--	--	--	--	--	SNWA	Well	614	01/16/06
CSVM-5	36.74758	-114.98045	--	--	--	-12.82	-94.0	--	--	--	--	--	--	--	--	--	65452	SNWA	Well	615	02/06/03
CSVM-5	36.74758	-114.98045	--	--	--	-12.67	-95.0	--	--	--	--	--	--	--	--	--	--	SNWA	Well	615	01/08/06
CSVM-6	36.83250	-114.90916	--	--	--	-12.94	-100.2	--	--	--	--	--	--	--	--	--	65454	SNWA	Well	616	03/20/03
CSVM-6	36.83250	-114.90916	--	--	--	-12.97	-100.7	--	--	--	--	--	--	--	--	--	--	SNWA	Well	616	01/11/06
CSVM-7	37.04701	-114.99571	--	--	--	-12.47	-93.9	--	--	--	--	--	--	--	--	--	65457	SNWA	Well	617	05/04/03
CSVM-7	37.04701	-114.99571	--	--	--	-12.51	-93.6	--	--	--	--	--	--	--	--	--	--	SNWA	Well	617	01/23/06
KPW-1	--	--	--	--	--	-13.63	-105.0	--	--	--	--	--	--	--	--	--	120744	SNWA	Well	618	12/15/05
RW-1	36.45565	-114.84709	--	--	--	-13.19	-100.9	--	--	--	--	--	--	--	--	--	112270	SNWA	Well	624	07/20/05
CAV6002X	38.36281	-114.82736	--	--	--	-14.27	-106.3	--	--	--	--	--	--	--	--	--	174083	SNWA	Well	627	12/03/07
CSV3009X	36.98363	-114.96546	--	--	--	-13.48	-100.2	--	--	--	--	--	--	--	--	--	200044	SNWA	Well	629	12/08/08
CSV3011X	36.98195	-114.93191	--	--	--	-12.83	-90.4	--	--	--	--	--	--	--	--	--	200046	SNWA	Well	630	12/16/08
CSV3011X	36.98195	-114.93191	--	--	--	-12.87	-94.0	--	--	--	--	--	--	--	--	--	200045	SNWA	Well	630	12/20/08
UMVM-1 (MRS1009M)	36.75808	-114.82324	--	--	--	-13.15	-98.9	--	--	--	--	--	--	--	--	--	65460	SNWA	Well	631	06/14/03
GV-1	36.43506	-114.95859	--	--	--	-13.15	-98.8	--	--	--	--	--	--	--	--	--	79439	SNWA	Well	634	01/15/04
GV-2	36.35828	-114.92445	--	--	--	-13.46	-96.8	--	--	--	--	--	--	--	--	--	69559	SNWA	Well	635	09/25/03
PW-1	37.89546	114.71828	24.4	-	-	-13.4	-101	37	19	37	3.9	15	190	32	--	--	SNWA	DL-2	Well	636	1/21/10

APPENDIX 2. AMOUNT OF PRECIPITATION AND ISOTOPIC COMPOSITION FROM BULK STORAGE GAUGES AT WR1 IN THE WHITE PINE RANGE, WR2 IN THE EGAN RANGE, WR3 IN THE SCHELL CREEK RANGE, AND WR4 IN THE DELAMAR MOUNTAINS.

Site	Start Date	End Date	Precipitation (in)	$\delta^{18}O$	δD
WR1 - Altitude 8,012 ft	10/23/03	3/23/04	7.10	-17.13	-124.1
	3/23/04	4/26/04	9.60	-16.19	-116.4
	4/26/04	6/21/04	1.32	--	--
	6/21/04	9/22/04	2.76	-11.95	-87.8
	9/22/04	1/21/05	12.96	--	--
	1/21/05	5/21/05	15.36	-16.19	-112.9
	5/21/05	8/14/05	0.60	-11.79	-82.1
	8/14/05	11/5/05	0.96	-8.95	-58.5
	11/5/05	2/24/06	6.00	--	--
	2/24/06	5/20/06	9.36	-15.12	-107.8
	5/20/06	8/29/06	3.00	-7.11	-48.4
	8/29/06	11/15/06	2.40	-13.59	-96.8
	11/15/06	5/6/07	8.40	-17.42	-126.7
	5/6/07	8/19/07	2.76	-10.82	-79.8
	8/19/07	11/3/07	1.44	-11.70	-83.1
	11/3/08	3/3/08	8.04	-16.82	-122.2
	3/3/08	5/29/08	0.96	-16.58	-121.3
	5/29/08	9/14/08	2.88	-9.82	-70.0
	9/14/08	10/31/08	0.96	-10.09	-68.1
	10/31/08	1/15/09	4.32	-18.32	-132.1
	1/15/09	5/19/09	10.32	-16.36	-119.0
	5/19/09	8/16/09	4.20	-10.64	-75.3
	8/16/09	11/16/09	2.52	-16.97	-122.9
WR2 - Altitude 8,747 ft	10/15/03	4/26/04	13.32	-16.93	-119.8
	4/26/04	6/23/04	1.8	--	--
	6/23/04	9/22/04	1.68	-13.15	-93.5
	9/22/04	2/9/05	14.04	-16.53	-117.7
	2/9/05	5/21/05	21.24	-17.59	-127.6
	5/21/05	7/26/05	1.32	--	--
	7/26/05	8/11/05	0.36	--	--
	8/11/05	11/7/05	2.4	-11.70	-79.1
	11/7/05	5/24/06	16.92	-16.30	-116.4
	5/24/06	8/29/06	3.96	-9.28	-60.2

APPENDIX 2. AMOUNT OF PRECIPITATION AND ISOTOPIC COMPOSITION FROM BULK STORAGE GAUGES AT WR1 IN THE WHITE PINE RANGE, WR2 IN THE EGAN RANGE, WR3 IN THE SCHELL CREEK RANGE, AND WR4 IN THE DELAMAR MOUNTAINS (CONTINUED).

Site	Start Date	End Date	Precipitation (in)	$\delta^{18}O$	δD
	8/29/06	10/27/06	2.4	-13.82	-94.9
	10/27/06	5/8/07	9.84	-18.04	-131.5
	5/8/07	8/23/07	2.28	-13.46	-95.0
	8/23/07	11/3/07	1.68	-13.87	-94.2
	11/3/07	6/1/08	9.6	-18.22	-132.2
	6/1/08	9/10/08	1.8	-14.84	-105.8
	9/10/08	10/29/08	1.2	-13.20	-88.2
	10/29/08	5/19/09	9.72	-17.45	-124.7
	5/19/09	8/16/09	4.08	-11.91	-82.3
	8/16/09	11/13/09	2.88	-12.18	-82.2
WR3 – Altitude 7,484 ft	10/30/03	3/24/04	7.92	-16.25	-114.4
	3/24/04	4/27/04	3.72	-15.37	-104.3
	4/27/04	6/23/04	1.32	--	--
	6/23/04	9/23/04	2.64	-9.53	-69.3
	9/23/04	1/23/05	16.80	--	--
	1/23/05	5/20/05	13.20	-15.57	-110.5
	5/20/05	8/15/05	1.86	-7.12	-50.3
	8/15/05	11/7/05	2.76	-11.11	-74.9
	11/7/05	2/26/06	3.12	-13.77	-97.3
	2/26/06	5/23/06	6.60	-14.99	-105.6
	5/23/06	8/31/06	2.28	-8.88	-62
	8/31/06	10/28/06	2.16	-11.97	-84.5
	10/28/06	5/7/07	4.92	-17.49	-127.9
	5/7/07	8/20/07	2.04	-8.87	-63.4
	8/20/07	11/2/07	1.32	-11.32	-80.8
	11/2/07	3/4/08	7.56	-15.27	-109.2
	3/4/08	5/30/08	0.84	-16.96	-123
	5/30/08	9/11/08	0.84	-10.71	-81.3
	9/11/08	10/31/08	0.72	-10.87	-72.9
	10/31/08	1/14/09	3.41	-17.64	-126.1
	1/14/09	5/19/09	7.38	-15.33	-108
	5/19/09	8/17/09	4.08	-9.75	-67.3
	8/17/09	11/15/09	0.96	-9.34	-62.9
WR4 – Altitude 5,163 ft	04/29/04	10/19/04	2.88	-8.12	-61.8
	10/19/04	02/10/05	13.68	-11.86	-85.6
	02/10/05	05/19/05	8.04	-12.03	-87.3

United States Department of the Interior

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January 30, 2006
File No. 1-5-05-FW-536

Memorandum

To: Manager, California/Nevada Operations, Fish and Wildlife Service, Sacramento, California

From: Field Supervisor, Nevada Fish and Wildlife Office, Fish and Wildlife Service, Reno, Nevada

Subject: Intra-Service Programmatic Biological Opinion for the Proposed Muddy River Memorandum of Agreement Regarding the Groundwater Withdrawal of 16,100 Acre-Feet per Year from the Regional Carbonate Aquifer in Coyote Spring Valley and California Wash Basins, and Establish Conservation Measures for the Moapa Dace, Clark County, Nevada

This document transmits the Fish and Wildlife Service's (Service) programmatic biological opinion for the proposed Memorandum of Agreement (MOA) among the Southern Nevada Water Authority (SNWA), Moapa Valley Water District (MVWD), Coyote Springs Investment, LLC (CSI), Moapa Band of Paiutes (Tribe), and the Service. The Service has determined that the proposed action is likely to adversely affect the endangered Moapa dace (*Moapa coriacea*). No critical habitat has been designated for the Moapa dace; therefore, none will be affected and thus no further analysis is required. This biological opinion is being submitted in accordance with section 7 of the Endangered Species Act of 1973, as amended (Act) (16 U.S.C. 1531 *et seq.*). We have assigned 1-5-05-FW-536 to this programmatic consultation; please reference this number in future correspondence. Future actions pursuant to the MOA that may adversely affect Moapa dace will be tiered to this programmatic biological opinion.

This biological opinion evaluates, as the proposed action, the execution of the MOA by the Service. None of the activities included in the MOA will be implemented absent project or activity specific consultations. Since the MOA contemplates future groundwater development up to 16,100 acre-feet per year (afy), this total withdrawal and the potential effects to the Moapa dace are evaluated in this biological opinion. As part of the proposed action, the following biological opinion will evaluate the effects of the cumulative groundwater withdrawal of 16,100 afy from two basins within the regional carbonate aquifer to the federally listed as endangered Moapa dace at a programmatic level in light of the conservation measures proposed in the MOA. The groundwater is proposed to be withdrawn from the White River Groundwater

Flow System at the MX-5, RW-2 wells, CSI Well #1, and CSI Well #2 (SNWA 9,000 afy), and CSI Well #1 (Permit 70430) and CSI Well #2 (Permit 70429), and other wells (CSI 4,600 afy) in the Coyote Spring Valley (Basin 210), and from a well-field located in the southwestern third of the Moapa Reservation (2,500 afy) in the California Wash (Basin 218). Species not evaluated in this biological opinion but may be evaluated in the future as proposed actions are submitted in accordance with section 7 of the Act include, but are not limited to the following endangered species: (1) the Mojave population of desert tortoise (*Gopherus agassizii*) and its designated critical habitat; (2) southwestern willow flycatcher (*Empidonax traillii extimus*); and (3) the Yuma clapper rail (*Rallus longirostris yumanensis*); as well as, (4) the western U.S. distinct population segment of the Federal candidate yellow-billed cuckoo (*Coccyzus americanus*) (67 FR 40666).

This biological opinion is based on the following information: (1) the January 27, 2006, proposed MOA (Attachment A) and attached Exhibit (Attachment B); (2) the proposed final Water Supply Agreement among the Tribe, SNWA, MVWD, Las Vegas Valley Water District (LVVWD), and Muddy Valley Irrigation Company (MVIC) received on January 26, 2006, (Attachment C); (3) Bureau of Land Management's (BLM) July 8, 2003, Biological Assessment of the Coyote Spring Valley area (BLM 2003); (4) numerous meetings and discussions among MOA signatories; (5) discussions with species experts familiar with the ecology of the species; and (6) other sources of available information available in our files and cited herein. The Service has prepared this biological opinion in the absence of site-specific and spatially explicit information on future site-specific actions that would be tiered to this programmatic biological opinion. In the absence of this information, this biological opinion reflects the ecologically and hydrogeologically most conservative estimate of effects for the Moapa dace and its habitat. A complete administrative record for this consultation is on file at the Service's Southern Nevada Field Office.

PROGRAMMATIC CONSULTATION

This biological opinion was prepared in accordance with the July 16, 2003, guidance for programmatic-level consultations (Service 2003). Such consultations can provide the benefit of streamlining the consultation process while leading to a more landscape-based approach to consultations that can minimize the potential "piecemeal" effects that can occur when evaluating individual projects out of the context of a complete agency program. Some of the benefits of programmatic consultations include: (1) better and more cost effective integration of ecosystem/recovery planning activities with agency activities; (2) streamlined consultation processes; (3) added predictability for all signatories of the MOA; (4) minimization of the potential "piecemeal" effects that can occur when evaluating individual projects out of the context of a complete agency program; and (5) the opportunity to better and more efficiently integrate the action agency's 7(a)(1) responsibilities at the program level.

Due to the number of impending actions by different entities included in the proposed action, a tiered-programmatic approach has been taken by the Service in an attempt to analyze the effects of the proposed action. This approach does not cover future site-specific actions resulting from implementation of the proposed action, nor does it authorize any incidental take for programmatic impacts associated with the activities included in the MOA. The tiered approach is a two-stage consultation process with the two stages fulfilling the same purposes. The first stage biological opinion or concurrence, as appropriate, evaluates the landscape-level effects. The second stage results in the completion of project-specific documentation that addresses the specific effects of each individual project. Under the tiered approach, two complete biological opinions are completed for each proposed action, with the second-stage documents "tiering" to the first-stage document by incorporating portions of it by reference. Thus each action has its own individual consultation document that is supported by the programmatic document.

Project-level Consultation under the Tiered Programmatic Consultation Approach

As individual projects are proposed under the tiered programmatic consultation approach, project-specific information will be provided that: (1) describes each proposed action and the specific areas to be affected; (2) identifies the species and critical habitat that may be affected; (3) describes the manner in which the proposed action may affect listed species; (4) describes the anticipated effects; (5) specifies the *anticipated effects from the proposed project are consistent with those analyzed in the programmatic biological opinion*; (6) describes proposed measures to minimize potential effects of the action; and (7) describes any additional effects, if any, not considered in the programmatic consultation. The Service reviews this information and then completes a tiered biological opinion with a project-specific incidental take statement. This document, while meeting the basic requirements of biological opinions as specified at 50 CFR 402.14(h), generally requires less effort to complete because it references back, or tiers, to the program-level biological opinion.

The following assumptions regarding future consultation (second stage) are incorporated into this programmatic biological opinion:

1. Analysis for site-specific actions proposed under the "umbrella" of this proposed MOA will be submitted to the Service pursuant to section 7 or section 10 of the Act, as appropriate.

2. Specific actions that the Federal permitting agency or the Service determines may affect listed species will undergo consultation according to section 7(a) (2). These actions will be assessed on their own merits and be evaluated relative to the jeopardy and adverse modification criteria of the Act, as appropriate.

3. Specific actions that do not have a Federal nexus but may result in take of a listed species will require a section 10 incidental take permit. These actions will be assessed on their own merits and be evaluated relative to the jeopardy and adverse modification criteria and section 10 issuance criteria of the Act, as appropriate.

4. The Service will provide guidance on future site-specific actions in order to ensure that the project description is consistent with our biological opinion, such that our determination remains valid.

The effects of actions resulting from the proposed action will require future programmatic and/or site-specific section 7 consultations for the listed species covered in this biological opinion. This biological opinion does not issue exemption for any incidental take resulting from any action undertaken by Federal agencies or applicants.

Consultation History

On July 30, 2004, a meeting was held among SNWA, MVWD, and the Service to discuss conservation measures that would be identified and incorporated into an ongoing consultation for a proposed pipeline that would be necessary to comply with Nevada State Engineer Order 1169. It was determined that a Memorandum of Agreement was the appropriate mechanism to effectuate these commitments. The MOA would then become part of the project proposal and thus incorporated into the Description of the Proposed Action in the biological opinion.

On August 6, 2004, a meeting was held among SNWA, MVWD, and the Service to discuss, clarify, and continue development on the MOA.

On August 30, 2004, a meeting was held among SNWA, MVWD, and the Service to discuss, clarify, and continue development on the MOA.

On September 20, 2004, a meeting was held among SNWA, MVWD and the Service to negotiate average flow levels that would be necessary to protect in-stream flows that may be affected by the proposed project. These flow levels would then be incorporated into the MOA.

On October 5, 2004, the Office of the Solicitor sent a letter to the Tribe outlining technical and legal concerns with a Proposed Water Settlement Agreement that the Tribe had negotiated with other entities regarding water issues in the California Wash Basin.

On October 7, 2004, the MOA was revised to include CSI due to the potential effects to the Moapa dace from pumping their existing permitted water rights in Coyote Spring Valley for their proposed development in Clark County.

November 19, 2004, the National Park Service (NPS) and the Service met with the Tribe to discuss the technical concerns identified in the October 5, 2004, letter.

On December 15, 2004, the Service sent the Tribe a letter outlining technical concerns and suggesting that the Tribe participate in a Recovery Implementation Program to address species related groundwater issues consistent with that was developed in the MOA with SNWA, MVWD, and CSI.

On January 25, 2005, a meeting was held among the Tribe, NPS, and the Service to discuss the concerns identified in the December 15, 2005 letter. In addition, the Service discussed the MOA that was negotiated with SNWA, MVWD, and CSI and explained that this MOA did not bind or affect the Tribe or their resources in any way, but rather that the MOA may prove beneficial to the Tribe.

On March 7, 2005, a memorandum from the Office of the Solicitor was sent to the Acting Assistant Secretary for Water and Science recommending that bureau coordination of the two actions [(1) Tribal Water Settlement Agreement and (2) MOA] and to develop a recommendation on future water development in southern Nevada.

On March 17, 2005, a letter from SNWA was sent to the Office of the Solicitor requesting resolution of both actions before April 22, 2005, or they would pursue other options for development of their water rights.

On March 23, 2005, the Nevada BLM State Director (designated Liaison between DOI and SNWA) conducted a meeting with DOE Regional Managers and a separate meeting on the same day with SNWA to initiate discussions in an effort to resolve the two groundwater issues [(1) Tribal Water Settlement Agreement and (2) MOA].

On April 6, 2005, a meeting was held among the Tribe, SNWA, NPS, BLM, Bureau of Reclamation, Bureau of Indian Affairs, the Deputy Assistant Secretary for Fish, Wildlife, and Parks, and the Service to discuss including the Tribe into the MOA. Following this meeting, the Service made a decision to include the Tribe and formally conduct section 7 consultation on the MOA.

On June 6, 2005, a meeting was held among the Tribe, SNWA, and the Service to discuss, clarify, and continue inclusion of the Tribe into the MOA.

On June 27, 2005, a meeting was held among the Tribe, SNWA, and the Service to discuss, clarify, and continue inclusion of the Tribe into the MOA.

On July 14, 2005, a MOA was agreed to by the Tribe, SNWA, MVWD, CSI, and the Service to ensure that conservation actions were in place prior to potential impacts associated with the project's groundwater pumping. Also agreed to by MVWD and the Service was the Jones Spring Agreement which is an Exhibit to the MOA.

On July 14, 2005, a Water Supply Agreement was agreed to by the Tribe, SNWA, MVWD, LVVWD, and MVIC. Among other features under this Water Supply Agreement, the Tribe will receive the State groundwater permit and State groundwater applications which are to be provided to the Tribe by LVVWD under the Water Supply Agreement, and a lease of Muddy River water rights which in certain respects will be functionally similar to the federally-reserved Muddy River rights to be secured to the Tribe under the Water Supply Agreement.

On July 19, 2005, the Service determined that given the complexity of various entities, withdrawing groundwater from the regional carbonate aquifer system, a tiered programmatic approach for those actions included in the MOA would be the most effective approach to evaluate those effects, including proposed conservation measures to minimize the effects to the endangered Moapa dace. Other species may potentially be affected as a result of actions associated with the use of the groundwater withdrawals; however those proposed actions will be evaluated in subsequent biological opinions (tiered) as appropriate.

On October 5, 2005, the Service requested review of the draft Intra-Service Programmatic Biological Opinion for the Proposed Muddy River Memorandum of Agreement Regarding the

Groundwater Withdrawal of 16,100 afy from the Regional Carbonate Aquifer in Coyote Spring Valley and California Wash Basins, and Establish Conservation Measures for the Moapa Dace, Clark County, Nevada (File No. 1-5-05-FW-536) by the Parties of the MOA.

On October 18, 2005, a meeting was held among the Parties of the MOA, including the Service to discuss comments on the draft programmatic biological opinion (File No. 1-5-05-FW-536). It was determined at the meeting that the Parties of the MOA would provide a set of substantial written comments to the Service by November 10, 2005.

On October 27, 2005, the Service received preliminary written comments on the October 5, 2005, draft programmatic biological opinion (File No. 1-5-05-FW-536) from CSI.

On November 15, 2005, the Service received written comments on the October 5, 2005, draft programmatic biological opinion (File No. 1-5-05-FW-536) from SNWA, MVWD, and CSI, collectively.

On November 22, 2005, the Service received written comments on the October 5, 2005, draft programmatic biological opinion (File No. 1-5-05-FW-536) from the Tribe via their consultants Ziontz, Chestnut, Varnell, Berley & Slonim.

On November 29, 2005, the Service received written comments on the October 5, 2005, draft programmatic biological opinion (File No. 1-5-05-FW-536) from the Tribe via their consultants Mifflin & Associates, Inc.

On December 12, 2005, a meeting was held among the Parties of the MOA to discuss the Parties comments relative to the Service's representation of available information.

On January 11, 2006, the final draft programmatic biological opinion (File No. 1-5-05-FW-536) was emailed to the Parties of the MOA.

On January 27, 2006, the final MOA was agreed to by the Tribe, SNWA, MVWD, CSI, and the Service to ensure that conservation actions were in place prior to potential impacts associated with the project's groundwater pumping.

BIOLOGICAL OPINION

Description of the Proposed Action

The proposed action involves the cumulative withdrawal of 16,100 afy of groundwater by the SNWA (9,000 afy), MVWD, CSI (4,600 afy), and Tribe (2,500 afy) from two separate basins (Coyote Spring Valley and California Wash basins) within the White River Groundwater Flow System (Figure 1), which is part of a larger carbonate aquifer system. The White River Groundwater Flow System encompasses many smaller basins throughout several counties within the State of Nevada. These basins include Long Valley (175), Jakes Valley (174), White River Valley (207), Cave Valley (180), Garden Valley (172), Coal Valley (171), Pahroc Valley (208), Pahranagat Valley (209), Delamar Valley (182), Kane Springs Valley (206), Coyote Spring

Valley (210), Muddy River Springs Area (219), Hidden Valley (217), Lower Moapa Valley (220), California Wash (218), Garnet Valley (216), and Black Mountains Area (215).

The breakdown of proposed groundwater withdrawals associated with this action and evaluated in this programmatic biological opinion include: 1) SNWA's withdrawal of 9,000 afy from Coyote Spring Valley at the MX-5, RW-2, CSI Wells #1 and #2; 2) CSI's withdrawal of 4,600 afy from Coyote Spring Valley at CSI Well #1 (Permit 70430) and CSI Well #2 (Permit 70429) and other wells in Coyote Spring Valley; and 3) the Tribe's withdrawal of 2,500 afy from California Wash from a well-field located in the southwestern third of the Moapa Reservation. These proposed projects would require actions by other Federal agencies; however, their actions are only administrative in nature and would not change the scope of the projects or the effects analyzed in this biological opinion. Therefore, as long as the Federal action does not change the effects analysis, then future section 7 consultations for each Federal action could be tiered to this biological opinion as described above. Moapa Valley Water District is responsible for supplying the municipal water needs of Upper and Lower Moapa Valley in Clark County, Nevada, and owns several water rights including surface rights to spring flows in the Warm Springs Area and groundwater rights. Signatories to the MOA have proposed various minimization/conservation actions to offset effects to the Moapa dace.

State Engineer Rulings and Existing Groundwater Permits in Coyote Spring Valley (210), Muddy River Springs Area (219), and California Wash (218) Basins

There are three primary Nevada State Engineer rulings that affect the withdrawal of groundwater associated with the proposed action. In these ruling the Nevada State Engineer has employed a "staged development" approach that outlines an incremental approach for phasing in development of the carbonate aquifer with adequate monitoring in cooperation with other parties in order to assist in assessing affects. This approach was adopted by the Nevada State Engineer"…in order to predict, through the use of a calibrated model, the effects of continued or increased development with a higher degree of confidence." Two of these rulings (Order 1169 and Ruling 5115) held rights and applications in abeyance while allowing small projects to go forward "…that are possibly augmented gradually if conditions and confidence warrant. This approach allows the effects of development to be observed and analyzed continually, so that the benefits and adverse effects of development can be judged, and the effects reversed or mitigated if they prove to be detrimental to existing rights and the environment." These rulings are summarized below along with the existing permitted groundwater rights in the three hydrographic basins associated with the proposed action, as well as in Table 1.

Coyote Spring Valley (210)

In Order 1169 the Nevada State Engineer held in abeyance applications for new groundwater rights in certain groundwater basins (Table 1), and mandated that all water right holders (SNWA, LVVWD, MVWD, CSI and Nevada Power Company) conduct a regional groundwater study including the pumping of at least 50 percent of the permitted water rights within the Coyote Spring Valley hydrographic basin for a period of at least two consecutive years. Order 1169 is designed to evaluate how groundwater pumping activities in Coyote Spring Valley will impact water rights and the environment within the Warm Springs Area, including the Muddy River ecosystem. In an effort to meet the requirements of Order 1169, the SNWA is proposing to remove the 9,000 afy of groundwater rights they currently own from the Coyote Spring Valley basin at the MX-5 and RW-2 wells. However, SNWA may propose to redistribute development of their existing groundwater rights from other wells within the Coyote Spring Valley. Data obtained from the study will be used to evaluate groundwater development activities within the regional carbonate groundwater system. SNWA is cooperating with MVWD, which will accommodate the 9,000 afy of Coyote Spring Valley groundwater pump test for the Order 1169 study through a new SNWA pipeline and existing MVWD pipelines and facilities, terminating at the Bowman Reservoir. Flows in excess of the capacity of the Bowman Reservoir would ultimately enter the lower Muddy River.

As of 2002, the Nevada State Engineer had granted 16,300 afy of groundwater right permits in Coyote Spring Valley (Table 1). To date, there has been almost no pumping of the permitted rights in the basin.

Muddy River Springs Area (219) (Warm Springs Area)

In Ruling 4243 the Nevada State Engineer granted permits to MVWD for 5,800 afy, but with pumping phased in over a ten-year period while monitoring surface water flows and groundwater levels in order to assess potential effects to wells and springs. Annual volume pumped is limited to annual demand, up to the maximum permitted. Annual pumping has consistently been less than the amount allowed in the ruling.

As of 2002, the Nevada State Engineer had granted a total of approximately 14,800 afy of groundwater permits for the alluvial aquifer or the carbonate aquifer in the Muddy River Springs Area Basin or Warm Springs Area (Table 1). Included in these are the MVWD permits for the Arrow Canyon Well totaling 10 cubic feet per second (cfs) or 7,240 afy (1,440 afy prior to Ruling 4243 plus 5,800 afy from Ruling 4243). To date, the actual pumping from the Arrow Canyon Well (carbonate aquifer pumping) has been far less than the permitted volume. Approximately 2,400 afy has been pumped on average from 1998 to 2003. Nevada Power Company holds groundwater rights in the Warm Springs Area as well, but their groundwater pumping has been historically limited to the alluvial aquifer only.

California Wash (218)

In Ruling 5115 the Nevada State Engineer granted Application Number 54075, filed by the LVVWD on October 17, 1989, for a total duty of 2,500 afy with a diversion rate of 5.0 cfs within the California Wash hydrographic basin (Permit Number 54075). By separate agreement, the LVVWD will transfer ownership of Permit Number 54075 to the Tribe (Attachment C). The Tribe plans to divert and utilize groundwater under Permit Number 54075.

As of 2002, the Nevada State Engineer had granted 3,067 afy of permitted groundwater rights in California Wash Basin (Table 1). It is not known how much of the permitted groundwater rights are being pumped.

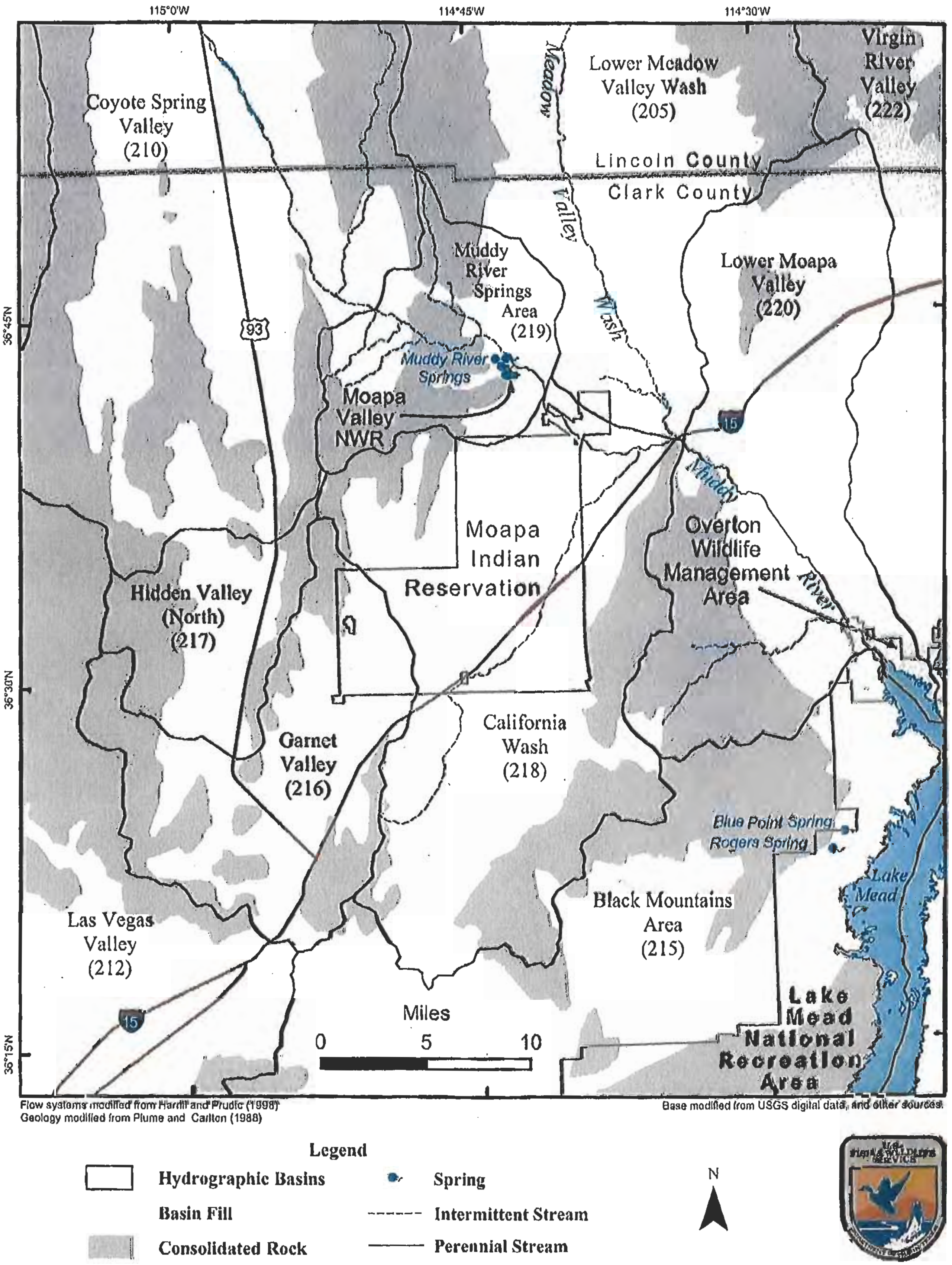

Figure 1.--Location of the Moapa Valley National Wildlife Refuge (NWR) and vicinity.

Table 1. Primary Nevada State Engineer's Rulings in the White River Groundwater Flow System 1995 to 2005

STATE ENGINEER'S DECISION	DATE OF DECISION	HYDROGRAPHIC AREA	APPLICANT	RIGHTS PERMITTED BY DECISION (afy)	RIGHTS HELD IN ABEYANCE BY DECISION (afy)	TOTAL GROUNDWATER RIGHTS PERMITTED IN BASIN AND MAJOR PERMIT HOLDERS (afy)	TOTAL GROUNDWATER RIGHTS PENDING IN BASIN AND MAJOR APPLICATION HOLDERS (afy)*
Ruling 4243	Oct 1995	Muddy River Springs Area	MVWD	5,800	0	~14,800 (MVWD and NPC)	22,000 (MVWD, Silver State Water Co)
Significant Points Of Ruling 4243:	1) State Engineer granted permits to MVWD but with pumping phased in incrementally over a ten-year period while monitoring to assess effects to wells and springs. A "staged development" approach. The ruling requires monitoring for impacts to resources or other water rights. The consequences of impacts are handled somewhat vaguely in the ruling. 2) Annual volume is limited to annual demand, up to the maximum permitted. Annual pumping has consistently been less than what is allowed in the ruling. 3) Monitoring to be conducted by applicant in cooperation with other parties (NPS, FWS, NPC, US Geological Survey (USGS), SNWA)						
Order 1169	March 2002	Coyote Spring Valley	LVVWD and CSI	0	27,500 (LVVWD) 108,600 (CSI)	16,300 (LVVWD/SNWA, CSI, NPC)	>200,000 (LVVWD/SNWA, CSI, Dry Lake Water Co.)
Significant Points of Order 1169:	1) State Engineer ordered that at least half of the existing permits be pumped for two consecutive years during a minimum five-year study period, continuing the "staged development" approach. A report on pumping-related impacts to groundwater and surface water resources is due to the State Engineer following the study. 2) Pending and any new water right applications in Coyote Spring Valley, Black Mtns Area, Garnet Valley, Hidden Valley, Upper Moapa Valley, and Lower Moapa Valley are held in abeyance until the pump test is completed. 3) Monitoring is to be conducted by applicants in cooperation with other parties (MVWD, NPC, FWS, NPS)						
Ruling 5115	April 2002	California Wash	LVVWD and Moapa Paiutes	2,500	7,200	~3,000 (LVVWD/Moapa Paiutes)	29,000 (LVVWD/Moapa Paiutes, Dry Lake Water Co., NPC, Oxford Power)
Significant Points of Ruling 5115:	1) State Engineer continued the "staged development" approach by granting a portion of one application and holding the other in abeyance until the development occurs and effects can be assessed. 2) Granted only the volume of water needed for an air-cooled power plant, stating that it was not prudent "..to use substantial quantities of newly appropriated groundwater for water-cooled power plants in one of the driest places in the nation, particularly with the uncertainty as to what quantity of water is available…" 3) State Engineer noted in the Ruling that SNWA intends to transfer the permits to the Moapa Band of Paiutes.						

*Estimates of pending groundwater rights should be viewed as approximate and subject to change.

Acronyms: CSI (Coyote Springs Investment), FWS (U.S. Fish and Wildlife Service), LVVWD (Las Vegas Valley Water District), SNWA (Southern Nevada Water Authority), MVWD (Moapa Valley Water District), NPC (Nevada Power Company), NPS (National Park Service), USGS

Proposed Groundwater Withdrawals Associated with the MOA

On July 14, 2005, an MOA was agreed to by the signatories to outline specific conservation actions that each party would complete in order to minimize potential impacts to the Moapa dace should water levels decline in the Muddy River system as a result of the cumulative withdrawal of 16,100 afy of groundwater from two basins within the regional carbonate aquifer system. The following descriptions summarize the signatories intended water withdrawals and conservation actions that would be implemented in order to offset potential impacts to the Moapa dace. Each of these proposed groundwater withdrawals will be the subject of a future tiered biological opinion prior to any such withdrawal occurring.

Southern Nevada Water Authority and Moapa Valley Water District

As part of Nevada State Engineer Order 1169, a minimum of half the existing permitted groundwater rights in Coyote Spring Valley are to be pumped consecutively for two years as part of a five-year study to monitor the effects of the pumping. The SNWA and LVVWD have existing water right permits for approximately 9,000 afy of groundwater in Coyote Spring Valley. SNWA has indicated that they will pump 9,000 afy to meet the minimum pumping requirement in Order 1169. MVWD shall have the right during the pump test to use the Arrow Canyon Well only in the event and to the extent SNWA is unable to supply MVWD with "all necessary municipal and domestic water supplies." In conjunction with the MVWD, SNWA will pump this water from Coyote Spring Valley to water users in Moapa Valley via a pipeline, which would be analyzed in a future project-specific tiered biological opinion. Any excess water that is not utilized by SNWA and MVWD will be sent to the Bowman Reservoir. If the capacity of the reservoir is reached, then the water will be discharged into the lower Muddy River. It is anticipated that construction of the pipeline would take two years upon issuance of a right-of-way permit, thus pumping of this 9,000 afy would not occur until construction of the pipeline was completed. SNWA and the LVVWD have begun implementing the study in cooperation with other water right holders and Federal agencies (Service, NPS, and BLM) by expanding existing monitoring efforts, and drilling eight additional monitoring wells in Coyote Spring Valley and the Warm Springs Area. Following the study period, it is assumed that the transmission system will continue to be utilized by SNWA and/or MVWD to convey the 9,000 afy of permitted water rights. It is anticipated that the permitted water right will ultimately be used as a resource option for MVWD and/or SNWA.

Coyote Springs Investment, LLC

CSI has initiated development of a residential community in the Coyote Spring Valley basin in Clark County. In order to meet the water demands of that community, CSI proposes to withdraw their State appropriated groundwater right of 4,600 afy from the basin at CSI Well #1 (Permit 70430) and CSI Well #2 (Permit 70429) well locations or other well locations approved by the Nevada State Engineer as production locations for CSI's water right in Coyote Spring Valley. However, CSI has anticipated a phased in approach over five years, for the production of the full water rights as follows: 1) first year, 600 afy, 2) second year, 1,600 afy, 3) third year, 3,600 afy, 4) fourth year, 3,600 afy, and 5) fifth year, 4,600 afy. Incidental take has been exempted for desert tortoise in Clark County under section 10(a)(1)(B) of the Act pursuant to the approved

Clark County Multiple Species Habitat Conservation Plan (MSHCP); however the Moapa dace is not included in the MSHCP, nor the associated incidental take statement. Utilization of the CSI water right and its affect to Moapa dace would be analyzed in a future project-specific tiered biological opinion.

Moapa Band of Paiutes

Through a Water Supply Agreement with LVVWD (Attachment C), the LVVWD will transfer to the Tribe, 2,500 afy groundwater water rights in the California Wash Basin. Although no proposal has been submitted for any specific action regarding groundwater withdrawals, the Tribe has indicated the potential use of 500 afy of that 2,500 afy right for commercial development within the next two years. Utilization of the Tribe's water right and its affect to Moapa dace would be analyzed in a future project-specific tiered biological opinion, as will any other future projects up to the maximum 2,500 afy right analyzed in this programmatic opinion.

<u>Proposed Conservation Measures</u>

In order to minimize effects to the Moapa dace, conservation actions have been identified by the signatories of the MOA that propose to withdraw groundwater from the regional carbonate groundwater system. In order to be considered a benefit to the species, it is assumed that the proposed conservation measures will be initiated or fully implemented prior to the proposed groundwater withdrawal of 16,100 afy associated with the proposed action. Since development of the 16,100 afy requires the construction of facilities, as identified above, there would be a two to five year timeframe in which to implement many of these actions prior to the pumping of the full amount of water analyzed in this biological opinion. However, as indicated above, CSI would utilize a small portion of their water right in Coyote Spring Valley prior to full implementation of all of the conservation measures. While the contribution of funding is crucial to any conservation action, the completed, on-the-ground activity that results from the funding is the action that will be the evaluated benefit to the species. The true benefit to the species will occur with the implementation of the intended conservation action. Each of these actions, either separately or in combination, will be the subject of a future tiered biological opinion prior to their implementation. The action items are identified in the MOA (Attachment A); the following is a summary of those actions:

1. Implement restoration of Moapa dace habitat on the Service's Apcar Unit of the Moapa Valley National Wildlife Refuge (MVNWR);

2. Develop a Recovery Implementation Program (Recovery Program), which will be used to effectuate the goals of the MOA by implementing measures necessary to accomplish the protection and promote the recovery of the Moapa dace, as well as, outline the development of regional water facilities and include additional parties as appropriate. The Recovery Program will be developed for the purposes of continuing to identify the key conservation actions that, when implemented, would continue to contribute to offset any pumping impacts that may result from groundwater pumping;

3. Assist in developing an ecological study designed specifically to determine effects of groundwater pumping on the Moapa dace and other aquatic dependent species in the Muddy River system;

4. Construct fish barriers in order to prevent additional non-native fishes from migrating into Moapa dace habitat;

5. Eradicate non-native fish, such as tilapia from the historic range of Moapa dace;

6. Restore Moapa dace habitat outside the boundary of the MVNWR;

7. Provide the use of the Tribal greenhouse to cultivate native plants for restoration actions in the Muddy River area;

8. Provide access to Tribal lands for the construction and maintenance of at least one fish barrier;

9. Dedication of an existing 1.0 cfs Jones Spring water right (MVWD) towards establishing and maintaining in-stream flows in the Apcar tributary system that empties into the Muddy River as outlined in Attachment B; and

10. Dedication of 460 afy of water rights (portion of CSI appropriated water rights) to the survival and recovery of the Moapa dace, in perpetuity.

In addition, minimum in-stream flow levels were also established in the MOA that trigger various conservation actions should those predetermined levels be reached. The flow levels will be measured at the Warm Springs West Flume located on MVNWR. These automatic actions are identified in the MOA (Attachment A) and are summarized below:

1. Should the water flows reach 3.2 cfs, the signatories will meet to discuss the issue and compare/evaluate hydrology data;

2. Should the water flows reach 3.0 cfs, during the pendency of the pump test, the Arrow Canyon well will shut down and SNWA will provide the MVWD with the sufficient water quantity necessary to meet their municipal demands. In addition, SNWA and CSI will take necessary actions to geographically redistribute groundwater pumping in Coyote Springs Valley if flows levels continue to decline;

3. Should the water flows reach 3.0 cfs or less but greater than 2.9 cfs, SNWA and CSI will restrict groundwater pumping from MX-5 and RW-2 wells, and CSI Well #1 (Permit 70430) and CSI Well #2 (Permit 70429) and CSI's pumping from other wells in Coyote Spring Valley, in combination, to 8,050 afy;

4. Should the water flows reach 2.9 cfs or less but greater than 2.8 cfs, SNWA and CSI will restrict groundwater pumping from MX-5 and RW-2 wells, and CSI Well #1 (Permit 70430) and CSI Well #2 (Permit 70429) and CSI's pumping from other wells in Coyote

Spring Valley, in combination, to 6,000 afy, and the Tribe will restrict their pumping (under permit number 54075) in the California Wash basin to 2,000 afy;

5. Should the water flows reach 2.8 cfs or less but greater than 2.7 cfs, SNWA and CSI will restrict groundwater pumping from MX-5 and RW-2 wells, and CSI Well #1 (Permit 70430) and CSI Well #2 (Permit 70429) and CSI's pumping from other wells in Coyote Spring Valley, in combination, to 4,000 afy, and the Tribe will restrict their pumping (under permit number 54075) in the California Wash basin to 1,700 afy;

6. Should the water flows reach 2.7 cfs or less, SNWA and CSI will restrict groundwater pumping from MX-5 and RW-2 wells, and CSI Well #1 (Permit 70430) and CSI Well #2 (Permit 70429) and CSI's pumping from other wells in Coyote Spring Valley, in combination, to 724 afy, and the Tribe will restrict their pumping (under permit number 54075) in the California Wash basin to 1,250 afy.

Action Area

The Action Area is defined as the hydrogeomorphic basins which have hydrologic connectivity to the Muddy River ecosystem. Although the entire White River Groundwater Flow System is hydrogeologically connected, only the basins that include the area of the proposed groundwater development and location of the Moapa dace and its habitat are included in the action area. These basins include the Coyote Spring Valley (Basin 210), Muddy River Springs Area (Basin 219) and California Wash (Basin 218).

Status of the Species

Moapa Dace

The Moapa dace was federally-listed as endangered under the Endangered Species Preservation Act of 1966 on March 11, 1967 (32 FR 4001), and has been protected under the Act since its inception in 1973. Critical habitat has not been designated for the Moapa dace. The Service assigned the Moapa dace the highest recovery priority because: (1) it is the only species within the genus *Moapa*; (2) the high degree of threat to its continued existence; and (3) the high potential for its recovery (Service 1996). A final recovery plan was approved by the Service in 1996 (Service 1996).

The Moapa dace was first collected in 1938 and was described by Hubbs and Miller (1948). Key identification characteristics are a black spot at the base of the tail and small, embedded scales, which create a smooth leathery appearance. Coloration is olive-yellow above with indistinct blotches on the sides, with a white belly. A diffuse, golden-brown stripe may also be present. Maximum size is approximately 4.7 inches fork length. The oldest known specimen on record is over four-years old (Scoppettone et al. 1992).

The Moapa dace is a member of the North American minnow family, *Cyprinidae*. The genus *Moapa* is regarded as being most closely related to the dace genera *Rhinichthys* (speckled dace) and *Agosia* (longfin dace) (Coburn and Cavender 1992). These three dace genera, along with the genera *Gila* (chub), *Lepidomeda* (spinedace), *Meda* (spikedace), and *Plagopterus* (woundfin), developed from a single ancestral type (monophletic) and are only associated with the Colorado River Basin (Service 1996).

The Moapa dace is thermophilic and endemic to the headwaters of the Warm Springs Area, typically occurring in waters ranging from 78.8 to 89.6° F (Hubbs and Miller 1948); however, one individual was collected in water temperatures of 67.1°F (Ono et al. 1983). Although, Rinne and Minckley (1991) rarely found the species below 86° F. Deacon and Bradley (1972) indicated that the species reaches its greatest abundance at warmer temperatures between 82.4 and 86.0° F. Reproduction occurs year-round and is confined to the upper, spring-fed tributaries (Scoppettone et al. 1992) where the water temperatures vary from 84.2 to 89.9° F and dissolved oxygen concentrations vary between 4.1 and 6.2 parts per million (Scoppettone et al. 1993). Juveniles are found almost exclusively in the spring-fed tributaries, whereas adults are also found in the mainstem of the Muddy River (Scoppettone et al. 1992). Adults show the greatest tolerance to cooler water temperatures, which appears to be 78.8° F (Scoppettone et al 1993). Given the species temperature tolerances and cooling pattern of the river (in a downstream direction), its range appears to be restricted to the warmer waters of the upper springs and tributaries of the Warm Springs Area (Deacon and Bradley 1972, Cross 1976, Scoppettone et al. 1992, Scoppettone et al. 1993).

In 1983, the Service prepared a recovery plan for Moapa dace which was updated in 1996, and identified various tasks to guide Recovery (Service 1996). The plan also addresses the current status, threats, and recovery needs of seven other endemic aquatic species. These include three fishes: the Virgin River chub (*Gila seminuda*) [this species is currently listed as endangered in the Virgin River and is under review for listing in the Muddy River], Moapa speckled dace (*Rhinichthys osculus moapae*), and the Moapa White River springfish (*Crenichthys baileyi moapae*); two snails: the Moapa pebblesnail (*Fluminicola avernalis*), and the grated tyronia (*Tryonia clathrata*); and two invertebrates: the Moapa Warm Springs riffle beetle (*Stenelmis moapa*) and the Amargosa naucorid (*Pelocoris shoshone shoshone*) that co-exist with the Moapa dace in the Muddy River ecosystem.

Threats to Moapa dace habitat include introductions of non-native fishes (e.g. tilapia and mollies), and parasites; habitat loss from water diversions and impoundments; increased threat of fire due to encroachment of non-native plant species such as palm trees, and reductions to surface spring-flows resulting from groundwater development which reduces spawning, and nursery habitats and the food base for the species. The Moapa dace is more vulnerable to catastrophic events due to their limited distribution in conjunction with these threats.

Hydrogeologic Setting

To understand the factors influencing the distribution and abundance of the Moapa dace, it is important to understand the unique hydrogeologic setting of Moapa dace habitat in the Warm Springs Area. The following description is based on past reports, monitoring information, and discussions with hydrology experts from the SNWA, NPS, USGS, Service, other agencies and organizations. We acknowledge that there are other interpretations of the hydrogeology and existing hydrologic data and the effects of current groundwater pumping that have been expressed by Parties of the MOA (refer to the Journal of Nevada Water Resources Association, Volume 1, pg. 14 and pg [40], Johnson and Mifflin, 2003 and 2005). While these interpretations are plausible and differ from ours, the goal of the pump test as identified in Order 1169 is to gain a better understanding of the effects of groundwater pumping on existing rights and the environment, which will further our understanding of the hydrogeology of the area.

The Warm Springs Area is a groundwater discharge area consisting of about 20 regional springs, with numerous seeps and wetlands (Figure 2). This area is part of the White River Groundwater Flow System, a regional groundwater flow system located in Southern Nevada (Eakin 1966, Harrill et al. 1988, Prudic et al. 1993). As originally defined by Eakin (1966), the flow system encompasses 13 topographic basins, extending over 400 km and terminating at the Warm Springs Area. The flow system consists of numerous local basin fill aquifers underlain by a large regional carbonate aquifer that transmits groundwater from basin to basin, beneath topographic divides. This regional carbonate aquifer varies considerably in thickness, saturated zones ranging from 4,000 to 17,000 feet thick (Dettinger et al. 1995). The identification of the regional groundwater flow system was based on: (1) the hydrologic properties of the rocks in the area; (2) the movement of groundwater inferred from hydraulic gradients; (3) the relative distribution and quantities of estimated recharge and discharge in the system; (4) the relative uniformity of the discharge of the principal springs; and (5) the chemical composition and warm temperature of the discharge from the principal springs (Eakin 1966).

Groundwater inflow or recharge to the regional carbonate aquifer is primarily through precipitation. Nevada is the most arid State in the United States, and precipitation is strongly dependent on elevation. Most precipitation recharging the flow system occurs as snow in the higher elevation areas of the northern part of the flow system. The regional groundwater flow is inter-basin and is generally south and southeast through the system. Outflow or discharge from the system occurs primarily through spring discharge in three areas: (1) the White River Valley; (2) Pahranagat Valley and; (3) the Warm Springs Area.

The terminal discharge of the regional flow system is most likely to be the Warm Springs Area in the Upper Moapa Valley. However, there has been some speculation that a portion of the regional flow reaches the Colorado River. Eakin (1966) estimated that approximately 37,000 afy or 51 cfs of discharge occurs here annually from about 20 springs, as well as subsurface seepage, although the river discharge at the Moapa gage has decreased significantly since that time (LVVWD 2001). The springs are warm (thermal), discharging at a nearly constant temperature of 89.6° F (Scoppettone et al. 1992), and occur within a 2-km radius and form the headwaters of the Muddy River. Historically, this river was a major tributary to the Virgin River, which then joined the Colorado River; however, after the construction of the Hoover Dam, it now flows into Lake Mead at the Overton Arm.

The source water supporting spring discharge in the Warm Springs Area is primarily groundwater flowing beneath Coyote Spring Valley, with a small contribution possibly from Lower Meadow Valley Wash to the northeast (Eakin 1966, Prudic et al. 1993, Thomas et al. 1996, Bassett 2003). The average age of spring discharge water is approximately 6,100 years, based on carbon-14 dating (Thomas et al. 1996). Coyote Spring Valley is also the location of the groundwater pumping described in the proposed action. The two wells, MX-5 and RW-2, in

Coyote Spring Valley that have been identified as the withdrawal points for Order 1169 are located about 10 to 12 miles northwest of the Warm Springs Area.

Groundwater flow from Coyote Spring Valley to the Warm Springs Area appears to be through a zone of high permeability. Estimates of groundwater transmissivity, based on measurements from MX-5 in Coyote Spring Valley and the Arrow Canyon Well in the Warm Springs Area, range from 230,000 to 360,000 ft^2/day (Van Liew et al. 2004). Such high permeability zones are commonly observed upgradient of areas of regional spring discharge. Dettinger et al. (1995) analyzed 39 well tests in southern Nevada and determined that the aquifer transmissivity measured at wells located within 10 miles upgradient from regional springs is about 10-20 times more transmissive, on average, than that portion of the aquifer located further away. However, other measurements indicate the zone of high transmissivity may be spotty and localized. The transmissivity of Arrow Canyon Well No. 2, adjacent to the Arrow Canyon well, is 92,000 ft^2/day. Downgradient of the Warm Springs Area, a normal fault juxtaposes low permeability rock of the Muddy Spring Formation against the carbonate aquifer, forming a barrier of sorts to regional subsurface flow. This low permeability barrier is responsible for the location of the springs.

Carbonate potentiometric heads at MX-4 and MX-5 in Coyote Spring Valley are about 4 feet (ft) greater than carbonate potentiometric heads at EH-4 and EH-5B wells, which are located in the Warm Springs Area about 12 miles to the southeast (Figure 2) (SNWA 2003). The resulting hydraulic gradient of 6.3×10^{-5} is very low. The high transmissivities and low hydraulic gradients suggest the presence of a zone of well-developed hydraulic continuity and high flow rates extending from Coyote Spring Valley to the Warm Springs Area (Figure 1). Pumping stresses imposed at any point in this zone are expected to be readily propagated to all areas in the high transmissivity zone. Johnson and Mifflin (2003) essentially came to the same conclusion. They state that “Extractions from the "northern" flow field, which extends northwestward from the Muddy River springs and includes Coyote Spring Valley, will impact Muddy River flows on essentially a one-to-one basis.”

The other area of potential groundwater development included in the MOA is the California Wash hydrographic basin (Basin 218). This basin is located to the south of the Warm Springs Area and includes the Moapa Indian Reservation. There is less information on the hydrologic properties of the carbonate aquifer underlying the basin. Some areas within the California Wash basin appear to be highly transmissive and the potentiometric surface is generally quite flat, with a small east-southeast gradient (Johnson et al. 2001). The hydraulic connectivity of the California Wash basin to the Warm Springs Area is unknown although there are some indications that the area is connected with the Warm Springs Area based on monitoring well data that was shared with the Service in July 2004. However, Johnson and Mifflin (2003, 2005) suggest that there is a hydraulic barrier that will prevent pumping in the southern part of California Wash from impacting the Warm Springs Area.

Moapa Valley National Wildlife Refuge

The MVNWR is a 106-acre area of springs and wetlands located in the Warm Springs Area of the Upper Moapa Valley (Figure 3). The MVNWR was established in 1979 for the protection of the endangered Moapa dace. The thermal headwaters of the springs on the MVNWR are some of the most productive spawning habitat in the area. The MVNWR consists of three units encompassing the major spring groups: the Pedersen Unit, Plummer Unit, and Apcar Unit (upper Apcar). The MVNWR also provides protection for the Moapa White River springfish and other aquatic fauna including endemic snails and other aquatic invertebrates native to the Warm Springs Area.

Pedersen Unit

The Pedersen Unit was the first parcel acquired for the MVNWR and is one of the important strongholds for the Moapa dace reproduction. The Pedersen Unit contains five major springs or spring groups: Pedersen Spring; the East Pedersen Spring group; the Spring 13 group; the Spring 12 group; and Spring 11. Pedersen Spring, at an elevation of 1,810 ft (Mayer 2004), is the highest elevation spring in the Warm Springs Area. The other major spring groups range in elevation from 1,792 to 1,807 ft (Mayer 2004). As discussed later, spring elevation is significant if and when groundwater levels in the regional carbonate aquifer decline due to groundwater development. Therefore, higher elevations springs will be impacted first and with a relative reduction in flow than lower elevation springs.

The Service holds a State-appropriative water right for spring discharge on the Pedersen Unit with a priority date of 1991. The water right is for 3.5 cfs as measured at the Warm Springs West gage, which is located near the downstream boundary of the MVNWR and discharges into the Refuge Stream.

The USGS monitors the total spring discharge from the Pedersen Unit of the MVNWR through a one-ft Parshall flume at the Warm Springs West Gaging Station (USGS Station Number 09415920). The site has been monitored continuously since 1985, except for a data gap from October 1994 through May 1996, due to a lack of funding. Until January 1998, there was an un-metered irrigation diversion upstream of the Warm Springs West flume. The diversion was set up such that water in excess of the irrigation needs could be returned to the stream channel, but downstream of the flume. Water was probably not diverted continuously; however, there is no record of when the diversion was open or closed or how much water was diverted. The flow that was diverted for irrigation was not accounted for in the flume measurements, resulting in an underestimate of the total spring discharge from the MVNWR. For this reason, the period of record prior to January 1998 does not adequately represent the total volume of water emanating from the springs on the Pedersen Unit. The diversion was metered by MVWD beginning in February 1998. The farmer ceased irrigating through this diversion after May 1999, and no water has been diverted since that time. The February 2001, seepage run reported a flow of 3.82 cfs at this site (USGS 2001) although flows have decreased since then (Mayer 2004).

Figure 2

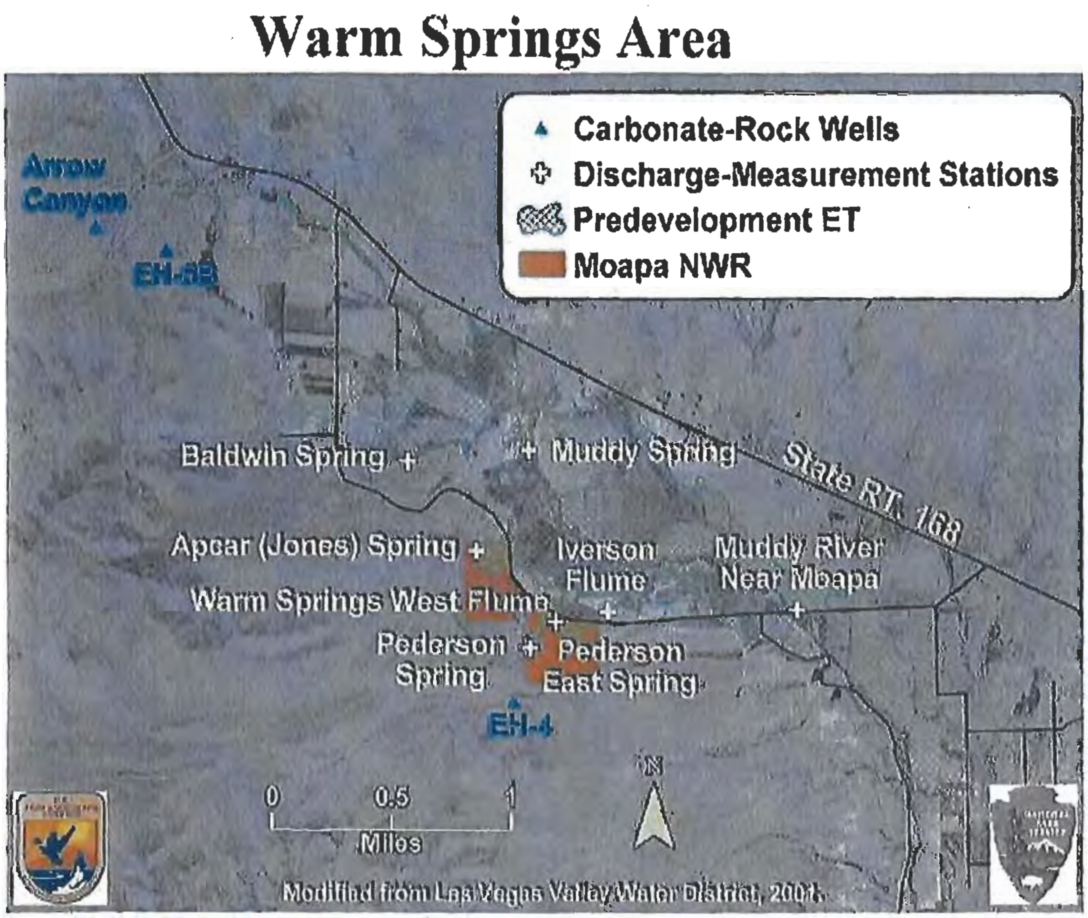
Warm Springs Area
Carbonate-Rock Wells
Discharge-Measurement Stations
Predevelopment ET
Moapa NWR
Arrow Canyon
EH-5B
Baldwin Spring
Muddy Spring
State RT. 168
Apcar (Jones) Spring
Iverson Flume
Muddy River Near Moapa
Warm Springs West Flume
Pederson Spring
Pederson East Spring
EH-4
0
0.5
1
Miles
N
Modified from Las Vegas Valley Water District, 2001.

Figure 3
Moapa Valley National Wildlife Refuge

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Plummer Unit

The Plummer Unit is the second parcel acquired for the MVNWR and is located just east of the Pedersen Unit. It contains three major springs or spring groups: Plummer West; Plummer Central; and Plummer East. The elevations of all three of the spring groups are about 1,755 to 1,760 ft, which is lower than the springs on the Pedersen Unit. The total spring discharge from the Plummer Unit, as measured at Plummer Main, averages about 2.5 cfs, based on periodic measurements by the Service and the USGS. The February 2001, seepage run reported a flow of 2.39 cfs at Plummer Main (USGS 2001).

The discharge from the Plummer and Pedersen units combines to become the Refuge Stream, downstream of the MVNWR boundary. The Iverson flume (USGS Station Number 9415927) on the Refuge Stream measures the flow leaving the MVNWR, plus any additional losses or gains between the MVNWR boundary and the gaging station. The February 2001, seepage run reported a flow of 8.00 cfs at the flume with an additional 1.13 cfs being diverted upstream of the flume, for a combined total of 9.13 cfs (USGS 2001). The combined total at the Iverson Flume was about 150 percent of the sum of the two flows measured upstream on the same day at Warm Springs West gage and Plummer Stream (USGS 2001). The additional flow measured at the downstream site is assumed to result from subsurface seepage gain into the channel along this reach.

Apcar Unit

The Apcar Unit is the third and most recent parcel acquired for the MVNWR. There is just one spring emanating in this area, the Apcar or Jones Spring. The elevation of the spring orifice is reported to be 1,788 ft although the orifice is buried and the elevation may be difficult to determine accurately. Flows from Apcar Spring are reported by MVWD and have averaged about 1.5 to 1.6 cfs since January 2001. MVWD currently diverts 1.0 cfs of the total flow from Apcar Springs continuously for municipal use (Water Right Certificate Number 10060). The undiverted portion of the spring discharge flows east into Apcar Stream. The February 2001, seepage run reported a flow of 2.54 cfs downstream of Apcar Stream at the Pipeline Jones flume and 3.86 cfs just above the confluence with the Refuge Stream. MVWD reported an average daily flow of 1.55 cfs during February 2001, (flow measurements for specific days were not available, only an average daily flow based on a monthly total). Presumably, 1.0 cfs of this 1.55 cfs was being diverted by MVWD, leaving 0.55 cfs in the channel. The additional flow measured during the seepage run at the two measurement sites downstream of the Apcar Unit is assumed to result from un-metered springs on private property and subsurface seepage gain into the channel along the entire stream.

Historic Distribution and Abundance of the Moapa dace

Between 1933 and 1950, Moapa dace was abundant in the Muddy River and was estimated to inhabit as many as 25 individual springs and up to 10 miles of stream habitat (Ono et al. 1983). La Rivers (1962) considered the species "common" until at least 1950. However, by 1983, the species only occurred in springs and 2 miles of spring outflows (Ono et al.1983). The species appears to have declined since 1938, when Hubbs and Miller considered the species "rather common" in all warm water habitats in the headwaters of the Moapa River (Muddy River), including spring pools, small creeks and the mainstem.

During 1984-87, the Service's Seattle National Fisheries Research Center, now part of the USGS-Biological Resources Division (BRD), extensively surveyed Moapa dace habitats and estimated the adult Moapa dace population to be between 2,600 and 2,800 individuals (Scoppettone et al. 1992). These areas were re-surveyed by USGS-BRD in August 1994, when approximately 3,841 Moapa dace were recorded (Scoppettone et al. 1996). There was a substantial reduction in the number of individuals counted in 1997, with less than 1,600 adult Moapa dace observed, which was believed to be a result of the introduction of tilapia (Scoppettone et al. 1998). In January 2001, a total of 934 Moapa dace were recorded by a consortium of agencies, including the Nevada Department of Wildlife, USGS-BRD, SNWA, and the Service. In February 2002 and 2003, annual surveys enumerated approximately 1,085 and 907 individuals, respectively (Table 2).

Table 2. Moapa dace survey results [a]

Stream Survey Segment	1994	1997	Feb 1999	Feb 2000	Jan 2001	Feb 2002	Feb 2003	Feb 2005
Muddy River Mainstem	2,088*	260*						
– NP to REF	N/A	N/A	X	X	X	8	0	X due to turbidity
– REF to N/S forks	N/A	N/A	X	X	34	49	19	49
Apcar (off MVNWR)	407*	528*						
– Lower			X	43	85	55	30	157
South Fork	355	28	13	9	18	24	14	10
North Fork	426	106	77	73	46	37	33	9
Muddy Spring	236	28	14	X	5	2	0	0
Apcar-Upper (MVNWR)			5	X	87	86	40	6
Plummer (MVNWR)	0	20	113	X	59	53	60	177
Pedersen (MVNWR)			185	163	184	172	204	174
Refuge Stream	313*	595*						
– Warm Springs Road to A/R	N/A	N/A	566	643	416	599	507	652
– A/R to Gabion Structure	N/A	N/A	X	X	X	X	X	62
TOTALS	3841	1565	973	931	934	1085	907	1,296

[a]2004 surveys not completed throughout the species entire range and not used for comparison

A/R = just above confluence of Refuge and Apcar Streams; N/S = confluence of North and South Forks; NP = Nevada Power diversion; MVNWR = spring heads to Warm Springs Road; REF = confluence of Refuge Stream and Muddy River; X= stream reach not surveyed.

* entire reach surveyed, not broken into segments. 2005 population surveys were broken into distinct reach segments and did include juveniles in the Refuge Stream and Plummer Unit on the MVNWR

Current Distribution and Abundance of the Moapa Dace

The Moapa dace currently occupies a variety of habitats in the Warm Springs Area, including spring pools, tributaries (spring outflows), and the upper 2.48 miles of the 24.8 mile-long mainstem Muddy River (post-Hoover Dam). Habitat use varies among larval, juvenile, and adult life stages. Larval dace are observed only in the upper-warmest reaches of tributaries and occur most frequently in slack water, suggesting that spawning only occurs near the spring heads in the extreme upper end of the Muddy River headwaters. Juveniles occur throughout tributaries and occupy habitats with increasing flow velocities as they grow (Service 1996). Adults inhabit both tributaries and the mainstem of the Muddy River, but are most often seen in the mainstem except during spawning when they are in the upper end of the thermal tributaries (Scoppettone et al. 1987, 1992). Larger adults are typically associated with higher velocity flows of 2.6 to 3.0 ft per second (fps) (Cross 1976), with the largest occurring in the Muddy River (Scoppettone et al. 1987). In the Warm Springs Area, water emerges at 89.6° F, cools and increases in turbidity as it travels downstream (Scoppettone et al. 1992). Cooler water temperatures in the lower Muddy River likely form a natural barrier to downstream movement of the Moapa dace (La Rivers 1962).

Moapa dace surveys continue to be conducted annually on both public and private lands throughout the upper Muddy River system. The 2005, survey data indicate that there are approximately 1,300 fish in the population that occur throughout 5.6 miles of habitat in the upper Muddy River system. Approximately 95 percent of the total population occurs within one major tributary that includes 1.78 miles of spring complexes that emanate from the Pedersen, Plummer, and Apcar (a.k.a. Jones) spring complexes on the MVNWR and their tributaries(upstream of the gabion barrio Figure 4). Approximately 28 percent of the population was located on the MVNWR and 55 percent occupied the Refuge Stream supplied by the spring complexes emanating from the MVNWR (Table 3 and Figure 4). This Refuge Stream reach accounts for the highest density of Moapa dace, with the 2nd and 3rd highest densities occurring on the MVNWR's Plummer and Pedersen units, respectively (Table 3 and Figure 4).

Although the stream segment downstream from the convergence of the Refuge Stream and the mainstem Muddy River to the USGS Gaging station (Survey Reach Number 11) (Figure 4) was not surveyed in 2005, due to lack of visibility, available information indicate that no Moapa dace have been present in this portion of the Muddy River since 2002, when only eight dace were reported (Table 2). This loss is likely the result of competition with and predation by non-native tilapia. Since the Moapa dace is a thermally restricted species, water temperatures that drop below the preference range would not provide sufficient habitat for spawning, foraging, or shelter. The species shows varying water temperature tolerances for different life stages; however, the adult stage shows a lower tolerance of approximately 79° F (Scoppettone et al. 1993); therefore, any temperature cooler than 79° F would not provide long-term habitat for the species, thereby creating a thermal barrier for species. While the species has always had a natural thermal barrier due to the warm spring water cooling as it travels downstream, the tail of the temperature threshold can fluctuate due to reduced flows in the system (as explained later in the thermal loads section). Thermal losses can occur as a result of decreasing flows from warm

Figure 4

2005 Fish Population Survey

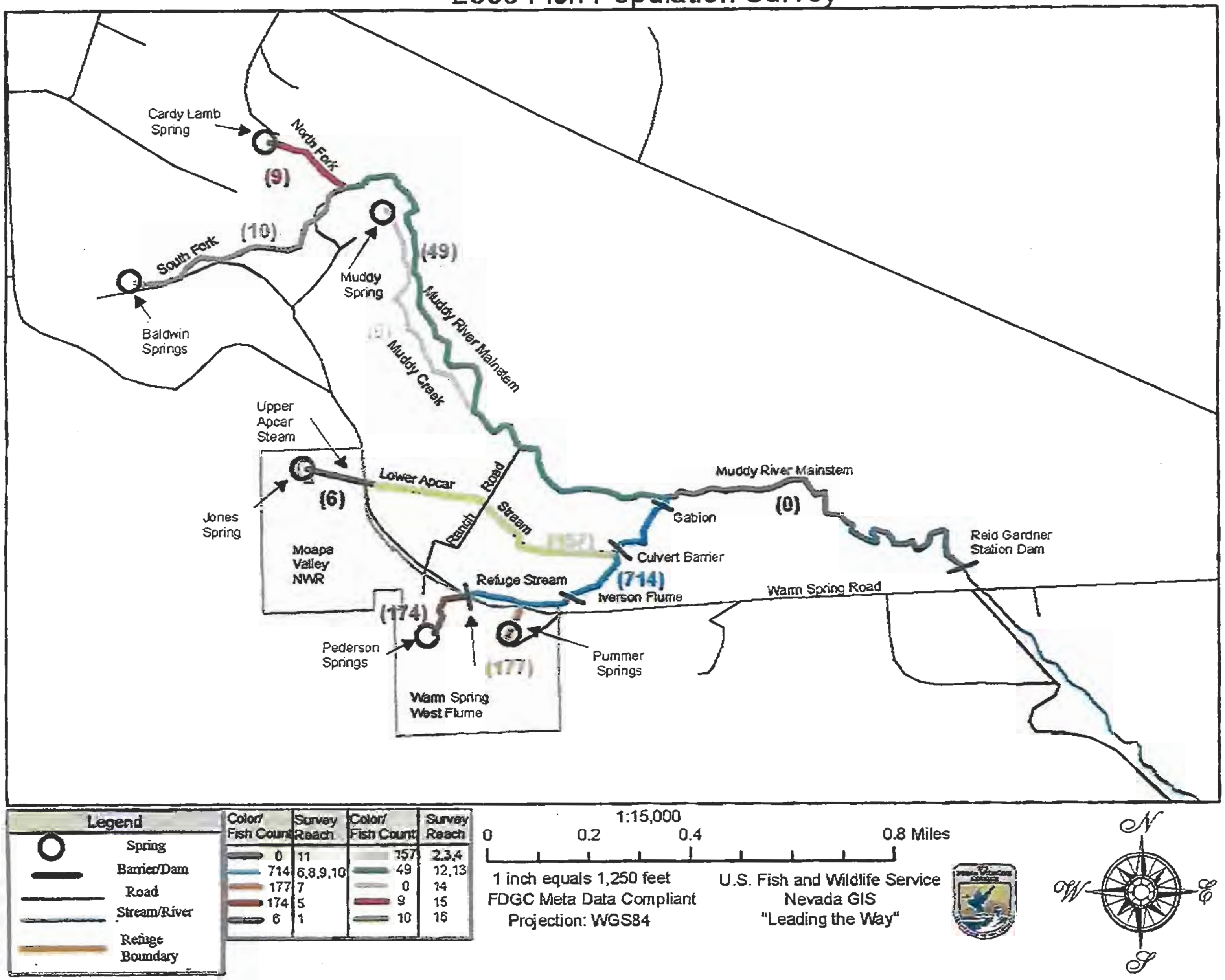

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Table 3. Moapa dace density and population estimates for 2005

Stream Segment	Available Habitat *	Fish Density (# fish/10 Ft)	Fish Density	Total Number of Fish (2005 Survey)
Muddy River Mainstem (N/S forks convergence to WSR Bridge)	11,743 ft or 2.22 mi	0.04	1 fish/239 ft	49
Apcar – Lower (off MVNWR)	3,145 ft or 0.60 mi	0.50	1 fish/20 ft	157
South Fork	3,085 ft or 0.58 mi	0.03	1 fish/309 ft	10
North Fork	2,640 ft or 0.50 mi	0.03	1 fish/293 ft	9
Muddy Spring	2,743 ft or 0.52 mi	0	0	0
Apcar -Upper (MVNWR)	733 ft or 0.14 mi	0.08	1 fish/122 ft	6
Plummer (MVNWR)	860 ft or 0.16 mi	2.06	1 fish/5 ft	177
Pedersen (MVNWR, includes all springs and tributaries)	1,839 ft or 0.35 mi	0.95	1 fish/11ft	174
Refuge Stream (off Pedersen Unit of MVNWR-Warm Springs Road to confluence with the mainstem of the Muddy River)	2,849 ft or 0.53 mi	2.51	1 fish/4 ft	714
Totals	29,637 ft or 5.6 mi	--	--	1,296

* Stream segment lengths are approximations derived from digitized aerial photos (USGS In Draft see Lit. Cited).
Note: shaded areas indicate the 3 stream segments with the highest Moapa dace densities.

water springs, water diversion structures, and/or surface sheet flow (water that flows freely out of stream banks across the land) and result in an overall reduction in the species' distribution potential. With the potential loss of these warmer waters contributing to the overall decrease in thermal load in the system, the Muddy River cools more rapidly, thus decreasing the distribution potential for the species.

Reproduction

Moapa dace larvae have been observed year-round, indicating year-round reproduction; however, peak spawning activity likely occurs in the spring, with lesser activity in autumn, probably linked to food availability (Scoppettone et al. 1992). Sexual maturity occurs at one year of age, at approximately 1.6 to 1.8 inches fork length (Hubbs and Miller 1948, Scoppettone et al. 1987, 1992). Fecundity is related to fish size; egg counts range from 60 eggs in a 1.77-inch fork length dace to 772 eggs in a 3.5-inch fork length dace (Scoppettone et al. 1992).

Reproduction of Moapa dace is believed to occur within a very narrow temperature range of 86° to 89.6 °F (Scoppettone et al. 1992) and is likely isolated with the warmer springs (headwaters) of the Muddy River. Although Moapa dace have never been observed spawning, Scoppettone et al. (1992) observed recently emerged larvae within 492 ft of the warm water spring discharge, over sandy silt bottoms in temperatures ranging from 86° to 89.6 °F, and dissolved oxygen levels of 3.8 to 7.3 ppm. Sexually mature Moapa dace must migrate upstream from the Muddy River into thermal tributaries to spawn successfully (Scoppettone et al. 1987). Several depressions in the sand were similar to "redds" described by Minckley and Willard (1971) for longfin dace (*Agosia chrysogaster*). Depth and velocity at the suspected redds were representative of the outflow channel and similar to other suspected spawning areas in the Warm Springs (Scoppettone et al. 1992). Redds were in sandy-silt substrate at depths of 5.9 to 7.5 inches, water velocities near the nesting redds ranged from 0.12 to 0.24 fps, and mean water column velocities from 0.5 to 0.6 fps (Scoppettone et al. 1992).

The duration of egg incubation is unknown, but is likely relatively short due to the high water temperatures (Service 1996). Emigration of young-of-the-year Moapa dace from the Refuge Stream is believed to peak in May (Scoppettone et al. 1987), and dispersal is likely similar in other tributaries with comparable water temperatures. Mortality rates for Moapa dace have been estimated to be 68 percent for the first year (juveniles) and 65 percent in the second year (adults) (Scoppettone et al. 1987).

Visual observations of Moapa dace have revealed that they are omnivores, feeding primarily on drift items, but adults forage from the substrate as well. Larval dace feed on plankton in the upper water column, in areas with little or no current, and juveniles feed at mid-water (Service 1996). Schools of 30 or more Moapa dace have been observed congregating at drift stations to feed (Scoppettone et al. 1987). They often use sites where cover is provided by overhanging vegetation (Service 1996). Drift stations are also located in reaches of low to moderate water velocity adjacent to depressions in the substrate. These depressions may be located downstream of a pebble riffle, thus creating turbulent flows. Moapa dace actively feed 24 hours a day, but peak feeding occurs around dawn and dusk (Scoppettone et al. 1987).

Threats

Moapa dace are thermophilic and endemic to the headwaters of the Muddy River (Figure 5). The Muddy River originates from spring discharges in the Warm Springs Area. When it was described by Eakin (1964), the Muddy River at the Moapa gage had an average annual discharge of 46.5 cfs and temperatures ranging from 87.8 to 89.6°F at its sources. Flows have declined over the last 40 years to about 35 cfs due to a combination of surface water diversions and groundwater pumping (LVVWD 2001). The Muddy River is a unique system due to the fact that its headwaters emanate from warm water springs. Given the warm sources, the water does not get warmer as it travels downstream like most riverine systems but rather cools as it travels downstream. Although the flow in the headwaters is nearly constant seasonally, flow in the mainstem of the Muddy River varies with precipitation events, seasonal water diversions, groundwater recharge, vegetation transpiration, evaporation, and irrigation return flows. Before reaching Lake Mead, nearly 75 percent of the annual inflow is lost to diversions, evaporation, and transpiration (Soil Conservation Service 1993).

Physical alteration of Moapa dace habitats in the Warm Springs Area, initially for irrigation purposes, began even before the species was discovered in 1938 (Scrugham 1920). These habitats have since been developed for recreational, industrial, and municipal uses. Spring orifices and outflow streams have been dug out, lined with concrete and/or gravel, mechanically and/or chemically treated to eliminate aquatic vegetation, and chlorinated to create private and public swimming pools. Several springs are capped and piped directly from the orifices for municipal use, desiccating associated outflow streams. Chlorination and agricultural activities in the Warm Springs have decreased in recent years, but some spring outflow streams continue to flow through culverts and/or dirt and cement irrigation ditches. Historically, irrigation return flows and runoff from pasture land and alfalfa fields carried significant quantities of sediment into the upper Muddy River. Encroachment of non-native vegetation [i.e., palm trees *(Washingtonia filifera)*, and tamarisk *(Tamarix ramosissima)*] within and along stream channels has also modified habitat. The root system of palm trees has modified stream morphology by obstructing the stream channel and/or lining the channel bed.

The upper Muddy River has also been subjected to various physical perturbations. In 1944, the Bureau of Reclamation constructed a 10-ft-high Cipoletti weir gaging station at the Warm Springs Road Bridge. The USGS took ownership of the gage in 1948, and continues to measure flows at this gaging station. This concrete dam impounds approximately 150 ft of riverine habitat. Although the structure serves as a barrier to fish migration upstream during normal flows, it also hinders movement of Moapa dace from accessing the upstream spawning tributaries or escaping turbid river conditions. The structure also cools the river water as it cascades over the structure to a temperature below that preferred by Moapa dace (Deacon and Bradley 1972).

It is believed that the first non-native, mosquito fish (*Gambusia affinis*) became established in the Muddy River by 1938 (Hubs and Miller 1948). A decline in the abundance of Moapa dace was first noted in the 1960s, shortly after the introduction of non-native shortfin mollies (*Poecilia mexicana*) (Deacon and Bradley 1972, Cross 1976). The concurrent decline in the abundance of Moapa dace was likely related in part to interactions between these two species. Habitat use by mollies is similar to that of larval and juvenile Moapa dace (Deacon and Bradley 1972, Scoppettone et al. 1987), and laboratory experiments have demonstrated that shortfin mollies are predators of fish larvae (Scoppettone 1993). Together, these species have introduced fish parasites into the ecosystem, including tapeworms (*Bothriocephalus acheilognathi*), nematodes (*Contracaecum* spp.), and anchor worms (*Lernaea* spp.), which have negatively impacted native fishes of the Muddy River, including Moapa dace (Wilson et al. 1966, Heckman 1988).

The blue tilapia (*Oreochromis aurea*) is the only non-native fish to become established in the Warm Springs Area since the introduction of the shortfin molly (Scoppettone et al. 1998). With the exception of waters on the MVNWR, Apcar and Refuge streams, tilapia occur in the Warm Springs' tributaries and have had devastating effects on Moapa dace and other native fish populations. The Moapa dace population has declined dramatically since the invasion of tilapia. The tilapia is detrimental to native fish species in a number of ways. Shortly after the invasion of tilapia into the Warm Springs Area, most of the aquatic vegetation disappeared. This vegetation provided habitat for invertebrates that Moapa dace rely upon as a food resource. Analysis of tilapia stomach contents revealed the presence of Moapa dace and Moapa White River springfish, indicating that tilapia further degrade native fish populations through predation (Scoppettone et al. 1998). Additionally, tilapia significantly altered the stream bed through the creation of nesting areas.

The introduction and establishment of tilapia in 1997 and other non-native fishes have been a major factor in the deterioration of the Muddy River as habitat for native fishes (Deacon and Bradley 1972). Currently, the springs and streams on the MVNWR, and Apcar and Refuge streams are the only Muddy River tributaries free of tilapia; therefore, making them more vulnerable to catastrophic events. The occurrence of tilapia is likely the primary cause for reductions in Moapa dace populations in the South Fork, North Fork, and Muddy River tributaries (Scoppettone et al. 1998). Deacon and Bradley (1972) stated, "The marked decrease in abundance of native fishes that follows establishment of a non-native species could conceivably carry a native species to the point of extinction."

A threat in recent years to the Moapa dace is the increased occurrence of fire, primarily due to the encroachment of non-native vegetation. In June of 1994, a flash fire swept through the upper Refuge Stream that either killed or displaced individual Moapa dace that were occupying affected stream reaches. Surveys conducted post-fire in 1994, indicated that only 34 Moapa dace survived on the MVNWR (Scoppettone et al. 1998), and subsequent surveys indicated an overall decline in the total population of Moapa dace (Table 2). Given the restricted range of the species, and the associated mortality from the fire, it is apparent that the species is vulnerable to stochastic and catastrophic events.

Figure 5

2005 Moapa Dace Existing/Historic Range

Legend	
Spring	Stream/River Historic
Barrier/Dam	Stream/River Existing
Road	
Refuge Boundary	

1:12,500

0 0.15 0.3 0.6 Miles

1 inch equals 1,041.666667 feet
FDGC Meta Data Compliant
Projection: WGS84

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Nevada GIS
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Environmental Baseline

Groundwater Elevation/Spring Discharge Relationships

It is well established that the spring discharge in the Warm Springs Area emanates from the regional carbonate aquifer (Eakin 1966, Prudic et al. 1993, Thomas et al. 1996). The regional carbonate aquifer underlying the area is confined and the potentiometric surface of the carbonate aquifer is greater than the land surface elevation of the springs. This hydraulic head differential causes groundwater in the carbonate aquifer to rise to the land surface through cracks and fissures, manifesting itself as spring discharge. Darcy's Law states that flow through a porous medium is proportional to the hydraulic head differential or hydraulic gradient (Fetter 1994). The law is valid for groundwater flow in any direction. In the case of spring discharge, the greater the hydraulic head differential between the elevation of the spring orifice and the hydraulic head of the aquifer, the greater the spring discharge, all other things being equal.

Groundwater development activities in the Coyote Spring Valley or Warm Springs Area will lead to the development of a drawdown cone around the pumping center. We assume that if the drawdown cone extends to the area underlying the springs, then the hydraulic head differential at the springs will be reduced. Darcy's Law states that a reduction in the hydraulic head differential will result in a proportional decrease in flow. For example, if the head differential at a spring is initially 10 ft but groundwater pumping lowers the potentiometric surface of the aquifer by 2 ft, then the head differential will only be 8 ft, a 20 percent decrease. The proportionality relationship in Darcy's Law implies that the spring discharge will also be decreased by a similar amount, or 20 percent.

The elevations of spring pool orifices in the Warm Springs vary by more than 60 ft (SNWA 2003). Considering the head/discharge relationship described above, it becomes evident that for a given decline in the potentiometric surface of the aquifer, the springs in a system with the smallest head differential, the highest elevation springs, will be the most susceptible to groundwater pumping impacts. Figures 6 and 7 illustrate this concept with two hypothetical springs of different elevations. Following a decrease of 5 ft in the groundwater elevations, the hydraulic head at the higher elevation spring is reduced by 50 percent. The discharge at the spring is expected to be reduced proportionately (Figures 6 and 7). By contrast, the same 5 ft decrease in groundwater elevations only reduces the hydraulic head at the lower elevation spring by 25 percent. The spring discharge would be reduced by a much smaller percentage (25 percent) compared to the higher elevation spring. The underlying assumption in this example is that the drawdown is uniform at both springs, a reasonable assumption in a highly transmissive system with a shallow, extensive drawdown cone. In such a system, the springs that will be most susceptible will be the highest elevation springs and not necessarily the springs that are closest to the pumping center.

Figure 6

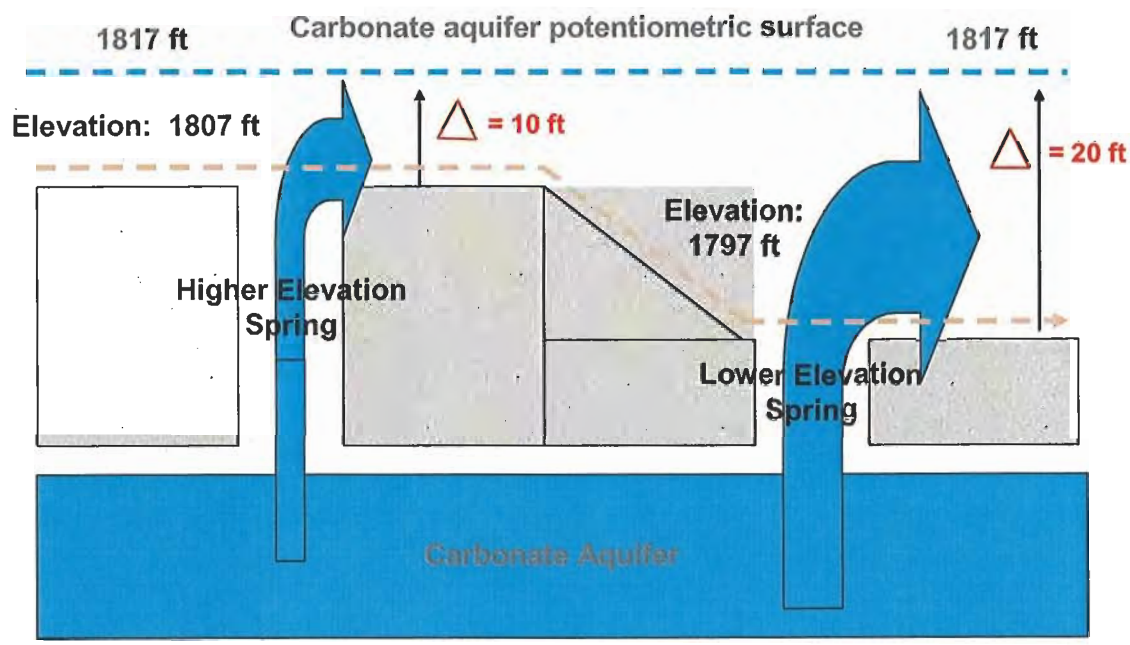
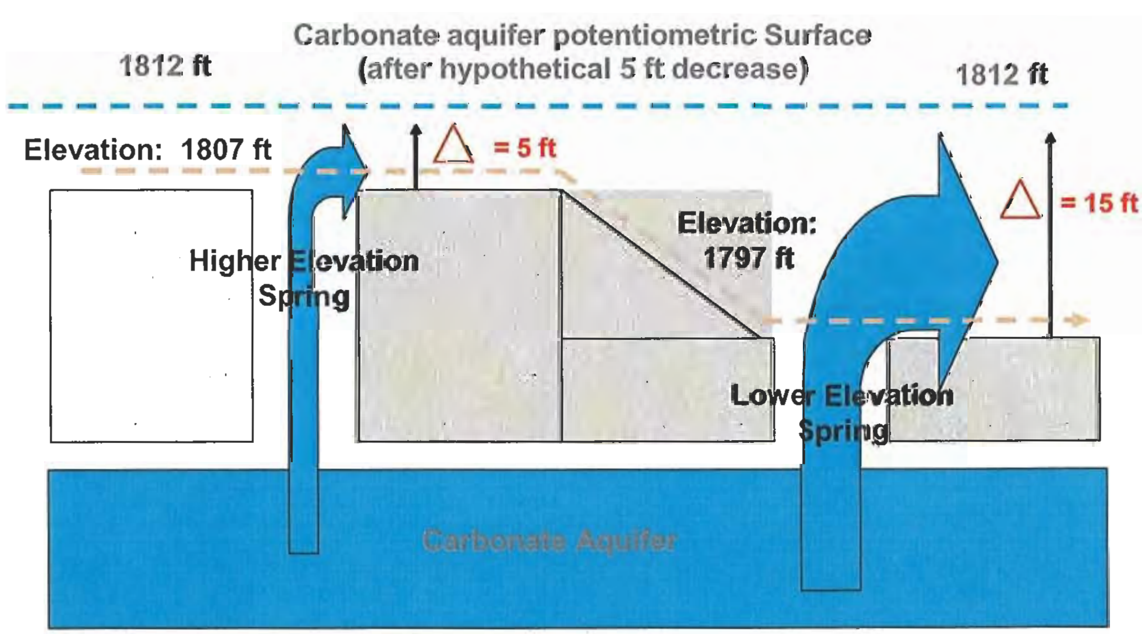


Figure 7



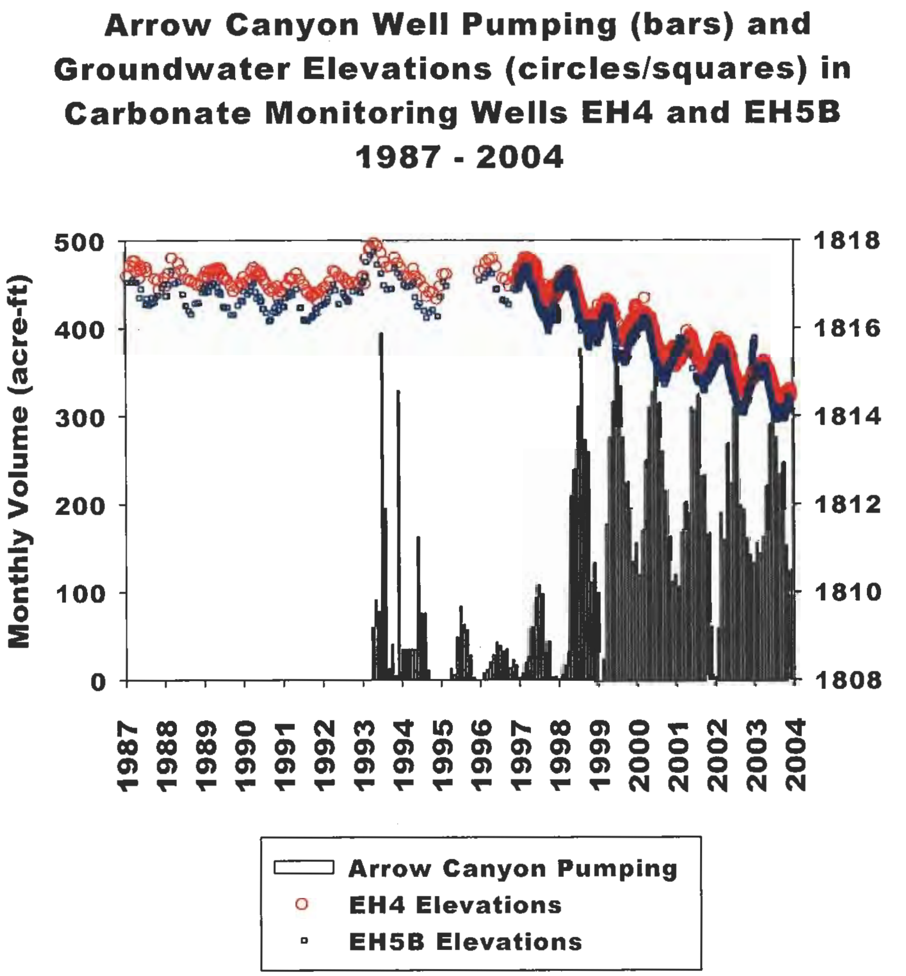
Current groundwater pumping at the Arrow Canyon Well and impacts

In the following discussion, the groundwater/spring discharge relationships described above have been used to base our current analysis of impacts from current pumping and to project the impacts of future groundwater development on the springs. It is anticipated that upon completion of the pump test required in Order 1169, that additional hydrogeologic information will be available to assist in a better understanding of this relationship. In the interim, the Service recognizes that there are different interpretations and opinions regarding the timing and causes of recent groundwater level declines in the flow system than that discussed in this programmatic biological opinion (Buqo 2004, Johnson and Mifflin 2003 and 2005).

In 1990 and 1992, MVWD applied for water rights of an additional 3.0 and 5.0 cfs, respectively, of groundwater for municipal purposes from the carbonate aquifer in the Warm Springs Area. The point of diversion is the Arrow Canyon Well, located about 2.3 miles west of the MVNWR. The MVWD had existing water rights in the area, including a right for 2.0 cfs from the Arrow Canyon Well. MVWD forecasts of growth in the Moapa area indicated the need for additional water. The water right applications were formally protested by the Service, NPS, and Nevada Power Company, primarily due to concerns about Moapa dace and injury to senior water rights, including the Service's water right for the Pedersen Unit of the MVNWR. In 1995, the Nevada State Engineer overruled the protests but ordered (in Ruling 4243) that pumping be phased in incrementally from 1996 through 2004, with monitoring to evaluate any impacts to springs or groundwater levels (Nevada State Engineer 1995).

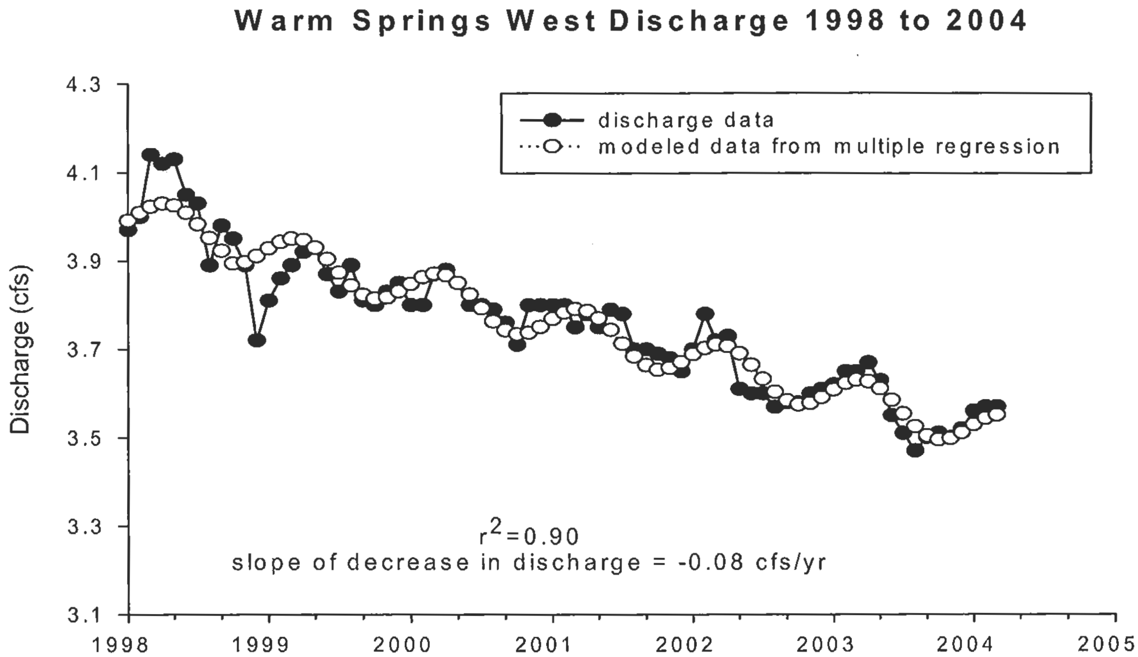
Growth in demand was less than forecasted by the MVWD and groundwater pumping from the Arrow Canyon Well has lagged behind the incremental pumping rate ordered by the State Engineer in Ruling 4243. Pumping was stepped up to 2.7 cfs in 1998, in part at the request of the Federal agencies to allow collection of data related to the effects of groundwater production from the carbonate aquifer, and has averaged 3.3 cfs or 2,400 acre-ft annually since that year (Mayer 2004). Concurrent with the increased pumping, groundwater levels and spring discharge in the Warm Springs Area have been consistently decreasing since 1998. Water levels in the two carbonate monitoring wells, EH-4 and EH-5B, have decreased by 0.38 ft/yr or a little more than 2 ft over the six-year period (Figures 2 and 8). Over the same period, the total spring discharge from the Pedersen Unit, as measured at Warm Springs West, has decreased from 4.00 cfs to 3.55 cfs. The rate of decrease is about 0.08 cfs/year, representing an 11 percent decrease over the period (Figure 9). The discussion in Mayer (2004) shows that the observed decreases in spring discharge are consistent with expected decreases based on the two-foot decline in groundwater levels observed in the carbonate monitoring wells in the Warm Springs Area. The relationship between groundwater levels and spring discharge at Warm Springs West was used to predict a 13 percent decrease in spring flows over the period from 1998 to 2003, in response to the 2-ft drawdown that has occurred (Table 4). The actual measured decrease of 11 percent is in close agreement with the predicted value.

Figure 8



Arrow Canyon Well Pumping (bars) and Groundwater Elevations (circles/squares) in Carbonate Monitoring Wells EH4 and EH5B 1987 - 2004
Monthly Volume (acre-ft)
500
400
300
200
100
0
1818
1816
1814
1812
1810
1808
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Arrow Canyon Pumping
EH4 Elevations
EH5B Elevations

Figure 9



The exact timing of the groundwater level decline is important because if the actual decline precedes in time any action or event suspected of causing the decline (such as increased pumping or drought), then this is strong evidence that there are other factors causing the decline. We have attempted to analyze the timing of the decline here.

Figure 10 is a plot of the periodic water level readings in EH-5B. Also shown is a lowess smooth of the data. Lowess (locally weighted scatterplot smoothing) is a smoothing technique used to emphasize trends in xy data (ex. water levels with time). The lowess says nothing about the statistics of a trend, it is simply a method of ascertaining any trend. The lowess of the EH-5B data shows that while there was variability prior to 1998 (possibly due to climatic impacts, seismic activity, barometric changes, earth tides, existing pumping), the slope of the decline clearly became more negative starting in this year. In other words, the rate of decline increased from 1998 through 2004. Looking at similar data from EH-4, Mayer (2004) showed through multiple regression analysis that the slope of the decline changed from -0.06 ft/yr in the period 1989 to 1993, to -0.38 ft/yr in the period 1998 to 2003, and that this change in slope was statistically significant. The magnitude and extent of the decline is unlike anything observed in the earlier record. This rate and magnitude of the 1998 to 2004 decrease is what is of concern to the Service. The start of the decline coincides with MVWD's increased pumping from the carbonate aquifer (see Figure 8). It also coincides with a very wet year (see Figure 11), which has implications for likelihood of drought or climatic impacts causing this decline, as discussed below.

Figure 10

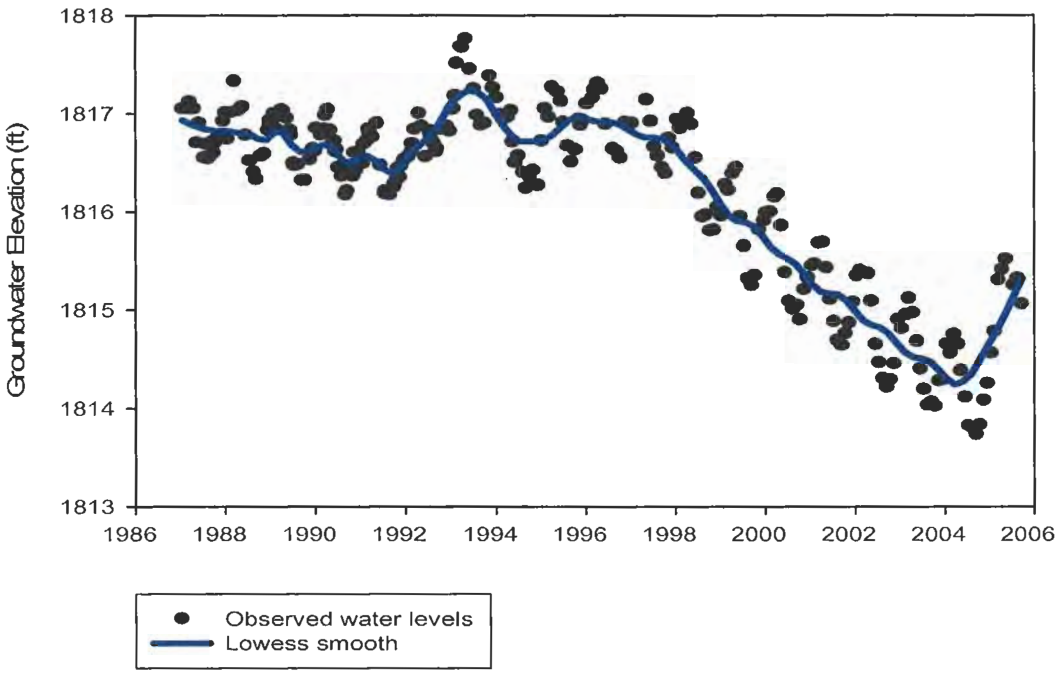


Figure 10. Periodic Measurements of Water Level Elevations in EH-5B for the period 1987 to 2005. Lowess smooth added as discussed in text.

In order to address the possibility that drought caused the groundwater level declines, we compiled precipitation records from a number of stations in the southeastern Nevada area. Four of these stations (Desert Game Range, Las Vegas Weather Service Office (WSO) airport, Valley of Fire, St George Utah) have precipitation records of 30 years or more. A fifth station (Red Rock Canyon) has a 27-year period of record. We averaged the precipitation from these five stations for a measure of local precipitation (Figure 11). In addition, we compiled the Palmer Drought Severity Index (PDSI) and the Palmer Hydrological Drought Index (PHDI) for a 30-year period of record for both Region 4 (southeastern Nevada) and Region 3 (Central Nevada). Our analysis shows that the decline from 1998 to 2004 was not likely to be drought-related for the following reasons.

Figure 11

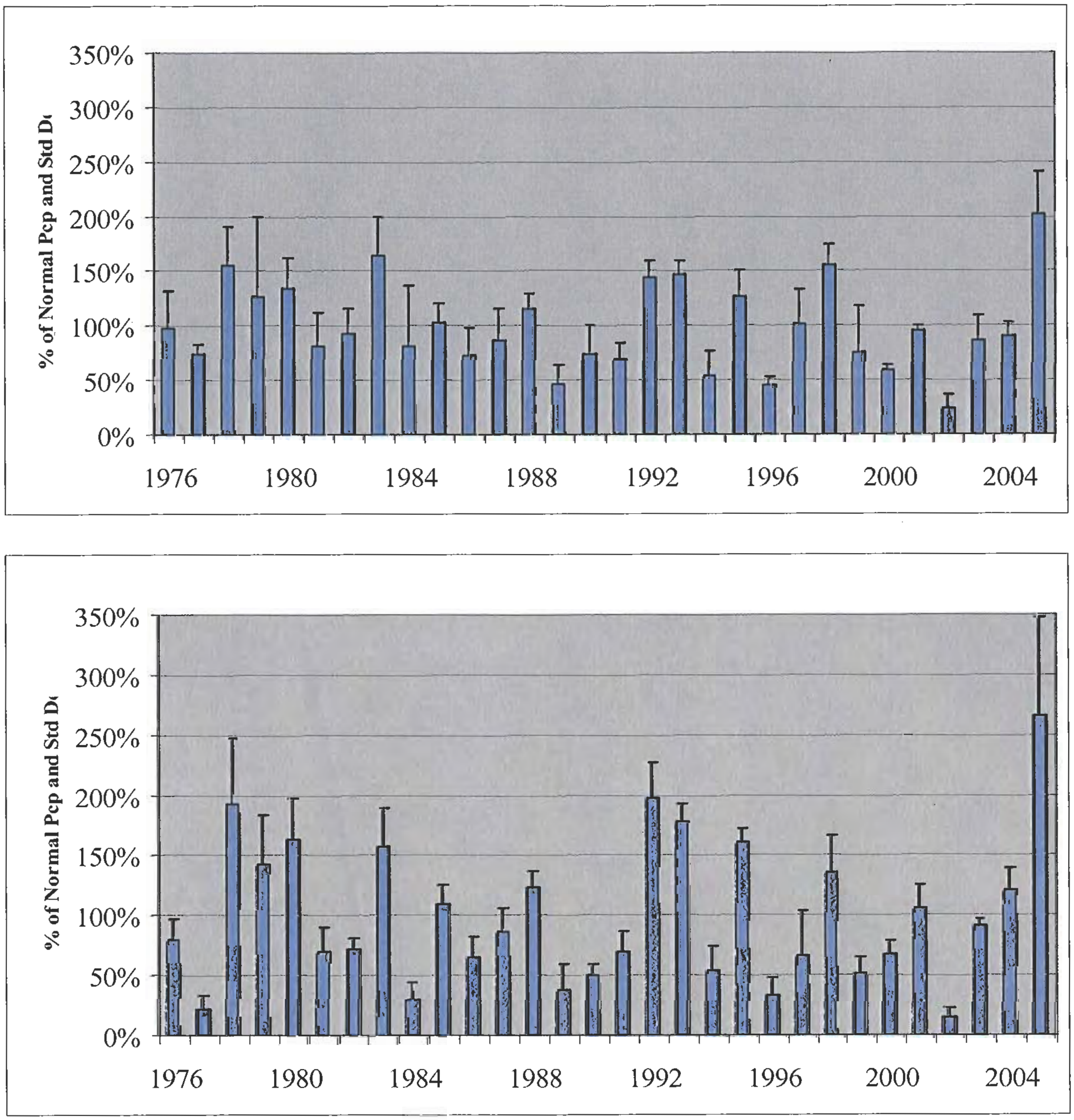


Figure 11. Percent of normal precipitation for the water year (top) and Nov-Apr period (bottom) averaged at five precipitation stations in or near southeastern Nevada. Station locations are discussed in the text.

Figure 11 shows the percent of normal precipitation from the five precipitation stations for the winter and water year. 2002 was an exceptionally dry year (24 percent of normal water year) but the other years were not unexpectedly dry and were not much different from earlier periods in the preceding decade (Figure 11). 1998 was a fairly wet year (156 percent of normal for the water year and 134 percent of normal for the winter), yet the groundwater level decline started in 1998. 1999 and 2000 were dry years (75 percent and 59 percent, respectively of the normal water year), but 2001 was close to average (95 percent of normal for the water year and 106 percent of normal for the winter), yet the groundwater level decline continued through this year.

The PHDI for southeastern Nevada indicates similar trends, a period of mild drought from 1999 through 2000, a recovery in 2001, followed by a period of severe or extreme drought from 2002 to 2003 (Fig 12). There were periods of severe drought observed from 1989 to 1991 and 1996 to 1997 without groundwater level declines of similar magnitude. Furthermore, the average precipitation for the four year period from 1998 to 2001 was 96 percent. There were two other periods in the 1990s that were significantly drier than this. From 1989 to 1991, the average precipitation was 67 percent of normal. From 1996 and 1997, the average precipitation was 76 percent of normal. There is a slight decline in water levels corresponding to the 1989 to 1991 dry period, but it is nothing of the magnitude of the decline from 1998 to 2004. Finally, overlaying the plots of EH-5B water levels and PHDI on the same time series suggests that while climate likely has some effect on groundwater levels in the area, the decline from 1998 to 2004 does not seem to be related to a change in the PHDI. (Figure 13)

With respect to the increase in water levels in 2005, it should be noted that both the local precipitation stations and the PHDI and PDSI show this to be an extraordinarily wet year. The average water year precipitation for the five local stations was 200 percent of normal. Thus, this increase in precipitation has resulted in groundwater level increases. However, the long-term effect of the extremely wet year is unknown and not likely to influence the downward trend in groundwater levels. Understanding the factors responsible for influencing trends and variability in the groundwater level record will become more apparent as more data and information is collected.

The declines observed since 1998, have occurred not only locally in the Warm Springs Area, but have also occurred in monitoring wells 12 miles upgradient in Coyote Spring Valley and 15 miles south to monitoring wells in California Wash, based on USGS monitoring well data and monitoring well data shared with the Service in July 2004, respectively. Both of these locations are areas of potential groundwater development under the terms of the MOA.

The flow from the Pedersen Unit of the MVNWR, as measured at the Warm Springs West gage, has declined at an annual rate of 0.08 cfs/yr since 1998. If the current decline continues unabated, the flow will reach a monthly minimum of 2.7 cfs by 2014. It is not certain that the current rate of decrease will continue as it has for the past six years. While the system could begin to equilibrate and the rate of decrease could slow, there is no evidence to suggest that this could occur. On the other hand, if the rate of groundwater pumping increases then the rate of decline could increase.

Figure 12

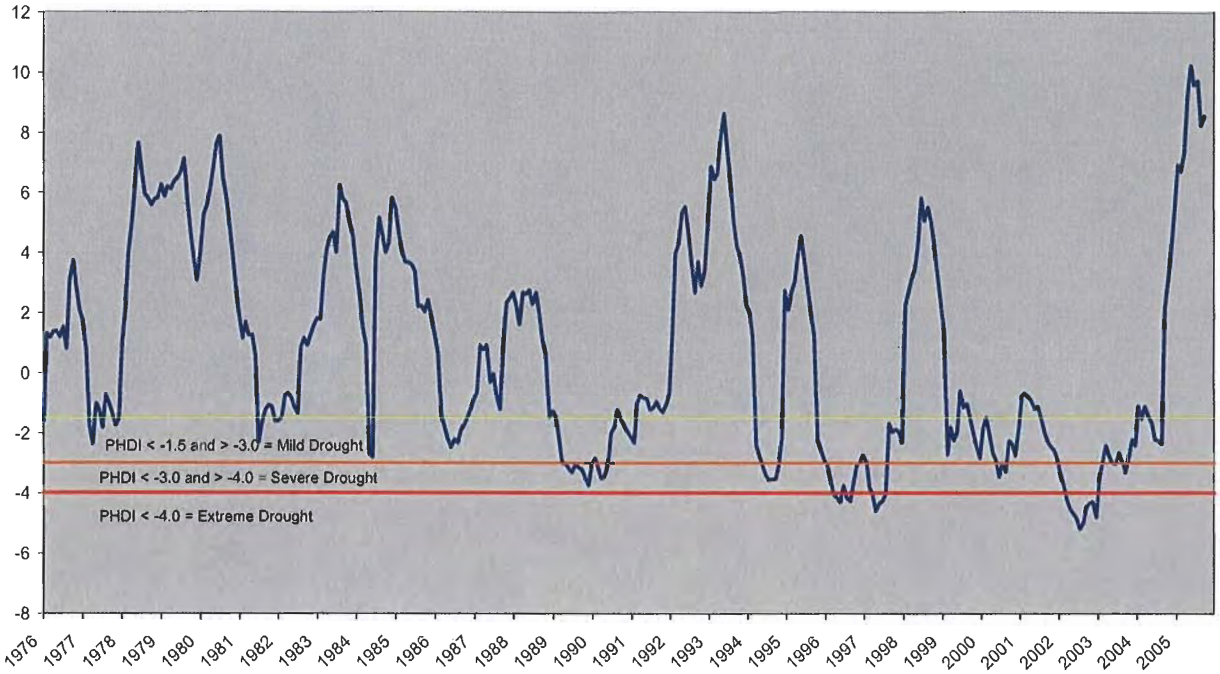


Figure 12. Palmer Hydrological Drought Index for U.S. Climate Division, Nevada Region 4, southeastern Nevada (positive values indicated wetter years, negative values indicate drier years)

Figure 13

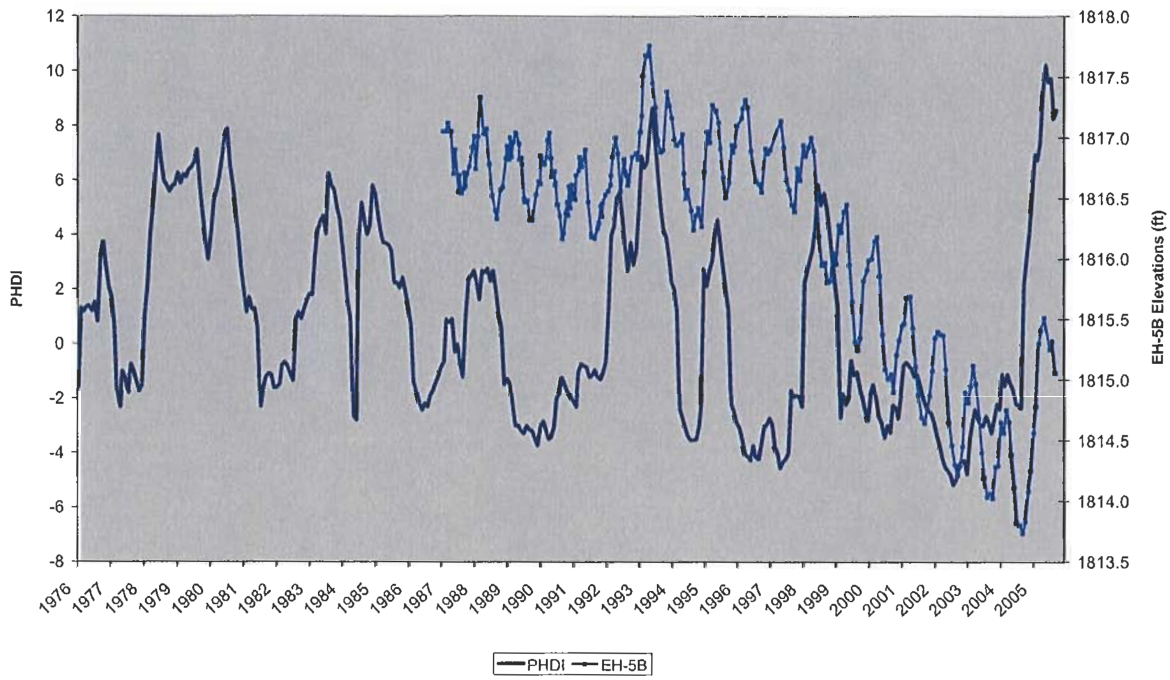


Figure 13. Relationship of Palmer Hydrological Drought Index (NV Region 4) and EH-5B Water Level Elevations

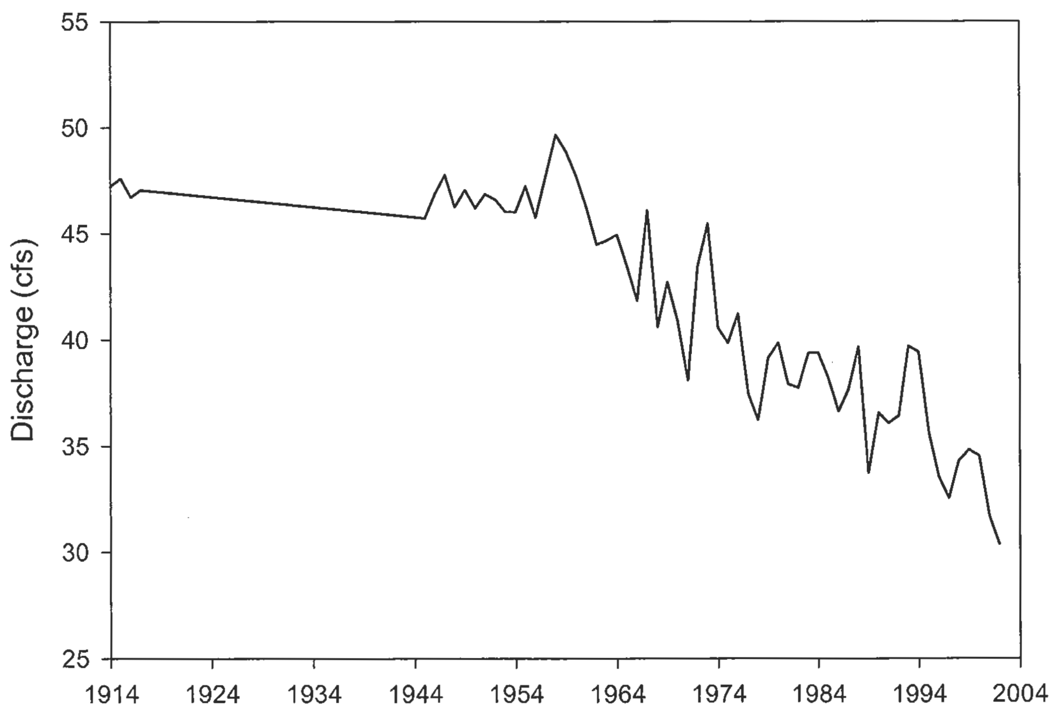
The current pumping rate and volume and associated groundwater declines are not affecting all springs in the Warm Springs Area to the same degree as those on the Pedersen Unit, despite the fact that the water level decline in the carbonate aquifer is believed to be uniformly distributed throughout the area. As discussed above, those springs at lower elevation are less susceptible to the current groundwater declines. The springs on the Plummer Unit of the MVNWR range in elevation from 1,755 to 1,760 ft, much lower than the springs on the Pedersen Unit. These springs have shown very little change in flow in the last six years although the measurements from Plummer Unit are less frequent and the period of record is not as long as Warm Springs West. The lack of decline in flow at these springs is consistent with the estimated change in the hydraulic head differential at the springs over the last six years.

The Apcar Spring, at 1,788 ft, is intermediate between the spring elevations on the Pedersen Unit and the Plummer Unit. According to the annual reports from MVWD, the flow at Apcar has decreased in the last six years from about 2 cfs to 1.5 cfs. A large decrease in flow occurred during 2000 (from an average of 1.9 cfs in 1999 to 1.6 cfs in 2001). The cause of this decline is not known.

The USGS has a continuous record of flow on the Muddy River at Moapa (USGS Station Number 9416000) from 1945 to the present, with discontinuous or periodic measurements as far back as 1913 (Figure 14). This is one of the longest periods of records for any measuring site in the area. The flow at this location in the river is much greater than the sum of all the spring discharge measurements (Eakin 1964, USGS 2001). About half of the flow measured at the gage is unaccounted for at the springs, and is believed to come from subsurface seepage gains into the river channel and its tributaries. The annual flow in the river changed little between 1913 and about 1960. The average flow during this period was 47 cfs. There is a steady significant decline in flow starting in the 1960s and continuing until the present. The decline is believed to be due to groundwater pumping from both the alluvial and carbonate aquifers, which has decreased subsurface seepage into the river, and to a lesser extent, from surface water diversions. The mean annual flow from 1960 to 1969 was 44 cfs. From 2000 to 2004, the flow has averaged 32 cfs. This equates to a decrease of approximately 0.4 cfs/yr or 28 percent over the 40-year period. At the present rate of decline, the mean annual flow in the river will decline to 28 cfs in another 10 years and 22 cfs in 25 years.

Figure 14

Mean Annual Flow in the Muddy River near Moapa
USGS Site No. 09416000 1914 - 2002



Completed or Ongoing Conservation Actions

- A piscicide called rotenone was used to successfully remove tilapia from waters on the MVNWR, Refuge Stream and the Apcar Stream to the gabion structure (just upstream of the Refuge Stream and Mainstem convergence);
- Various fish barriers (gabion and culvert) have been constructed in the Refuge Stream to prevent further encroachment of non-natives;
- The Pedersen and Pedersen East (a.k.a. Playboy pool) spring heads have been restored to make use of all available surface water and to maintain good flow records;
- Old concrete channels in portions of the Pedersen Unit have been removed to facilitate a more natural flow and recruitment of invertebrates (one food source for the dace);
- The development stage of restoring habitat on the Plummer Unit has been completed to provide more suitable habitat for and public viewing of the Moapa dace;
- Prevention of wild fire threats has continued through the removal of potential fire sources such as palm trees;
- Hydraulic geometry, water temperature, and groundwater flow models were developed to predict both existing and future conditions that may modify water quality and quantity that supply the warm water supply necessary for the Moapa dace and other aquatic species in the Warm Springs Area; and
- Multi-agency, annual Moapa dace surveys continue to be conducted throughout the range of the species (depending on access to private lands).

Conservation Needs of the Moapa Dace

- Placement of additional fish barriers in the lower reaches of the historic range of the Moapa dace in order to facilitate reestablishment in these areas;
- Eradication/control of remaining non-native invasive species including, but not limited to, fishes, bullfrogs, spiny softshell turtles, and non-native plant species such as palm trees, *Vallisneria*, Russian olive and salt cedar throughout the range of the dace;
- Continued fire maintenance activities to reduce the threat of wild fires;
- Minimization/elimination of surface water sheet flows that decrease the natural thermal load of water within dace habitat;
- Prevention of illegal water diversions that reduce or modify water quality and quantity in the Muddy River and its tributaries;
- Securing adequate water flows for Moapa dace recovery at the MVNWR and other spring sources, to provide long-term habitat for reproduction, nursery, forage, shelter, etc;

- Enhancement of existing occupied habitat [i.e. restoring stream dynamics, eradication of non-native fish and vegetation, removal of barriers to native fish migration in upper Muddy River and tributaries];
- Expansion of research efforts to gain additional knowledge about the biological needs/requirements of the species;
- Establishment of easements or acquisition of private lands within the range of the Moapa dace to address the threat of habitat loss as a result of residential/commercial development; and
- Continuation of the multi-agency, annual Moapa dace surveys throughout its range.

<u>Major Activities Authorized Under Sections 7 and 10(a)(1)(A) of the Act in the Action Area</u>

File No. 1-5-98-FW-177. On November 2, 1998, the Service issued a non-jeopardy biological opinion to the Nevada Fish and Wildlife Office for the implementation of eradication of non-native fish activities and installation of fish barriers in the Apcar Stream in the Warm Springs Area of the Muddy River. The Service concluded that the project was not likely to jeopardize the continued existence of the Moapa dace. Incidental take was authorized and Reasonable and Prudent Measures were identified to minimize take to the species.

File No. 1-5-01-F-463. On December 26, 2001, the Service issued a non-jeopardy biological opinion to the Bureau of Indian Affairs for approval of the Tribe's lease for reservation lands on the Reservation for construction and operation of the Moapa Paiute Energy Center. Calpine Corporation would lease the lands from the Tribe for the project. The proposed project would disturb 222 acres of desert tortoise habitat, and could result in take of 6 desert tortoises by death or injury, and 70 desert tortoises by harassment; and up to 7 percent of the total available spawning habitat for the Moapa dace. As of the date of this biological opinion, the proposed project has not moved forward and the Service is not aware of any plans in the near future to construct the project. Should a decision be made to implement the project, re-initiation of consultation would be required based on new information.

File No. 1-5-02-FW-463. On March 13, 2002, the Service issued a non-jeopardy biological opinion to the Desert National Wildlife Refuge Complex, Las Vegas, Nevada for the implementation of riparian and aquatic habitat restoration activities in the Pedersen Unit of the MVNWR. The Service concluded that the incidental take of less than 10 percent of the 180-200 individuals (18-20 individuals) that may be present in the project area would not likely jeopardize the continued existence of the Moapa dace. Reasonable and Prudent Measures were identified and implemented to minimize take of the species.

Effects of the Action

Moapa Dace

The Moapa dace will be directly affected by the proposed groundwater withdrawals since those actions are likely to affect the spring flows upon which the dace depends. The signatories of the MOA are proposing to cumulatively pump 16,100 afy of groundwater from the White River Groundwater Flow System at the MX-5, RW-2, Coyote Springs Wells #1 and #2, and other wells in the Coyote Spring Valley Basin (Basin 210) and from a well-field located in the southwestern third of the Moapa Reservation in the California Wash Basin (Basin 218). The purposes of these water withdrawals are: 1) part of a Nevada State Engineer Order (Order 1169) to test the carbonate systems response to groundwater withdrawals and continued use for residential and commercial purposes (9,000 afy); 2) municipal uses for a residential community in Coyote Spring Valley (4,600 afy); and 3) Tribal commercial developments (2,500 afy). For the purposes of this programmatic biological opinion, this consultation will only evaluate the effects of the MOA (cumulative groundwater withdrawal of 16,100 afy and their minimization measures) to the endangered Moapa dace. The specific actions associated with the uses of the groundwater will be evaluated in subsequent tiered biological opinions as applicants apply for Federal permits in the area.

The pump test to be undertaken pursuant to the MOA is expected to generate additional data to better understand and predict the effects of development of the carbonate-rock aquifer and to reduce or mitigate the effects of its development on the environment. In the interim, the Service recognizes that there are different interpretations regarding the causes of recent groundwater level declines in the flow system than that discussed in this programmatic biological opinion (Buqo 2004, Johnson and Mifflin 2003 and 2005). However, for the purposes of this programmatic biological opinion, the Service is utilizing the information and data presented above and analysis below. Groundwater extracted through a well, typically results in a decline in groundwater levels around the well. The technical term for this zone of lowered water levels is the "cone of depression" or the "drawdown cone." For a given aquifer, the drawdown cone increases in depth and extent with increasing time of pumping. Drawdown at any point and time is directly proportional to the pumping rate and inversely proportional to the transmissivity and storativity of the aquifer (Freeze and Cherry 1979). Aquifers of high transmissivity develop shallow drawdown cones of wide extent. As discussed earlier, the regional carbonate aquifer between Coyote Spring Valley and the Warm Springs Area is a zone of high transmissivity; the drawdown cone in this area is expected to be shallow and wide. This high transmissivity zone is one reason that the pumping at the Arrow Canyon Well is assumed to have caused the drawdown in well levels 12 miles upgradient in Coyote Spring Valley (Van Liew et al. 2004).

The hydraulic connectivity of the California Wash basin to the Warm Springs Area is uncertain although there are some indications that the area is connected with the Warm Springs Area based on monitoring well data that were shared with the Service in July 2004. These data from California Wash show a downward trend in groundwater levels. While there are various opinions as to cause of the decline, based on the very limited available data, the Service assumes that groundwater pumping in California Wash is likely to cause a decline in spring flow in the Warm Springs Area.

The proposed groundwater development in Coyote Spring Valley and California Wash is likely to cause further declines in groundwater levels in the carbonate aquifer within the area of the proposed pumping, and the Warm Springs Area. Our analysis predicts that a reduction in head at springs in the Warm Springs Area and decreases in spring discharge and groundwater seepage into streams is likely to occur, although the magnitude and timing of impacts from pumping in Coyote Spring Valley and California Wash are uncertain. Differences in boundary conditions relating to the areal extent of the aquifer, location of the pumping, transmissivity, and permeability, all influence the magnitude and timing of pumping impacts. Also, if the proposed pumping lowers carbonate water levels in the Warm Springs Area further, not all springs will be affected equally. The decrease in spring discharge will be proportional to the decrease in head elevation at each spring. Higher elevation springs have a lower head difference initially and are therefore more susceptible to decreases in groundwater levels. Therefore, the higher elevation springs will be affected proportionately more for a given decline in groundwater levels. This relationship has been observed in the Warm Springs Area as a result of a 2-ft drawdown in groundwater levels that has occurred since 1998 (Mayer 2004). The highest elevation springs, which are the most susceptible to impacts from groundwater pumping, occur on the Pedersen Unit of MVNWR, an area which also comprises some of the most important spawning habitat for dace in the system.

As discussed above, existing data indicates a decline in the regional carbonate aquifer levels locally and in the Coyote Spring Valley, and a decrease in spring discharge in the warm Springs Area from the current groundwater pumping of the Arrow Canyon Well (Mayer 2004). In addition, existing data has suggested that the same pumping has led to a decrease in carbonate aquifer levels in the California Wash Area as well. The average pumping rate at the Arrow Canyon Well for the last five years has been 3.3 cfs or 2,400 afy. The proposed action includes pumping of an additional 22.2 cfs or 16,100 afy from the same regional carbonate aquifer, which is almost seven times the existing withdrawal rate. Much of the pumping (13,600 afy) will be located along the same flow path that supplies the Warm Springs Area and is within the low-gradient, high-transmissivity zone that connects the Coyote Spring Valley and Warm Springs Area. The remainder of the pumping (2,500 afy) will be located downgradient in California Wash which has uncertain hydrologic connection to Warm Springs Area.

Under the terms of the MOA, if flows reach 2.7 cfs at the Warm Springs West gage, the pumping from Coyote Spring Valley will be reduced to 724 afy and the pumping from California Wash will be reduced to 1,250 afy. This 724 afy will replace the flows (1 cfs) that MVWD once used from the Jones Spring (on the MVNWR's Apcar Unit) to meet their water demands, which would be utilized for the Moapa dace on the MVNWR per the MOA. The 1,250 afy will be available for use by the Tribe. The following assumptions are used relative to groundwater pumping if the 2.7 cfs "Average Flow Level" as identified in the MOA is reached:

- The Arrow Canyon Well will be turned back on and will resume pumping at the current rate of 2,400 afy to meet MVWD's existing municipal water demands;
- 724 afy will be pumped from MX-5 and RW-2 wells in the Coyote Spring Valley by SNWA to replace MVWD's municipal commitment from the Jones Spring;
- No additional pumping in Coyote Spring Valley will occur; and
- Pumping in the California Wash is assumed to be limited to 1,250 afy of the existing permitted water rights held by the Tribe.

The exact magnitude and timing of the impacts from pumping groundwater from the carbonate aquifer in Coyote Spring Valley and California Wash are unknown at this time, as are the effects of reduced or cessation of groundwater pumping or whether there will be some equilibration of the aquifer to the proposed pumping. Two approaches were used to bracket the range of potential impacts to groundwater levels and spring discharge at the Warm Springs West gage: (1) an extrapolation of the current groundwater impacts and trends; and (2) numerical groundwater modeling.

Extrapolation of Current Groundwater Impacts and Trends

Using this approach, the groundwater system is assumed to respond proportionally to increased pumping; that is, increasing the pumping rate by some factor will increase the rate of decline in groundwater levels by a similar factor. The assumption is that because of the high transmissivity of the carbonate aquifer in this area, the decline in groundwater levels will be relatively small, but widespread. The location of pumping within these three basins doesn't matter under these assumptions. Thus, the decline in groundwater levels would be similar in magnitude and timing to the decline in the Warm Springs Area for pumping at the Arrow Canyon Well; at MX-5, RW-2, or other wells in Coyote Spring Valley; or for wells in California Wash. This assumption is simplified and may tend to overestimate the effects because of different boundary conditions in Coyote Spring Valley and California Wash, and because the pumping in Coyote Spring Valley and California Wash is further from the Warm Springs Area than the Arrow Canyon well. Therefore, this represents a worst-case scenario that can be used to bracket the lower end of the possible range of effects.

Under the above assumption, increasing the total pumping from the system sevenfold, from 2,400 afy to 16,100 afy, will increase the rate of water level decline in carbonate levels approximately sevenfold, from the current rate of 0.38 ft/yr to 2.55 ft/yr. The rate of decline of the spring discharge from the Pedersen Unit of the MVNWR, as measured at the Warm Springs West gage, would increase proportionately as well, from 0.08 to approximately 0.6 cfs/yr, using the groundwater spring discharge relationships described in Mayer (2004). Initial projections based on these extrapolated rates suggest that the flow at Warm Springs West gage will decline during the two-year pump test. A decrease of 1.2 cfs (two years multiplied by 0.6 cfs/yr) is predicted. However, under the terms of the MOA, as flows are reduced below 3.0 cfs at Warm Springs West, the pumping at Arrow Canyon Well will be stopped and the pumping from Coyote Spring Valley and California Wash will be reduced. While the response of the aquifer to a reduction or cessation of pumping is not known and has not been tested, it is assumed that reducing and ceasing the pumping will slow the decline in water levels. Furthermore, it is not likely that the entire 16,100 afy of groundwater will be withdrawn during the two-year pump test. CSI has proposed a five year incremental approach to utilizing their full water right of 4,600 afy and the Tribe has not identified a use for all of its 2,500 afy of potential groundwater pumping in California Wash. For the purposes of identifying the lower bound of the range of impacts, this analysis will assume that the total volume of water will be pumped and that the Warm Springs West gage will reach 2.7 cfs upon or before completion of the two-year pump test. Using the head/spring discharge relationships described in Mayer (2004), the groundwater levels are estimated to be about 5 ft below 1998 levels at a flow of 2.7 cfs. At this point, pumping would be adjusted to the levels stipulated in the MOA.

Under the terms of the MOA, if the 2.7 cfs average flow level is reached at the Warm Springs West gage, then the pump test is ended even if this occurs before two years. Following the pump test, if the average flow level at Warm Springs West gage remains below 2.7cfs, the total volume of groundwater that could be pumped from the regional carbonate aquifer in Coyote Spring Valley, California Wash, and the Warm Springs Area is 2,400 afy from Arrow Canyon Well, 724 afy from the MX-5 well or other CSI wells or wells, and 1,250 afy from California Wash, or a total of 4,374 afy. However, it is not certain that this amount would be pumped. The 4,374 afy total volume represents about an 80 percent increase above the current pumping volume from the Arrow Canyon Well. Assuming a proportional response in groundwater levels and spring discharge (e.g., an increase of the pumping rate results in a proportional increase in the rate of decline), then groundwater levels are predicted to decline about 1.8 times the present rate, or 0.7 ft/yr. Likewise, the spring discharge at the Warm Springs West gage would decline by about 1.8 times the present rate, or 0.14 cfs/yr. Using this approach, groundwater levels are projected to be about 8.5 ft lower than 1998 groundwater levels five years after the completion of the pump test. Total spring discharge from the Pedersen Unit, as measured at the Warm Springs West gage, would be about 2.0. cfs five years after completion of the pump test, (approximately 50 percent of 1998 flows). This likely represents the worst-case or lower bound of the range of possible impacts. The system may not respond as predicted, the pumping may be less than assumed, or the system may equilibrate, resulting in less severe impacts to groundwater levels and spring discharge.

Numerical Groundwater Model

The Service, in cooperation with other Federal agencies, has developed a numerical groundwater model for the southern half of the White River Groundwater Flow System (GeoTrans 2001). Several elements of the model were recently modified, including updated pumping and water-level information and updated spring elevation and discharge data (GeoTrans 2003). The model was recalibrated based on the modifications. Predicted water levels in the Warm Springs Area are still approximately 10 ft too low, but drawdown matches to carbonate wells EH4 and EH-5B were improved for the period 1998 to 2001 (GeoTrans 2003). However, when the model output from January 2002 to January 2004, was compared against measured water levels in EH-4 and EH-5B for the same period, the model was under-predicting drawdown considerably. The observed decreases in groundwater levels from January 2002 to January 2004, in both of these carbonate monitoring wells are greater than the model predicted. The model appears to be predicting some kind of equilibration of the system that has not yet been observed in the field data. For this reason, the model output is believed to be an underestimate of the impact of pumping on groundwater levels and spring discharge in the Warm Springs Area. The model results should be viewed as a likely best-case or upper bound of the range of possible impacts.

The model was used to evaluate several pumping scenarios including a fivefold increase in total pumping in the system, to 12,400 afy (2,400 afy from Arrow Canyon Well and 10,000 afy from Coyote Spring Valley). This modeling was completed prior to the current MOA draft and does not include either the 4,600 afy of pumping by CSI or the 2,500 afy of pumping by the Tribe. The model predicted about 1 ft of drawdown in monitoring well EH4 and 1.5 ft of drawdown in monitoring well EH5-B after two years of pumping 10,000 afy in Coyote Spring Valley and 2,400 afy from Arrow Canyon Well pumping.

It is difficult to use the modeled drawdown to estimate spring discharge. A head loss of 1.0 to 1.5 ft is estimated to equate to a reduction of about 0.25 to 0.37 cfs in flow at the Warm Springs West gage (Mayer 2004). But the groundwater levels and spring discharge at the beginning of the pump test are not known. Pumping-related declines are expected to continue with the Arrow Canyon Well pumping until the pipeline is constructed and the pump test begins. However, groundwater levels have generally increased recently, likely in response to the extremely wet winter experienced by the region in 2005. This is expected to be a transient response but the timing and level of a return to equilibrium conditions is not known for certain. The pumping reductions identified in the MOA in response to decreases in the flow at Warm Springs West were not modeled either. So the validity and the applicability of the model results are difficult to ascertain. What can be noted is that the model predicts that there will be declines in groundwater levels with increased pumping, as opposed to no declines. This will affect spring discharge.

The potential effects on spring discharge at the Warm Springs West gage discussed above are applied below to predict potential effects to Moapa dace habitat.

<u>Moapa Dace Habitat Loss Within the Pedersen Unit of the MVNWR</u>

Hydraulic Geometry Modeling

The Hydraulic Geometry Modeling was only conducted for the Pedersen Unit because of the susceptibility of the higher elevation springs in this area to reductions in groundwater levels. The lower-elevation springs are not as susceptible to the decreases in groundwater level; therefore, these springs will not be as affected as those on the Pedersen Unit. The hydraulic model HEC-RAS was used to model the effect of reduced spring discharge on Moapa dace habitat on the MVNWR (Otis Bay 2003). The variation in width, depth, and velocity as a function of discharge is known as hydraulic geometry. Channel topographical survey data were collected at cross sections of the Pedersen Unit in order to estimate the changes in channel hydraulic geometry associated with declining spring discharge.

Representative cross-sections for pool and riffle habitats at two different locations on the Pedersen Unit were analyzed. The first pair of riffle/pool cross-sections was located just below the confluence of the outflows from the Pedersen and Pedersen East Spring complexes. The second pair of riffle/pool cross-sections was located below the outflows from the five major spring complexes on the Pedersen Unit. The latter site represents approximately the total spring discharge as measured at the Warm Springs West gage. The relationship between groundwater levels and spring discharge on the Pedersen Unit was used to estimate the reduced flow at both pairs of cross-sections given an incremental decline in groundwater levels (Mayer 2004). The HEC-RAS modeling results were then used to estimate the change in hydraulic geometry and dace habitat at each cross-section based on the flow reductions (Otis Bay 2003). It is important to understand that higher elevation springs will show a greater percent flow reduction for a given head loss. Therefore, an equal percentage reduction cannot be applied to both pairs of cross-sections; the upstream pair will have a higher percentage loss of flow for a given decline in groundwater levels. Table 4 presents the estimated head differential, estimated flows, percent flow reduction, and percent habitat reduction as a function of groundwater levels for the upstream site (Pedersen and Pedersen East Spring groups) and the downstream site (Warm Springs West) for 1998.

The results indicate that both spring discharge and dace habitat are reduced with declines in groundwater levels. Flows and habitat loss at both upstream and downstream sites are projected as a function of incremental declines in groundwater levels in Table 4. As described in the section entitled Extrapolation of Current Groundwater Impacts and Trends, if flows decrease to 2.7 cfs by the end of the pump test, then groundwater levels are predicted to be about 5 ft below 1998 levels. Using the results in Table 4, flow at the upstream site is projected to be roughly 40 percent less than 1998 conditions at this groundwater level. Habitat is projected to be about 43 percent less for riffle habitat and 25 percent less for pool habitat relative to 1998 conditions. Flow at the downstream site is projected to be 30 percent less than 1998 conditions. Habitat at the downstream site is projected to be about 22 percent less for riffle habitat and 16 percent less for pool habitat relative to 1998 conditions. These results likely represent a worst-case or lower bound of impacts as discussed above.

Five years after the pump test is completed, groundwater levels are predicted to be approximately 8.5 ft below 1998 levels, under the worst-case scenario. Flows are projected to be about 65 and 53 percent of 1998 levels at the upstream and downstream sites, respectively. At the upstream site, riffle and pool habitat are projected to be 60 percent and 40 percent less, respectively, relative to 1998 conditions. At the downstream site, riffle and pool habitat are projected to be about 40 percent and 30 percent less, respectively, relative to 1998 conditions. Again, these results likely represent a worst-case or lower bound of impacts as discussed above.

The primary effect to the Moapa dace of diminished flows within the spring channels will be a decrease in the hydraulic conditions that create the diversity of habitat. A decrease in velocity and depth within riffles would result in a decrease of invertebrate and phytoplankton (food) production. Drift stations in pools are maintained by the scouring effect of turbulent flow. Scour will decrease in pools as water velocity and depth at the upstream end of the pool decreases. Perhaps the most prominent impact that would occur, as a result of decreased discharge and subsequent depth, is the reduction of overall volume of water that will be available to the species within the channel. Scoppettone et al. (1992) demonstrated that Moapa dace size is scaled to water volume. Thus, larger water volumes provide the habitat necessary for increased food production and subsequently larger fish, therefore greater fecundity. Hence, more numerous, larger eggs provide a better opportunity for the long-term survival of the species.

As previously stated, decreasing flows in the headwater spring channels of the upper Muddy River were modeled and resulted in a decrease in the hydraulic parameters of width, depth, and velocity, for a loss of habitat available to the species. Additional factors that would influence channel and hydraulic characteristics within the stream channels following a decline in spring discharge include, but are not limited to, changes in sediment transportation rates, and the alteration of riffle and pool maintenance that is accomplished at the present rate of discharge in each spring channel. Additionally, vegetative encroachment and subsequent channel obstruction may also occur as the wetted cross sectional area of the channel decreases, and new surfaces become exposed for vegetation growth. Decreases in these parameters will likely have an adverse impact on the overall diversity and quantity of hydraulic habitat.

Table 4. Estimated Habitat Loss

Pedersen Unit - Upstream Site (Combined flow of Pedersen Spring and Pedersen East Spring Groups)				
Groundwater Level Reduction Since 1998 (ft)	Estimated Flow (cfs)	Estimated Percent Flow Reduction from 1998 Conditions	Estimated Percent Habitat Reduction in Riffles from 1998 Conditions	Estimated Percent Habitat Reduction in Pools from 1998 Conditions
0	1.47*			
2	1.23	16 percent	23 percent	9 percent
3	1.11	24 percent	33 percent	14 percent
4	0.99	33 percent	37 percent	20 percent
5	0.87	41 percent	43 percent	25 percent
6	0.75	49 percent	50 percent	31 percent
7	0.63	57 percent	55 percent	46 percent
8	0.57	62 percent	58 percent	39 percent
9	0.48	68 percent	63 percent	43 percent
Pedersen Unit - Downstream Site (Combined flow of the 5 major spring groups/upstream of Warm Springs West gage)				
Groundwater Level Reduction Since 1998 (ft)	Estimated Flow (cfs)	Estimated Percent Flow Reduction from 1998 Conditions	Estimated Percent Habitat Reduction in Riffles from 1998 Conditions	Estimated Percent Habitat Reduction in Pools from 1998 Conditions
1	4.03*			
2	3.51	13 percent	8 percent	6 percent
3	3.26	19 percent	13 percent	10 percent
4	3.02	25 percent	17 percent	13 percent
5	2.78	31 percent	22 percent	16 percent
6	2.50	38 percent	27 percent	20 percent
7	2.26	44 percent	32 percent	23 percent
8	2.03	51 percent	37 percent	27 percent
9	1.82	54 percent	42 percent	31 percent

* based on a back-calculated estimate of flows at this site, as described in text

Note: Highlighted row indicates the level at which groundwater pumping would be reduced to levels stipulated in the MOA.

Thermal Load Modeling

A Stream Segment Temperature Model (SSTEMP) was used to predict impacts of decreasing spring flows to the natural thermal load of the system (Brock 2004). A study area downstream of all the spring complexes was selected on the Pedersen Unit of the MNVWR that was approximately 220 meters (722 ft) long and appeared to have a minimal net accrual or loss of stream flows. The model was calibrated to the 220-meter-long segment and was based on inputs of meteorology, stream geometry, riparian shading, and hydrology. SSTEMP simulates downstream water temperature in a discrete homogenous segment of a flowing stream channel over a 24-hour day.

In all 16 scenarios the simulated result of the reductions in spring discharges was reduced water temperatures (Brock 2004); however, only 4 scenarios are presented herein (Table 5). The greatest impact of flow reduction to thermal load occurred during the winter (December) when air temperature is the coldest, relative to the temperature of the thermal spring channel. Since Moapa dace have a reproductive temperature threshold of 30° C (86° F) (Scoppettone et al. 1992) any area with cooler temperatures is not considered reproductive habitat. In the winter, a reduction in flow (3.6 cfs) by 10 percent (3.25 cfs), 20 percent (2.90 cfs), and 30 percent (2.50 cfs) brought about a respective decrease of 0.06° C, 0.14° C, and 0.25° C in the temperature of the spring channel at the end of the study segment (Brock 2004). These reductions of 10, 20, and 30 percent in spring flows would result in an upstream shift of the base thermal tail temperature by approximately 66 (20 meters), 131 (40 meters), and 197-ft (60 meters), respectively. Although under these scenarios the temperatures at the downstream reach of the study segment would remain above 30° C (86° F) and therefore within the reproductive temperature threshold, the model illustrates that reduced flows result in decreases in temperature and an upstream shift in the base thermal tail. Therefore, assuming that there is a minimal net accrual or loss of stream flows, the shift in base thermal tail in the downstream reach of the Pedersen Unit tributary (Refuge Stream off of MVNWR) would result in the loss of spawning habitat based on temperature.

Reductions in some of the headwater sources within the system will have downgradient repercussions to the Moapa dace. Since the springs on the MVNWR's Pedersen Unit are the highest in elevation of all the headwater sources, these springs would be the first to be affected by groundwater pumping. Reductions in the spring flows on the Pedersen Unit would cause the stream to cool more rapidly as it travels downstream resulting in a loss of thermal load, thereby decreasing the available downstream spawning habitat in the Refuge Stream.

Table 5. Estimated Thermal Loss with 4-Water Flow Scenarios on the Pedersen Unit of the MVNWR

Flow Scenario (cfs) (Warm Springs West gage)	3.60	3.25	2.90	2.50
Percent reduction	0.00	10.00	20.00	30.00
Distance from head of segment (meters)	Water Temperature (degrees C)			
0	31.20	31.20	31.20	31.20
10	31.17	31.16	31.16	31.16
20	31.14	31.13	31.12	31.12
30	31.11	31.10	31.09	31.07
40	31.08	31.06	31.05	31.03
50	31.05	31.03	31.01	30.99
60	31.02	30.99	30.98	30.95
70	30.99	30.96	30.94	30.91
80	30.95	30.93	30.90	30.86
90	30.92	30.89	30.87	30.82
100	30.89	30.86	30.83	30.78
110	30.86	30.82	30.79	30.74
120	30.83	30.79	30.75	30.70
130	30.80	30.76	30.72	30.65
140	30.77	30.72	30.68	30.61
150	30.74	30.69	30.64	30.57
160	30.71	30.65	30.61	30.53
170	30.68	30.62	30.57	30.49
180	30.64	30.59	30.53	30.44
190	30.61	30.55	30.50	30.40
200	30.58	30.52	30.46	30.36
210	30.55	30.48	30.42	30.32
220	30.52	30.45	30.38	30.28

Shading shows the loss of stream survey length with various scenarios of reduced spring flows.

Summary of Adverse Effects Caused by the Proposed Groundwater Pumping

As discussed in the Status of the Species section, there are 5.6 miles of available habitat for all life stages of Moapa dace (Figure 4, Table 3) within the Muddy Springs Area. Of the total amount, approximately 1.78 miles of stream are located above the gabion barrier that protects the stream reaches on the MVNWR and the Refuge Stream on private property from tilapia predation (Figure 4). The remaining 3.82 miles of habitat continues to be threatened by the presence of tilapia and has been relatively uninhabitable. The 2005 dace survey data reflect that 95 percent of the dace population is relegated to the 1.78 miles (32 percent) of habitat above the gabion (Table 3) due to the presence of predatory non-native tilapia. However, dace still exist, albeit in low numbers, in the upper Muddy River mainstem and north and south forks of the Muddy River.

The 5.6 miles of the springs, tributaries, and mainstem of the Muddy River are not utilized proportionately by all life stages of the species due to the different hydrologic conditions of the various stream segments and the specific life history needs of adult, juvenile, and larval fish. The appropriate hydrologic conditions including velocity, depth, and temperature are necessary to provide for adequate spawning conditions. These various habitat types have not been quantified throughout the entire 5.6 miles of occupied or potential habitat. However, for the purposes of our analysis we have focused on the MVNWR streams and stream reaches above the gabion and attempted to quantify the availability of spawning, rearing and adult habitat. It is generally known that most of the habitat on the mainstem Muddy River is adult and juvenile habitat, with some limited spawning occurring in the north and south forks, and historically in the Muddy Spring. We have estimated that of the 1.78 miles of available occupied habitat above the gabion, 1.15 miles or approximately 66 percent of the habitat is essential spawning and rearing habitats. This habitat includes the 0.35 miles on the Pedersen Unit, 0.16 miles on the Plummer Unit, 0.14 miles on the Apcar Unit, 0.30 miles in the lower Apcar Stream, and 0.20 miles in the Refuge Stream upstream of the Iverson Flume.

The Pedersen Unit of the MVNWR is one of the six spring complexes that the Moapa dace depends on for successful reproduction and is devoid of tilapia. It is also the highest spring in elevation, and therefore, most susceptible to groundwater level declines. The analysis presented above likely represents the worst-case scenario or lower bound of impacts and it is uncertain whether it is likely to occur. The analysis estimates that at 2.7 cfs there is a loss of 31 percent in flow on the Pedersen Unit from 1998 conditions. This loss in flow is estimated to reduce available riffle habitat by 22 percent and pool habitat by 16 percent within the Pedersen Unit only. In addition to the loss of habitat, decreased flows would also result in a loss of temperature that would extend downstream, thereby reducing the thermal load in the system and thus the amount of available habitat at the appropriate spawning temperature. This loss in flow and habitat could further impact Moapa dace by restricting its reproductive potential and make it more vulnerable to catastrophic events such as wildfire.

The seepage run study conducted in 2001 by USGS reported the cumulative flows of the Refuge Stream at its confluence with the Muddy River to be approximately 12.99 cfs. The Pedersen Unit contributed approximately 3.5 cfs or 27 percent of that flow (see Hydrologic setting discussion). Assuming a loss of .8 cfs (from 3.5 cfs to 2.7 cfs at the Warm Springs West gage) from the Pedersen Unit due to groundwater pumping proposed under the MOA, flows at the confluence would be reduced to 12.19 cfs for an overall reduction in flow by 6 percent. This reduction in flow assumes that flows in the lower elevation springs and subsurface seepage gains are not likely affected by the groundwater pumping. The Hydraulic Geometry Model indicated that habitat further upstream in the system would be affected greater than habitat lower in the system; however, given the existing information the extent of the affects of the groundwater pumping in these lower elevation springs and stream reaches is unknown at this time. Therefore, based on the seepage run (USGS 2001), we are assuming that spring discharge from the Plummer and Apcar units and the subsurface flows will continue to flow at a rate that would provide approximately 12 cfs above the gabion, thus providing spawning, juvenile, and adult habitat in those reaches.

Although the overall reduction in flow by 6 percent to the system above the gabion is relatively minor; it does not adequately reflect the importance of the Pedersen Unit to Moapa dace reproduction and recruitment throughout the system. The various units of the MVNWR and the tributaries downstream of the MVNWR are currently the primary areas that provide suitable spawning habitat due to the absence of predatory tilapia. Collectively, these reaches are extremely important to the survival and recovery of the species. Our analysis indicates that there would be a loss of 31 percent of the available spawning habitat currently on the Pedersen Unit due to the proposed groundwater pump test. However, it is also recognized that much of the available spawning habitat on the Plummer and Apcar Units, and the Refuge Stream would not be as affected by groundwater pumping since they are lower in elevation and would continue to provide adequate spawning habitat. The conservation measures described in the next section were identified as actions that would be implemented by the signatories to minimize the effects to the Moapa dace, including the loss of habitat on the Pedersen Unit and other reaches of the Refuge Stream. Such measures include the removal of non-native fishes, enhancing, and restoring habitat and restoring instream flows (Apcar Unit) to increase the amount of habitat available for use by all life stages of the species.

Conservation Measures Identified to Minimize Effects of the Proposed Action

The major threats to the continued existence of the Moapa dace are: (1) loss of suitable habitat caused by reduced spring discharge/water flows; (2) loss of suitable habitat and direct predation resulting from the presence of non-natives species such as tilapia; (3) degradation and loss of suitable habitat resulting from habitat modification and increased occurrence of fire facilitated by non-native vegetation invasion; and (4) a restricted distribution, which increases the species vulnerability to catastrophic and stochastic events. The signatories to the MOA are proposing conservation measures (Attachment A) to minimize these threats to the Moapa dace and its habitat. These conservation measures are generally grouped in two categories and will result in the following: (1) reduction in pumping and dedication of water (surface and ground); and (2) implementation of habitat restoration activities including removal of non-native fishes. Reduction of groundwater pumping, dedication of water, and implementation of restoration actions would result in providing improved long-term habitat for the Moapa dace, and would promote an increase in its population size and distribution. The overall expected outcome of these measures is an increase in the species distribution and abundance throughout the range of the species.

While some of the restoration activities are currently in the planning phase, the funding that is being provided pursuant to the MOA will ensure a more timely completion of those activities. It is anticipated that most of these conservation measures will be implemented before or during the construction phase of the infrastructure required to develop and transport the water identified in the MOA. It is also anticipated that the Moapa dace population will respond positively, increasing in its distribution and abundance above current conditions Therefore, the conservation benefit to the species would be realized prior to and would off-set the effect of groundwater development. The following is a description of each action and its benefit to the Moapa dace.

Guaranteed Groundwater Pumping Reductions (Threshold levels)

The groundwater pumping will be reduced to 724 afy in the Coyote Spring Valley and 1,250 in California Wash, should stream flows reach 2.7 cfs at the Warm Springs West gage. This conservation measure will result in a reduction in the rate of decline of water levels and spring discharge. The reduction in the rate of decline will depend on the effect of remaining groundwater pumping in the Coyote Spring Valley, California Wash, and the Warm Springs Area (2,400 afy at Arrow Canyon by MVWD). This conservation measure provides certainty that if our analysis is correct and groundwater pumping in fact lowers the groundwater level thereby decreasing spring flows, then pumping will be substantially reduced.

Dedication of the MVWD Jones Spring Water Right of 1.0 cfs

As stated earlier, the Jones (a.k.a. Apcar) Spring is lower in elevation than the Pederson Unit and is not anticipated to be affected by groundwater pumping to the magnitude that higher elevation springs would be. The Jones Spring Agreement (Attachment B) guarantees an additional 1.0 cfs of flow entering the Muddy River flow system via the Jones Spring system located on the Apcar Unit of the MVNWR (this is in addition to the .5 cfs that is currently flowing in this reach as long as 1.0 cfs is provided to MVWD by other sources). This increase in flow guaranteed under the Agreement will provide additional water to support important spawning habitat in the system that is not currently available to the Moapa dace for reproduction, nursery, forage or long-term survival. The additional flows would increase the habitat available to Moapa dace both on the Apcar Unit and the tributary downstream. It is anticipated that the dace will respond positively and there will be an increase in the population. The addition of the 1.0 cfs of warm water from the Jones Spring to the system would also provide additional spawning habitat downstream by increasing the thermal load in the system. The additional water flow will contribute a greater quantity of warm water to the system, thus lengthening the thermal tail and thereby extending the species spawning habitat (temperatures at and above 30° C). This could contribute to an increase in the population by increasing its reproduction and distribution potential within the Apcar system, both on and off the MVNWR. In the past, population numbers have reached

200 individuals on the Apcar Unit of the MVNWR (personal communication 2005, G. Scoppettone), whereas in 2005, only 6 individuals were enumerated. It is anticipated that with an increase in flows and implementation of habitat restoration, as described below, the Moapa dace population would respond positively. An expanded species distribution would provide a more secure population since the species would not be as vulnerable to catastrophic events.

Dedication of Portion of CSI Water Rights

As agreed to in the MOA, a conservation easement would be recorded dedicating 460 afy (an amount equal to 10 percent of CSI's water right in Coyote Spring Valley, which may be a portion of CSI's water rights in Coyote Spring Valley or water rights from an alternative source in lieu of water from Coyote Spring Valley), to the survival of the Moapa dace and its habitat. In addition, CSI agrees that it will dedicate water rights in an amount equal to 5 percent of the water rights above 4,600 afy that CSI may be authorized by the Nevada State Engineer to appropriate from the Coyote Spring Valley, or import into the Basin for use at its project. The actual water rights so dedicated to the survival and recovery of the Moapa dace might be from sources other than Coyote Spring Valley Basin. The specific method of these water rights contributions to the Muddy River system from CSI is unknown at this time. However, through the Recovery Implementation Program, described below, a determination will be made of the most effective method for utilizing such water rights for the benefit of the Moapa dace.

The transfer of certificated water rights by CSI from Coyote Spring Valley for the use in the recovery of Moapa dace and its habitat is a long term benefit to the species. The dedication of future water rights from basins outside of Coyote Spring Valley would be analyzed in a future tiered section 7 consultation and the resulting benefit to the species determined at that time.

Improve/Restore Moapa Dace Habitat on the Apcar Unit of the MVNWR

SNWA will provide $750,000 to implement this action. This area currently is not optimum habitat for Moapa dace reproduction, nursery, food forage, and shelter. The Apcar Unit is currently overgrown with non-native vegetation and requires stream restoration throughout the entire unit. Historically, this unit supported hundreds of Moapa dace, which now supports only six individuals (Table 3). The habitat on this parcel was neglected and became less than optimum prior to purchase by the Service. Given, the history, this Unit has the potential to support a much larger number of individuals. The proposed funding, in addition to the Service's funds, will be used to restore habitat conditions to an optimum level for the Moapa dace. With the improved habitat and additional flow guarantees discussed above, the Moapa dace will likely increase its distribution and population to levels prior to the invasion of tilapia.

Restore Moapa Dace Habitat Outside of the MVNWR Boundary

CSI has agreed to provide $50,000 annually for four years to be used for habitat restoration outside of the MVNWR boundary to promote recovery of the Moapa dace. This funding will be applied towards various on-going or proposed activities that would improve and secure habitat that is currently not being utilized due to degraded conditions (i.e. illegal diversions or non-native species presence). The funding will provide a mechanism to restore habitat to a level that would provide a higher quality habitat for the species. These habitat improvements would contribute to the long term survival of the species by increasing the food production potential, providing additional habitat types that would be available for the various life stages and providing an environment that is void of predatory non-native fishes. Implementation of these actions would occur on private property and is dependent upon landowner permission.

Eradicate Non-native Fishes in the Warm Springs Area

SNWA will provide $25,000 towards this effort. As discussed in the Status of the Species section of this biological opinion, the invasion of tilapia has had a devastating effect on the Moapa dace. Only the Refuge and lower Apcar streams and those springs and outflows located on the MVNWR are devoid of the non-native tilapia. Tilapia currently occur throughout the remaining 3.82 miles of Moapa dace habitat which is on privately-owned lands. Due to the presence of tilapia, only 5 percent (68 individuals, Figure 3) of the population occur in these reaches where tilapia are present. Currently, the property that includes the majority of habitat with tilapia is privately held; however, SNWA has an access agreement with the property owner. Removal of tilapia from the 3.82 miles of the upper Muddy River will result in a substantial increase in the Moapa dace population, and the potential for a return to previous population levels when there was over a thousand Moapa dace in this reach.

Construct Fish Barriers in the Muddy River

Funding has been secured through the Southern Nevada Public Lands Management Act by BLM and the Service to construct a set of fish barriers on the Muddy River to prevent the further migration of non-native fishes, especially tilapia. SNWA would provide an additional $50,000 to be used towards the construction of a smaller structure upstream in the Muddy River tributaries; although the land is privately owned, SNWA maintains an access agreement with the private landowner. Fish barriers are essential to the overall effort to remove the invasive tilapia from the system and result in successful eradication efforts in order to benefit the Moapa dace.

In addition, the Tribe will allow access for the construction of at least one fish barrier. The location of a fish barrier on Tribal lands would be beneficial in order to reduce the opportunity for upstream movement into Moapa dace habitat by non-native fishes.

Development of a Recovery Implementation Program (Recovery Program)

In order to effectuate the goals of the MOA, a Recovery Program will be established whereby recovery measures are identified, prioritized and funded in order to accomplish the protection and recovery of the Moapa dace, the operation and development of regional water facilities and the inclusion of necessary and interested third parties are outlined and implemented. The cooperation of other entities within the region that have an interest in the development and management of water and biological resources in the Muddy River system will be sought. This Recovery Program will become instrumental in future site-specific actions tiered to this biological opinion by allowing the Service to evaluate the development of regional water resources while providing for the protection and conservation of the Moapa dace. SNWA will provide $300,000 towards the development of this Recovery Program.

Development of an Ecological Model for the Moapa dace

The Muddy River Recovery Implementation Team has identified the need to obtain additional biological/ecological information to better understand the needs of the Moapa dace. A study to assess the species physiological and biological response to the changing environmental conditions will be conducted concurrently with groundwater pumping. This model may assist in making critical management decisions that could result in minimizing or avoiding long-term adverse affects to the Moapa dace. SNWA and the Service will each provide $125,000 for the development of this ecological model for the Moapa dace. While this conservation/minimization measure will not provide short-term protection for the Moapa dace, the information obtained from this model would assist in the long-term management and recovery efforts of the species.

Hydrologic Review Team

The signatories to the MOA have agreed to establish a Hydrologic Review Team (HRT) for the purpose of developing a coordinated regional monitoring effort of the groundwater pumping proposed under the MOA and to satisfy the State Engineer requirement for monitoring under the various orders. The objectives of the HRT are to establish technically sound analyses of impacts on Muddy River Springs and Muddy River flows resulting from regional groundwater pumping, and ensure accuracy and efficiency in data collection as required under the Regional Monitoring Plans. Another objective of the HRT is to collect sufficient information and to adjust, through consensus, pumping restrictions of the signatories to better reflect the extent to which the individual pumping action may be causing impacts to the Muddy River Springs and Muddy River flows. The monitoring of the springs and stream reaches within the Muddy Springs Area and River is a critical component of the MOA that would provide early detection of effects from the proposed groundwater pumping. The commitment of the signatories to develop a regional monitoring plan would assure that all pumping effects within the basins (Coyote Spring Valley, Muddy River Springs Area, and California Wash) are being monitored such that if the average flow threshold levels are reached as stipulated in the MOA, actions could be implemented to protect the Moapa dace.

Overall Summary of Effects of the Proposed Action with the Conservation Measures

As previously described, the proposed conservation measures would provide additional flows (1.0 cfs) from the Jones Spring on the Apcar Unit that would increase thermal habitat and the reproductive potential of the species in the Apcar (upper and lower) and Refuge streams. In addition to the increased flows, the proposed restoration activities would reduce the potential for fire and restore the overall spawning and rearing habitat sufficient to sustain several hundred Moapa dace on the Apcar Unit of the MVNWR.

The proposed action also provides funding for conservation actions outside the boundary of the MVNWR, which include the restoration of habitat in one or more tributaries including the Apcar

Stream, North and South Forks and Muddy Springs streams; the construction of fish barriers; and removal of non-native fishes (e.g., tilapia) throughout the species range. These conservation measures would provide more secure habitat should water flows decline from groundwater development activities in the future. The implementation of the conservation actions assured by the funding committed in the MOA will improve habitat throughout the range of the species and will reduce the species vulnerability to catastrophic events. The expansion of the species within its range and increase in its current population size will minimize or off-set the effects of decreased flows within the Pedersen Unit that are anticipated to occur from the proposed groundwater development.

It is assumed that the conservation actions identified above would be initiated upon signature of the MOA with most of them completed prior to the actual groundwater development pump test. During the construction of facilities (18-24 months), and the subsequent pump test, critical conservation measures, including barrier construction, non-native species removal, and habitat restoration will all be initiated, if not completed, during the construction period and before the pump test. In addition, the Recovery Program will also be developed during the construction period and in advance of the pump test. It is anticipated that with the commencement of the pump test, the Recovery Program would have identified and funded additional conservation measures above and beyond those described herein to further the conservation of the species. The signatories to the MOA and the participants in the Recovery Program will be identifying and funding future conservation actions such as land acquisition and monitoring of groundwater pumping which are key to the success of the Recovery Program.

The conservation measures identified in this programmatic biological opinion and future actions developed as part of the Recovery Program would be implemented within the range of the Moapa dace in an effort to increase the population and expand its range from current levels and distribution in order to assure the continued existence of the species.

Cumulative Effects

Cumulative effects include the effects of future State, tribal, local or private actions that are reasonably certain to occur in the action area considered in this biological opinion. Future Federal actions that are unrelated to the proposed action are not considered in this section because they require separate consultation pursuant to section 7 of the Act.

Future demand for groundwater will continue to threaten spring flows and surface water important for aquatic species such as the Moapa dace. In the Muddy Springs Area, MVWD's existing permit would allow more groundwater to be pumped from the Arrow Canyon Well in the future. The maximum permitted pumping rate at the Arrow Canyon Well is 7,200 afy or 10.0 cfs, as compared with the annual average of 2,400 afy or 3.3 cfs pumped currently. Depending on the outcome of the five-year study mandated in the State Engineer Order 1169 and subsequent ruling by the State Engineer, additional groundwater could potentially be pumped in Coyote Spring Valley. While the MOA includes the removal of 13,600 afy in Coyote Spring Valley, the total volume of permitted water rights in Coyote Spring Valley is 16,100 afy. Any of the remaining permitted water rights (2,500 afy) could be developed. The maximum volume that could be removed from the Coyote Spring/Warm Springs Area under existing permits is 23,300 afy. This represents almost a tenfold increase from current withdrawals in the system.

In addition to the existing permitted water rights, there are pending applications for a far greater volume of groundwater above and beyond the permitted amount in the Coyote Spring/Warm Springs Area as well as in Kane Springs Valley, both areas that are part of the White River Flow System, and where pumping could potentially affect groundwater levels and spring discharge in the Warm Springs Area. The State Engineer, through Order 1169, held all of these pending applications in abeyance until the completion of the two-year pump test and evaluated results. Given the possible impacts already associated with the current pumping at Arrow Canyon and the proposed pumping in Coyote Spring Valley and California Wash, further groundwater development in the area would have very serious impacts on the water resources and biota in the Warm Springs Area. However, if these applications are granted, it is uncertain which would require a future Federal action in order to develop the rights upon approval.

Any future groundwater pumping by private parties above that analyzed in this biological opinion that is determined to affect or take Moapa dace could only legally occur under the authorization of a Habitat Conservation Plan section 10(a)(1)(B) and its associated incidental take permit issued by the Service. The Service's action of issuing such a permit would involve an internal consultation to affirm that section 7(a)(2) of the Act would not be violated.

Conclusion

After reviewing the current status of and environmental baseline for the Moapa dace, the effects of the proposed MOA, and the cumulative effects, it is the Service's biological opinion that the Service becoming a signatory to the MOA, as proposed and analyzed, is not likely to jeopardize the continued existence of the endangered Moapa dace. Our finding is based on implementation of the MOA and its associated conservation actions that would be implemented within the range of the Moapa dace prior to the initiation of groundwater pumping, in an effort to increase the population and expand its range from current levels and distribution in order to assure the continued existence of the species, and that the groundwater pumping proposed in the MOA and the associated effects of such pumping occur as analyzed in this biological opinion.

The Service's signing of the MOA does not waive any of the statutory duties or authorities of the Service or the United States, nor relieve the participants of the MOA from complying with any Federal laws, including but not limited to, National Environmental Policy Act, Endangered Species Act, National Wildlife Refuge System Improvement Act of 1997, and Federal Land Policy and Management Act of 1976, and any and all rules and regulations thereunder. In addition, future site-specific actions for pumping groundwater identified in the MOA would require additional section 7 consultation that would be tiered to this programmatic biological opinion.

Incidental Take Statement

No exemption from Section 9 of the Act is issued through this biological opinion. The cumulative withdrawal of 16,100 afy from Coyote Spring Valley and California Wash is likely to adversely affect listed species. However, the proposed action of signing the MOA, in and of itself, does not result in the pumping of any groundwater, and is one of many steps in the planning process for proposed groundwater withdrawal projects identified in the MOA and in the action area. Therefore, the Service has taken a tiered-programmatic approach in an attempt to analyzing the effects of the action. This programmatic biological opinion does not authorize any incidental take for programmatic impacts associated with the activities included in the MOA. The likelihood of incidental take, and the identification of reasonable and prudent measures and terms and conditions to minimize such take, is anticipated to be addressed in future project-specific consultations (second stage). These tiered-consultations would incorporate conservation measures outlined in the MOA at the specific project level. Any incidental take and measures to reduce such take cannot be effectively identified at the programmatic level of the proposed action because of the number of impending actions by different entities and its regional scope. Incidental take and reasonable and prudent measures may be identified adequately through subsequent actions subject to section 7 consultation, and tiered to this programmatic biological opinion. Future site-specific projects that are in the Description of the Proposed Action section and identified in the MOA would require additional section 7 consultation (second stage) that would be tiered to this programmatic biological opinion.

Reporting Requirements

Upon locating a dead or injured endangered or threatened species, initial notification must be made to the Service's Division of Law Enforcement in Las Vegas, Nevada, at (702) 388-6380. Care should be taken in handling sick or injured fauna in order to ensure effective treatment and care. In addition, care should be given in the handling of dead specimens to preserve biological material in the best possible state for later analysis of cause of death. In conjunction with the care of sick or injured species or preservation of biological materials from a dead animal or fish, the finder has the responsibility to carry out instructions provided by the Service's Division of Law Enforcement to ensure that evidence intrinsic to the specimen is not unnecessarily disturbed. All deaths, injuries, and illnesses of Moapa dace, whether associated with project activities or not must be reported to the Service.

The following actions should be taken for injured or dead dace if directed by the Service's Division of Law Enforcement:

Dead Moapa dace suitable for preparation as museum specimens shall be frozen immediately and provided to the Southern Nevada Field Office in Las Vegas, Nevada.

Conservation Recommendations

Section 7(a)(1) of the Act directs Federal agencies to use their authorities to further the purposes of the Act, by carrying out conservation programs for the benefit of endangered and threatened species. Conservation recommendations are discretionary agency activities to minimize or avoid adverse effects of a proposed action on listed species or critical habitat, to help implement recovery plans, or to develop information. In any future consultation related to this programmatic biological opinion, the following conservation recommendations should be considered.

1. Acquire Moapa dace habitat and/or water rights that are currently privately owned and secure the management of these rights for the long-term benefit of the Moapa dace in perpetuity;
2. Restore and enhance additional Moapa dace habitat. This includes funding restoration actions at Baldwin Spring, Cardy Lamb, and/or Muddy Spring or other areas identified by the Muddy River Recovery Implementation Team;
3. Provide funding for pre- and post-construction monitoring of water quality and quantity throughout the range of the species;
4. Establish an access agreement with Warm Springs Ranch private property owners for the continued implementation of recovery actions; and
5. Develop and implement a Moapa dace habitat restoration plan.

Reinitiation Notice

This concludes formal consultation on the actions outlined in your request. As required by 50 CFR § 402.16, reinitiation of formal consultation is required where discretionary Federal agency involvement or control over an action has been retained (or is authorized by law) and if: (1) The amount or extent of incidental take is exceeded; (2) new information reveals effects of the agency action that may affect listed species or critical habitat in a manner or to an extent not considered in this opinion; (3) the action is subsequently modified in a manner that causes an effect to the listed species that was not considered in this opinion; (4) a new species is listed or critical habitat designated that may be affected by the action; or (5) there is failure to meet any of the measures or stipulations in the MOA. In instances where the amount or extent of incidental take is exceeded, any operations causing such take must cease pending reinitiation.

If we can be of any further assistance, please contact me at (775) 861-6300 or Cynthia Martinez in the Southern Nevada Field Office at (702) 515-5230.

Robert D. Williams

Attachments

cc:
President, Coyote Springs Investment, LLC, Sparks, Nevada
Deputy General Manager, Engineering Operations, Southern Nevada Water Authority, Las Vegas, Nevada
General Manager, Moapa Valley Water District, Moapa, Nevada
Chairman, Moapa Band of Paiutes, Moapa, Nevada
Chief, Planning Division, Department of Army, Los Angeles District Corps of Engineers Office, Los Angeles, California
Project Leader, Desert National Wildlife Refuge Complex, Las Vegas, Nevada
Refuge Manager, Moapa Valley National Wildlife Refuge, Moapa Valley, Nevada
Assistant Regional Director, Ecological Services, Fish & Wildlife Service, Portland, Oregon (electronic copy only)

Literature Cited

Bassett, R. L. 2003. Evaluation of spring and aquifer isotopic data associated with the Muddy River Springs Geographic Area, Southeastern Nevada. Report prepared for the U.S. Fish and Wildlife Service by Geochemical Technologies Corp., Wheat Ridge, CO.

Buqo, T. S. 2004. Allometric responses in coupled groundwater-surface water-reservoir systems. Journal of Nevada Water Resources Association, Volume 1, pg. 40

Bureau of Land Management. 2003. Coyote spring Well and Moapa Transmission System Project Biological Assessment. Prepared by Wildland International for Bureau of Land Management, Las Vegas District on behalf of and in cooperation with the Southern Nevada Water Authority. 78 pages.

Clark County Department of Comprehensive Planning and U.S. Fish and Wildlife Service. 2000. Clark County Multiple Species Habitat Conservation Plan and Environmental Impact Statement. Report prepared by RECON, San Diego, California. June 2000.

Coburn, M.M. and T.M. Cavendar. 1992. Interrelationships of North American cyprinid. Pages 328-273 *in* Systematics, Historical Ecology, and North American Freshwater Fishes. R.L. Mayden (ed.). Stanford University Press, Stanford, California.

Cross, J. N. 1976. Status of the native fish fauna of the Moapa River (Clark County, Nevada). Transactions of the American Fisheries Society 105(4):503-508.

Deacon, J. E. and W. C. Bradley. 1972. Ecological distribution of the fishes of the Moapa (Muddy) River in Clark County, Nevada. Transactions of the American Fish Society 101(3): 408-419.

Brock, James T. 2004. Preliminary analysis of effects of reduced discharge on thermal habitat of Pedersen Warm Springs channel on the Moapa Valley National Wildlife Refuge, Clark County, Nevada. Desert Research Institute. 22 pages.

Dettinger, M. D., J. R. Harrill, and D. L. Schmidt. 1995. Distribution of carbonate-rock aquifers and the potential for their development, Southern Nevada and adjacent parts of California, Arizona, and Utah. U. S. Geological Survey Water Resources Investigations Report 91-4146.

Eakin, T. E. 1964. Groundwater appraisal of Coyote Spring and Kane Spring Valley and Muddy River springs area, Lincoln and Clark Counties, Nevada. Nevada Department of Conservation and Natural Resources. Groundwater Resources–Reconnaissance Series. Report 25.

Eakin, T. E. 1966. A regional interbasin groundwater system in the White River Area, Southeastern Nevada. Water Resources Research 2(2):251-271.

Fenlen, J.M. and M.T. Moreo. 2002. Trend analysis of groundwater levels and spring discharge in the Yucca Mountain Region, Nevada and California. U.S. Geological Survey Water Resources Investigations Report 02-4178.

Freeze, R. A. and J. A. Cherry. 1979. Groundwater. Prentice hall, Inc., Englewood Cliffs, New Jersey.

GeoTrans, Inc. 2001. Groundwater modeling of the Muddy River Area and surrounding basins with an emphasis on evaluating pending groundwater applications in Coyote Spring Valley. A Report prepared by GeoTrans, Inc. for the U. S. Fish and Wildlife Service, Portland ,OR.

GeoTrans, Inc. 2003. Addendum to groundwater modeling of the Muddy River Area and surrounding basins with an emphasis on evaluating pending groundwater applications in Coyote Spring Valley. A Report prepared by GeoTrans, Inc. for the U. S. Fish and Wildlife Service, Portland, OR.

Heckman, R. A. 1988. Presence of the Asian fish tapeworm, (*Bothriocephalus acheilognathi*), in the Moapa-Muddy River area, Nevada. Brigham Young University, Provo, Utah. 6 pages.

Hubbs, C. L. and R. R. Miller. 1948. Two new, relict genera of cyprinid fishes from Nevada. University of Michigan Museum of Zoology Occasional Paper 507:1-30.

Johnson, C., Mifflin, M., Johnson, R.J., Haitjema, H., 2001. Hydrogeologic and Groundwater Modeling Analyses for the Moapa Paiute Energy Center, a Calpine Company Project in cooperation with the Moapa Band of Paiute Indians, Moapa Indian Reservation, Clark County, Nevada: 218p. (Appendix to Moapa Paiute Energy Center DEIS (2001) and Supplemental DEIS (2002)).

Johnson., C., Mifflin, M., 2003. Evidence for a Sub-Regional Hydraulic Barrier in Southeastern Nevada (abstract). Geological Society of America 115th annual meeting, Seattle, WA.

Johnson, C., Mifflin, M., 2005. The AEM and regional carbonate aquifer modeling. Groundwater (in press).

La Rivers, I. 1962. Fishes and fisheries of Nevada. Nevada Fish and Game Commission; Reno, Nevada. 782 pages.

Las Vegas Valley Water District. 2001. Water resources and groundwater modeling in the White River and Meadow Valley Flow Systems, Clark, Lincoln, Nye, and White Pine counties, Nevada. A report prepared by the Las Vegas Valley Water District, Las Vegas, Nevada.

Mayer, T. 2003. Presentation at the Nevada Water Resource Association's 2003 annual meeting held on February 26, 2003.

Mayer, T. 2004. Possible impacts of groundwater pumping on spring discharge and dace habitat at Moapa Valley National Wildlife Refuge. Fish and Wildlife Service; Region One, Portland, Oregon. 16 pages.

Minckley, W. L. and W. E. Willard. 1971. Some aspects of biology of the longfin dace, a cyprinid fish characteristic of streams in the Sonoran Desert. Southwest Naturalist 15: 459-464.

Nevada State Engineer. 1995. Ruling Number 4243. The Office of the State Engineer of the State of Nevada; Carson City, Nevada.

Nevada State Engineer. 2002. State Engineer Order 1169. State Engineer of the State of Nevada; Carson City, Nevada.

Ono, R. D., J. D. Williams, and A. Wagner. 1983. Vanishing fishes of North America. Stone Wall Press, Washington, D.C. 257 pages.

Otis Bay Environmental Consultants. 2003. Hydraulic geometry of the Pedersen and Plummer streams. Report submitted to the Fish and Wildlife Service.

Prudic, D. E., J. R. Harrill, and T. J. Burby. 1993. Conceptual evaluation of regional ground-water flow in the carbonate-rock province of the Great Basin, Nevada, Utah, and adjacent states. U.S. Geological Survey Open-File Report 93-170.

Rinne, John N. and W.L. Minckley. 1991. Native fishes of arid lands: a dwindling resource of the desert southwest. General Technical Report RM-206. Fort Collins, Colorado; U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 45 pages.

Scoppettone, G. G, H. L. Burge, P. L. Tuttle, and N. K. Parker. 1987. Life history and status of the Moapa dace (*Moapa coriacea*). U.S. Fish and Wildlife Service, National Fisheries Research Center. Seattle, Washington. 77 pages.

Scoppettone, G. G, H. L. Burge, and P. L. Tuttle. 1992. Life history, abundance, and distribution of Moapa Dace (*Moapa coriacea*). Great Basin Naturalist 52 (3):216-225.

Scoppettone, G. G. 1993. Interactions between Native and Non-native Fishes of the Upper Muddy River, Nevada. Transactions of the American Fisheries Society 122:599-608.

Scoppettone, G. G., P. H. Rissler, M. B. Nielsen, and J. E. Harvey. 1996. Abundance of Moapa dace *(Moapa coriacea)* and Virgin River chub *(Gila seminuda)* in the Muddy River, with information on fish distribution. Unpublished Report: National Biological Service, California Science Center, Reno Filed Station, Reno, Nevada. 29 pages.

Scrugham, J. G. 1920. Order of determination of relative rights to the Muddy River and its tributaries. Judgment and decree, Case No. 377. State Engineer, Carson City, Nevada. 23 pages plus exhibits.

Soil Conservation Service. 1993. Salinity control plan and final environmental impact statement. Moapa Valley Unit, Nevada. Colorado River Salinity Control Program. Nevada State Office, Reno. 105 pages plus appendices.

Southern Nevada Water Authority [SNWA]. 2003. Survey of wells and stream gages in the Black Mountain Area, California Wash Basin, Coyote Spring Valley, Garnet Valley, Hidden Valley, and the Muddy River Springs Area, Nevada. Las Vegas, Nevada.

Southern Nevada Water Authority [SNWA]. 2004. Addendum No. 1 to Southern Nevada Water Authority's 2003 Annual Monitoring Report for Coyote Spring Valley, Garnet Valley, Hidden Valley, and California Wash Basin-Permit Numbers 49414, 49660-49662, 49987-49987, and 54073-54075. Submitted to Hugh Ricci, State Engineer on February 11, 2004. 18 pages.

Thomas, J. M., A. H. Welch, and M. D. Dettinger. 1996. Geochemistry and isotope hydrology of representative aquifers in the Great Basin region of Nevada, Utah, and adjacent states. U.S. Geological Survey Professional Paper 1409-C.

U. S. Fish and Wildlife Service [Service]. 1996. Recovery plan for the rare aquatic species of the Muddy River ecosystem. Service; Portland, Oregon. 60 pages.

U.S. Fish and Wildlife Service [Service]. 2003. Draft Programmatic Consultation Guidance. 31 pages.

U.S. Geological Survey. In Draft. Discharge, Water-Property and Water-Chemistry measurement for Muddy River Springs, Muddy River, Nevada, February 7, 2001. Scientific Investigation Report.

Van Liew, W. P. 2003. The effects of increase groundwater pumping in the Muddy River Springs area on water levels in nearby wells. Presented at the Nevada Water Users Association Annual Conference, February 2003, Reno, Nevada.

Van Liew, W. P., B.E. Gillies, and M.A. Aldhamari. 2004. The effects of increased groundwater pumping in the Muddy River Springs area on water levels in nearby carbonate-rock wells. July 12, 2004. National Park Service, Water Resources Division; Fort Collins, Colorado.

Wilson, B. L., J. E. Deacon, and W. G. Bradley. 1966. Parasitism in the fishes of the Moapa River, Clark County, Nevada. Transactions of the California-Nevada Section of the Wildlife Society 1966:12-23.

Final 1/27/06

MEMORANDUM OF AGREEMENT

This Memorandum of Agreement ("MOA") is entered into this _______ day of ___________, 2006, (the "Effective Date") by and between the Southern Nevada Water Authority ("SNWA"), a political subdivision of the State of Nevada, the United States Fish and Wildlife Service ("FWS"), Coyote Springs Investment LLC, a Nevada limited liability company ("CSI"), the Moapa Band of Paiutes ("Tribe") and the Moapa Valley Water District ("MVWD"), a political subdivision of the State of Nevada. For convenience, SNWA, FWS, CSI, the Tribe and MVWD are at times herein referred to individually as "Party" and collectively as "Parties."

RECITALS

A. In Order No. 1169 the Nevada State Engineer held in abeyance applications for new groundwater rights in certain groundwater basins, and mandated that SNWA, MVWD and other parties conduct a regional groundwater study including the pumping of at least 50 percent of the permitted water rights within the Coyote Spring Valley hydrographic basin for a period of at least two consecutive years ("Pump Test").[1] SNWA currently owns 9,000 afy of water rights with points of diversion within the Coyote Spring Valley hydrographic basin under Permit Nos. 49414, 49660 through 49662 and 49978 through 49987 ("SNWA Water Rights").

B. To facilitate the Pump Test and delivery of SNWA Water Rights, SNWA applied to the Bureau of Land Management ("BLM") for a right-of-way across Federal land for the

[1] Currently there are 16,100 acre-feet per year ("afy") of permitted groundwater rights in the Coyote Spring Valley hydrologic basin, including the SNWA Water Rights and CSI Water Rights, defined in Recitals A and D herein, and Order No. 1169 requires the continuous diversion of 8,050 acre-feet per year during the Pump Test.

construction and operation of a pipeline to deliver groundwater from the Coyote Spring hydrographic basin to either the Muddy River System or to MVWD's service system.

C. In Ruling No. 5115 the Nevada State Engineer granted Application No. 54075, filed by the Las Vegas Valley Water District ("District") on October 17, 1989, for a total duty of 2,500 afy with a diversion rate of 5.0 cubic feet per second ("cfs") within the California Wash hydrographic basin ("Permit No. 54075"). By separate agreement, the District has transferred ownership of Permit No. 54075 to the Tribe. The Tribe plans to divert and utilize groundwater under Permit No. 54075.

D. CSI is a private landowner in the Coyote Spring Valley hydrographic basin and owns 4,600 afy of water rights with points of diversion within the basin under Permit Nos. 70429 and 70430 ("CSI Water Rights").

E. MVWD is responsible for supplying the municipal water needs of Upper and Lower Moapa Valley located in Clark County, Nevada. MVWD owns several water rights within Upper Moapa Valley including surface rights to spring flows in the Muddy Springs area and groundwater rights (Permit Nos. 52520, 55450 and 58269) with points of diversion at the Arrow Canyon well and a right to 1.0 cfs of spring flow from the Jones Spring (Certificate No. 10060) ("Jones Water Right").

F. FWS is a Federal agency within the Department of the Interior. FWS' responsibilities include implementation of the Endangered Species Act and administration of the National Wildlife Refuge System. FWS holds a Nevada State water right certificate for a flow rate of not less than 3.5 cfs as measured at the Warm Springs West flume (Permit No. 56668; Certificate No. 15097 issued subject to the terms of Permit No. 56668) for the maintenance of habitat of the Moapa dace and other wildlife purposes ("FWS Water Right").

G. The Moapa dace (*Moapa coriacea*) is an endemic fish that inhabits the upper Muddy River and tributary thermal spring systems within the Warm Springs area in Clark County, Nevada. The Moapa dace was federally listed as endangered on March 11, 1967 (32 FR 4001). FWS manages the Moapa Valley National Wildlife Refuge established in 1979 as part of the National Wildlife Refuge System.

H. Based upon its evaluation of available data, FWS postulates that current groundwater pumping by MVWD at the Arrow Canyon well is causing a decline in spring flows in the Warm Springs area and that future withdrawals of groundwater by SNWA and/or CSI in the Coyote Spring Valley hydrographic basin and/or by the Tribe in the California Wash hydrographic basin may cause spring flows to decline. SNWA, CSI, and MVWD do not believe the available hydrologic data supports these conclusions.

I. The Tribe believes that regional groundwater monitoring and scientifically valid, but conservative, regional computer modeling have demonstrated and will continue to demonstrate that on-Reservation groundwater pumping authorized under Permit No. 54075 will not cause appreciable declines in spring flows in the Warm Springs area.

J. Prior to the issuance of Order No. 1169, a stipulation was executed on July 19, 2001, between Federal agencies and SNWA regarding protests filed by Federal agencies against SNWA applications for new groundwater rights in the Coyote Spring Valley hydrographic basin. The Federal agencies and SNWA agreed to implement a monitoring study that was clarified in a Monitoring, Management, and Mitigation Plan for Existing and Future Permitted Groundwater Development in Coyote Spring Valley ("3M Plan") attached to and incorporated in that stipulation.

K. As part of the approval of the MVWD water rights at the Arrow Canyon well, the Nevada State Engineer required a monitoring plan. A monitoring plan has been developed and agreed upon jointly by MVWD, Nevada Power Company, FWS and National Park Service, with the most recent amendments to that plan being submitted to the State Engineer in September 2002 ("MVWD Monitoring Plan").

L. State Engineer Ruling No. 5115 requires that "[a] monitoring program approved by the State Engineer prior to the diversion of any water [under Permit No. 54075] be prepared in conjunction with the [Pump Test] ordered in State Engineer's Order No. 1169."[2] The Tribe will develop, in coordination with the other Parties, a monitoring plan approved by the Nevada State Engineer prior to applying any groundwater to beneficial use under Permit No. 54075 ("Tribal Monitoring Plan").

M. On March 11, 2005, the Nevada State Engineer approved a document entitled "Southern Nevada Water Authority's Monitoring Plan for Groundwater Applications and Permits in Coyote Spring Valley, Hidden and Garnet Valleys, and California Wash Hydrographic Basin, Clark and Lincoln Counties March, 2005" ("SNWA Monitoring Plan"). The State Engineer directed that the SNWA Monitoring Plan serve as the monitoring plan required by the State Engineer for the SNWA Water Rights and the CSI Water Rights.

N. The Parties share a common interest in the conservation and recovery of the Moapa dace and its habitat. Each Party also has an interest in the protection, use and enjoyment of its water rights and entitlements. To serve these interests, the Parties have identified certain conservation measures with the objective of making measurable progress toward the conservation and recovery of the Moapa dace, and have agreed to coordinate the monitoring, management and mitigation measures included and to be included in the 3M Plan, MVWD

Monitoring Plan, SNWA Monitoring Plan, and Tribal Monitoring Plan (collectively the "Regional Monitoring Plans").

O. The Parties desire that FWS engage in consultation and prepare a formal biological opinion under the provisions of Section 7 of the Endangered Species Act and its implementing regulations prior to execution of this MOA. The consultation shall consider the effects on the Moapa dace from the pumping of 9,000 afy under the SNWA Water Rights, 4,600 afy under the CSI Water Rights, and 2,500 afy by the Tribe under Permit No. 54075, together with the implementation of the monitoring, management and conservation measures identified herein.

NOW, THEREFORE, in consideration of the mutual promises and covenants contained herein, the Parties do agree as follows:

I. Conservation Measures. The Parties agree that in order to make measurable progress toward protection and recovery of the Moapa dace and its habitat concurrent with the operation and development of water projects for human use, it is beneficial to the public interest to establish the following conservation measures:

1. Establishment of Recovery Implementation Program. To effectuate the goals of this MOA the Parties agree to establish a Recovery Implementation Program ("RIP") whereby measures necessary to accomplish the protection and recovery of the Moapa dace, the operation and development of regional water facilities, and the inclusion of necessary and interested third parties are outlined and implemented. To facilitate establishment of the RIP:

a. The Parties agree to cooperate in the selection of qualified personnel and/or contractors to oversee the development of the RIP.

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[2] Ruling No. 5115 at 40.

b. SNWA agrees to provide funding in the amount of $300,000.00 to develop the RIP. SNWA agrees to execute such documents as may be necessary to ensure that these funds are available to meet the needs of those persons designated by the Parties with the task of establishing the RIP.

c. The Parties agree to seek the cooperation of other parties within the region that have an interest in the development and management of water and biological resources. To achieve the goals of the RIP, the Parties agree to employ principles of adaptive management to further the current understanding of the habitat and aquatic needs of the Moapa dace. The Parties will jointly negotiate the participation of any other party in the RIP.

2. Dedication of the Jones Water Right. The Parties agree that the recovery of the Moapa dace will be enhanced by the guarantee of additional in-stream flows in areas of historical Moapa dace habitat. One such area is the Apcar Stream down gradient of the Jones Spring. The Parties concur that the dedication of the Jones Water Right to the purpose of providing in-stream flows will be beneficial to the Moapa dace population in this area and further the recovery of the species. To effectuate the dedication of the Jones Water Right to the provision of in-stream flows in the Apcar Stream, the Parties agree as follows:

a. MVWD agrees to record an agreement between MVWD and FWS ("Jones Springs Agreement") on the Jones Water Right with both the Nevada State Engineer and the Clark County, Nevada, Recorder's Office that requires the entire 1.0 cfs flow right under the Jones Water Right to be dedicated to the purpose of maintaining in-stream flows in the Apcar Stream subject to the provisions of paragraph 7 of the Jones Springs Agreement. MVWD shall retain ownership of the Jones Water Right. The Jones Springs Agreement shall be executed and recorded promptly upon execution of this MOA. A draft of the Jones Springs Agreement is attached hereto as "Exhibit A." The Jones Springs Agreement ultimately recorded pursuant to this paragraph shall be in substantially the same form as Exhibit A.

b. SNWA agrees to transfer to MVWD, at no cost, a portion of Permit No. 49414 equal to 724 afy. This transferred portion of Permit No. 49414 shall remain of equal priority date with that portion of Permit No. 49414 retained by SNWA.

c. MVWD agrees to transfer to SNWA, at no cost, the first 724 afy, or any portion thereof if less than 724 afy is permitted, of any permit(s) issued by the Nevada State Engineer pursuant to Application Nos. 54055 through 54059, inclusive.

d. The Parties agree to cooperate with MVWD in the filing and processing of any change applications, including applications to change the manner or place of use that are filed by MVWD with the Nevada State Engineer in order to effectuate the Jones Springs Agreement referenced in paragraph I(2)(a) above.

e. Subject to paragraph 2 of the Jones Springs Agreement, the Parties agree to cooperatively determine the best methods to ensure that the Jones Water Right accomplishes the purpose stated in paragraph I(2)(a) above, as related to the recovery of the Moapa dace and other endemic species, including the possibility of restoration of the springhead at Jones Spring.

3. <u>Dedication of Portion of CSI Water Rights</u>.

a. CSI agrees to record a conservation easement with both the Nevada State Engineer and the Clark County, Nevada, Recorders Office dedicating 460 afy of the CSI Water Rights to the survival and recovery of the Moapa dace and its habitat. The use of this water would be at the discretion of the FWS in consultation with the CSI and the Parties.

b. In addition, CSI agrees to dedicate 5 percent of all water rights above 4,600 afy that CSI may in the future be entitled to withdraw from Coyote Spring Valley hydrographic basin or any water rights that CSI imports into and uses in the basin. The Parties, consistent with the RIP, will determine the most effective method for utilizing such water rights. CSI shall execute and record such documentation, including conservation easements, deeds, change applications and reports of conveyance, as may be necessary to effectuate the dedication of that portion of such water rights that is subject to the terms and conditions contained herein.

4. Habitat Restoration and Recovery Measures. To restore the habitat necessary for the Moapa dace and take other steps to protect and recover the species, the Parties agree as follows:

a. SNWA agrees to provide funding in the amount of $750,000.00 for the restoration of Moapa dace habitat under the direction of FWS on the Apcar Unit of the Moapa National Wildlife Refuge or otherwise. All tasks funded under this paragraph I(4)(a) shall be agreed to in advance by SNWA and FWS in consultation with the other Parties. SNWA agrees to execute such documents as may be necessary in order to ensure that these funds are available for such habitat restoration.

b. FWS agrees to provide funding in the amount of $125,000.00 and SNWA agrees to provide funding in the amount of $125,000.00 to develop an ecological model designed to investigate the effects of habitat change on the ecology of the Moapa dace. FWS and SNWA shall, in consultation with the other Parties, agree upon the selection of a contractor to prepare the model.

c. SNWA agrees to provide funding in the amount of $50,000.00 to construct fish barriers to help eliminate the predacious Tilapia from areas of Moapa dace habitat. FWS and SNWA shall, in consultation with the other Parties, agree upon the selection of a contractor to perform such work.

d. SNWA agrees to provide funding in the amount of $25,000.00 to implement programs related to the eradication of non-native fish species, including predacious Tilapia, in the Warm Springs area. FWS and SNWA shall, in consultation with the other Parties, agree upon the selection of a contractor to perform such work.

e. CSI agrees to provide FWS with funding on an annual basis in the amount of $50,000.00 for a period of four years following the execution of this MOA for the restoration of Moapa dace habitat outside the boundaries of the Moapa National Wildlife Refuge along the Apcar Stream, or at such other locations as CSI and FWS, in consultation with the other Parties, agree.

f. The Tribe agrees to use a reasonable portion of the existing on-Reservation greenhouse facility for a reasonable period of years, for the purpose of cultivating native vegetation for use in RIP-approved habitat restoration. The Parties understand that the greenhouse is in a state of major disrepair and that such use of the greenhouse will require repairs and a water supply. FWS will work with the Tribe to obtain the funding necessary to provide for such repairs and to identify and secure a water supply adequate for such use. The Tribe reserves the right to pursue, and if feasible implement, separate arrangements for the improvement and commercial operation of the remainder of the greenhouse.

g. The Tribe agrees to provide access to the Tribe's Reservation for the construction and subsequent maintenance of at least one fish barrier, at a mutually agreeable location, to help eliminate the predacious Tilapia from Moapa dace habitat. FWS will work with the Tribe to obtain the funding necessary for construction, maintenance and repair of such barrier(s).

h. The Tribe agrees to provide the services of the Tribe's Environmental Director for in-kind staff services and participation in the RIP.

5. Protection of In-Stream Flows. The Parties recognize that maintenance of minimum in-stream flows in the Warm Springs area is essential for the protection and recovery of the Moapa dace. Although those flows are unknown at this time, the Parties agree as follows:

a. For purposes of this paragraph I(5), all "Average Flow Levels" specified herein shall be determined by flow measurements at the Warm Springs West flume. Average Flow Levels will be determined to have reached a particular level within a range specified in paragraphs I(5)(b) through (g) ("Trigger Range"): (1) if the daily average flow for each of 45 consecutive days decreases to an amount within the Trigger Range, or if the 90 day average flow over any 90 consecutive day period decreases to an amount within the Trigger Range; or (2) if the daily average flow for each of 90 consecutive days increases to an amount within the Trigger Range, or if the 135 day average flow over any 135 consecutive day period increases to an amount within the Trigger Range. If determined to be necessary by the Parties, the Parties will cooperate in removing phreatophytes, repairing or replacing the flume or taking any other steps to ensure the accuracy of flume measurements. Any adjustment in the rating curve for the Warm Springs West flume shall result in a pro-rata adjustment of the Trigger Ranges. The remaining provisions of this paragraph I(5) apply both during and after the Pump Test, except for paragraphs I(5)(c)(i) and (ii) which apply only during the Pump Test.

b. If the Average Flow Level decreases to an amount within the Trigger Range of 3.2 cfs or less, the Parties agree to meet as soon as practicably possible to discuss and interpret all available data and plan for mitigation measures in the event flows continue to decline.

c. If the Average Flow Level decreases to an amount within the Trigger Range of 3.0 cfs or less, the following Parties agree to take the following further actions:

i. During the pendency of the Pump Test, MVWD agrees to immediately cease pumping from the Arrow Canyon well; and

ii. While the Arrow Canyon Well is shut down pursuant to paragraph I(5)(c)(i) above, SNWA agrees to supply MVWD with all necessary municipal and domestic water supplies from the MX-5 and RW-2 wells or other sources available to the SNWA. Except for the express provision contained in paragraph I(2)(b) of this MOA, nothing in this MOA will obligate SNWA to supply MVWD with any water from SNWA's existing permits in the Coyote Spring Valley following the completion of the Pump Test; and

iii. SNWA and CSI agree to take necessary actions to prepare to geographically redistribute their groundwater pumping in the Coyote Spring Valley should flow levels continue to decline; and

d. If the Average Flow Level is within the Trigger Range of 3.0 cfs or less but greater than 2.9 cfs, the pumping of SNWA from the MX-5, RW-2, CS-1 and CS-2 wells in combination with the pumping of CSI from the MX-5, RW-2, CS-1 and CS-2 and CSI's pumping from other wells within the Coyote Springs Valley ("CSV") shall be restricted to 8,050 afy.

e. If the Average Flow Level is within the Trigger Range of 2.9 cfs or less but greater than 2.8 cfs, the pumping of SNWA from the MX-5, RW-2, CS-1 and CS-2 wells in combination with the pumping of CSI from the MX-5, RW-2, CS-1 and CS-2 and CSI's pumping from other wells in CSV shall be restricted to 6,000 afy, and the pumping of the Tribe under Permit No. 54075 shall be restricted to 2,000 afy.

f. If the Average Flow Level is within the Trigger Range of 2.8 cfs or less but greater than 2.7 cfs, the pumping of SNWA from the MX-5, RW-2, CS-1 and CS-2 wells in combination with the pumping of CSI from the MX-5, RW-2, CS-1 and CS-2 and CSI's pumping from other wells in CSV shall be restricted to 4,000 afy, and the pumping of the Tribe under Permit No. 54075 shall be restricted to 1,700 afy.

g. If the Average Flow Level is within the Trigger Range of 2.7 cfs or less, the pumping of SNWA from the MX-5, RW-2, CS-1 and CS-2 wells in combination with the pumping of CSI from the MX-5, RW-2, CS-1 and CS-2 and CSI's pumping from other wells in CSV shall be restricted to 724 afy, and the pumping of the Tribe under Permit No. 54075 shall be restricted to 1,250 afy.

h. The Parties agree that any pumping of the 460 afy of CSI Water Rights dedicated to the survival and recovery of the Moapa dace pursuant to paragraph 3.a. of this MOA shall be at the discretion of FWS and not counted against the pumping restrictions set forth in paragraphs 5(d) through 5(g) of this MOA.

6. Hydrologic Review Team. Upon execution of this MOA, the Parties shall establish a Hydrologic Review Team ("HRT") which shall be constituted and function as follows:

a. Membership. Each Party shall appoint two representatives ("HRT Representatives"), including at least one with substantial formal training and experience in hydrogeology ("Technical Representative"). Except as otherwise provided herein, the two HRT Representatives shall together have one vote on HRT matters. By consensus, the HRT

Representatives may offer voting or non-voting HRT membership to others who provide regional monitoring records and analyses to the HRT.

b. Objectives. The objectives of the HRT shall be: (1) to identify opportunities and make recommendations for the purpose of coordinating and ensuring accuracy, consistency and efficiency in monitoring, other data collection, and analytical activities performed under the Regional Monitoring Plans; (2) to establish technically sound analyses of impacts on Muddy River Springs and Muddy River flows resulting from regional groundwater pumping; (3) to assess based thereon whether the pumping restrictions, but not the Trigger Ranges, under paragraphs I(5)(c) through (g) above (or any successors thereto) should be adjusted to better reflect the extent to which regional groundwater pumping by the respective Parties causes, or is likely to cause, impacts on Muddy River Springs and Muddy River flows; and (4) to adopt by consensus appropriate adjustments to such restrictions, if warranted.

c. Regional Baseline Pumping Analysis. Within one year following the execution of this MOA, the Technical Representatives shall prepare a written analysis of regional groundwater pumping data and impacts ("Regional Baseline Pumping Analysis"). In preparing such baseline analysis, the HRT shall consider all relevant and available data and analytical materials. The Regional Baseline Pumping Analysis shall set forth all shared and dissenting analyses, interpretations and recommendations of the participating Technical Representatives. All modeling analyses contained therein shall be based on modeling codes in the public domain and data files that are available for comprehensive review by all Technical Representatives.

d. Annual Determination. Based on the Regional Baseline Pumping Analysis, and no later than one year after preparation of that analysis and annually thereafter, the HRT shall endeavor to determine by consensus ("Annual Determination") whether the groundwater pumping restrictions, but not the Trigger Ranges, under paragraphs I(5)(c) through (g) above (or any successors thereto) should remain in place, or whether and how any of such restrictions should be adjusted ("Pumping Restriction Adjustments") to better reflect the extent to which regional groundwater pumping by the respective Parties causes, or is likely to cause, impacts on Muddy River Springs and Muddy River flows. However, no Pumping Restriction Adjustments will be made within the first five years following the Effective Date of this MOA. All Annual Determinations (including any Pumping Restriction Adjustments adopted by HRT consensus) shall be final and binding on all Parties, except that by consensus the HRT may at any time modify or vacate any Annual Determination.

e. Annual Determination Reports. Each Annual Determination shall be set forth and explained in a written Annual Determination Report which includes as appendices the Regional Baseline Pumping Analysis, all previously submitted Annual Technical Representative's Reports, and any other data or analytical materials considered by the HRT. If the Annual Determination is not made due to lack of consensus or any other reason, the positions thereon of the HRT Representatives shall be set forth and explained in the Annual Determination Report. Furthermore, if the HRT fails to adopt Pumping Restriction Adjustments recommended in a timely submitted Annual Technical Representative's Report, the Annual Determination Report shall briefly explain why such recommendation was not adopted.

f. Annual Technical Representative's Reports. Within six months after the close of the year of this MOA and annually thereafter, based on the best available scientific data and information, any Technical Representative may submit to all other HRT Representatives a written report ("Annual Technical Representative's Report") containing both: (1) a welldocumented professional analysis of monitored regional pumping and pumping impacts; and (2) recommendations, if any, for Pumping Restriction Adjustments.

g. Provision for Peer Review. If the HRT Representatives are unable to reach consensus on an Annual Determination, the Parties shall refer the matter to a qualified panel of third party reviewers ("Panel") consisting of three scientists unaffiliated with any Party and having substantial formal training and experience in hydrogeology. If the Parties cannot agree by consensus on the make-up of the Panel, one member of the Panel shall be designated by each of the following from its own ranks: U.S. Geologic Survey, Desert Research Institute and a private firm with the requisite expertise designated by a majority of the Parties ("Appointing Entities"), provided that the Parties by consensus may designate different similarly qualified Appointing Entities. If any Appointing Entity for any reason is unable or refuses to designate a member of the Panel, the Parties by majority vote shall designate a qualified replacement Appointing Entity. The purpose of the referral to the Panel will be to obtain peer review of the then-current Annual Determination Report, the data upon which it is based, all previously submitted Annual Technical Representative's Reports, and any other relevant and available data and analytical materials. The Panel will be asked to make its recommendation based on the foregoing information concerning the appropriate content of the Annual Determination. All Parties shall have a fair and reasonable opportunity to present factual and analytical submissions in person and/or in writing to the Panel. The Parties contemplate that a determination of the Panel on the Annual Determination will constitute the best available scientific information concerning the impacts on Muddy River Springs and Muddy River flows resulting from regional groundwater pumping, and the appropriateness of any proposed Pumping Restriction Adjustments. The cost of the Panel shall be borne equally by the Parties.

7. Acquisition of Additional Land and Water Rights. As a potential conservation measure, the Parties agree to work cooperatively to identify both land and water rights that, if acquired and dedicated to the recovery of the Moapa dace, will assist in making measurable progress towards the recovery of the Moapa dace. SNWA agrees to make a good faith effort to acquire land and water rights identified by the Parties. The Parties expressly agree that the reasonableness of any terms and conditions for any acquisition of land or water rights by SNWA shall be determined by SNWA at SNWA's sole discretion, and that SNWA shall have no obligation to acquire any land or water rights upon terms and conditions that SNWA finds unreasonable. When such land or water rights are acquired by SNWA, SNWA will cooperate with FWS in establishing restrictions upon the use of such lands and water rights consistent with existing laws so as to effectuate the conservation of these resources and the recovery of the Moapa dace.

8. Operational Coordination Among FWS, SNWA, CSI and MVWD. Consistent with the terms of this MOA and to accomplish the goals of protecting and recovering the Moapa dace, and accommodating the operation of municipal water supply infrastructure, FWS, SNWA, CSI and MVWD agree to examine all reasonable water operational scenarios and agree to implement feasible scenarios that will minimize impacts to the Moapa dace and its habitat, including, but not limited to the provision of water to MVWD from the Coyote Spring Valley hydrographic basin during the Pump Test or other water supplies available to SNWA and MVWD. MVWD shall have the right during the Pump Test to use the Arrow Canyon Well only in the event and to the extent SNWA is unable to supply MVWD with "all necessary municipal and domestic water supplies" pursuant to the provisions of paragraph I(5)(c)(ii) of this MOA. Except for the express provision contained in paragraph I(2)(b) of this MOA, nothing in this

MOA will obligate SNWA to supply MVWD with any water from SNWA's existing permits in the Coyote Spring Valley hydrographic basin following the completion of the Pump Test.

SNWA and CSI agree, following the execution of this MOA, and in coordination with FWS, to cooperate in locating and drilling one or more production wells in the northern part of the Coyote Spring Valley hydrographic basin. The details of this cooperative effort shall be contained in a separate agreement between CSI and SNWA.

9. Adaptive Management Measures. The Parties agree to carry out additional conservation measures that will need to be taken to protect and recover the Moapa dace following the initiation of the RIP and as more data becomes available both as to the biology of the Moapa dace and regional hydrology. Thus, the Parties agree to cooperate in carrying out the following measures as may be appropriate:

a. Funding, preparation and implementation of biological and hydrological studies and activities supporting the recovery of the Moapa Dace; and

b. Establish a regional monitoring and management plan that will include science-based management and mitigation measures for RIP participants; and

c. Assessing the feasibility of augmenting and/or restoring in-stream flows and establishing those flows as deemed feasible.

d. Continue to re-evaluate necessary measures to protect and recover the Moapa dace.

II. Current Access Agreement. SNWA currently has an access agreement with the owners of the Warm Springs Ranch, which contains Moapa dace habitat, in order to conduct biological surveys of the Moapa dace. SNWA agrees to use its best efforts to seek to amend this access agreement so that each of the Parties to this MOA will have similar rights of access to the Warm Springs Ranch.

III. Modification of MVWD Monitoring Plan. Pursuant to the MVWD Monitoring Plan, submitted to the Nevada State Engineer in September 2002, FWS and MVWD agreed to a monitoring plan for development of MVWD's water rights at the Arrow Canyon well that contained certain management and mitigation measures that would be taken if flows at the Warm Springs West flume reached 3.17 cfs and 2.94 cfs respectively. This monitoring plan was recognized by the Nevada State Engineer in Ruling No. 5161. The Parties agree that, in order to effectuate a uniform regional monitoring and management plan, that the flow level restrictions and mitigation measures contained in this MOA shall replace the flow and water level restrictions and mitigation measures contained in the MVWD Monitoring Plan.

IV. No Assertion of FWS State Water Right. Provided that the other Parties to this MOA are in full compliance with the terms of this MOA, FWS expressly agrees not to assert a claim of injury to the FWS Water Right against either MVWD for pumping at the Arrow Canyon Well, against the Tribe for pumping within the California Wash hydrographic basin or against SNWA or CSI for any pumping in the Coyote Spring Valley for any diminution in flows at the Warm Springs West flume above 2.7 cfs. This provision shall in no way prejudice the FWS' ability and/or right to assert any and all rights inherent to the FWS Water Right for any diminution in flows at the Warm Springs West flume below 2.7 cfs.

V. No Waiver of Statutory Duties or Legal Rights. This MOA does not waive any of the authorities or duties of the FWS or the United States, nor does it relieve SNWA, CSI, the Tribe and MVWD from complying with any Federal laws, including but not limited to, the National Environmental Policy Act, Endangered Species Act, National Wildlife Refuge System

Improvement Act of 1997, and Federal Land Policy and Management Act of 1976, and any and all rules and regulations thereunder. Except as provided in paragraph IV of this MOA, it is the expressed intention of the Parties that FWS and the United States are not waiving any legal rights or obligations of any kind, including obligations to consult or re-consult under the Endangered Species Act, by entering into this MOA. Further, this agreement is entered as a good faith resolution of certain issues and is not intended to waive any party's rights in a subsequent legal proceeding regarding those issues. In addition, except for the restrictions set forth in paragraphs I(5)(e) through (g) above, this MOA does not in any respect waive, limit, or diminish any rights or claims of the Tribe to any federally-reserved or State surface or groundwater rights.

VI. <u>No Modification of Previous Agreements</u>. The Parties recognize that CSI, SNWA and MVWD have previously entered into multiple agreements concerning the sale, purchase and settlement of water rights within the Coyote Spring Basin including a certain *Agreement For Settlement Of All Claims To Groundwater In The Coyote Spring Basin* entered into between MVWD, CSI, SNWA and the District on March 7, 2002, and a certain *Agreement For Option, Purchase and Sale of Water Rights, Real Property and Easements* entered into between SNWA and CSI on April 16, 1998. Nothing contained herein is intended to abrogate or modify in any manner any of the provisions contained in any of those agreements except as expressly provided in paragraphs I(2)(b) and I(2)(c) of this MOA.

VII. <u>Miscellaneous Provisions</u>.

1. <u>Notices</u>. If notice is required to be sent by the Parties, the addresses are as follows:

If to FWS:

Supervisor
Nevada Fish and Wildlife Office
Fish and Wildlife Service
1340 Financial Blvd., #234
Reno, Nevada 89502

If to SNWA:

General Manager
Southern Nevada Water Authority
1001 South Valley View Boulevard
Las Vegas, Nevada 89153

If to MVWD:

General Manager
Moapa Valley Water District
Post Office Box 257
Logandale, Nevada 89021

If to CSI:

Carl Savely, General Counsel
Wingfield Nevada Group
6600 North Wingfield Parkway
Sparks, Nevada 89436

If to the Tribe:

Chairperson, Moapa Band of Paiute Indians
Post Office Box 340
Moapa, Nevada 89025
Fax: 702-865-2875

With copies to:

Steven H. Chestnut
Richard M. Berely
Ziontz, Chestnut, Varnell, Berely & Slonim
2101 Fourth Avenue, Suite 1230
Seattle, Washington 98121
Fax: 206-448-0962

2. Choice of Law. This MOA shall be governed in accordance with applicable Federal laws, and the laws of the State of Nevada to the extent not inconsistent with Federal law.

3. Funding. Any commitment of funding by FWS, MVWD or SNWA under this MOA is subject to appropriations by the respective governing bodies of those entities.

4. Amendment. This MOA may be amended in writing by mutual agreement of the Parties.

5. Integration. This MOA sets forth the entire agreement of the Parties and supercedes all prior discussions, negotiations, understandings or agreements with respect to the subject matter hereof. No alteration or variation of this MOA shall be valid or binding unless contained in an amendment in accordance with paragraph VI(4) of this MOA.

6. Binding Effect, Withdrawal From MOA. The terms and conditions of this MOA shall be binding upon and inure to the benefit of the Parties hereto and their respective personal representatives, successors, transferees and assigns. However, the Parties expressly agree that should the execution of this MOA, or any consultation held or biological opinion issued under Section 7 of the Endangered Species Act which is premised thereon, be challenged in a court of competent jurisdiction and be found in violation of the Endangered Species Act or any other law, any of the Parties may withdraw from the MOA upon thirty days written notice to the other Parties. Upon such withdrawal, the withdrawing Party shall have no further obligation to perform any commitment contained in this MOA.

7. Effective Date, Counterparts. This MOA will become effective as between the Parties upon all Parties signing this MOA. The Parties may execute this MOA in two or more counterparts, which shall, in the aggregate, be signed by all Parties; each counterpart shall be deemed an original as against any party who has signed it.

8. Additional Parties. Other entities may become Parties to this MOA by mutual written assent of the Parties.

9. Headings. The underlined paragraph headings used in this MOA are for the convenience of the Parties only, and shall not be deemed to be of substantive force in interpreting the MOA.

10. No Third Party Beneficiaries. This MOA does not create any right or benefit, substantive or procedural, enforceable by any third parties against the Parties or against any other person or entity. The terms of this MOA are not enforceable by any person or entity other than a Party.

IN WITNESS WHEREOF, the Parties have executed this Memorandum of Agreement on the ______ day of __________________, 2006.

MOAPA VALLEY WATER DISTRICT

____
By: Ivan Cooper
Title: Chairman

FISH AND WILDLIFE SERVICE

____
By: Steve Thompson
Title: Manager, California/Nevada Operations Office

SOUTHERN NEVADA WATER AUTHORITY

____
By: Amanda M. Cyphers
Title: Chair

COYOTE SPRINGS INVESTMENT, LLC

By: Robert R. Derck
Title: General Manager

MOAPA BAND OF PAIUTES:

By: Dalton Tom,
Title: Chairman

ATTACHMENT B

When Recorded Mail To:

____
____
____

Jones Springs Agreement

This Jones Springs Agreement ("Agreement") is entered into for the purposes described herein this ____ day of ____________________, 2004 by between Moapa Valley Water District ("MVWD") and the U.S. Fish and Wildlife Service ("FWS").

RECITALS

1. MVWD was created in 1983 by an act of the Nevada Legislature and is the municipal water purveyor in upper and lower Moapa Valleys and serves the communities of Moapa, Glendale, Logandale and Overton, and the surrounding areas, located in Clark County, Nevada.

2. One of MVWD's water sources is a spring known locally as Pipeline Jones Spring ("Jones Spring"). MVWD holds Certificate No.10060 issued by the Nevada State Engineer to divert 1 c.f.s. of flow of water from Jones Spring for municipal purposes. The waters of Jones Spring and Certificate No.10060 constitute a portion of the Muddy River Decreed water rights.

3. Water from Jones Spring, as well as numerous other springs, form small streams which make up the Muddy River ("Tributary Streams").

4. There lives in the upper reaches of the Muddy River and in the Tributary Streams, a small minnow known as the Moapa Dace ("Dace"). The Dace was listed as endangered in 1967 under the Endangered Species Preservation Act of 1966 and continues to be so listed and protected under the Endangered Species Act of 1973 as amended.

5. MVWD needs the quantity of water represented by Certificate No.10060 to serve its municipal customers.

6. As an inducement to MVWD to grant this Agreement, the Southern Nevada Water Authority ("SNWA") has agreed to furnish to MVWD a quantity of water equal to MVWD's rights under Certificate No.10060 from SNWA's wells and water rights in Coyote Spring Valley ("Coyote Spring Water"). The terms and conditions of SNWA's obligations are set forth in a separate agreement.

7. MVWD desires to help in the recovery and preservation of the Dace.

NOW THEREFORE, for the purpose of aiding in the recovery and preservation of the Dace, MVWD and FWS hereby agree as follows:

ATTACHMENT B

1. Effective on MVWD receiving Coyote Spring Water from Southern Nevada Water Authority, the water from Jones Spring shall not be diverted for municipal purposes pursuant to Certificate No.10060, but shall be allowed to flow down the Tributary Streams to the Muddy River.

2. MVWD may, as soon as Coyote Spring Water is available and being furnished to MVWD for municipal purposes disconnect their existing pumping facilities from the Jones Spring diversion pipe and or otherwise affix appurtenances that will allow the entire flow of water from Jones Spring to flow down to the Muddy River, thus increasing the flow of water in one or more Tributary Streams.

3. MVWD shall file any necessary change applications with the State Engineer as may be required by Nevada Law as a result of this Agreement.

4. The Agreement herein granted shall be for a non-consumptive use of water, with no warranty as to quality or quantity of flow.

5. MVWD reserves the right, in the future when it can use surface water, to change the point of diversion for its consumptive use right to the water from Jones Spring to a point on the Muddy River, below the Glendale gauging station. Any such change shall not affect the flow of water at Jones Spring for in-stream purposes.

6. This Agreement will be recorded with the Clark County Recorder and filed with the Nevada State Engineer.

7. So long as MVWD is in full compliance with the terms and conditions applicable to MVWD in the Memorandum of Agreement dated November ____, 2004 and attached hereto as Attachment 1, then, if for any reason, whether natural, man-made or otherwise, any portion of the Coyote Spring Water becomes unavailable or unusable to meet MVWD's municipal needs previously supplied by Certificate 10060 (Jones Spring), then MVWD shall have the right to utilize a like portion of water from Jones Spring to replace such portion of the Coyote Spring Water that remains unavailable to MVWD for so long as the Coyote Spring Water remains unavailable.

IN WITNESS WHEREOF, MVWD and FWS have executed this Agreement the date first above written.

MOAPA VALLEY WATER DISTRICT

By: ______________________________
Ivan Cooper, Chairman of the Board

U.S. FISH AND WILDLIFE SERVICE

By: ______________________________
Steve Thompson, Manager
California/Nevada Operations Office

Attachment C

WATER SUPPLY AGREEMENT

WATER SUPPLY AGREEMENT ("Agreement") effective ______________, 2006, among the Moapa Band of Paiutes ("Tribe"), Las Vegas Valley Water District ("LVVWD"), Southern Nevada Water Authority ("SNWA"), Muddy Valley Irrigation Company ("MVIC") and Moapa Valley Water District ("MVWD") referred to herein individually as a "Party" and collectively as the "Parties."

Recitals

A. The Tribe, LVVWD, SNWA, MVIC, MVWD and the State of Nevada ("State") have negotiated a proposed written Water Settlement Agreement and remain committed to consummating the Water Settlement Agreement substantially in its current form (the "WSA"). The proposed WSA is attached hereto as Exhibit A. The United States must approve and join in the WSA.

B. SNWA, Coyote Springs Investment LLC, MVWD and the United States Fish and Wildlife Service ("FWS") have negotiated a proposed Memorandum of Agreement (the "MOA") regarding certain planned groundwater pumping in the Coyote Spring Hydrographic Basin and measures to mitigate potential impacts of such pumping on the endangered Moapa dace. The proposed MOA is attached hereto as Exhibit B. This Agreement has been negotiated by the Parties to obtain and facilitate the Tribe's joinder in the MOA.

C. The Tribe will execute the MOA upon execution of this Agreement by all Parties and the satisfaction of certain conditions precedent which are explicitly set forth below. Among other features, subject to conditions set forth below, under this Agreement the Tribe will receive the State groundwater permit and State groundwater applications which are to be provided to the Tribe by LVVWD under the WSA, and a lease of Muddy River water rights which in certain respects will be functionally similar to the federally-reserved Muddy River rights to be secured to the Tribe under the WSA.

Terms and Conditions

The Parties hereto agree as follows:

1. **Commitment to WSA.** The Tribe, LVVWD, SNWA, MVIC and MVWD:

   a. shall make best efforts to secure Federal approval and execution of the WSA substantially in its current form;

b. on the securing of such Federal approval, shall execute the WSA; and

c. shall make best efforts to secure mutually satisfactory written confirmation from the State that it continues to support consummation of the WSA.

2. **Commitment by Tribe to Execute the MOA.** The Tribe shall execute the MOA upon satisfaction of the following conditions precedent:

a. **Condition Precedent No. 1.** Provision by the State of Nevada of the written confirmation described in ¶ 1.c above.

b. **Conditions Precedent Nos. 2 - 5.** The conditions precedent set forth in ¶¶ 3.e and 4.c below.

3. **Provision of Groundwater Rights.**

a. **2500 acre-feet per year (afy) Permit and Related LVVWD Groundwater Applications.** In 1989, LVVWD filed two State applications to appropriate groundwater from the California Wash Hydrographic Basin (Applications 54075 and 54076) totaling

20 cubic feet per second (cfs) and 14,480 afy. On April 18, 2002, the Nevada State Engineer issued Ruling 5115, which granted LVVWD a permit to withdraw 2,500 afy of groundwater under Application 54075 ("2500 afy Permit"), denied the balance of Application 54075, and held Application 54076 in abeyance pending completion of the groundwater study ordered in State Engineer's Order 1169.

b. **Tribal Appeal.** The Tribe has appealed Ruling 5115 to the Eighth Judicial District Court of Clark County, Nevada (the "Appeal"), and LVVWD has intervened as a defendant in the Appeal (which remains pending). Through the Appeal, the Tribe is seeking an increase in the quantity of groundwater currently permitted to be withdrawn under Application 54075 and restoration of the balance of Application 54075 pending further action by the State Engineer. This Agreement does not resolve the Tribe's claims in the Appeal. Application 54076 and any balance of Application 54075 which may be restored as a result of the Appeal are referred to herein as the "LVVWD Groundwater Applications" and individually as an "LVVWD Groundwater Application."

c. **Pending LVVWD Change Applications.** In July 2003, in contemplation of the consummation of the WSA, LVVWD in consultation with the Tribe filed three applications ("LVVWD Change Applications") with the State Engineer to change the point of diversion under the 2500 afy Permit to locations on the Moapa Indian Reservation ("Reservation"). The LVVWD Change Applications were not protested and are pending for approval before the State Engineer. LVVWD shall make best efforts to secure the promptest possible State Engineer approval of the LVVWD Change Applications.

d. **Transfer of 2500 afy Permit and LVVWD Groundwater Applications to Tribe.** Contemporaneous with the Tribe's execution of the MOA, LVVWD shall transfer to the Tribe, at no charge and free and clear of liens and encumbrances, full ownership of the 2500 afy Permit and the LVVWD Groundwater Applications, subject to reversion under ¶ 7 below. If the Tribe subsequently establishes a federally-reserved right to groundwater appurtenant to any portion of the Reservation, an equal quantity of State groundwater rights acquired by the Tribe under the 2500 afy Permit and/or LVVWD Groundwater Applications shall be deemed relinquished by the Tribe.

e. **Conditions Precedent Nos. 2 and 3.** The following are two additional conditions precedent that must be satisfied to trigger the Tribe's obligation to execute the MOA:

i. approval of the LVVWD Change Applications by the State Engineer on no conditions unacceptable to the Tribe; and

ii. transfer of the 2500 afy Permit and LVVWD Groundwater Applications to the Tribe as provided in ¶ 3.d above.

f. **LVVWD Disclaimers.** LVVWD makes no representation or warranty to the Tribe as to the quantity or quality of water that: (i) will ultimately be permitted by the State Engineer in response to the LVVWD Groundwater Applications; or (ii) can ultimately be developed under the 2500 afy Permit.

g. **Issuance of Further Rights to Tribe under LVVWD Groundwater Applications.** All Parties hereto shall withdraw their pending protests, if any, against the LVVWD Groundwater Applications. No Party shall oppose (or assist others to oppose), in any administrative or judicial proceeding or otherwise, any issuance to the Tribe by the State Engineer of additional groundwater rights under an LVVWD

Groundwater Application in the form of a permit or certificate ("Further Permit or Certificate"), except that LVVWD may contend in the Appeal or any remand therefrom that, as provided in State Engineer Ruling 5115, the 2500 afy Permit should be for 2500 afy with a maximum diversion of 5 cfs and that Application 54076 should be held in abeyance pending completion of the groundwater study ordered in State Engineer Order 1169. No Party hereto may oppose (or assist others to oppose) in any administrative or judicial proceeding or otherwise, any Tribal application to have an LVVWD Groundwater Application acted on by the State Engineer on a piecemeal basis over time, by dividing the LVVWD Groundwater Application into increments or by comparable means.[1]

h. **Change Applications.** No Party hereto may oppose (or assist others to oppose) in any administrative or judicial proceeding or otherwise, the granting by the State Engineer of the LVVWD Change Applications, or any Tribal application under a LVVWD Groundwater Application, the 2500 afy Permit, or a Further Permit or Certificate: (i) to change any point of groundwater diversion thereunder to any location on or off the Reservation within the

[1] The Tribe acknowledges that the State has previously advised that the State Engineer does not decide groundwater applications on a piecemeal basis.

California Wash Hydrographic Basin, which lies at least one mile (in the case of a carbonate aquifer well) and two miles (in the case of an alluvial well) from Muddy Springs and the Muddy River; or (ii) to change any use or place of use of groundwater thereunder to facilitate the beneficial use thereof on or off the Reservation.

i. **Tribal Acquisition of Additional Groundwater Rights.** Subject to the protest rights of any other Party hereto (except for those relinquished under ¶¶ 3.g and h above), nothing in this Agreement shall prejudice the Tribe's right to apply under State law to the State Engineer either (i) for further groundwater rights appurtenant to the Reservation, or (ii) for transfer to the Reservation of State law-based groundwater rights having points of diversion or places of use located off the Reservation.

4. **Provision of Surface Water Rights.**

a. **Muddy River.** The Muddy River flows through the Reservation and the Tribe claims an unadjudicated 1873 federally-reserved water right in the river. MVIC holds legal title to certain State surface water rights in the Muddy River ("MVIC Surface Water Rights") awarded in a Judgment and Decree dated March 12, 1920, ("Muddy River Decree"), in *Muddy Valley Irrigation Co., et al. v. Moapa and Salt Lake Produce Co., et al.*, in Nevada's Tenth Judicial District Court (now Nevada's Eighth Judicial District Court). The Muddy River Decree also purported to award the Tribe surface water rights in the Muddy River appurtenant to the Reservation of 1.242 cfs (Apr. - Sept.) and 0.87 cfs (Oct. - Mar.). However it is the position of the Tribe that the Court did not have jurisdiction to adjudicate the Tribe's water rights, and the Tribe shall not claim or use the awarded right while the Surface Water Lease provided under ¶ 4.b below is in force. Each shareholder in MVIC holds, pursuant to its shares, a beneficial interest in MVIC Surface Water Rights, and collectively all MVIC shareholders hold all beneficial interests in all MVIC Surface Water Rights.

b. **Lease of MVIC Surface Water Rights.** Contemporaneous with the Tribe's execution of the MOA, MVIC and the Tribe shall enter into the lease attached hereto as Exhibit C ("Surface Water Lease"). The Surface Water Lease provides a rent-free 99-year lease of a portion of MVIC Surface Water Rights to the Tribe, sufficient to provide the Tribe with the right to divert at the existing Muddy River diversion points on the Reservation and beneficially use on the Reservation 11.5 cfs (Apr. - Sept.) and 10.5 cfs (Oct. - Mar.), subject to a maximum consumptive use limit of 3700 afy. The Surface Water Lease further provides that if the Tribe wishes, at any time during the term thereof, to change the manner of use or place of beneficial use within the Reservation of MVIC Surface Water Rights covered by the Surface Water Lease, MVIC shall fully cooperate with the Tribe in the preparation, filing and pursuit of State Engineer approval of a change application necessary to effect such change. No other Party hereto shall oppose (or assist others to oppose) the granting of such change application. The Surface Water Lease further provides that the Tribe's right to divert and use water pursuant to the Surface Water Lease is, as a matter of contract, functionally senior to the rights of all shareholders in MVIC to divert and use water pursuant to the MVIC Surface Water Rights. The Surface Water Lease is renewable on the same terms and conditions at the end of the 99-year term for an additional 99 years at the Tribe's option, <u>provided</u> that the Surface Water Lease is terminable as provided in ¶ 8 below. In exercising its rights under the Surface Water Lease, the Tribe shall otherwise have all rights and privileges, and be bound by all substantive and procedural laws, principles and rules, applicable to owners of MVIC Surface Water Rights, including without limitation with respect to beneficial use and changes in the point of diversion, place of use and manner of use. The foregoing notwithstanding, the Surface Water Lease does not expressly or impliedly have the effect, in law or in equity, of making the Tribe a shareholder in MVIC for any purpose.

c. **Conditions Precedent Nos. 4 and 5.** The following are two additional conditions precedent that must be satisfied to trigger the Tribe's obligation to execute the MOA:

i. execution and delivery to the Tribe of the Surface Water Lease; and

ii. State Engineer approval of the two filed change applications authorizing the Tribe to divert at the existing points of diversion for the Reservation and beneficially use on the Reservation the MVIC Surface Water Rights covered by the Surface Water Lease.

5. Provision of Mitigation Surface Water Rights.

a. **Pumping Limits.** As reflected in paragraph I(5)(e) - (g) of the attached MOA, the Tribe is prepared to agree therein that on-Reservation pumping under the 2500 afy Permit shall be reduced to specified amounts ("Pumping Limits") if flow levels at the Warm Springs West flume decline to specified levels. The Tribe believes, however, that monitoring data and sound hydrogeologic analysis show and will continue to show that on-Reservation pumping under the 2500 afy Permit will not appreciably impact flows as measured at the Warm Springs West flume. Nevertheless, the Tribe is prepared to agree to the Pumping Limits principally because:

   i. as provided in paragraph I(6) of the MOA, the validity of the Pumping Limits will be regularly reconsidered by the Hydrologic Review Team on the basis of monitoring data and hydrogeologic analysis, and, as appropriate, adjusted; and

   ii. MVWD has agreed to mitigate the effects of the Pumping Limits as provided in ¶ 5.b below.

b. **Mitigation Surface Water Rights.** To mitigate the effects of the Pumping Limits, the surface water rights described in subparagraph i. below (the "Mitigation Surface Water Rights") shall be available for use by the Tribe:

i. Subject to the approval of any necessary change application(s) as provided in subparagraph ii(3) below, upon the Tribe's execution of the MOA, the Tribe shall have the right, at no charge and free and clear of liens and encumbrances, to divert water from the Muddy River, at the existing Muddy River diversion points on the Reservation, at a maximum rate of 1 cfs, subject to a maximum diversion and consumptive use limit of 520 afy, from MVWD's "Jones Water Right" (Certificate No. 10060) dedicated to in-stream flows in accordance with paragraph I(2)(a) of the MOA. Such Mitigation Surface Water Rights shall be useable by the Tribe only during times, and only to the extent, that a Pumping Limit of less than 2500 afy is being implemented. At all times, and in all other respects, MVWD's Jones Water Right shall remain under the ownership and control of MVWD. The Tribe's use of the Mitigation Surface Water Rights will be monitored in accordance with ¶ 10 below.

ii. **Characteristics of Mitigation Surface Water Rights.** The Mitigation Surface Water Rights shall have the following characteristics:

(1) they shall be subject to reversion under ¶ 7 below;

(2) they shall provide to the Tribe a right to divert and use such water from the Muddy River;

(3) they shall be available for municipal use anywhere on the Reservation and, to facilitate such diversion and use, MVWD in consultation with the Tribe shall timely develop, file and secure issuance by the State Engineer of all legally required approvals of any necessary change applications. Any costs associated with the securing necessary approvals of any such change applications shall be born equally by the Tribe and MVWD;

(4) they shall be additive to the Tribe's rights under the Surface Water Lease to be provided under ¶ 4.b above; and

(5) in exercising the Mitigation Surface Water Rights, the Tribe shall have all rights and privileges, and be bound by all substantive and procedural laws, principles and rules, applicable to other owners of surface water rights in the Muddy River, including without limitation with respect to beneficial use and changes in the point of diversion, place of use and manner of use.

(6) MVWD agrees to keep the Jones Water Right or successor rights in good standing for so long as MVWD's obligation under this paragraph 5 is in existence. A copy of this Agreement shall be filed with the Office of the Nevada State Engineer and any successor to or assignee of MVWD shall be bound this paragraph 5.

6. **State Law.** The 2500 afy Permit, LVVWD Groundwater Applications and any Further Permit or Certificate acquired by the Tribe under ¶ 3 above, the Surface Water Lease acquired by the Tribe under ¶ 4.b above, and the Tribe's right to use the Mitigation Surface Water Rights under ¶ 5.b above, and any Tribal change application with respect to any of the foregoing, shall be held, sought, made and utilized by the Tribe in accordance with State law, both substantive and procedural. Without limitation, no such water right may be

transferred by the Tribe for use at an off-Reservation location without compliance with State law. In addition, the provisions of ¶¶ 7 and 8 below shall be interpreted and enforced in accordance with State law. All of the foregoing shall be enforceable in administrative and judicial forums specified in State law for injunctive or declaratory enforcement of such water rights matters, and the Tribe hereby waives its sovereign immunity for the exclusive purpose of such enforcement in such forums, and as to any appeals therefrom in any appellate courts with jurisdiction over such appeals under State law. The Tribe hereby waives and foregoes any right to claim that exhaustion of Federal or Tribal court remedies is a prerequisite to any action by any Party to enforce the provisions of this ¶ 6 in the specified State administrative or judicial forums. However, no Party shall ever contend that any water right acquired by the Tribe under ¶¶ 3, 4.b or 5.b above has been abandoned or forfeited.

7. Reversion of 2500 afy Permit, LVVWD Groundwater Applications, Further Permit or Certificate, and Mitigation Surface Water Rights. Ownership of the 2500 afy Permit, LVVWD Groundwater Applications and any Further Permit or Certificate acquired by the Tribe under ¶ 3 above and the Tribe's entitlement to the Mitigation Surface Water Rights under ¶ 5.b above (collectively "Rights Subject to Reversion") shall revert to LVVWD or MVWD, as the case may be, as follows:

a. **Reversion.** The Rights Subject to Reversion shall revert if, prior to consummation of the WSA, the Tribe (or the United States on behalf of the Tribe), in any administrative or judicial proceeding, seeks federally-reserved groundwater rights appurtenant to the Reservation in excess of 14,480 afy ("Groundwater Reversion Trigger") or seeks federally-reserved surface water rights in the Muddy River appurtenant to the Reservation having diversion rates in excess of 11.5 cfs (Apr. - Sept.) and 10.5 cfs (Oct. - Mar.), a consumptive use limit in excess of 3700 afy, or a priority date earlier than March 12, 1873 ("Surface Water Reversion Trigger").

b. **Notice.** To exercise the above right of reversion, LVVWD or MVWD, as the case may be, must give the Tribe written notice of its intention to do so and the grounds therefor, and 120 days to reverse or terminate the Groundwater Reversion Trigger or Surface Water Reversion Trigger, as the case may be.

8. **Termination of Surface Water Lease.** The Surface Water Lease provided to the Tribe under ¶ 4.b above will instantly terminate upon the first occurrence of any of the following:

a. **Surface Water Reversion Trigger.** Occurrence of the Surface Water Reversion Trigger as defined in ¶ 7.a above, the giving of notice thereof by MVIC in the same manner provided in ¶ 7.b above, and the failure of the Tribe to reverse or terminate the Surface Water Reversion Trigger within the 120-day period specified in the notice.

b. **WSA.** "Judicial Confirmation" of the Tribe's federally-reserved water rights in the Muddy River as contemplated by the WSA.

c. **Adjudication.** Failing consummation of the WSA, adjudication in a court of competent jurisdiction of the Tribe's federally-reserved rights in the Muddy River appurtenant to the Reservation.

9. Change Applications in Case of Reversion or Termination. In the event of a reversion of Rights to Subject to Reversion under ¶ 7 above, or termination of the Surface Water Lease under ¶ 8 above, the Tribe shall cooperate with and not oppose the granting of any change applications reasonably necessary to restore the involved water rights to their original place of diversion, place of use and manner of use.

10. Monitoring Plan. The Parties shall in good faith diligently and cooperatively establish, agree on, and as necessary adjust over time a written plan for monitoring their respective uses of Muddy River water and groundwater from the California Wash Hydrographic Basin and adjacent hydrographic basins, and the water-related impacts therof, if any. Existing on-Reservation monitoring wells shall be incorporated in the monitoring plan and the plan shall be integrated with the Regional Monitoring Plans referred to in recital N of the MOA.

a. **Elements of Monitoring Plan.** Without limitation, such plan shall provide for: installation of appropriate metering devices by all Parties including parshall flumes (if not already installed) to meter the Parties' respective Muddy River diversions, provided that SNWA shall pay all costs of acquiring and installing (if not already installed) parshall flumes at the Muddy River diversion points on the Reservation (which shall be installed within 120 days of the effective date of this Agreement) ; the right of each Party to inspect diversion facilities, measuring devices (including any well meters) and pumping and diversion data of all other Parties; and appropriate methods for determining the Muddy River diversion rates, annual diversion amounts, and annual consumptive use amounts of each

Party, and the groundwater pumping rates and annual groundwater withdrawals of each Party.

b. **Interim Monitoring.** Pending finalization of such monitoring plan, each Party, on written notice, shall be accorded the right to reasonably monitor all ground and surface water diversions of any other Party from the Muddy River, the California Wash Hydrographic Basin and the hydrographic basins adjacent thereto, including reasonable access to and inspection of diversion facilities, measuring devices (including well meters) and pumping and diversion data.

11. **Notices.** All notices and communications given hereunder shall be in writing and shall be delivered by fax and first class, certified or registered mail, postage prepaid, to the fax numbers and addresses shown below, or to such other fax number or addressee as the Party entitled to notice may designate from time to time. Any notice given hereunder shall be deemed to be effective upon receipt.

If to Tribe: Chairperson, Moapa Band of Paiute Indians
Post Office Box 340
Moapa, Nevada 89025
Fax: 702-865-2875

with copies to: Steven H. Chestnut
Richard M. Berley
Ziontz, Chestnut, Varnell, Berley & Slonim
2101 Fourth Avenue, Suite 1230
Seattle, Washington 98121
Fax: 206-448-0962

If to LVVWD: General Counsel
Las Vegas Valley Water District
1001 South Valley View Boulevard
Las Vegas, Nevada 89153
Fax: 702-258-3268

If to SNWA: General Counsel
Southern Nevada Water Authority
1001 South Valley View Boulevard
Las Vegas, Nevada 89153
Fax: 702-258-3268

If to MVIC: General Manager
Muddy Valley Irrigation Company
Box 665
Overton, Nevada 89040
Fax: 702-397-6013

If to MVWD: General Manager
Moapa Valley Water District
Post Office Box 257
Logandale, Nevada 89021
Fax: 702-397-6894

12. No Waiver. No failure by a Party to insist upon the strict performance of any term or condition of this Agreement, or to exercise any right or remedy consequent upon noncompliance therewith, shall constitute a waiver of any such term or condition, it being understood that any such waiver shall require the written agreement of such Party.

13. Amendment. All amendments or modifications of this Agreement shall be effective only when reduced to writing and signed by all Parties.

14. Further Documents and Action. The Parties shall execute all further documents and do all further things as may reasonably be necessary to give full force and effect to the provisions of this Agreement.

15. Interpretation. This Agreement shall be construed as a whole and in accordance with its fair meaning. Captions are used for convenience and shall not be used in construing meaning.

16. Successors. Every obligation, term and condition of this Agreement shall extend to and be binding upon, and every right and benefit hereunder shall inure to, the assignees, transferees or other successors of the respective Parties by operation of law or otherwise.

17. Representations and Warranties of Authority. Each Party represents and warrants as follows: (a) that it and the individual executing the Agreement on its behalf is fully empowered and authorized to execute and deliver this Agreement; (b) that it is fully empowered and authorized to approve and perform this Agreement; (c) that this Agreement is binding on its interest at the moment of execution and for so long as this Agreement is in effect; (d) that its governing body has authorized and approved the foregoing representations and warranties by duly adopted written resolution, a copy of which will be provided to the other Party on execution of this Agreement; and (e) that it has obtained all approvals necessary to enter into and perform this Agreement, including without limitation the Tribe's taking of all actions necessary to accomplish the Tribe's waivers of sovereign immunity set forth herein and delivery by MVIC to the Tribe of a shareholder resolution approving this Agreement and the Surface Water Lease.

18. Counterparts. This Agreement may be executed and approved in multiple counterparts, each of which shall be deemed an original.

19. Dispute Resolution. In ¶ 6 above, the Tribe has expressly granted a waiver of sovereign immunity with respect to the enforcement of certain matters set forth in ¶ 6. Further, if a dispute should arise among the Tribe and any other Party or Parties with respect to the meaning or enforcement of any provision of this Agreement, any Party to the dispute may seek to resolve it only through a suit among such Parties brought in the Eighth Judicial District Court, Clark County, Nevada. The Tribe hereby waives its sovereign immunity as to such suits in such Court with respect to declaratory or injunctive relief only, and as to any appeals therefrom in appellate courts with jurisdiction over such appeals under State law. The Tribe hereby waives and foregoes any right to claim that exhaustion of Federal or Tribal court remedies is a prerequisite to any action brought in State court under this ¶ 19.

20. Entire Agreement. This Agreement constitutes the entire agreement among the Parties with respect to the matters covered hereby, and subsumes and incorporates all prior written and oral statements and understandings.

MOAPA BAND OF PAIUTE INDIANS

By ______________________________ Date: ______________________________

Chairman

LAS VEGAS VALLEY WATER DISTRICT

By ______________________________ Date: ______________________________

President

SOUTHERN NEVADA WATER AUTHORITY

By ______________________________ Date: ______________________________

Chair

MUDDY VALLEY IRRIGATION COMPANY

By ______________________________ Date: ______________________________

Chairman of the Board

MOAPA VALLEY WATER DISTRICT

By ______________________________ Date: ______________________________

Chairman of the Board