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A Conceptual Model OF Groundwater Flow in Spring Valley, NV, AND Snake Valley, NV-UT

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A CONCEPTUAL MODEL OF GROUNDWATER FLOW IN SPRING VALLEY, NV, AND SNAKE VALLEY, NV-UT

by

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of a thesis submitted by

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BRIGHAM YOUNG UNIVERSITY

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ABSTRACT

A CONCEPTUAL MODEL OF GROUNDWATER FLOW IN SPRING VALLEY, NV, AND SNAKE VALLEY, NV-UT

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Master of Science

A geochemical study of major springs and wells in Spring Valley, Nevada, and Snake Valley, Utah-Nevada was initiated in response to the Clark, Lincoln and White Pine Counties Groundwater Development Project proposed by the South Nevada Water Authority (SNWA). Water budget estimates suggest that interbasin flow accounts for a significant portion (~25%) of the water budgets in Spring and Snake Valleys. Although interbasin flow is possible in some areas, alternative plausible explanations place significant uncertainty on water budget allocations.

To examine the plausibility of local and interbasin flow paths the groundwater flow in Spring and Snake Valleys was evaluated using solute and isotopic data. Evidence for local flow paths includes: 1) stable isotope values in local areas which are similar to isotope values in adjacent recharge zones; 2) measurable ^{3}H content and ^{14}C activities $\geq$ 50 pmc in most samples, which suggests short residence times; and 3) plausible geochemical models of local flow paths.

Previously defined interbasin flow paths in southern Spring Valley are marked by samples that have low ^{14}C content (mean = 20.14 pmc), which is consistent with long residence times and can be explained by either interbasin flow from adjacent basins or deep circulation in the basin-fill sediments of Spring Valley. Interbasin flow from southern Spring Valley to southern Snake Valley cannot be confirmed or rejected based on the current data and modeling constraints, which result in plausible models involving both local flow paths and interbasin flow paths. Interbasin flow from northern Spring Valley to northern Snake Valley is unlikely and can be explained by the deep circulation of groundwater that is mixed with modern recharge.

The plausibility of alternative explanations to describe previously defined interbasin flow paths suggests that water budget allocations in Spring and Snake Valleys should be redistributed or reevaluated. The use of existing water budgets that allocate large components of water to interbasin flow to determine the distribution of water resources may result in incorrect estimations of resource availability.

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INTRODUCTION

Rapid population growth in the southwest United States places increasing pressure on finite water resources. As a result large population centers, such as Las Vegas, are exploring interbasin water transfers as a means to increase water supplies. Of particular interest is a recent proposal by the Southern Nevada Water Authority (SNWA) to extract 167,000 acre-feet/yr of groundwater, primarily from Spring Valley, Nevada and Snake Valley Nevada-Utah and transport it by pipeline to the Las Vegas Valley, as much as 475 km away. Approximately 60,000 acre-ft/yr would come from Spring Valley and about 50,000 acre-ft/yr would come from Snake Valley (SNWA, 2007). In April of 2007 the Nevada State Engineer approved applications by the SNWA for 60,000 acre-ft/yr in Spring Valley (SNWA, 2007).

Spring and Snake Valleys are located in the central portion of the Great Basin Province, near the Utah-Nevada border (Figure 1). The basins contain two main aquifers supported by: a) unconsolidated and semi-consolidated basin-fill sediments, and b) the underlying carbonate-rock aquifer (Welch and Bright, 2007). Basin-fill sediments are up to 7,000 m thick, although basin thickness is typically ~2,000 m (Welch and Bright, 2007). Basin-fill sediments generally consist of gravel, sand, silt, clay and some volcanic material (Harrill and Prudic, 1998). The carbonate-rock aquifer is regionally extensive and, where continuous, is thought to form a regional groundwater flow system, explained by the concept of interbasin flow (Plume, 1996; Figure 2). Data from the carbonate-rock aquifer is sparse and sampling locations that allow direct investigation of the carbonate-rock aquifer do not occur in the study area, therefore, all valley springs and wells sampled in this study discharge from or are completed in the basin-fill aquifer. Existing water budgets and groundwater elevations have been used to indirectly evaluate the occurrence and movement of groundwater in the carbonate-rock aquifer.

Estimates of interbasin flow have been made previously for Snake and Spring Valleys by Rush and Kazmi (1965), and Nichols (2000) (Table 1). More recently, the Basin and Range Carbonate Aquifer System Study (BARCASS) water budgets assigned 27% of the total recharge in Snake Valley to subsurface interbasin flow via the carbonate-rock aquifer and 24 % of total recharge in Spring Valley as interbasin flow from Lake and Steptoe Valleys (Welch and Bright, 2007; Figure 3). BARCASS estimates of interbasin flow are based on water budget imbalances (i.e. estimated surface recharge minus estimated near surface discharge). Systematic errors in estimations of the various components of the water budget may result in overestimation or underestimation of total water resources, and interbasin flow rates, which could have adverse affects on the long-term interbasin transfers of water supply.

Welch and Bright (2007) suggest that the carbonate-rock aquifer and basin-fill aquifer in Snake and Spring Valleys are hydraulically connected in certain areas, which results in the upward movement of regional groundwater from the carbonate-rock aquifer into the overlying basin-fill aquifer. This implies that some of the recharge entering the valleys as interbasin flow can be analyzed indirectly using groundwater in the basin-fill aquifer. Interbasin flow contributions should have older groundwater ages, due to the longer travel times, may be more chemically evolved, and may have other distinguishing isotopic features.

The purpose of this study is to create a conceptual model of groundwater flow in Spring and Snake Valleys and to evaluate interbasin flow using solute chemistry and stable and radioactive isotopes. The radio-isotopes ^3H and ^{14}C were used to evaluate groundwater residence times and dissolved chemical constituents and environmental isotopes such as $\delta^{18}O$, δD and $\delta^{13}C$ were used to evaluate possible groundwater flow paths, including suggested interbasin flow paths. Geochemical groundwater modeling techniques were used to incorporate geochemical data into a conceptual model and to test the plausibility of flow paths.

Geologic Setting

The geologic history of eastern Nevada can be summarized into 3 main phases: 1) during late-Precambrian to middle Paleozoic Era, ~ 9,200 m of carbonate sediment and minor amounts of clastic sedimentary interbeds were deposited along a passive continental margin, ultimately resulting in the formation of the so called carbonate-rock aquifer (Plume, 1996); 2) episodic Devonian to Eocene crustal compression due to plate collisions to the west, resulting in regional scale folding, crustal thickening, metamorphism and emplacement of plutons (Gans, 1987); 3) Cenozoic extensional faulting accompanied by volcanism and local sedimentation resulting in the formation of modern Basin and Range topography as valleys were down-dropped relative to the adjacent mountain ranges (Welch and Bright, 2007; Figure 4).

Spring and Snake Valleys are located in the Basin and Range Province and are topographically similar to other valleys in eastern Nevada. They are elongated north to south and are bound by north trending faults and mountain ranges (Figure 1). The valleys are filled with unconsolidated sediments that cover the underlying bedrock (Figure 4).

Gently sloping alluvial fan surfaces flank the mountain fronts and transition into relatively flat valley floors.

Snake Valley is 240 km long (including Hamblin Valley) and is bounded on the west by the Snake Range and to the southwest by the Limestone Hills (Figure 1). The Snake Range rises to a maximum elevation of 3,982 m above sea level (asl), and is as much as 2,430 m above the average valley floor elevation (1,580 m). Snake Valley is bounded on the east by numerous small mountain ranges, the most prominent being the Confusion Range. These ranges generally have low elevations (~2,130 m asl). The major extensional fault in Snake Valley is the Snake Range decollement, which is located on the west side of the valley and is a shallow east-dipping detachment fault that is exposed in the Snake Range and has been imaged beneath Snake Valley using deep seismic reflection data (Miller et al, 1999: Hauser et al, 1987). The thickness of basin fill sediments averages 1,525 m, but individual sub-basins contain thicker deposits (Welch and Bright, 2007).

Spring Valley is 177 km long and bound on the west by the Schell Creek Range and to the southwest by the Fortification Range (Figure 1). The Snake Range and Limestone Hills bound Spring Valley on the east and the Antelope Range and Kern Mountains bound Spring Valley to the north-northwest. The Schell Creek Range and Snake Range commonly exceed 3,000 m asl, with peaks in the central Schell Creek Range close to 3,670 m asl. Spring Valley is a broad, deep graben containing on average 2,000 m of basin-fill sediments (Welch and Bright, 2007). The major extensional structure is the Schell Creek fault which bounds Spring Valley on the west and has caused as much as 10 km of displacement creating an asymmetric geometry with the deepest part of the basin on the eastern side (Hauser et. al, 1987). The eastern margin of Spring Valley exhibits numerous normal faults that have fractured and offset the Paleozoic carbonate rocks (Gans et al, 1985).

The Schell Creek Range, Fortification Range, Snake Range, Limestone Hills, and Confusion Range contain folded and faulted Precambrian basement rocks, Paleozoic carbonate and non-carbonate shallow marine deposits, Tertiary intrusive rocks and volcanic rocks. However, the predominant bedrock is Paleozoic carbonate rock (Figure 4). The Schell Creek Range, which separates Spring Valley from Steptoe Valley to the west, is comprised mainly of Pre-Cambrian to Cambrian siliciclastic rocks and Paleozoic carbonate rocks (Figure 4). To the south the Fortification Range consists of Paleozoic carbonate rocks in the northern half and volcanic rocks in the southern half (Dixon and Rowley, 2006).

The Snake Range separates Spring and Snake Valleys. The core of the range contains low permeability granitic rocks and metamorphosed siliciclastic rocks and is flanked by carbonate rocks that have been displaced by the Snake Range decollement (Figure 4). Directly south of the Snake Range, the Limestone Hills are composed of carbonate rock and are bound by north-striking normal faults on the western and eastern sides. The Confusion Range located to the east of Snake Valley is composed of Paleozoic carbonates that were deformed during the Sevier Orogeny into a broad regional syncline (Welch and Bright, 2007).

Hydrogeologic Setting

Three groundwater systems have been identified in the area: mountain block, basin-fill alluvial, and the carbonate-rock (Plume, 1996; Kirby and Hurlow, 2005; Wilson and Guan, 2004). Mountain block groundwater systems are recharged by direct infiltration that flows through the soil zone and fractured carbonate, plutonic and siliciclastic bedrock. The resulting flow paths can vary from local to regional spatial scales. Local flow paths are typically short and involve shallow water circulation that generally discharges at springs or in streams. Regional mountain flow paths involve infiltration to deep groundwater, which may discharge into adjacent basins (Wilson and Guan, 2004).

The basin-fill system contains near-surface, coarse-grained alluvial fans that extend into the valleys and transition into the relatively flat valley floor where finer grained Quaternary sediments occur (Figure 4). The Quaternary sediments are underlain by a thick sequence of older Tertiary clastic sediments and in certain locations Oligocene volcanic rocks (Welch and Bright, 2007). Clastic sediment layers include interbedded gravel, sand, and fine-grained lake deposits (Hood and Rush, 1965).

The hydraulic conductivity of the basin-fill aquifer varies greatly because of the interbedded deposition of sands and impermeable shale layers creating confined to semi-confined aquifer conditions in some locations. Hydraulic conductivity also decreases with depth as a result of compaction. The size and depth of the aquifers vary greatly based on the geometry of the bedrock basins and sub-basins. Welch and Bright (2007) suggest that Spring Valley contains 4 sub-basins that deepen to the north. A maximum sediment depth of 5,000 m has been reported; however typical depth to bedrock in sub-basins ranges from 450 to 2000 m (Welch and Bright, 2007). Snake Valley consists of 5 sub-basins that generally contain west-tilted clastic sediments. A maximum thickness of 7,000 m has been observed in the most northern sub-basin (Welch and Bright, 2007).

Groundwater in the basin-fill aquifer flows from the mountain fronts along the margin of valleys to the center of valley floors (Figure 5a). Clusters of springs discharge at the base of alluvial fans near the valley floor where topographic gradients decrease. In general, the basin-fill groundwater in Snake Valley flows to the north. Welch and Bright (2007) suggests that there is a groundwater divide in Spring Valley near Highway 6/50 in the center of the valley that partitions groundwater flow to the north and south of the divide, although water elevations in the map they created do not support this assumption (Figure 5a).

The Paleozoic carbonate-rock aquifer is regionally extensive, covering the majority of the Basin and Range Province and underlying the basin-fill (Plume, 1996; Figure 2). Harrill and Prudic (1998) suggest that, where continuous, the carbonate-rock aquifer forms a regional aquifer system. These rocks are thought to have high horizontal hydraulic conductivity caused by fractures and joints that have been widened or sustained by dissolution (Plume, 1996). The aquifer consists primarily of limestone and dolomite and contains varying amounts of silt and interbedded shale (Plume, 1996).

Groundwater flow in the carbonate-rock aquifer is approximately eastward, based on groundwater elevations in wells completed in basin-fill sediments that are thought to represent the regional hydraulic head in carbonate-rock aquifer (Lewis, 2007; Figure 5b). Eastward groundwater flow thought to be accommodated by suggested interbasin flow paths via the carbonate-rock aquifer from southern Steptoe Valley into Spring Valley, and from Lake Valley into southern Spring Valley (Figure 3 and Figure 5b). Interbasin flow is also thought to occur from Spring Valley into Snake Valley both south and north of the Snake Range and also exiting Spring Valley to the north into Tippet Valley.

Previous Studies/Interbasin Flow

Interbasin flow was initially conceptualized as the subsurface movement of groundwater from one basin to an adjacent basin, often via the so-called carbonate-rock aquifer (Winograd, 1962; Eakin and Moore, 1964; Eakin, 1966; and Maxey and Mifflin, 1966). Evidence cited for interbasin flow involving Spring and Snake Valleys includes: 1) the presence of fractured carbonate rocks, 2) water level elevation difference in alluvium between the two valleys, and 3) imbalances in calculated water budgets. The evidences cited are necessary for interbasin flow to occur but do not confirm directly that groundwater is actually flowing across interbasin boundaries.

Early studies suggested 4,000 acre-ft/yr of interbasin flow occurs from southern Spring Valley to Snake Valley (Hood and Kazmi, 1965) and 19,500 acre-ft/yr from Pine and Wah Wah Valleys into Snake Valley (Hood and Rush, 1965; Figure 3; Table 1). About 2,000 acre-ft/yr of interbasin flow was also suggested from Tippet Valley to Spring Valley (Hood and Kazmi, 1965). Subsequent studies also invoked interbasin flow to balance surface-groundwater budgets in Spring and Snake Valleys (Nichols, 2000; Welch and Bright, 2007). Nichols (2000) estimated 14,000 acre-ft/yr of interbasin flow occurs from Spring Valley to Snake Valley north and south of the Snake Range (Figure 3). BARCASS estimates of interbasin flow are 4-5 times greater than previous estimations and represent a large portion of the recharge entering Spring and Snake

Valleys (Welch and Bright, 2007). Large interbasin flow volume estimates tend to be related to systematic regional errors in calculated recharge and discharge values and demonstrate the sensitivity of water budget calculations to inputs and other assumptions. Interbasin flow into Spring Valley was estimated to be 24% of the total recharge and inflow into Snake Valley was estimated to be up to 27% of the total recharge. Inflow into Spring Valley is thought to occur from Steptoe, Lake and Tippet Valleys and from Spring Valley into Snake Valley (Welch and Bright, 2007; Figure 3 and Table 1).

METHODS

Field Methods

Forty locations were sampled for major ion chemistry (40), stable isotopes (40), tritium (40), and carbon-14 (24) (Figure 6, Appendix A-1). Some of these samples were collected in conjunction with the Utah State Geological Survey. Three 1 L high-density brown polyethylene bottles were used to collect water for major solutes, stable isotopes ($\delta^{18}O$ and δD) and ^{3}H. Splits of water for cation and anion analysis were filtered in the laboratory with a 0.45 µm filter. Cation splits were acidified with 5–6 drops of 7 N of trace-metal grade nitric acid in ~50 mL of filtered water. Temperature, pH, and conductivity were determined in the field using a VWR Scientific (model 2000) pH meter and YSI 30/10 conductivity meter.

Splits for $\delta^{18}O_{VSMOW}$ and δD_{VSMOW} analysis were taken in ~50 mL amber vials with polyseal caps. $\delta^{13}C_{VPDB}$ and ^{14}C samples were collected in high-density polyethylene containers. Samples were treated with centrifuged (to remove extraneous carbonate) 10 M NaOH-$BaCl_2$ solutions until a pH>11 was achieved. Additional $BaCl_2$

was then added to quantitatively precipitate carbonate species as $BaCO_3$. Samples were decanted and rinsed with >18.2 MΩ/cm de-ionized water under normal tank N_2: (1) to avoid atmospheric contamination, and (2) to eliminate excess Ba^{2+} ions that could lead to further precipitation of $BaCO_3$ from atmospheric CO_2 during storage. Slurries were stored in amber glass bottles with polyseal caps prior to analysis.

Analytical methods

Analytical methods described below apply only to samples collected specifically for this study. Anion concentrations were determined at Brigham Young University (BYU) using a Dionex 4100 ion chromatograph. Cation abundances were measured with a Perkin Elmer 5100C Atomic Absorption Spectrometer. The acceptable charge balance error was less than 5%. Stable isotope ratios, $\delta^{18}O_{VSMOW}$, δD_{VSMOW}, and $\delta^{13}C_{VPDB}$, were measured at BYU with a Finnigan Delta^{plus} isotope ratio mass spectrometer. The methods used were similar to Epstein and Mayeda (1953); Gehre et al. (1996); McCrea (1950). $\delta^{18}O_{VSMOW}$ and δD_{VSMOW} values were normalized to the VSMOW/SLAP scale (Coplen, 1988; Nelson, 2000; Nelson and Dettman, 2001). Reproducibility was evaluated using an internal laboratory standard with results of 0.4‰ (n=111) for δD_{VSMOW} and 0.15‰ for $\delta^{18}O_{VSMOW}$ (n=80). $\delta^{13}C_{VPDB}$ values were measured against NBS-19 calibrated reference gases. Tritium (^3H) and ^{14}C samples were measured by liquid scintillation counting at Brigham Young University (BYU). Water was analyzed for ^{14}C from $BaCO_3$ precipitates. It was then synthesized to benzene after the methods of Noakes (1963). Beta decays were then counted with PerkinElmer Guardian and Quantulus liquid scintillation counters (LSCs) and the results reported as percent modern carbon (pmc) in a process similar to the methods described in Clark and Fritz (1997), Polach and Stipp (1967) and Stuvier and Polach (1977). Water was analyzed for ^3H also using a PerkinElmer Quantulus LSC. Tritium concentrations are reported in ^3H units (TU; 1 TU = 3.2 pCi/L). All samples were electrolytically enriched due to low ^3H abundances and have associated uncertainties of about 0.1 TU.

Compilation of Existing Data

In addition to the 40 sites sampled for this investigation, data for 54 locations were obtained from the literature (Hershey et al, 2007: Hershey, 1995; Figure 6, Appendix A-1). Solute data were checked for charge balance and only samples with a charge balance of less than 5% were used for solute analysis. Average values were calculated for sampling sites that contain multiple sets of solute and isotopic data except where noted otherwise. The average values were then used to represent the sampling location.

Data Analysis

Groundwater temperatures were estimated using the computer code GEOTHERM (Trunsdal, 1976). Adabatic and conductive silica geothermometers were used to estimate aquifer temperatures in select samples (Fournier and Rowe, 1966: Fournier and Potter, 1982). Circulations depths were calculated according to Mayo and Loucks (1995) using the spring discharge temperatures and temperatures estimated from the adabatic and conductive silica geothermometers (Table 2).

Statistical cluster analysis was used to group samples with similar solute concentrations into related groups. Clusters were then analyzed and regrouped in some cases according to aquifer rock type. This was used in order to distinguish possible flow paths and groundwater systems (i.e. local and regional). Temperature, pH and major cations and anions were used as criteria for the analysis. Table 3 summarizes the solute concentrations of cluster groups (Appendix A-2).

The major ion chemistry of cluster groups was also evaluated by using stiff diagrams and piper diagrams (Figures 7 & 8). Stiff diagrams were plotted geographically using ARC GIS to illustrate and compare spatially the distribution of major ions in the groundwater system. Piper diagrams were used to recognize mixing patterns, chemical evolution along flow paths and to identify water types.

The $\delta^{18}O$ and δD in mountain springs with short flow paths were used as surrogates for modern recharge and were compared to basin-fill samples (Figure 9). $\delta^{18}O$ vs. δD values were also compared with the global meteoric water line (GMWL) to evaluate the possibility of evaporation (Figure 9). A contour map of $\delta^{18}O_{VSMOW}$ and δD_{VSMOW} was also created to analyze the distribution of stable isotope values (Figure 10).

$\delta^{13}C$ values were used as indicators of flow paths and to show carbonate species evolution along a flow path (Figure 11). Radio-isotopes (^3H and ^{14}C) were used to evaluate mean residence times and potential flow paths. ^3H concentrations were used as indicators of modern recharge. Contour maps were created to compare the ^{14}C content and ^3H content of samples and to illustrate the distribution of relative groundwater ages (Figure 12 and 13).

Chemical mass balance calculations were performed using NETPATH (Plummer et al., 1991) to test the plausibility of interbasin flow paths from Spring Valley to Snake Valley. Modeling constrains include C, Ca^{2+}, Na^{+}, S, Cl^{-}, Mg^{2+} and $\delta^{13}C$ values. Mineral phases used in NETPATH models were determined by the rock types found in the study area and include calcite, CO_2 gas, dolomite, halite, gypsum and Ca^{2+} and Na^{+} ion exchange. Paleozoic carbonates are the most common rock type and therefore calcite and dolomite were included as phases. Calcite can act as either a source or a sink for Ca^{2+} and C. Dolomite provides a source of Ca^{2+}, C and Mg^{2+}. CO_2 gas was included as a source and sink for C. Cation exchange of Ca^{2+} and Na^{+} in alluvium was also permitted in models. Gypsum and halite were included as phases because of the presence of alluvium at discharge locations, which may contain evaporite minerals and because of minor amounts of residual evaporite minerals in the carbonate rock. They provide sources of Na^{+}, SO_4^{2-}, Ca^{2+} and Cl^{-}.

RESULTS

Temperature and Circulation Depth

Groundwater temperatures range from 3.5 – 28.2 ºC, with a mean of 12.8 ºC (Appendix A-1). Mean annual air temperature is ~10 ºC (8.6 ºC at Great Basin National Park, 10.3ºC at Garrison, UT and Eskdale, UT 10.5; Western Regional Climate Center). Circulation depths based on discharge temperatures for low temperature (<30 ºC) geothermal samples are as high as 530 m using the average western United States geothermal gradient of 34ºC/km (Nathenson and Guffanti, 1988). Adiabatic and conductive silica geothermometers estimated groundwater temperatures for select samples that ranged from 56 to 95 ºC using the computer code GEOTHERM (Truesdell, 1976; Table 2). Estimated circulation depths were as much as 2,000 m greater than circulation depths based on discharge temperature alone. The estimated circulation depth for Big Springs was 2,500 m and was shallower for Gandy Spring and South Fox well which had estimated circulation depths of 1,750 and 1,367 m respectively (Table 2). Shoshone Ponds well had an estimated circulation depth of 1,705 m.

Geochemistry

Total Dissolved Solids (TDS) and Solute Composition

Mountain block TDS and solute concentrations are influenced by contact with carbonate, plutonic, volcanic and siliciclastic rocks. In general springs that discharge from siliciclastic/plutonic rocks have low TDS (<200 mg L^{-1}), which averages 171 mg L^{-1} (Figure 14). The TDS of groundwater discharging from volcanic rock is slightly greater and averages 228 mg L^{-1}. Groundwater discharging from carbonate bedrock typically has greater TDS and averages 466 mg L^{-1}.

Samples were grouped into clusters that have similar solute compositions using a cluster analysis (Table 4, Appendix A-2). Clusters 1 and 2 represent the solute concentration of springs that discharge from siliciclastic/plutonic rocks (Figure 7). They are dilute Ca^{2+}-HCO_3^- water types that have an average TDS of 80 and 180 mg L^{-1}, respectively (Figure 8). The low TDS is likely the result of water-rock interactions with silicate minerals such as feldspar in siliciclastic and plutonic rocks. Springs in volcanic rock contain slightly greater TDS and are generally represented by Cluster 2. Clusters 3 and 4 represent the solute chemistry of water has been in contact with carbonate bedrock.

Cluster 3 is a Ca^{2+}-HCO_3^- water that contains high TDS (311 mg L^{-1}) with relatively little Mg^{2+} resulting from the interaction with mainly limestone rock. Cluster 4 is similar to Cluster 3 but contains higher TDS and significant Mg^{2+} resulting from increased interaction with dolomite (Figure 7).

Solute concentrations of mountain springs represent the initial water chemistry of local groundwater systems that recharge basin-fill aquifers. In certain locations the solute chemistry of the basin-fill mimics the concentrations of bedrock springs, such as at the base of the Schell Creek Range in northern Spring Valley and near the Snake Range in southern Spring Valley, where low TDS springs represented by Cluster 1 discharge water that is geochemically similar to adjacent mountain block springs (Figure 7).

Samples represented by Cluster 6 are located in northern Spring Valley and have TDS (283 mg L^{-1}) that is lower than Clusters 3 and 4 but greater than Clusters 1 and 2 suggesting a mixture of groundwater that has been in contact with carbonate and siliciclastic/plutonic rocks. Cluster 7 waters represent groundwater that has undergone ion exchange with basin-fill sediments resulting in the addition of considerable Na^+. Cluster 8 is a Mg^{2+}-Ca^{2+}-HCO_3^- water that is located in southern Spring Valley.

Clusters 9, 10 and 11 represent groundwater that has interacted with basin-fill sediments including evaporite minerals halite and gypsum. Cluster 9 samples are generally shallow wells that represent shallow groundwater systems that have been in contact with near-surface basin-fill sediments. The groundwater along the eastern margin of Snake Valley fits into Clusters 10 and 11 and contains relatively greater TDS (average 480 mg L^{-1}) and is geochemically distinct compared to other springs in Spring or Snake Valleys. It has a Ca^{2+} to mixed cation concentration and contains greater amounts of Na^+,

Mg^{2+}, SO_4^{2-} and Cl^- (Figure 7). In general TDS and solute concentrations increase to the north-northeast, perhaps resulting from water-rock interactions with predominantly carbonate bedrock and from possible interaction with lake sediments.

Stable Isotopes

Most sampling sites lie parallel to, but below the global meteoric water line (GMWL, $\delta D=8*\delta^{18}O_{vsmow}+10$; Craig, 1961; Figure 9). In general $\delta^{18}O$ and δD values vary geographically from north to south with the latter being more enriched (Figure 10). In a small geographic area variations in stable isotopes are generally related to temperature differences resulting from elevation changes or climatic factors (Clark and Fritz, 1997). However, the stable isotopes in Spring and Snake Valleys are not influenced by elevation differences but seem to be controlled by latitudinal variations (Figures 15-16). On average, the mountains to the north including the Schell Creek Range, Antelope Range and Kern Mountains are relatively depleted in $\delta^{18}O$ and δD values compared to the Snake Range and the Fortification Range (Figure 17).

The variation in mountain block isotopes results in isotopic differences in adjacent basin-fill samples. $\delta^{18}O$ and δD values in Spring and Snake Valleys overlap but on average are more enriched in Snake Valley (Figure 17). Locally δD values in northern Spring Valley basin-fill samples range from -109.0 to -126.0‰ and overlap with δD values in adjacent mountain ranges such as the Schell Creek Range, Antelope Range and the northern Snake Range where the δD values range from -113.4 to -124.0‰. Southward, stable isotope compositions become more enriched in the southern Snake Range and Fortification Range where δD values vary from -105.6 to -114.5‰. Southern

Spring Valley basin-fill samples have δD values that are similar to the isotope compositions of the southern Snake Range and Fortification Range and vary from -104.9 to -115.4 ‰.

$\delta^{13}C$

Mountain spring $\delta^{13}C$ values range from -6.6 to -18.7‰ (Table 4). The $\delta^{13}C$ values for Spring and Snake Valleys range from -2.8 to -14.3‰. $\delta^{13}C$ in samples located in the central portion of Spring and Snake Valleys range from -6.8 to -13.55 ‰, which is consistent with the dissolution of soil zone carbonate minerals in the presence of soil gas. However, groundwater becomes increasingly enriched in $\delta^{13}C$ along the western margin of southern Spring Valley near proposed interbasin flow paths where $\delta^{13}C$ ranges from -2.8 to -6.94 ‰ (Figure 11). The mean $\delta^{13}C$ in southern Snake Valley is -8.14 ‰, but one sample is as high as -3.2‰. Springs located along the eastern margin of Snake Valley also contain enriched $\delta^{13}C$ values (mean = -5.52‰).

Tritium (^3H)

Mountain springs located in the Snake Range can be used as surrogates for modern recharge and contain ^3H concentrations similar to local precipitation (Table 4). ^3H contents range from 0.4 - 9.8 TU with an average of 5.5 TU. This compares to precipitation samples collected between 1998 and 2005 in Lindon, UT that have an average of 6.8 TU (Mayo, personal communication). Small quantities of ^3H were found in most basin-fill samples, and range from below detection (<0.2) to 4.3 TU in Snake Valley and from below detection (<0.2) to 5.3 TU in Spring Valley (Figure 13). In general, groundwater near efficient areas of recharge such as the Snake Range or the Schell Creek Range has a large component of modern recharge (i.e. high ^{3}H; Figure 13). ^{3}H content decreases in samples located further from the Snake Range and is lowest at the valley margins (Figure 13). Springs and wells that are near low elevation mountains, such as the Confusion Range and Fortification Range, that are not directly recharged by the Snake Range or Schell Creek Range (i.e. springs on the eastern side of Snake Valley or on the western side of southern Spring Valley) generally have ^{3}H concentrations of < 1 TU.

Carbon 14

^{14}C activities range from 12.8 to 108 percent modern carbon (pmc; Table 4). The majority of samples (26 out of 42) have ^{14}C activities of ≥ 50 pmc, indicating modern groundwater in a carbonate terrene (Clark and Fritz, 1997). Similar to the distribution of ^{3}H contents, samples located near areas of significant recharge have modern water (>50 pmc). Groundwater with low ^{14}C content (i.e. relatively older groundwater) is found on the western margin of southern Spring Valley, on the eastern margin of Snake Valley and near the eastern base of the Limestone Hills (Figure 12). The distribution of older groundwater in southern Spring and Snake Valleys mimics suggested interbasin flow paths (Figures 3 and 12). On the western margin of southern Spring Valley four samples contain ^{14}C activities that range from 12.8 - 28 pmc and average 20.14 pmc. These samples include North Spring, South Spring, South Fox well and USGS MX (Spring Valley Central) well (Table 4). These samples are located near proposed interbasin flow paths from Lake and Steptoe Valley (Figure 3). Big Springs and USGS-MX (Hamblin

Valley South) well are located in Snake Valley near the proposed interbasin flow path from Spring Valley. They have ^{14}C activities of 35.14 and 23.0 pmc respectively, although there are other samples in the area that contain more modern ^{14}C activities (i.e. Hyde Well, North Little Spring).

Geochemical Modeling

Mass balance models (NETPATH; Plummer et al., 1991) were employed to evaluate local and proposed interbasin flow paths in Spring and Snake Valleys (Figure 19). The origin of water was evaluated by examining: (1) reactions required for recent recharge (mountain springs) to evolve to the composition of groundwater in the interior of Spring and Snake Valleys (i.e. local recharge), (2) reactions required for Spring Valley water to evolve to the composition of Snake Valley water (i.e. interbasin flow), and (3) reactions required for contributions from both local recharge and interbasin flow (Figure 19).

Local Flow Paths

The mean solute composition of Clusters 3 and 4 was used as an initial water to represent the solute chemistry of water that has been in contact with carbonate rocks (i.e. carbonate bedrock water). Cluster 1 was used as the initial water for flow paths that interact with siliciclastic rocks (i.e. Siliciclastic water). Initial and final waters used in geochemical models are summarized in Table 5. Local flow paths include mountain bedrock to basin-fill sediments, and mountain bedrock to mountain front fault systems. Local flow paths are briefly described below and are shown in Figure 19 according to the corresponding numbers:

1. Carbonate to Basin-Fill Water Type: The evolution of carbonate bedrock water to basin-fill water includes calcite precipitation, acquisition of CO_2 gas, dissolution of dolomite, halite and gypsum, and ion exchange (Figure 20). Plausible NETPATH models calculate $\delta^{13}C$ values that are slightly enriched compared to observed values (Table 6). This flow path represents shallow basin-fill groundwater systems located near predominantly carbonate bedrock.

2. Siliciclastic to Basin-fill Water Type: The evolution of siliciclastic bedrock water to basin-fill water includes the acquisition of CO_2 gas, dissolution of calcite, dolomite, halite and gypsum, and ion exchange (Figure 20). Plausible NETPATH models also calculate comparable $\delta^{13}C$ values (Table 6). The evolution of this flow path can be used to represent other dilute basin-fill groundwaters that are located near siliciclastic or plutonic bedrock.

3. Mixed Siliciclastic and Carbonate Water Type: The abundance of siliciclastic and carbonate bedrock in adjacent mountain ranges results in the mixture of waters influenced by flow through siliciclastic and carbonate rocks. The resulting mixture of mountain block water influenced by rock type creates a hybrid of TDS and solute concentrations in basin-fill samples. The groundwater in northern Spring Valley is almost entirely of this origin and is mainly represented by Cluster 6, although Cluster 5 also exhibits some mixing. NETPATH models result in ion exchange and the dissolution of calcite, dolomite and the exsolution of CO_2 gas (Figure 20). Calculated mixing ratios suggest that approximately 60 % of the water has been contact with siliciclastic rock and 40 % originates from carbonate interaction (Table 6). In northern Spring Valley Cluster 5 samples result from the mixing of 70 % carbonate bedrock water and 30% siliciclastic bedrock water. NETPATH models also require the dissolution of very small amounts of dolomite, gypsum, halite and ion exchange.

4. ***Carbonate to Basin-Fill (Mg^{2+}-Ca^{2+}-HCO_3^-) Water Type***: Samples on the western margin of southern Spring Valley contain Mg^{2+}-Ca^{2+}-HCO_3^- water represented by Cluster 8. NETPATH models were created that show the potential evolution from carbonate bedrock water to Mg^{2+}-Ca^{2+}-HCO_3^- water (Table 5). TDS is greater in carbonate bedrock water and must decrease by either precipitation or dilution along the flow path. NETPATH models require calcite precipitation, CO_2 gas exsolution and dissolution of gypsum, halite and dolomite (Figure 21). Observed $\delta^{13}C$ values are comparable to computed values (Table 6). Mg^{2+} concentrations are greater than Ca^{2+} concentrations suggesting that additional Mg^{2+} does not simply result from the dolomite dissolution. Additional Mg^{2+} could result from reactions with basin-fill sediments (Ca^{2+} and Mg^{2+} exchange) or could result from mixing with water that has a poorly-defined but elevated Mg^{2+} concentration.

5. Confusion Range Thermal Water: Relatively warm water (19.8 °C) discharges on the eastern margin of Snake Valley and is represented by Cluster 10. Initial waters were represented by the mean composition of carbonate bedrock water because of the proximity to carbonate bedrock in the Confusion Range. Models require the dissolution of halite and gypsum to account for Na^+, Cl^- and SO_4^{2-} increases but also require the dissolution of marine carbonate minerals to enrich $\delta^{13}C$ values to match observed discharge values. With $\delta^{13}C$ as a constraint NETPATH did not calculate plausible models. Models that did not contain $\delta^{13}C$ as a constraint resulted in ion exchange, calcite precipitation and the dissolution of halite, gypsum and CO_2 gas (Figure 22). Models computed $\delta^{13}C$ to be significantly depleted, -9.58‰, compared to observed values of -5.52‰ (Table 6). The inability to model modern recharge to Cluster 10 suggests that the flow paths are more complicated than direct flow from the Confusion Range to the basin-fill. The warm discharge temperature (19.8 ºC) and low ^{14}C (35.14 pmc) content suggests relatively longer residence times and deeper groundwater circulation possibly along range bounding faults. The enrichment of $\delta^{13}C$ values is interpreted to result from the upwelling of enriched fault zone CO_2.

6. Suggested Interbasin Flow Final Waters: Gandy Spring in northern Snake Valley and Big Springs and USGS MX (Hamblin Valley South) well in southern Snake Valley represent final waters for interbasin flow scenarios. Although interbasin flow is considered below, these three samples were given additional attention to determine the possibility of local recharge. They are relatively warm (17.1 – 27.0 ºC) suggesting deep circulation and are considered to have similar flow paths based on their proximity to carbonate bedrock. Mixing with modern water is suggested by their elevated ^3H contents, which vary from 1.9 TU at Big Springs to 4.3 TU at Gandy Spring.

Local flow paths for Gandy Spring include initial waters influenced by contact with carbonate bedrock and siliciclastic bedrock (Table 5). NETPATH could not calculate plausible models to Gandy Spring with $\delta^{13}C$ values as a constraint. Without $\delta^{13}C$ as a constraint, models that evolve carbonate bedrock water to Gandy Spring require the precipitation of calcite, the exsolution of CO_2 gas, the dissolution of gypsum and halite, and ion exchange (Figure 23). NETPATH computed depleted $\delta^{13}C$ values (-9.4 ‰), compared to the observed values that range from -4.33 to -7.0‰ (Table 6). Models that evolve a mixture of carbonate bedrock water and siliciclastic/plutonic water require computed $\delta^{13}C$ values are extremely depleted.

The relatively high discharge temperatures suggest deep circulation but ^{3}H and ^{14}C contents suggest short residence times. Gandy Spring represents a mixture of deeply circulated groundwater and shallow modern recharge resulting in high ^{3}H concentrations. Although no geothermal end-member waters exist in the study area, Monte Neva Hot Spring located in the adjacent Steptoe Valley was used as an analogue for deeply circulated (i.e., > 3,000 m) geothermal water. NETPATH models that evolve Monte Neva Hot Spring with carbonate bedrock water produce plausible models that exhibit $\delta^{13}C$ values that are within the range of observed $\delta^{13}C$ values (Table 6). Models require the dissolution of halite, gypsum and dolomite, the precipitation of calcite, the exsolution of CO_2 gas and ion exchange (Figure 23). Mixing ratios suggest that geothermal water comprise 30-40 % of the water discharging at Gandy Spring (Table 6).

The solute composition of Big Springs is similar to carbonate bedrock water although the TDS is slightly lower. Local flow paths to Big Springs require either precipitation or dilution to account for the minor TDS differences. Plausible NETPATH models that evolve carbonate bedrock water to Big Springs require the precipitation of calcite, exsolution of CO_2 and the dissolution of dolomite (Figure 24). Computed $\delta^{13}C$ values are comparable to observed values (Table 6).

USGS MX (Hamblin Valley South) well is located near Big Springs and has a similar solute composition. The chemical evolution of carbonate bedrock water to USGS MX (Hamblin Valley South) well results in ion exchange, the precipitation of calcite and the dissolution of CO_2 gas, gypsum and halite (Figure 24). Computed $\delta^{13}C$ values are comparable to observed values (Table 6).

Groundwater models that use Monte Neva Hot Spring from Steptoe Valley as a geothermal analogue do not result in plausible NETPATH models to Big Springs or USGS MX (Hamblin Valley South) well. Geochemical modeling suggests that local flow paths alone can account for the water discharging at Big Springs and USGS MX (Hamblin Valley South) well.

Suggested Interbasin Flow Paths

Interbasin flow has been used as a mechanism to explain water budget imbalances in Spring and Snake Valleys that in some cases represent a significant portion (~25%) of the water budget (Table 1). The area south of the Snake Range near the Limestone Hills has been repeatedly suggested as an interbasin flow path between southern Spring and Snake Valleys (Figure 3). In recent studies the area north of the Snake Range has also been identified as an interbasin flow path from northern Spring

Valley to Snake Valley. These two suggested interbasin flow paths are described below and are shown in Figure 25:

*7. **Southern Interbasin Flow Path:*** Initial waters in Spring Valley are not easily defined, although previous authors have used South Fox well to represent flow from Spring Valley to Snake Valley (Rush and Kazmi, 1965: Hershey, 2007). South Spring, North Spring and USGS MX (Spring Valley Central) well are located near South Fox well and have similar ^{14}C content (average 20.14 pmc) and $\delta^{13}C$ values (-6.51) which are characteristic of interbasin flow (Figure 25). Although isotopic values are similar, they contain distinct solute compositions resulting in two possible initial waters to represent the composition of Spring Valley water. Initial waters in Spring Valley are represented by the mean solute concentrations of South Fox well/South Spring (Initial water #1) which is a Mg^{2+}-Ca^{2+}-HCO_3^- water and North Spring/ USGS MX (Spring Valley Central) well (Initial water #2) which is a Ca^{2+}-HCO_3^- water (Table 5; Figure 25). The choice of final waters in Snake Valley is also unclear, although Big Springs and USGS MX (Hamblin Valley South) contain low ^{14}C activities and are therefore most likely representative of final waters (Table 5; Figure 25).

The direct chemical evolution of groundwater from initial waters in Spring Valley to final waters in Snake Valley is not plausible because $\delta^{13}C$ values become more depleted and ^{14}C activities are higher in final waters. Big Springs and USGS MX (Hamblin Valley South) well also contain measurable ^{3}H. Thus, realistic interbasin flow models must include a component of modern recharge.

Modern recharge was represented as carbonate bedrock water (mean values of clusters 3-4) because of the proximity to carbonate bedrock in the Snake Range. Multiple NETPATH models were created that evolve initial Spring Valley waters #1 and #2 with some percentage of modern carbonate bedrock water to final waters Big Springs and USGS MX (Hamblin Valley South) well.

Big Springs TDS (330 mg L^{-1}) is less than or slightly greater than the TDS of initial (269 – 336 mg L^{-1}) and carbonate bedrock waters (311 to 420 mg L^{-1}). In particular Na^{+} and SO_4^{2-} concentrations at Big Springs are slightly less than initial and carbonate bedrock waters resulting in the apparent required precipitation of gypsum and halite or reverse ion exchange along flow paths. The compositional differences are minimal although they do result in otherwise unrealistic models; therefore, Na^{+} and SO_4^{2-} were ignored as constraints.

The evolution of initial water #1 and carbonate bedrock water to Big Springs results in the acquisition of CO_2 gas, and the dissolution of dolomite and calcite (Table 5; Figure 26). Computed $\delta^{13}C$ values are comparable to observed values (Table 6). Mixing ratios suggest that 92 % of the water that discharges at Big Springs is from Spring Valley based on this model. The evolution of initial water #2 and carbonate bedrock water to Big Springs results in the precipitation of calcite, the exsolution of CO_2 gas and the dissolution of dolomite (Figure 26). Computed $\delta^{13}C$ values are comparable to observed values (Table 6). Mixing ratios suggest that 80-60 % of the water that discharges at Big Springs is from modern carbonate bedrock.

NETPATH models to USGS MX (Hamblin Valley South) well used C, SO_4^{2-}, Na^{+}, Cl^{-}, Ca^{2+} and $\delta^{13}C$ as constraints. The concentration of Mg^{2+} in USGS MX

(Hamblin Valley South) well is slightly less than initial and modern carbonate water component resulting in unrealistic models. USGS MX (Hamblin Valley South) well generally has less Ca^{2+} and HCO_3^- requiring calcite precipitation. The evolution of initial water #1 and carbonate bedrock water to USGS MX (Hamblin Valley South) well involves ion exchange, the precipitation of calcite and the dissolution of gypsum and halite (Table 5; Figure 26). Computed $\delta^{13}C$ values are comparable to observed values (Table 6). The mixing ratio suggests that 57 % of the water that discharges at USGS MX (Hamblin Valley South) well is from modern carbonate bedrock water. The evolution of initial water #2 and carbonate bedrock water requires the precipitation of calcite, the dissolution of gypsum and halite and ion exchange (Figure 26). Computed $\delta^{13}C$ values are comparable to observed values. Mixing ratios suggest that 75 % of the water that discharges at USGS MX (Hamblin Valley South) well is from modern carbonate bedrock water (Table 6).

The modeling scenarios discussed above suggest that it is possible to model local or interbasin flow paths to adequately represent the water at Big Springs and USGS MX (Hamblin Valley South) well.

8. Northern Interbasin Flow Path: Geochemical modeling from northern Spring Valley to northern Snake Valley is complicated by inaccuracy and an overall lack of data. Gandy Spring in Snake Valley has been suggested as a discharge point for interbasin flow from northern Spring Valley (Nichols, 2000; Hershey, 2007). Hershey et. al. (2007) used the solute composition of Elderidge well to represent the geochemical composition of interbasin flow water from Spring Valley. However two factors suggest that the use of Elderidge well to represent interbasin flow water is incorrect: first, the solute data does not properly charge balance, and second, water level elevations do not suggest eastward groundwater flow in the basin-fill other than the obvious elevation differences between Spring and Snake Valleys (Figure 5a).

In order to fully address the complications of choosing an initial water in northern Spring Valley a more complete understanding of the mechanism of interbasin flow from northern Spring Valley to Snake Valley is needed. Assuming that Elderidge well does represent the solute composition of interbasin flow water, the mean composition of Cluster 9 samples, which appear to have a similar solute chemistry, were used as substitutes for Elderidge well because the charge balances are acceptable.

The direct chemical evolution of groundwater from Spring Valley (Cluster 9) to Gandy Spring is not plausible because of the abundant ^{3}H at Gandy spring and similar ^{14}C activities at initial and final waters. Thus, realistic models must include component of modern recharge.

Modern recharge mixing options along the flow path include carbonate bedrock water and siliciclastic water because of these prominent bedrock types in Snake Range and Kern Mountains. NETPATH did not calculate plausible models with $\delta^{13}C$ as a constraint for any combination of modern recharge components and initial waters. The evolution of initial waters in Spring Valley (Cluster 9) and carbonate bedrock springs results in ion exchange and the dissolution of CO_2 gas, dolomite, gypsum and halite (Figure 23). $\delta^{13}C$ values computed by NETPATH are depleted (-10.11 ‰) compared to the observed range of -4.33 to -7.0 ‰ (Table 6). All models from northern Spring Valley to Snake Valley produce similar reactions and compute similar $\delta^{13}C$ values that do not account for the enriched $\delta^{13}C$ values at Gandy Spring and therefore suggest that interbasin flow from Spring Valley is unlikely.

DISCUSSION

Conceptual Underpinnings of Data

Data directly from the carbonate-rock aquifer is not available in the study area, therefore, the direction of groundwater flow and also water budget allocations to interbasin flow are largely based on assumptions and not actual data from the carbonate-rock aquifer. BARCASS geochemical modeling of interbasin flow paths is based on the presumed “upward leakage” from the carbonate-rock aquifer into the basin-fill sediments (Hershey et. al., 2007). This study is constrained by the same limitations, as all inferences drawn are based on samples that have interacted with basin-fill sediments even if the waters have flowed upward from the carbonate aquifer.

The production capacity of the carbonate-rock aquifer is also largely unknown because of the lack of direct observation and testing, although this has not hindered the allocation of water resources.

Local Flow Systems

Local flow paths that originate in the mountain block system and discharge in basin-fill sediments as springs or are lost to evapotransporation (ET) is suggested by geochemical and isotopic data for much of the study area. First, stable isotope values in local areas, such as, northern Spring Valley plot near local recharge sources relative to the GMWL, suggesting local recharge in the mountains and local groundwater flow down gradient to the adjacent basin-fill sediments (Figure 18).

Second, ^{3}H and ^{14}C data suggests that most mountain block to adjacent basin-fill groundwater flow systems contain modernly recharged water and have short residence times (Figures 12 & 13). ^{3}H contents for mountain springs average 5.5 TU which is in the range of precipitation samples collected in Lindon, Utah, which average 6.8 TU (Mayo, personal communication). It appears that mountain spring ^{3}H values generally represents local precipitation and that modern precipitation on average contains approximately 6 TU.

The ^{3}H content of basin-fill samples decreases away from the Snake Range, except in northern Spring Valley where ^{3}H values are generally consistent and average 2.2 TU (Figure 17). This suggests, as expected, increasing residence times down gradient. Samples located near the western margin of southern Spring Valley and the eastern margin of Snake Valley have low ^{3}H contents (average = 0.4 TU) (Figure 13). Assuming that the ^{3}H content of the nuclear testing atmosphere was appreciably greater than 6 TU, measurable ^{3}H content in most samples suggests, at a minimum, a component of modern recharge is present.

Except for samples collected from the eastern margin of Snake Valley and the western margin of southern Spring Valley, where ^{14}C contents range from 12.8 to 36.35 pmc, ^{14}C activities are $\geq$ 50 pmc for most basin-fill waters (Figure 12). High ^{14}C activities are consistent with ^{3}H values and suggest that most groundwater in the study area has relatively short residence times.

Third, NETPATH modeling also suggests that most groundwater occurs as local flow paths that include flow from mountain bedrock to basin-fill sediments, mountain bedrock to mountain front fault systems and mixtures of mountain block systems with varying rock type to basin-fill sediments. The occurrence of local flow paths with short residence times infers good sustainability of the water resources in the basin-fill system.

Potential Interbasin Flow Systems

Southern Spring Valley

Lack of geochemical data prevents chemical mass balance modeling from Lake or Steptoe Valleys to Spring Valley in this study, although Hershey (2007) suggests that interbasin flow from Lake Valley to Spring Valley is unlikely, and concludes that most groundwater in southern Spring Valley originates in the Snake Range or from the basin-fill sediments of central Spring Valley (i.e. local recharge).

Samples, such as South Fox well, located along the western margin of southern Spring Valley have low ^{14}C pmc values which are consistent with lengthy subsurface residence via interbasin flow from adjacent Lake or Steptoe Valleys or from long, deep circulation within the basin-fill sediments of Spring Valley. South Fox well has an estimated circulation deep of ~1360 m (Table 2). Chemical mass balance models of local flow paths (local flow path #4; Figure 21) produce reasonable results, including $\delta^{13}C$ values, suggesting that local flow paths are geochemically plausible. Interbasin flow, however, is also consistent with the observed ^{14}C activities, although it is not required to explain the occurrence of older groundwater in southern Spring Valley.

Southern Spring to Southern Snake Valleys

The proposed interbasin flow path from southern Spring Valley to Snake Valley is complicated by the lack of obvious initial and final waters. Hershey (2007) suggested that interbasin flow was geochemically plausible from southern Spring Valley to Snake Valley, although he also suggested that local recharge could account for 100 percent of the flow. Geochemical modeling done by Hershey (2007) is problematic based on the use of questionable solute data. Hershey (2007) used Monument Well, Hyde Well and Big Springs to represent the solute composition of final waters in Snake Valley. However, the solute data for Hyde and Monument wells does not charge balance. Also, Monument well does not have $\delta^{13}C$ or ^{14}C data to constrain the models. Big Springs was also used to represent the composition of final waters in Snake Valley and in other models was used to represent modern recharge. Big Springs has a ^{14}C content of 35.14 pmc that suggests relatively longer residence times that are not typical of other mountain springs (Table 4). The low ^{14}C content of Big Springs is consistent with a component of interbasin flow and has been indirectly thought to represent a final water by Myers (2007), Kirby and Hurlow (2005) and Elliot et al (2006).

Based on the modeling results it is possible to evolve modern recharge (i.e. local flow paths) to final waters in Snake Valley; however, it is also possible to evolve interbasin flow waters from Spring Valley to final waters in Snake Valley, suggesting that additional data is needed to further constrain possible flow paths. Mixing ratios for interbasin flow models range from 92% initial interbasin flow water to as much as 80% modernly recharged carbonate bedrock water, suggesting that the model solutions are not unique and are strongly influenced by the compositional differences of Spring Valley initial waters (Table 6). Mixing ratios in all but one model indicate that modern recharge accounts for the majority of water. Regardless, modern recharge water must represent a significant component because of the elevated ^{3}H content at Big Springs (1.9 TU).

Another possible scenario to represent the discharge at Big Springs is by comparing the flow history of Big Springs to McGill Spring in Steptoe Valley. McGill Spring has a similar ^{3}H content, ^{14}C activity, solute composition, geologic setting and geothermal history and can thus be used as an analogue to groundwater flow at Big Springs. McGill Spring is interpreted as being recharged by underflow from the adjacent Schell Creek Range where it is subsequently mixed near the surface with modern water and then discharged along a fault near the base of the range (Alan Mayo, personal communication, 2008).

McGill Spring discharges at 26 ºC and has a ^{14}C activity of 34 pmc and a ^{3}H content of approximately 3 TU, which are similar to Big Springs which has a discharge temperature of 17.1 ºC, a ^{14}C content of 35.14 pmc and a ^{3}H content of 1.9 TU. Silica geothermometers estimate that temperatures of Big Springs water have reached at least 95ºC and depths of approximately 2,500 m (Table 3). The location of Big Springs at the base of the Snake Range and near an identified fault zone (Welch and Bright, 2007: Dixon and Rowley, 2006) suggests that Big Springs may represent~~s~~ recharge and subsequent underflow from the adjacent Snake Range and deep circulation along a fault.

Based on the current data and model constraints, interbasin flow cannot be confirmed or rejected from southern Spring Valley to Snake Valley. It also places additional uncertainty on BARCASS water budget estimations, which include 29,000 acre-ft/yr of interbasin flow along this flow path, and their use to determine the total water resources in Spring and Snake Valleys. The confirmation interbasin flow requires a better understanding of the mechanism of interbasin flow in this area and preferably data directly from the carbonate-rock aquifer that would allow direct investigation of groundwater flow and would provide the geochemical composition of possible interbasin flow waters.

Northern Spring to Northern Snake Valleys

The chemical composition of groundwater discharging at Gandy Spring, which is thought to represent interbasin flow from northern Spring Valley (Nichols, `2000: Hershey, 2007) cannot be readily explained by local recharge (Flow Path #6) or by interbasin flow (Flow path #8). Local flow paths compute $\delta^{13}C$ values of -9.4‰ and interbasin flow models compute $\delta^{13}C$ of -11.64‰ that are relatively depleted compared to the observed $\delta^{13}C$ values that range from -4.33 to -7.0‰ (Table 6).

Estimated temperatures (70 ºC) and circulation depths (1,750 m) are consistent with a component of deeply circulated groundwater (Table 2). Geochemical models that include Monte Neva Hot Spring to represent the composition of the geothermal water along with modern carbonate bedrock water produce plausible models that compute $\delta^{13}C$ values that range from -5.6 to -6.74‰ compared to the observed values of -4.33 to -7.0‰ (Table 6). The agreement of computed $\delta^{13}C$ values with observed values suggests that the origin of Gandy Spring water can be explain as a component of deeply circulated groundwater that mixes with modern carbonate bedrock water prior to discharge, which does not require the mechanism of interbasin flow.

BARCASS estimated that 14,000 acre-ft/yr of interbasin occurs along this flow path, which now appears to be unlikely based on the results of this study. This interpretation suggests that interbasin flow estimates by Welch and Bright (2007) and Nichols (2000) should be reallocated or estimated water budgets should be reevaluated.

Implications

The possible occurrence of interbasin flow is not ruled out in all cases but it is evident that equally plausible alternative explanations exist. The mechanism of interbasin flow in Spring and Snake Valleys is not well understood and has not been described in detail, although significant portions of the water budget have been allocated to interbasin flow primarily based in imbalances in estimated water budgets. Alternative explanations of interbasin flow waters suggest that there is more uncertainty that previously recognized. The evidence for alternative explanations suggests that water budget allocations are less certain and in some cases, such as from northern Spring Valley to Snake Valley, should be redistributed or reevaluated. The use of current water budgets that allocate large components of water to interbasin flow to determine water right distributions, with regard to the SNWA groundwater development project, may result in an incorrect estimation of available water resources.

CONCLUSIONS

The flow of groundwater in Spring and Snake Valleys can summarized as local flow paths that originate in the mountain block system as recharge and flow down gradient to the adjacent basin-fill sediments and discharge as springs or are lost to evapotransporation (ET). Geochemical and isotopic data in the much of the study area support local flow paths. ^{3}H and ^{14}C content in samples suggests that most mountain block to adjacent basin-fill groundwater flow systems contain modernly recharged water and have short residence times (Figures 12 &13), which implies, that with proper management the basin-fill water resources may provide adequate sustainability.

The ^{14}C content of samples located near the western margin of southern Spring Valley is consistent with interbasin flow from Lake or Steptoe Valleys, although it has also been suggested that interbasin flow from Lake Valley to Spring Valley is unlikely, and that most groundwater in southern Spring Valley originates in the Snake Range or from the basin-fill sediments of central Spring Valley (i.e. local recharge). Additional samples need to be collected to geochemically analyze the plausibility of interbasin flow into Spring Valley from Lake and Steptoe Valleys.

Interbasin flow from southern Spring Valley to southern Snake Valley cannot be confirmed or rejected based on the current data and modeling constraints. Geochemical modeling suggests that local flow paths or interbasin flow paths can be evolved to the final waters in Snake Valley, suggesting that additional data is needed to further constrain possible flow paths. The confirmation of any model or interbasin flow in general requires a better understanding of the mechanism of interbasin flow in this area and preferably data directly from the carbonate-rock aquifer that would allow direct investigation of groundwater flow and would provide the geochemical composition of possible interbasin flow waters.

Interbasin flow from northern Spring Valley to northern Snake Valley (i.e. Gandy Spring, Flow path #8) is unlikely and can readily be explained as deeply circulated groundwater that mixes with modernly recharged water prior to discharge. This interpretation suggests that interbasin flow does not occur from northern Spring Valley to Snake Valley and suggests that interbasin flow estimates suggested by Welch and Bright (2007) and Nichols (2000) should be reallocated or estimated water budgets should be reevaluated.

Equally plausible alternative explanations to interbasin flow exist and suggest that interbasin flow paths are more complicated than previously recognized. The evidence for alternative explanations suggests that water budget allocations are less certain and should be redistributed or reevaluated. The use of current water budgets that allocate large components of water to interbasin flow to determine water right distributions, with regard to the SNWA groundwater development project, may result in an incorrect estimation of available water resources.

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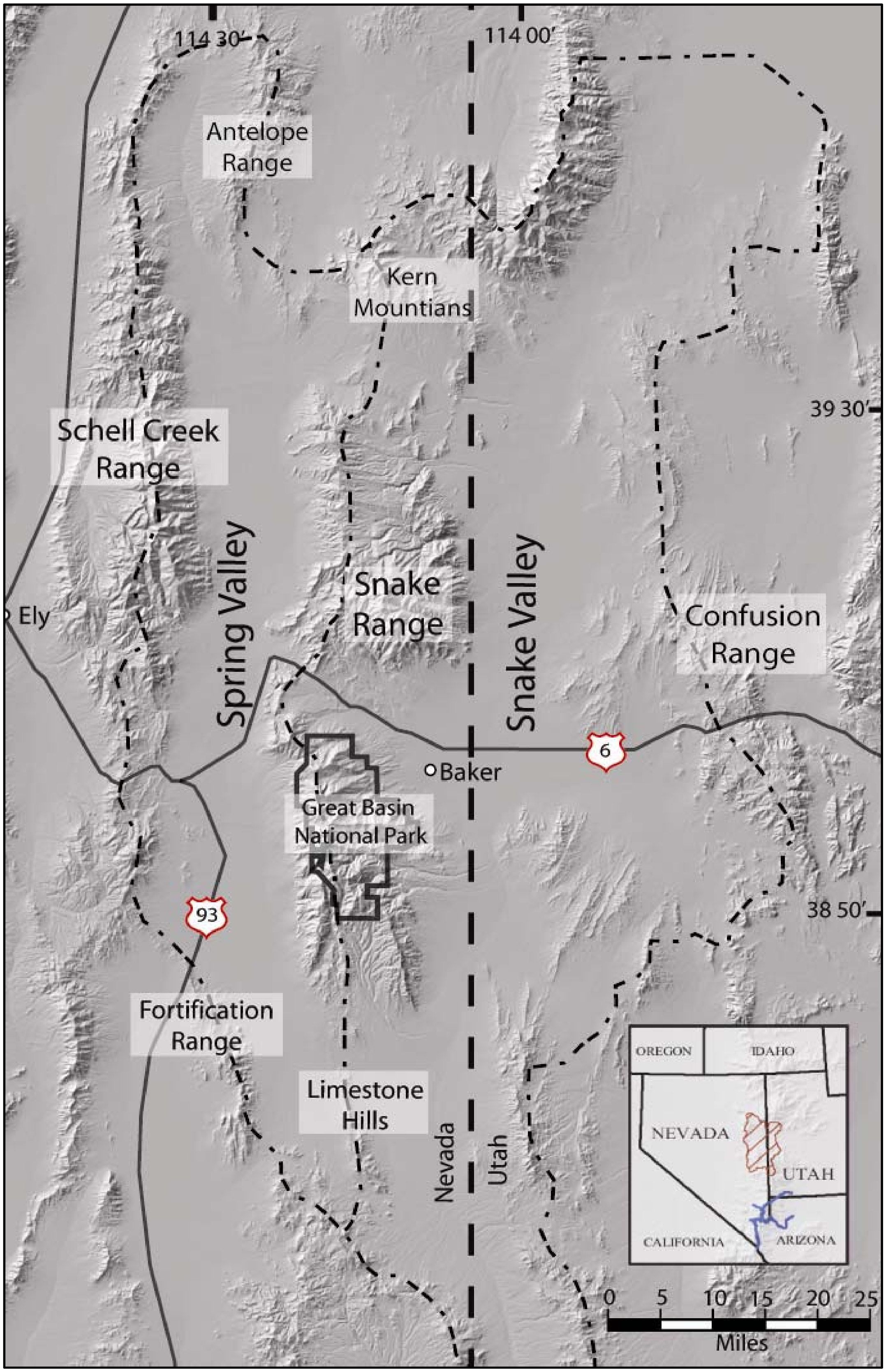

Figure 1, Index map of study area showing prominent mountain ranges. Shaded relief map courtesy of USGS Seamless Data, 2006.

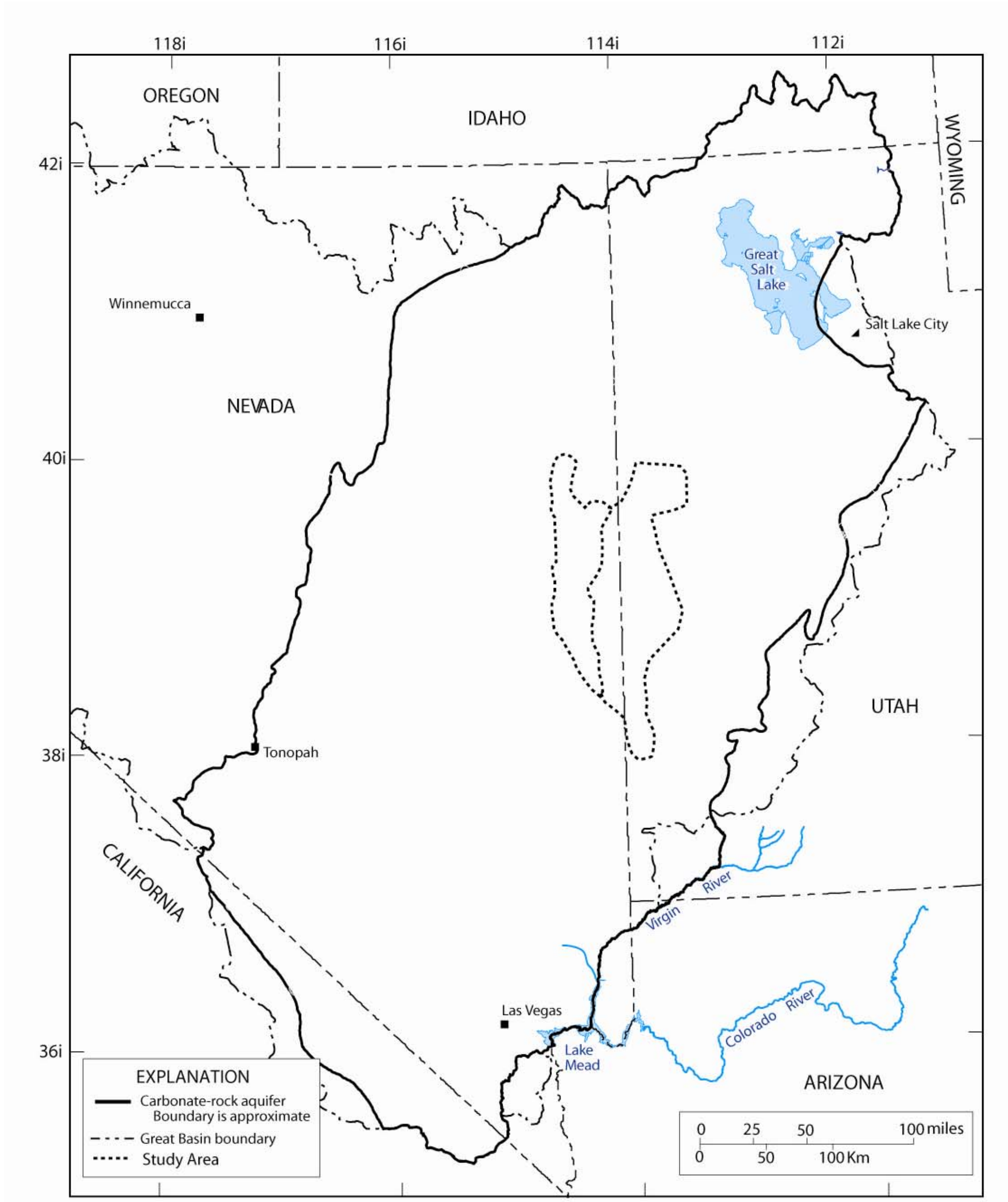

Figure 2 Illustrates the extent of the carbonate-rock aquifer. Modified from Schaefer et al.,(2003).

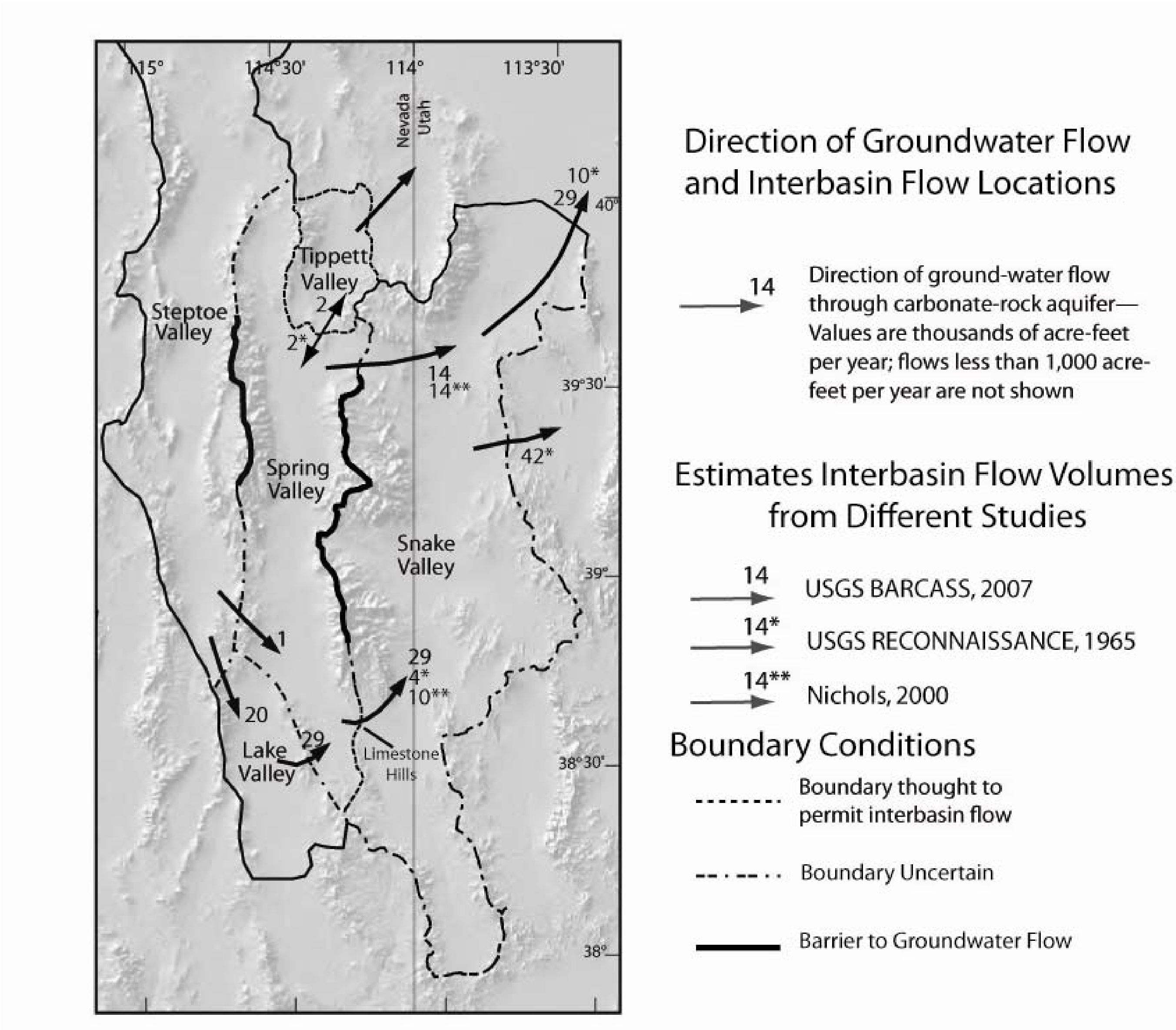

Figure 3 Map of study area and basin boundaries. Illustrates locations where previous studies have identified interbasin flow to occur. Estimates of interbasin flow volumes are also shown (see Table 1). Boundary conditions pertain to their ability to permit groundwater flow. Boundaries labeled as "uncertain" require additional study but in most cases were thought to permit flow (Welch and Bright, 2007) Figure modified from Welch and Bright (2007). Additional studies cited, Rush and Kazmi (1965) and Nichols (2000).

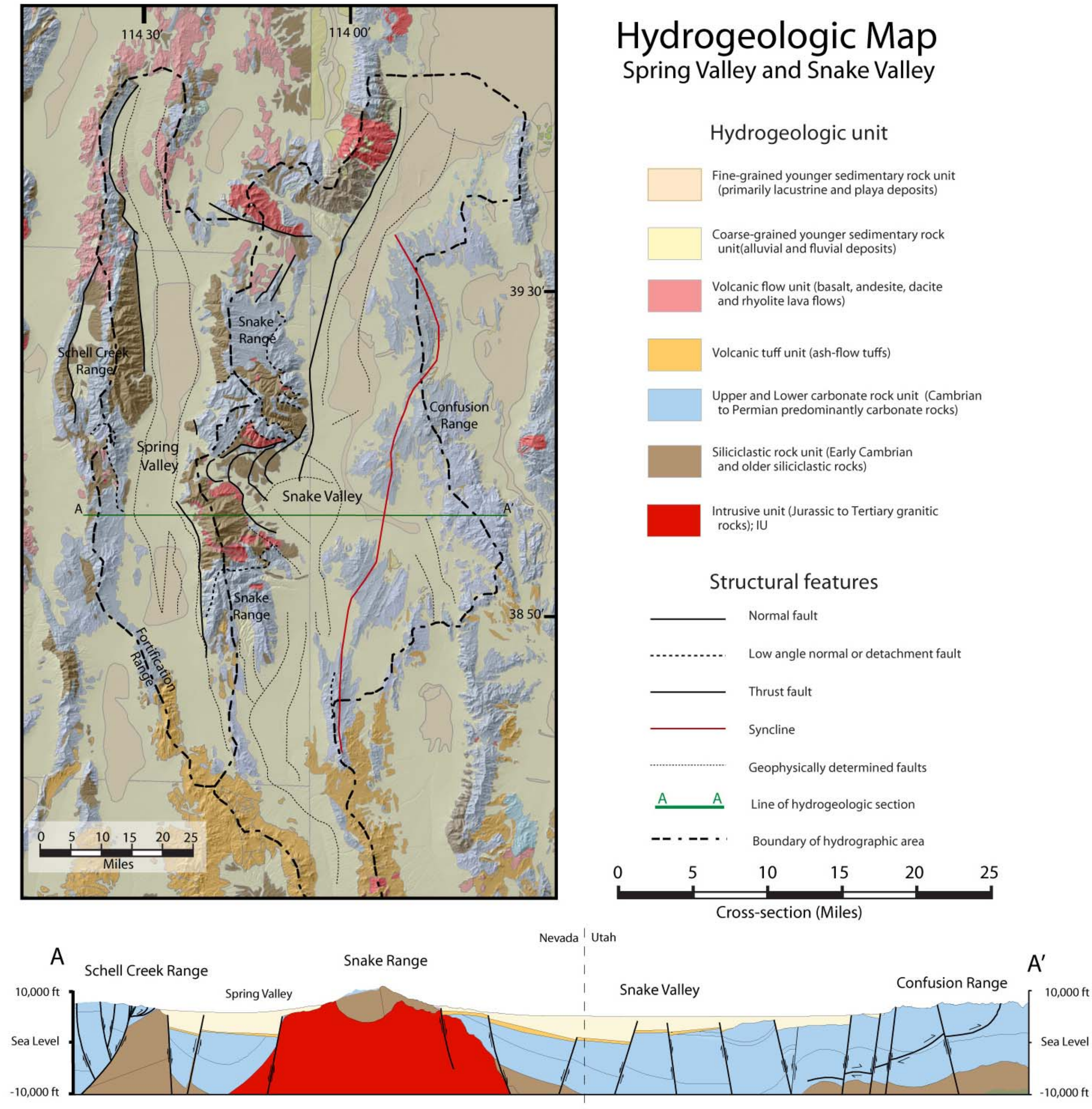

Figure 4 Simplified hydrogeologic map and cross-section of Spring and Snake Valleys. Modified from Lundington et al, 2006, Welch and Bright, 2007 and SNWA, 2006. Cross-section vertically exaggerated (2x)

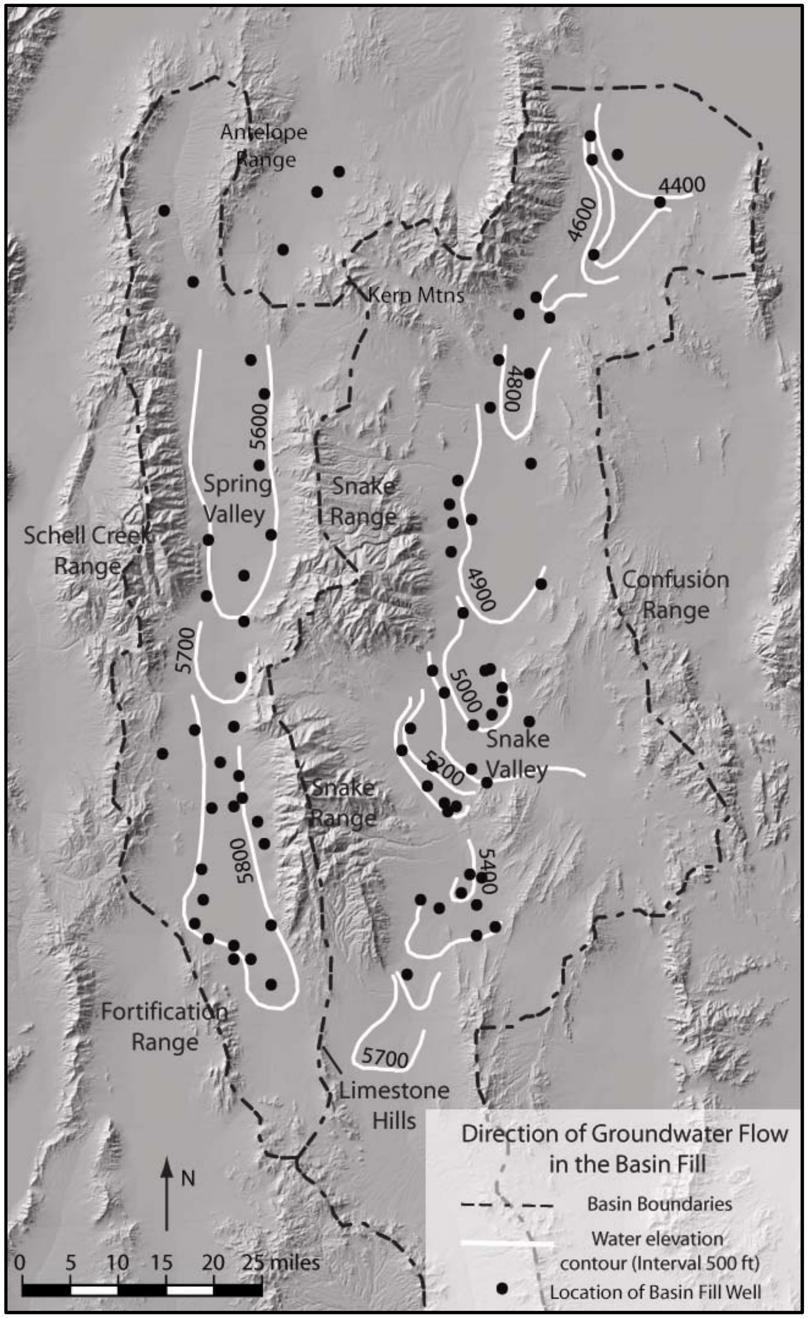

Figure 5a Illustrates the general direction of groundwater flow in the basin-fill aquifer.

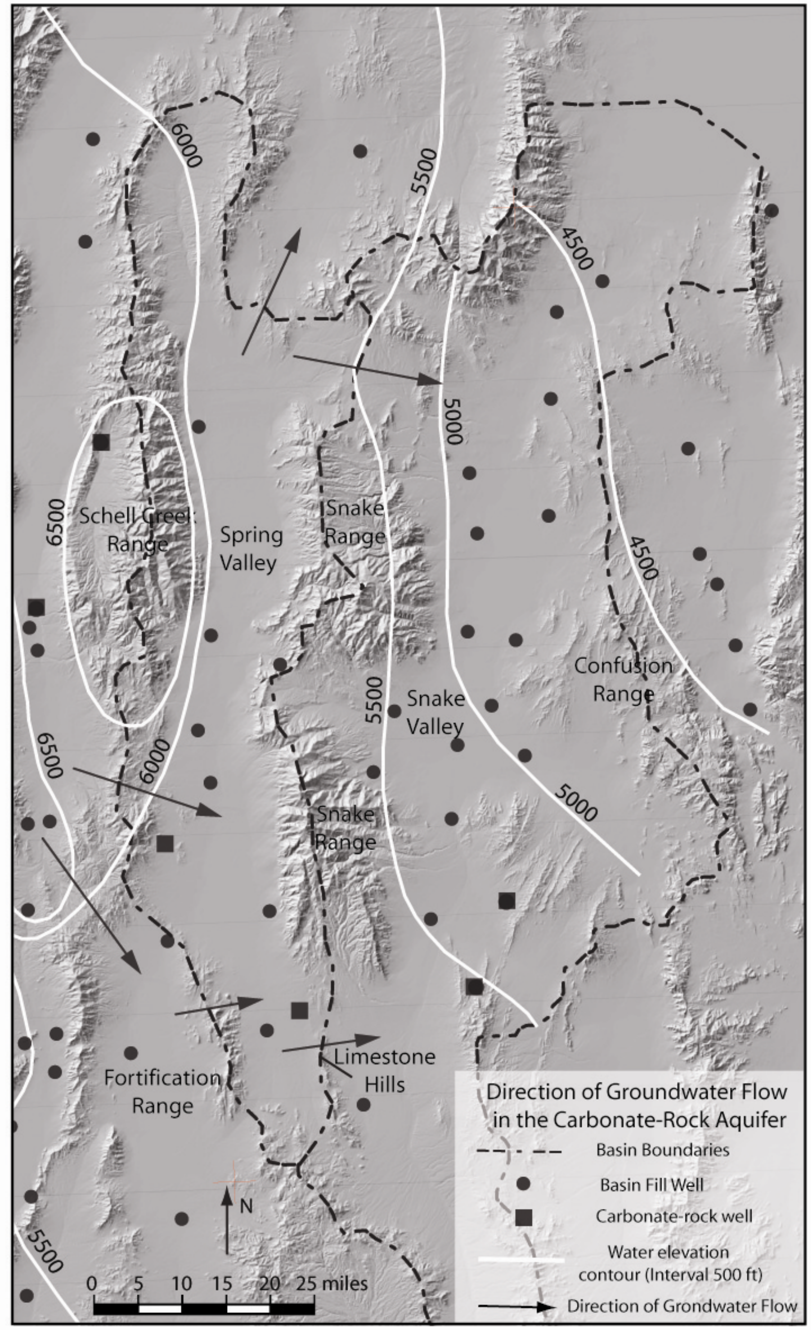

Figure 5b Illustrates the general direction of groundwater flow in the carbonate-rock aquifer. Note that water level measurements were taken almost entirely from basin-fill wells not wells completed in the carbonate-rock aquifer.

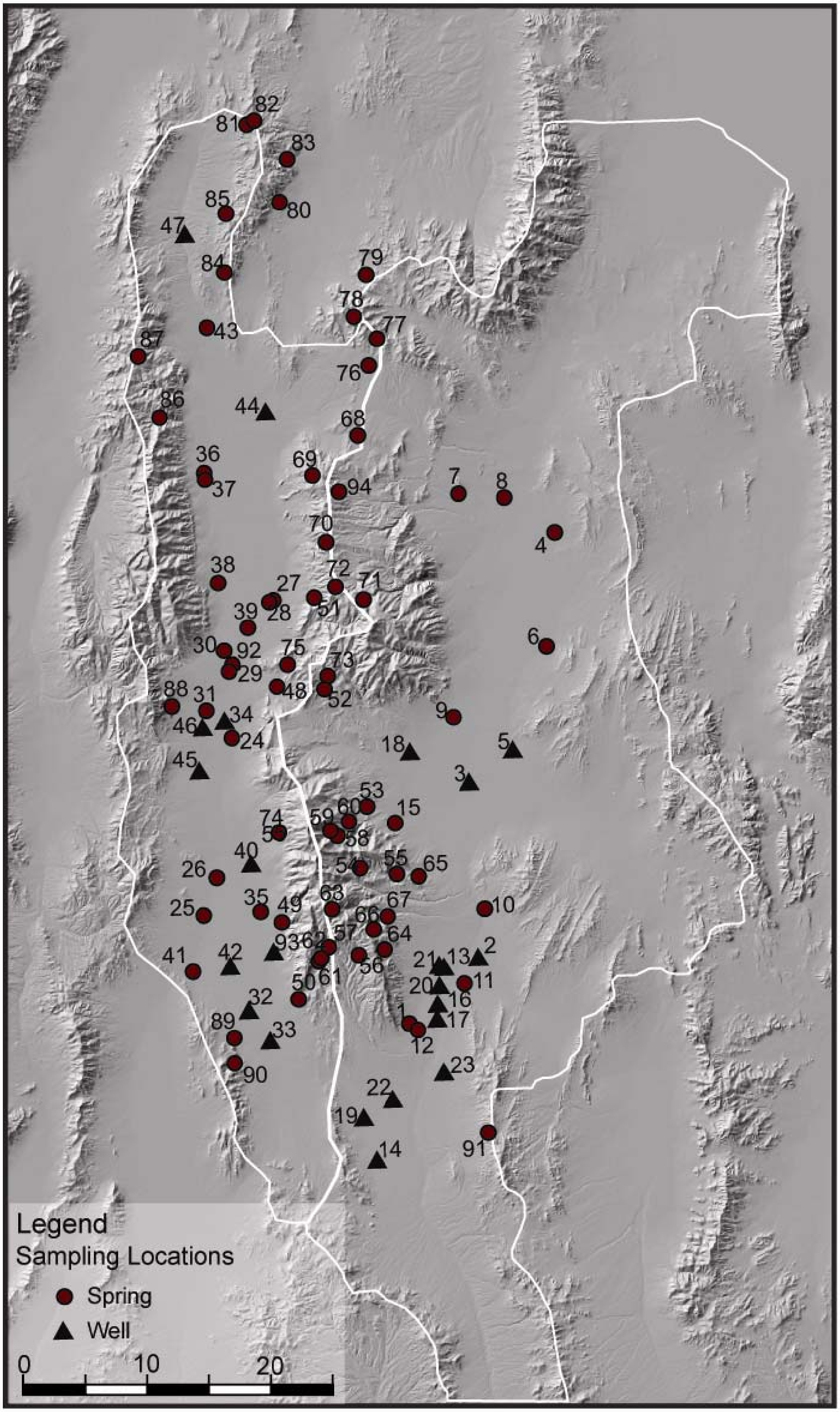

Figure 6 Sample locations. Numbers correspond to samples listed in Appendix 1-A.

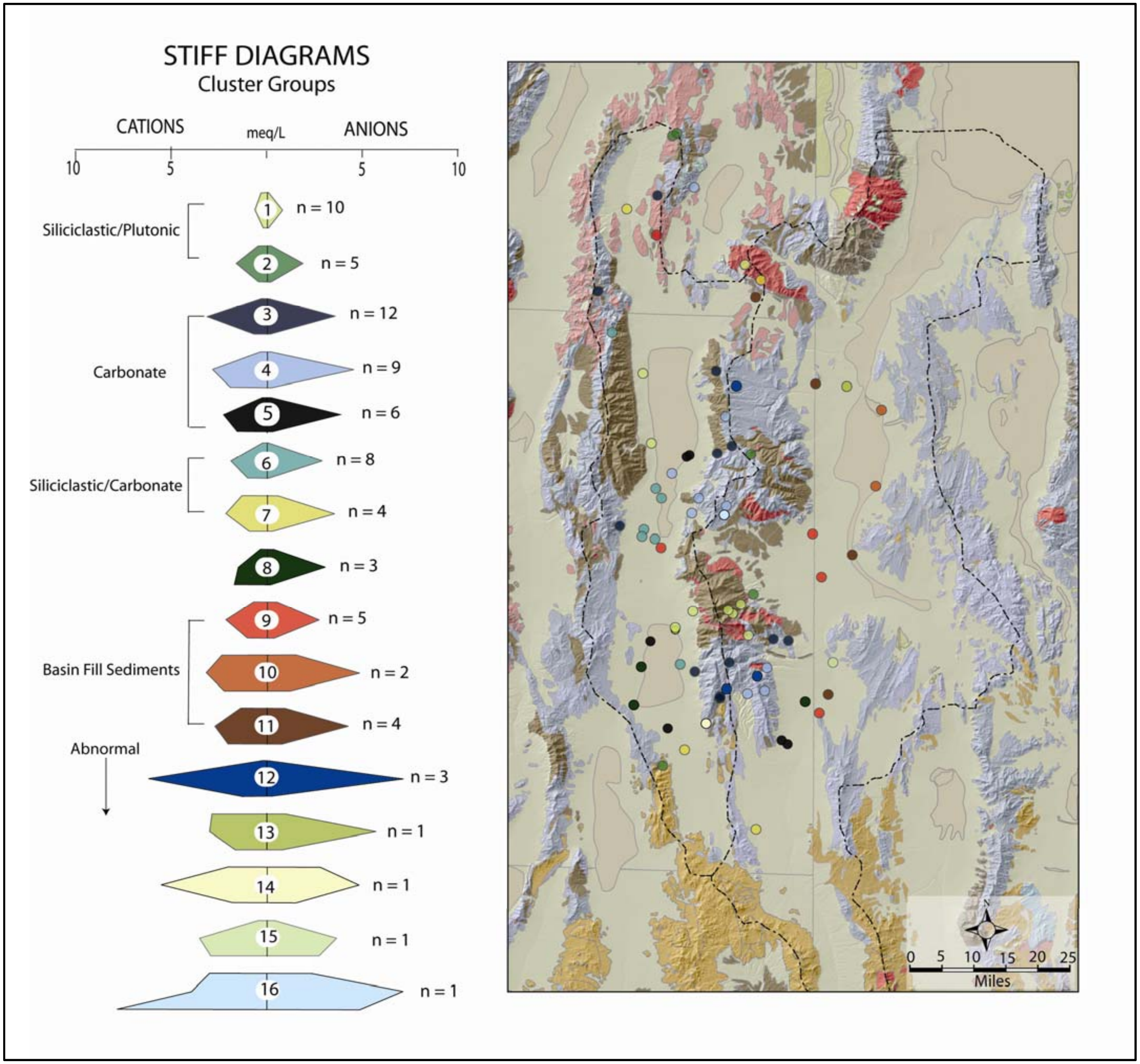

Figure 7 Stiff Diagrams plotted according to cluster groups. Color of sample corresponds to cluster group and stiff diagram. Stiff diagrams were plotted on Hydrogeologic map to show the influence of rock type on solute chemistry. Stiff diagrams are labeled according to cluster and n=number of sampling sites. Refer to Figure 4 for information relating to the Hydrogeologic map.

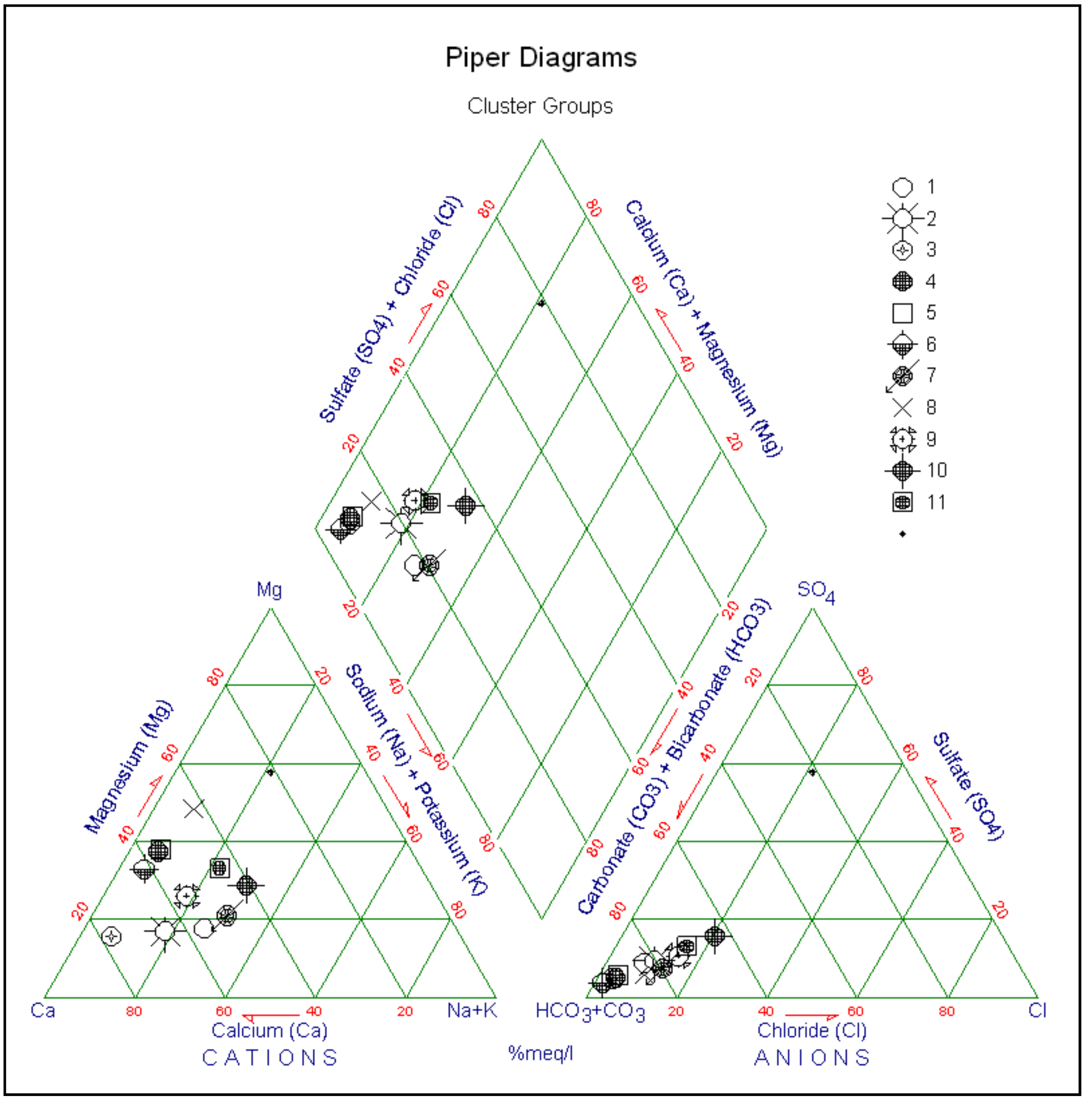

Figure 8 Figure Cluster groups plotted on a Piper diagram showing water types in the study area. For solute concentrations of cluster groups see Table 3.

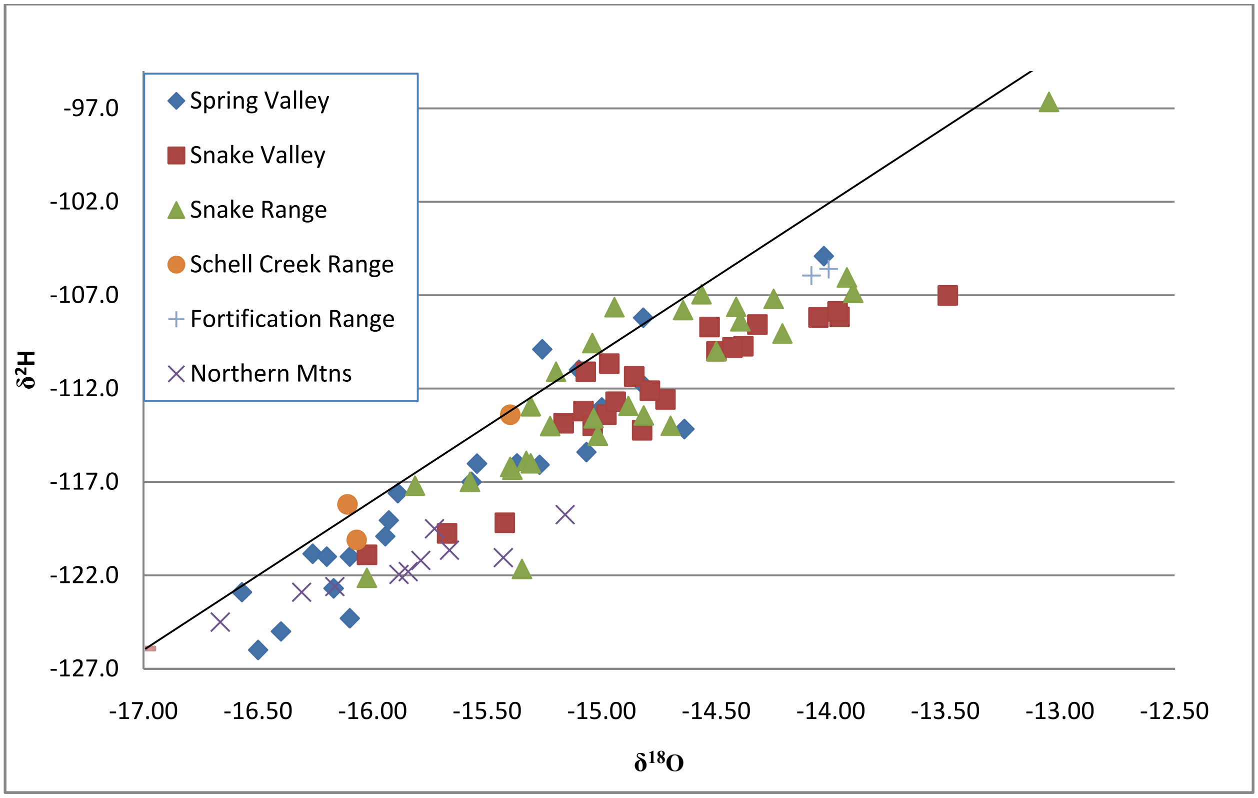

Figure 9 Scatter plot of stable isotope compositions of all groundwater in the study area plotted against the GMWL (Craig, 1961). Samples were grouped according to geographic areas such as valleys and mountain ranges.

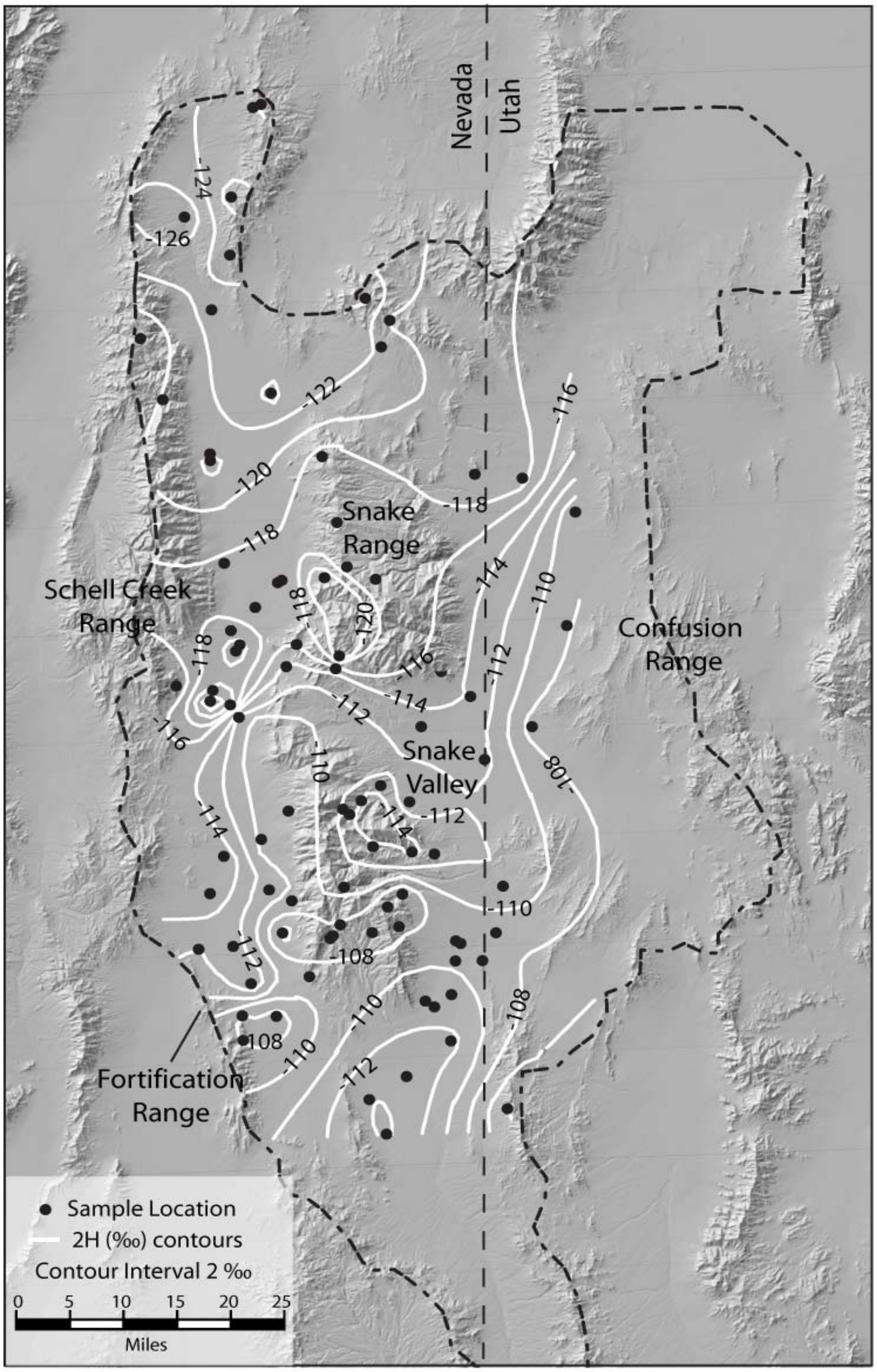

Figure 10. Contour map of δD values illustrating the isotopic variation from north to south.

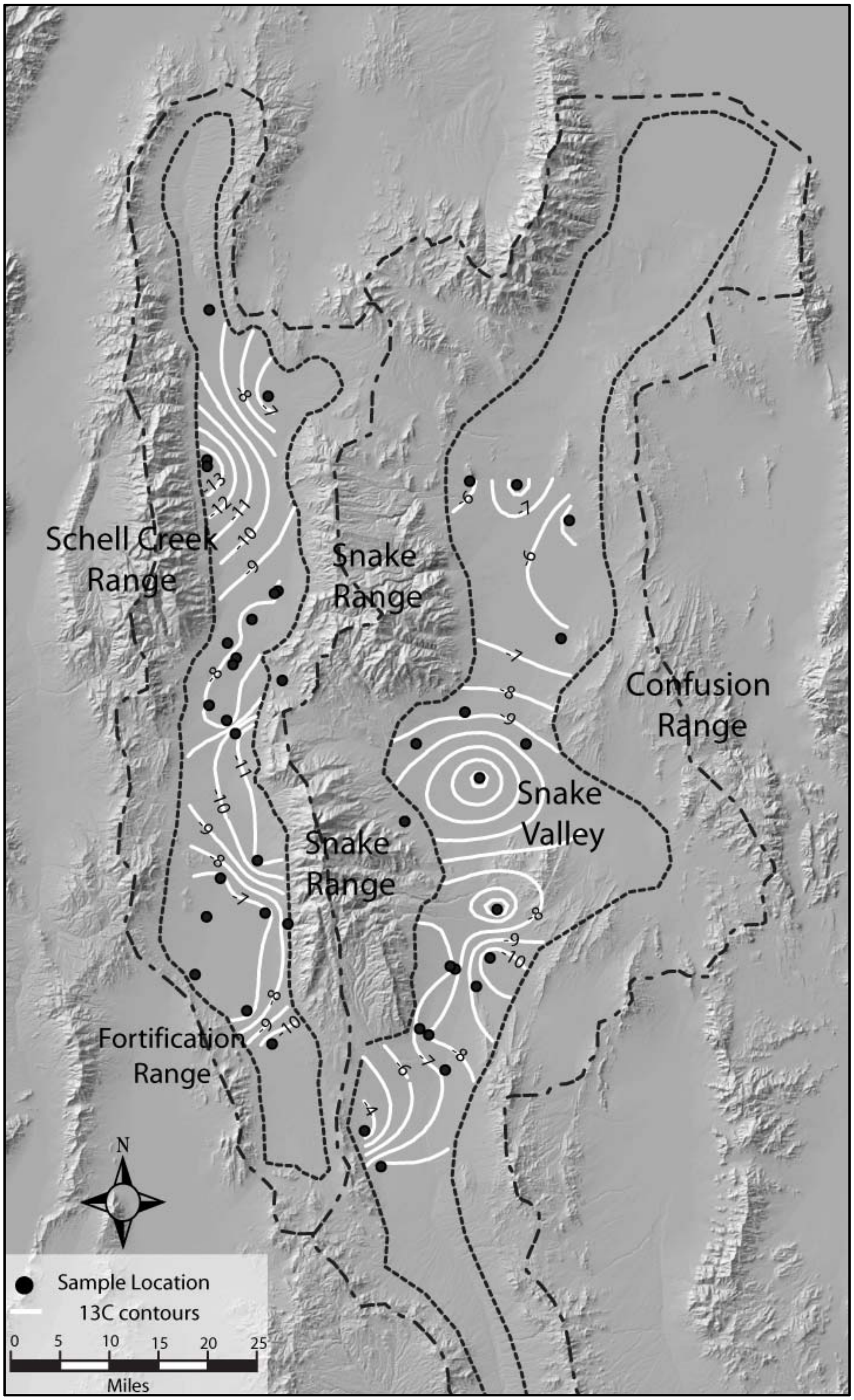

Figure 11 Contour map of $\delta^{13}C$ values

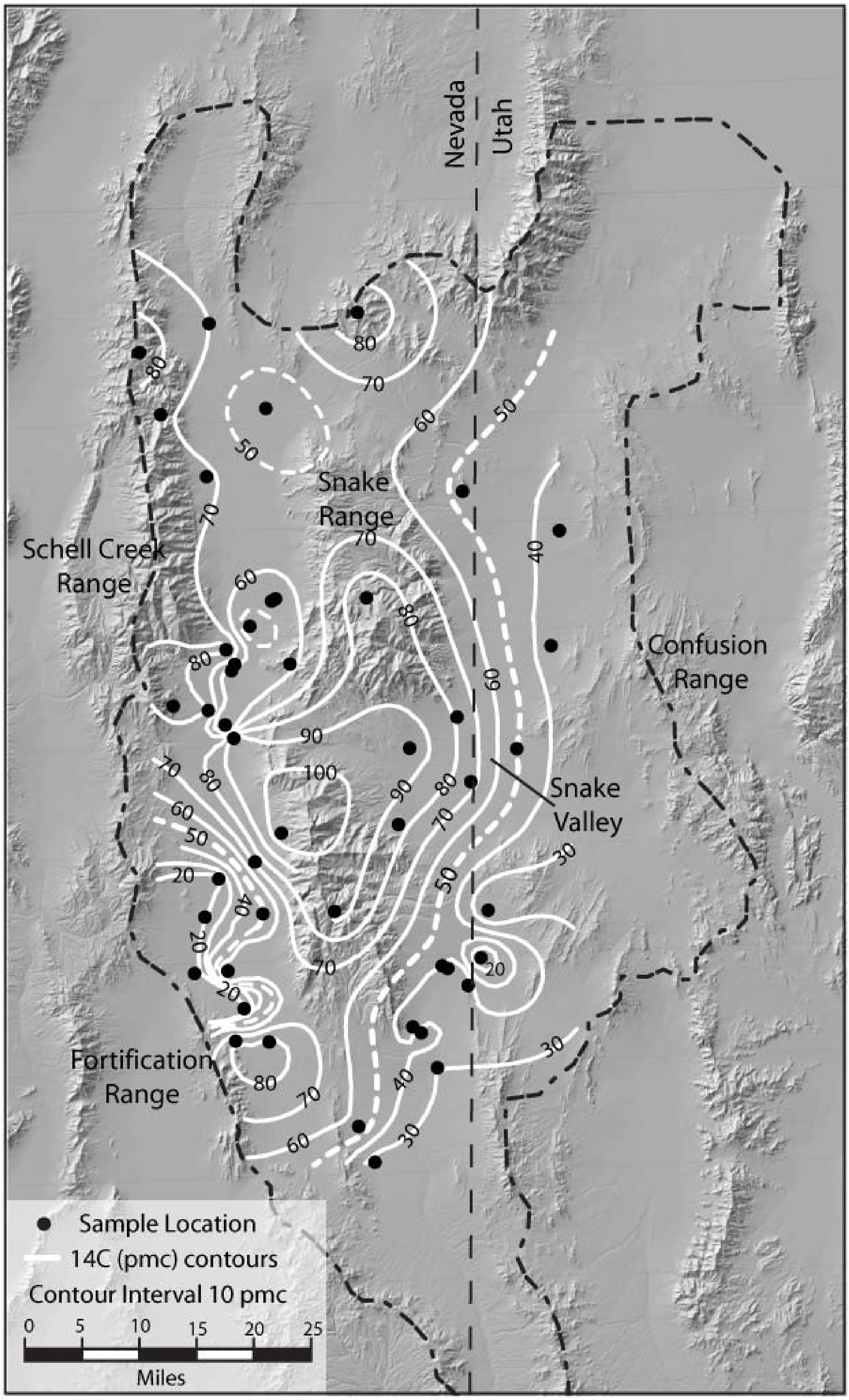

Figure 12 Contour map of ^{14}C activities (pmc). Note the location of samples with low ^{14}C content on the western margin of southern Spring Valley and along the eastern margin of Snake Valley.

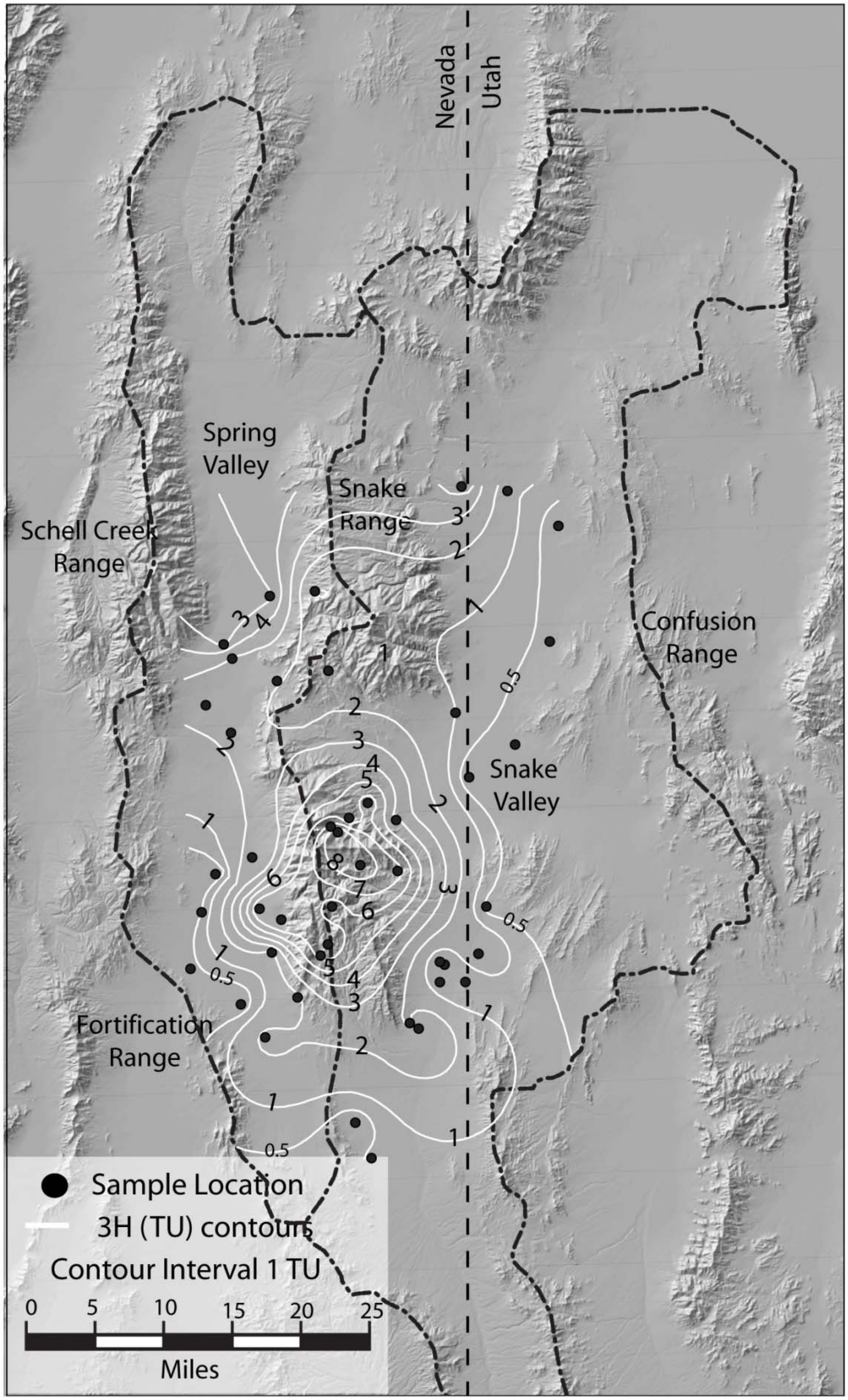

Figure 13 Contour map of ^{3}H content.

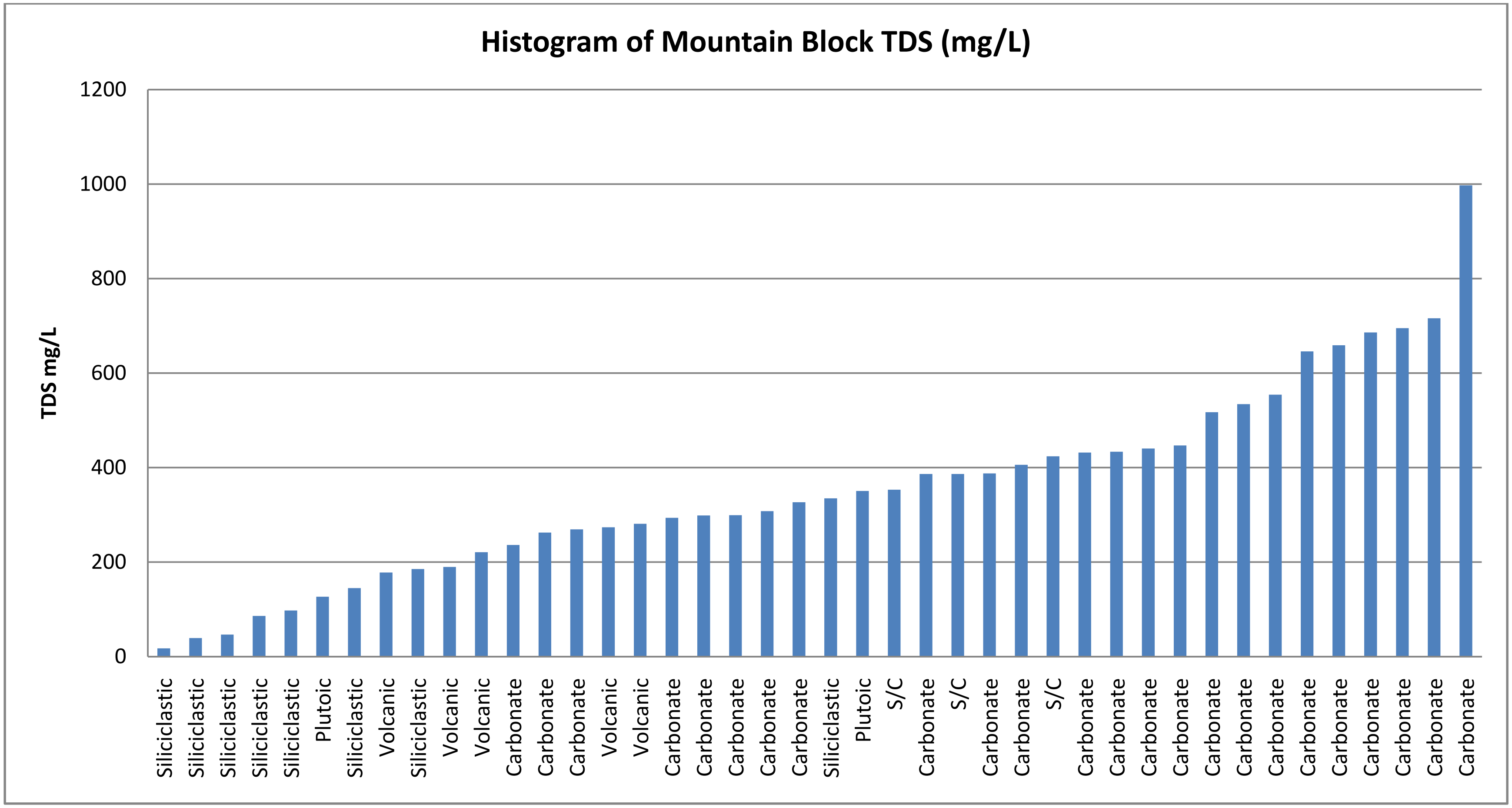

Figure 14 Histogram of TDS values labeled according to rock type.

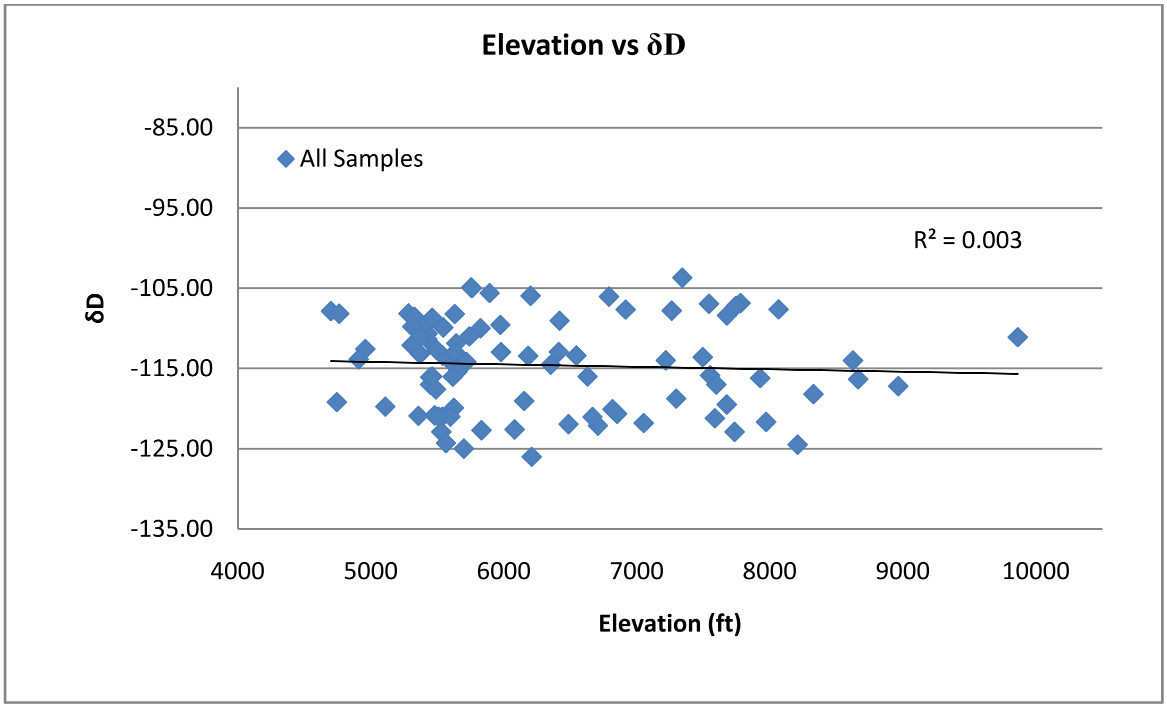

Figure 15 Elevation vs. δD illustrating that elevation differences do not strongly influence isotopic variations in the study area

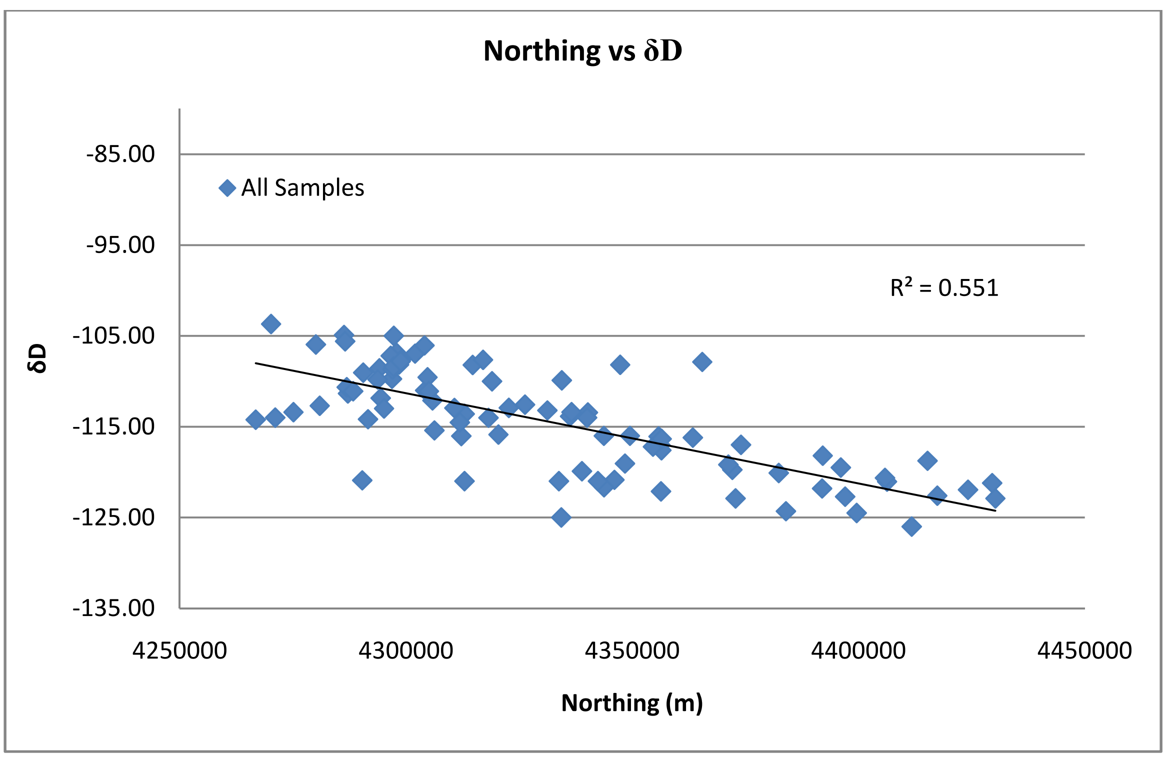

Figure 16 Northing vs. δD showing the latitudinal variation in isotopic compositions

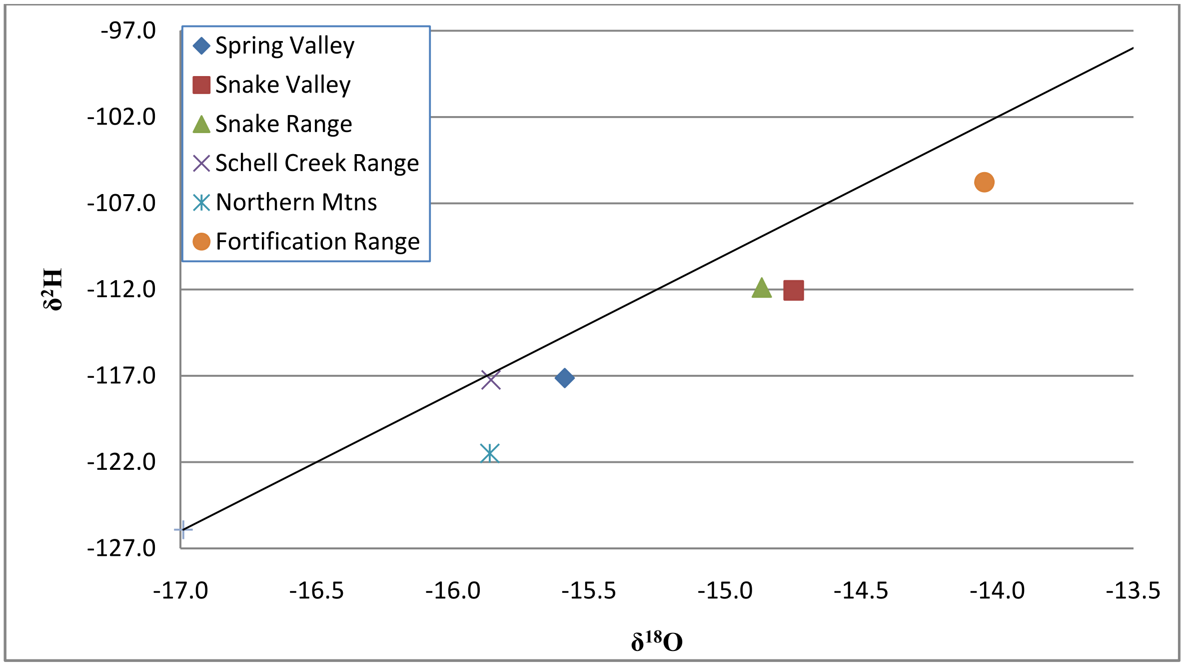

Figure 17 Average isotopic compositions for valleys and mountains plotted against the GMWL. On average the Snake Range and Snake Valley are very similar and are relatively enriched compared to Spring Valley, the Schell Creek Range, Antelope Range and Kern Mountains.

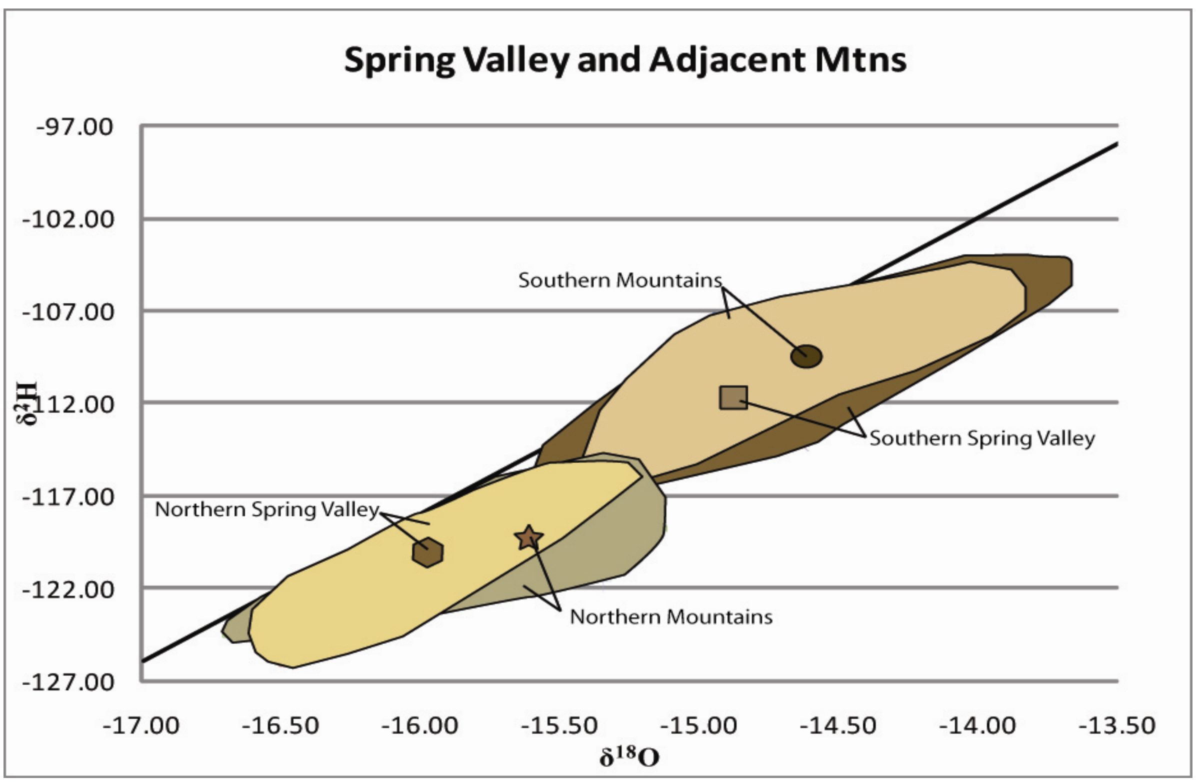

Figure 18 Shows variation in stable isotope composition in Spring Valley from north to south. Also illustrates that local mountain isotope values plot in the same area as basin-fill isotope values.

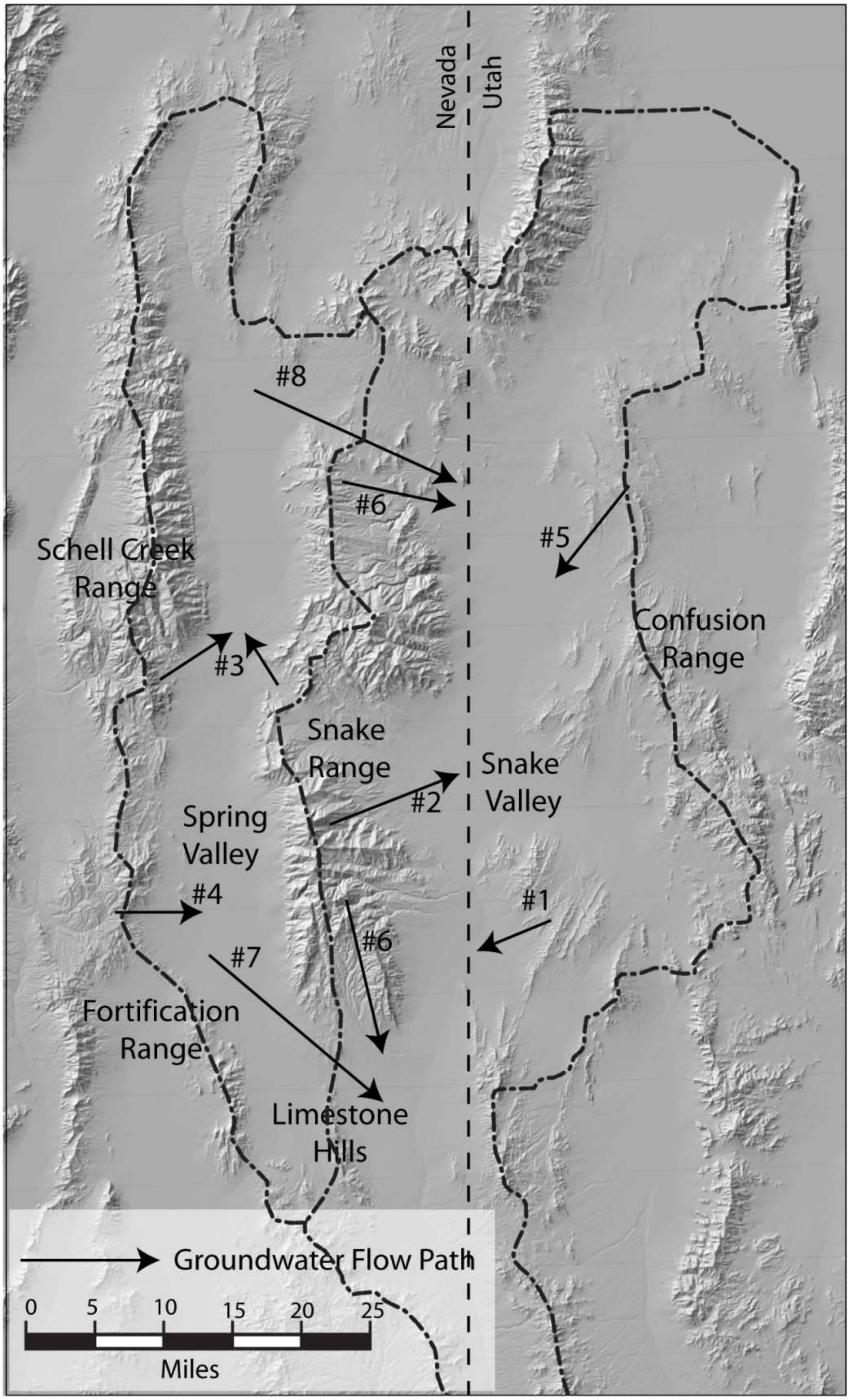

Figure 19 Locations of local and interbasin flow models.

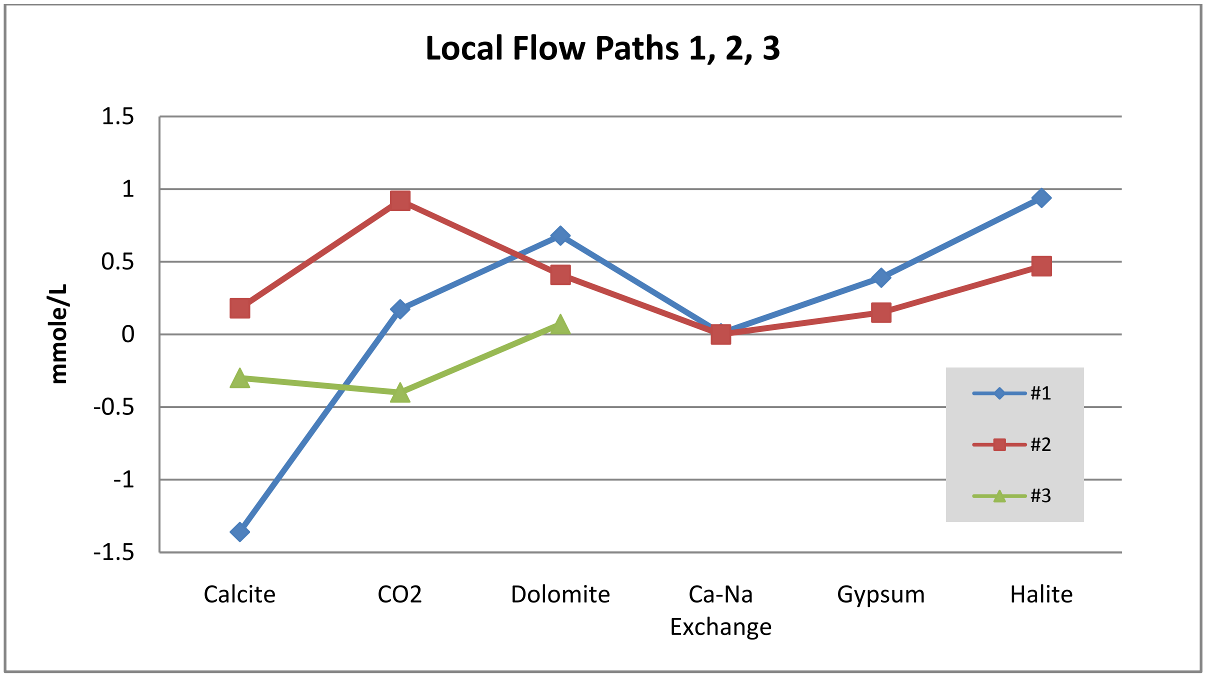

Figure 20 NETPATH results of the chemical evolution of local flow paths #1, 2 and 3. Positive results indicate mineral dissolution or gas consumption.

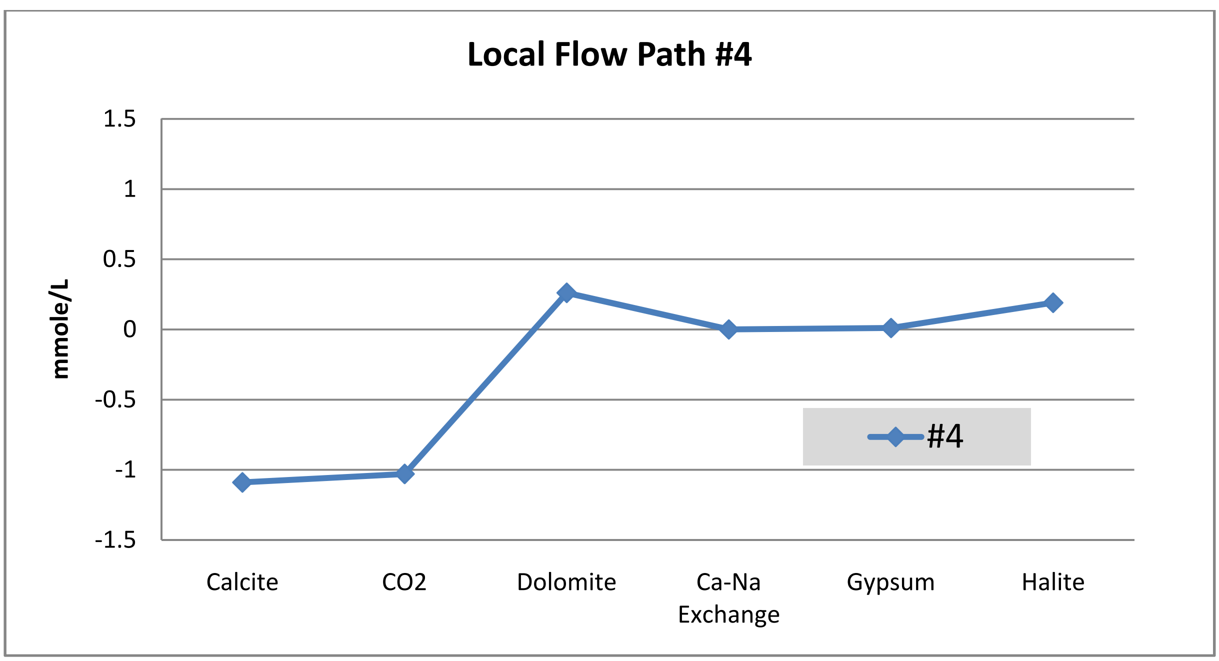

Figure 21 NETPATH results of the chemical evolution of local flow path #4

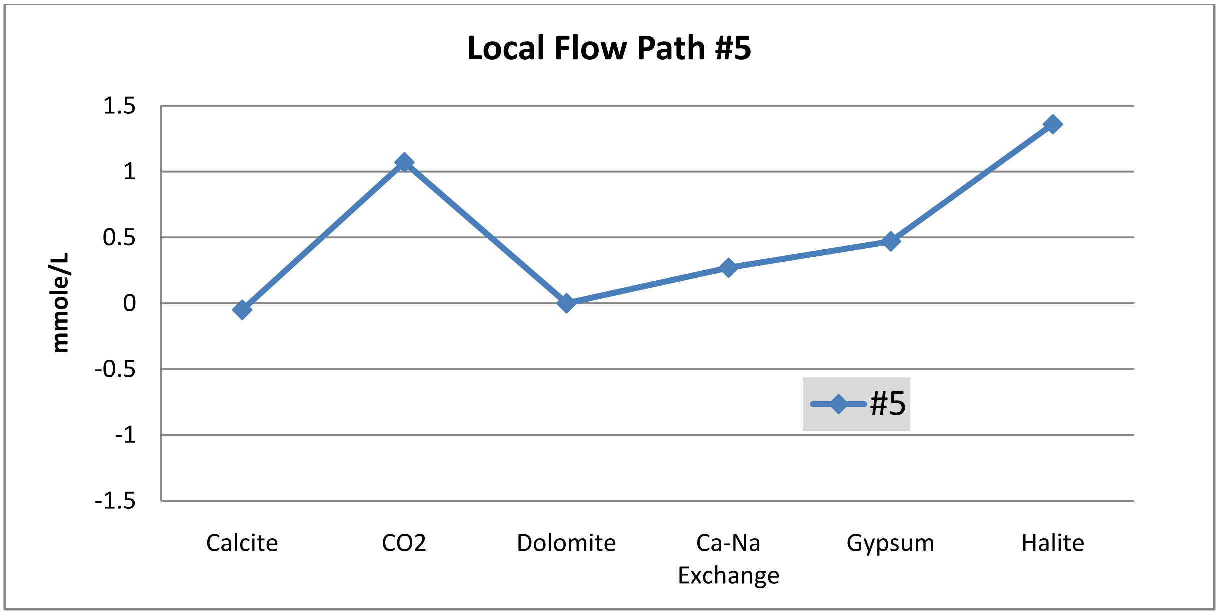

Figure 22 NETPATH results of the chemical evolution of local flow path #5

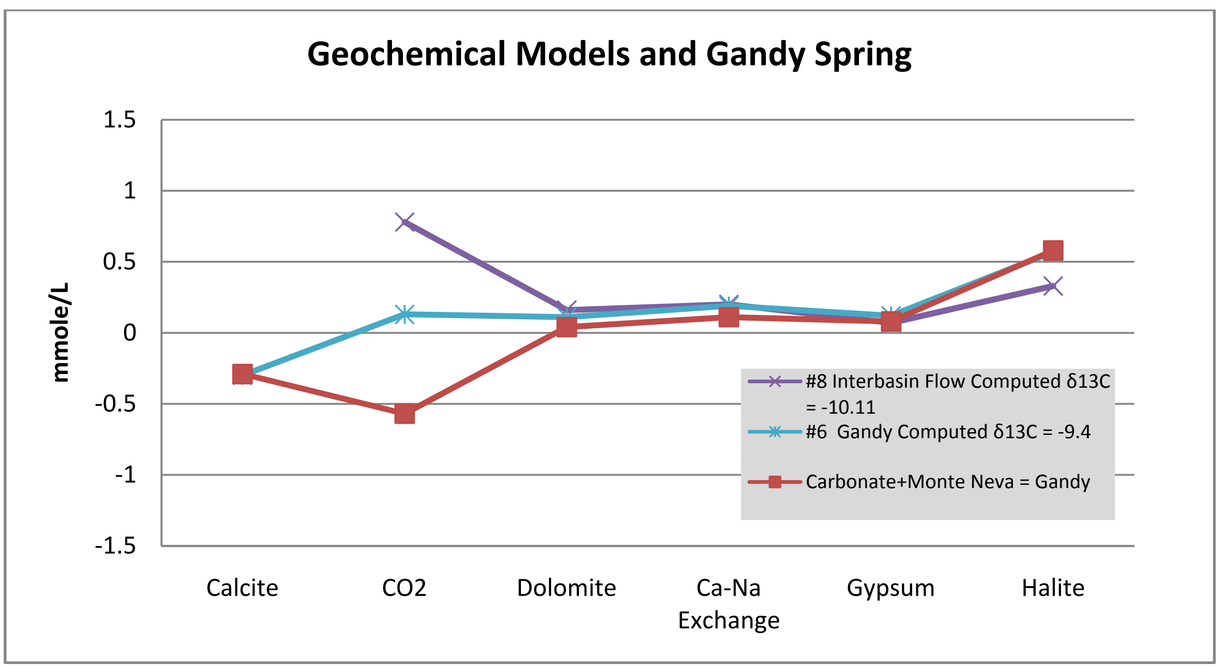

Figure 23 NETPATH results of the chemical evolution of local flow path #6 to Gandy Spring, interbasin flow paths to Gandy Spring (Flow path #8) and also carbonate bedrock water and Monte Neva Hot Spring to Gandy Spring.

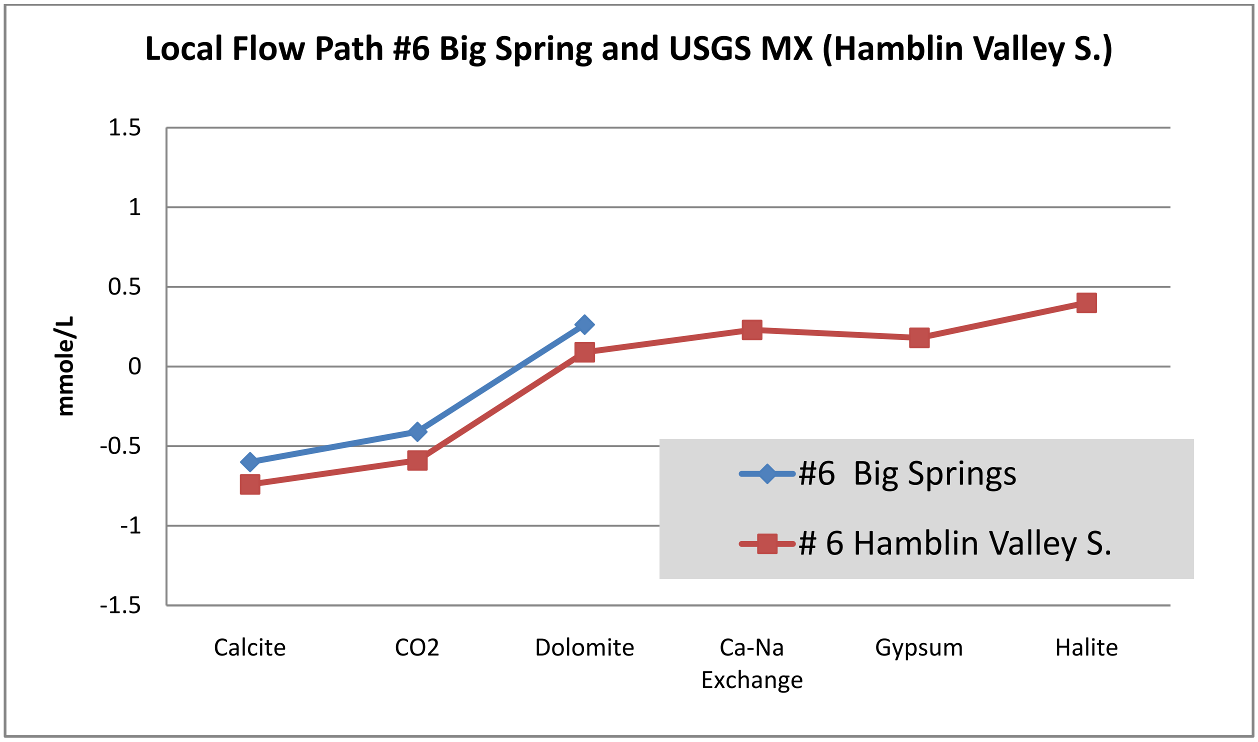

Figure 24 NETPATH modeling results of local flow paths to Big Springs and USGS MX (Hamblin Valley South) well

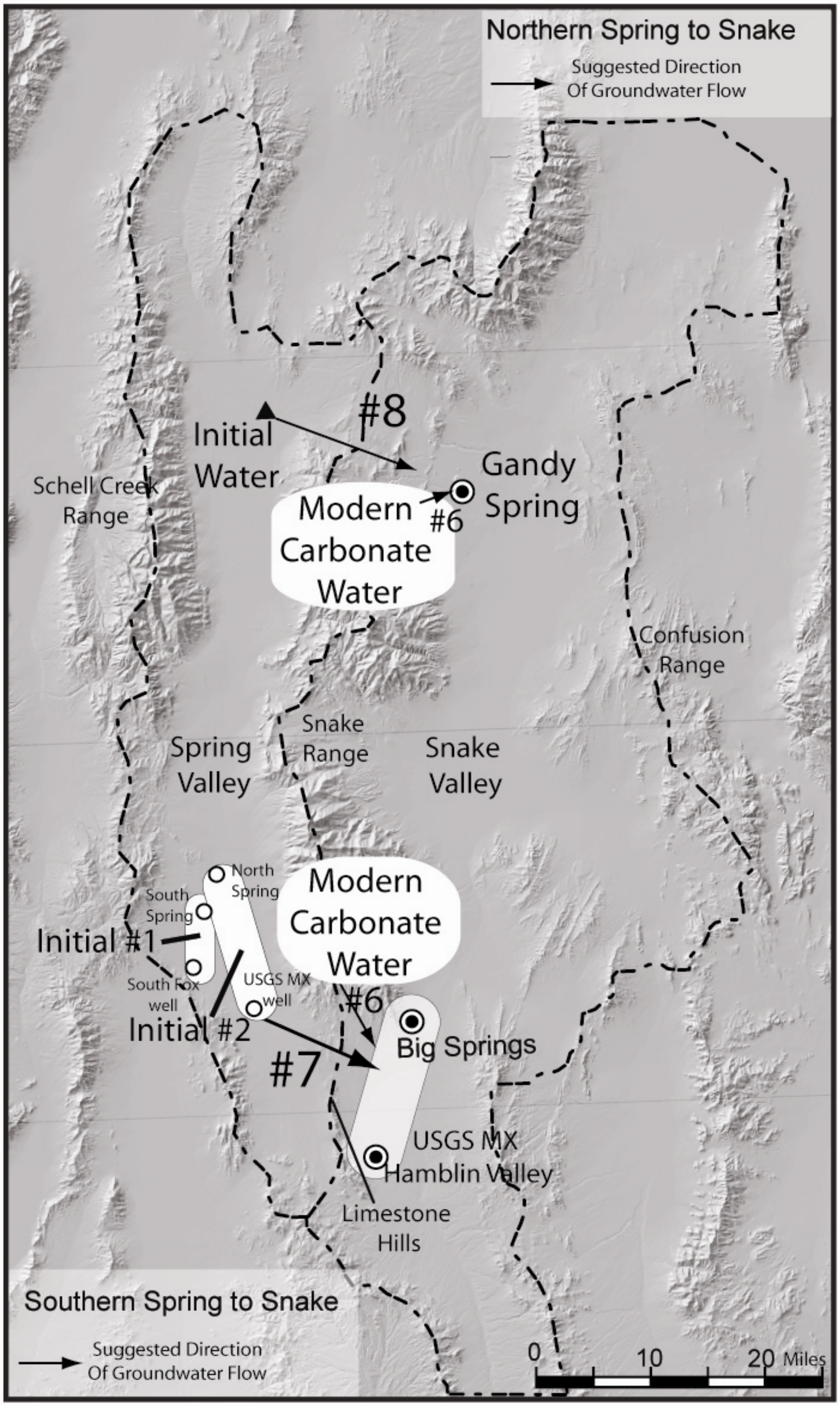

Figure 25 Location of local and interbasin flow paths to final waters in Snake Valley. Shows the initial, mixing and final waters used in Flow paths #6, 7 and 8. Also refer to Table 5 for the geochemical data used in modeling

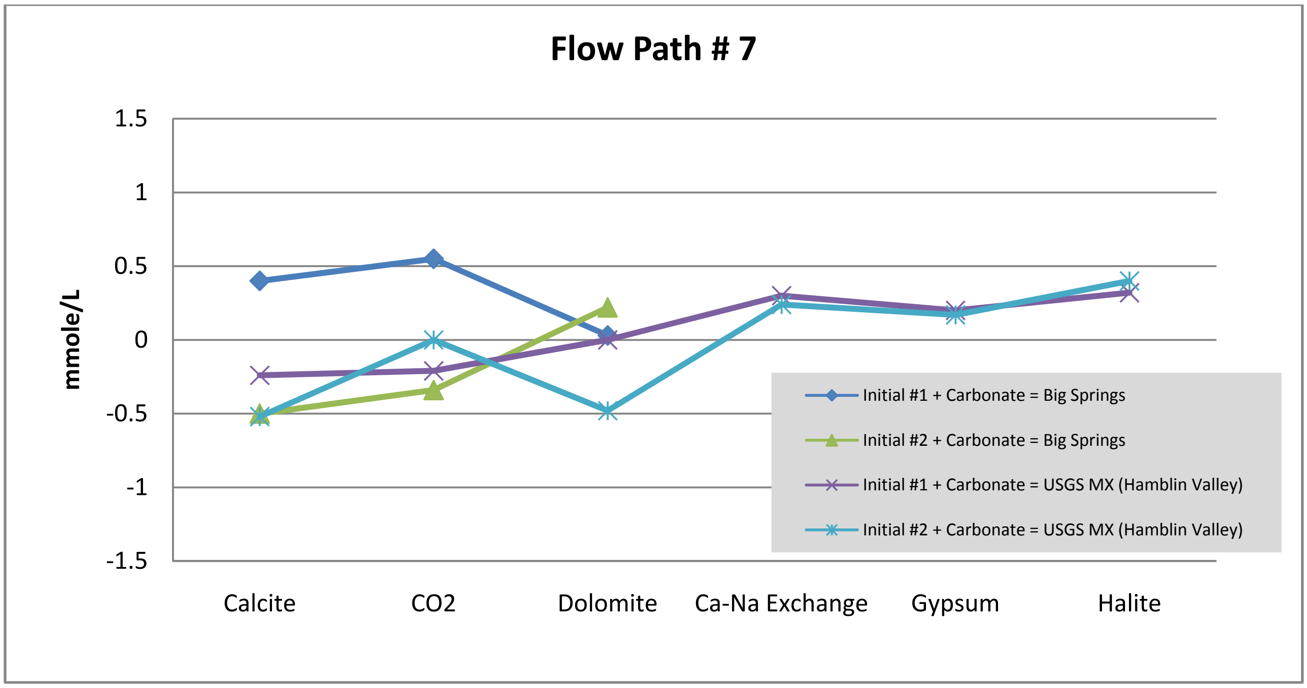

Figure 26 Results of the geochemical modeling of flow path #7, interbasin flow from southern Spring Valley to Snake Valley.

Table 1. Summary of water budgets for Spring and Snake Valleys. Values given in acre-ft/yr

	Recharge				
	Recharge	Interbasin Inflow	Inflow From-	Total Recharge	Interbasin Flow % of Recharge
	USGS, 1965 (Rush and Kazmi, 1965)				
Snake Valley	103,000	23,500	Spring Valley (4,000), Pine Valley, Wah Wah Valley (10,000)	126,500	18.58
Spring Valley	75,000	2,000	Tippett Valley (2,000)	77,000	2.60
	Nichols, 2000				
Snake Valley	--	17,600	Spring Valley (14,000)	--	--
Spring Valley	104,000	--		104,000	0.00
	BARCASS, 2007 (Welch and Bright, 2007)				
Snake Valley	111,000	43,000	Spring Valley (43,000)	154,000	27.92
Spring Valley	93,000	30,000	Lake Valley (29,000),	123,000	24.39
	Discharge				
	Discharge	Interbasin Outflow	Outflow to	Total Discharge	Interbasin Flow % of Discharge
	USGS, 1965				
Snake Valley	80,000	52,000	Tule Valley (42,000), Great Salt Lake (10,000)	132,000	39.39
Spring Valley	70,000	4,000	Snake Valley (4,000)	74,000	5.41
	Nichols, 2000				
Snake Valley	--	--	--	--	--
Spring Valley	90,000	14,000	Snake Valley (14,000)	104,000	13.46
	BARCASS, 2007				
Snake Valley	132,000	28,000	Great Salt Lake (29,000)	160,000	17.50
Spring Valley	76,000	45,000	Tippett Valley (2,000), Snake Valley (43,000)	121,000	37.19
	Total Water Budget				
	Recharge + Discharge	Interbasin Flow		Total Water Budget	Interbasin Flow % of Water Budget
	USGS, 1965				
Snake Valley	183,000	75,500	--	258,500	29.21
Spring Valley	145,000	6,000	--	151,000	3.97
	Nichols, 2000				
Snake Valley	--	17,600	--	--	--
Spring Valley	194,000	14,000	--	208,000	6.73
	BARCASS, 2007				
Snake Valley	243,000	71,000	--	314,000	22.61
Spring Valley	169,000	75,000	--	244,000	30.74

Table 2. Depth of Circulation according to discharge temperature and silica geothermometers						
Samples	Discharge °C	Silica Conducitve °C	Silica Adabatic °C	Average GEOTHERM °C	Circulation Depths m (Discharge Temperature)	Silica Calculated Circulation Depth (m)
South Fox well	14.6	53	60	56.5	135.29	1367.65
Shoshone Ponds Well	24	65	71	68	411.76	1705.88
Big Springs	17.1	94	96	95	208.82	2500.00
Gandy Spring	27	67	72	69.5	500.00	1750.00

Table 3. Summary of Cluster Solute Compositions

Cluster Group	Temp (°C)	pH	Cations (mg/L)				Anions (mg/L)				TDS	n=
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	F^{-}		
1	10.85	7.01	11.88	2.27	6.02	0.77	51.82	4.38	3.00	0.06	80.18	10
2	9.96	6.67	31.78	5.03	9.00	2.17	116.20	10.68	8.65	0.22	183.73	5
3	9.24	7.18	62.57	7.66	5.94	0.77	220.66	9.22	4.50	0.08	311.39	12
4	13.29	7.28	56.90	23.02	6.65	1.33	278.59	12.30	6.99	0.09	385.86	9
5	14.22	7.39	48.87	20.33	5.83	1.67	249.34	12.24	6.78	0.14	345.20	6
6	12.64	7.70	39.07	12.71	3.48	0.98	186.08	5.82	1.93	0.06	250.14	8
7	13.85	7.31	43.08	11.17	27.22	4.84	217.55	15.90	20.87	0.47	341.10	4
8	12.93	7.86	29.92	20.41	6.03	1.87	188.47	10.37	12.79	0.27	270.12	3
9	14.52	7.42	43.07	12.22	14.88	2.58	167.57	18.82	19.62	0.22	278.94	5
10	19.83	6.90	63.28	26.83	50.34	5.54	296.48	57.87	55.27	0.49	556.08	2
11	16.91	7.11	54.14	24.39	29.33	2.49	261.00	38.07	33.18	0.39	442.98	4
12	6.45	6.78	122.55	15.57	4.15	0.71	435.15	13.88	4.59	0.05	596.65	3
13	14.10	7.34	59.86	19.81	62.20	6.35	347.30	38.85	34.41	0.63	569.41	1
14	12.85	6.98	110.75	21.82	45.23	2.43	293.70	72.49	99.42	0.23	646.06	1
15	13.70	7.00	70.31	35.35	8.13	2.29	224.00	131.27	14.03	1.53	486.92	1
16	9.90	7.48	79.10	94.70	67.80	1.14	437.00	234.00	83.60	0.15	997.49	1

Table 4. Isotope Chemistry						
Sample No.	Name	^{3}H (TU)	δ^{2}H (‰)	δ^{18}O (‰)	δ^{13}C (‰)	^{14}C (pmc)
1	Big Spring	1.9	-111.35	-14.86	-8.09	35.14
2	Davies Well	2.0	-108.16	-13.96	-11.14	74.42
3	Shell Baker	< 0.2	-112.57	-14.72	-13.55	73.40
4	Twin Spring	0, 0.3	-107.87	-13.97	-4.91	36.35
5	West Buckskin	0.3	-107.01	-13.49	-9.39	49.27
6	Knoll Spring	0.4	-108.19	-14.05	-6.13	32.90
7	Gandy Spring	4.3	-119.75	-15.68	(-4.33 / -7)	52.57 / 39.55
8	Cold Spring	1.2	-119.19	-15.42	-8.59	--
9	Caine Spring	1.0	-113.85	-15.17	-8.66	78.79
10	Clay Spring	0.3	-112.11	-14.79	-5.81	16.00
11	Needle Point Spring	<0.2	-108.58	-14.32	-9.95	39.40
12	North Little Spring	3.6	-110.66	-14.97	-8.17	48.12
13	MX-100	0.4	-109.73	-14.38	-7.79	23.60
14	USGS-MX (Hamblin Valley South)	0.6	-114.23	-14.82	-8.51	23.00
15	Kious	3.4	-110.00	-14.50	-10.4	83.1
16	BARCASS 2A	--	-120.90	-16.03	-6.5	1.02
17	BARCASS 3A	--	-111.10	-15.07	--	--
18	USGS-MX (Snake Valley S.)	--	-113.20	-15.08	-9 1/3	96.4
19	Hyde Well	0.1	-114.00	-15.04	-3.2	57.35
20	Needle Springs Well	0.5	-109.80	-14.43	--	--
21	MX well 36bd	0.1	-108.70	-14.53	-6.5	41.01
22	Monument Well	--	-113.40	-14.98	--	--
23	Sec 14 well	--	-112.70	-14.94	-7.1	29.41
24	Layton Spring	0.2	-109.90	-15.26	-11.16	98.94
25	South Spring (north fox)	0.5	-115.41	-15.07	-6.94	19.03
26	North Spring	0.2	-116.02	-15.54	-6.58	20.10
27	North Millick	0.5	-117.00	-15.57	-7.68	53.38
28	South Millick	5.200	-116.08	-15.27	-8.17	60.05
29	Rustler Spring (Cleveland)	1.7	-120.85	-16.26	-7.53	63.29
30	North Fourmile (Cleveland)	5.3	-119.05	-15.93	-8.53	86.54
31	South Bastian	1.3	-119.91	-15.94	-7.97	82.50
32	USGS-MX (Spring Valley Central)	0.1	-114.17	-14.64	-6.46	22.70
33	MX-28	2.4	-104.91	-14.03	-10.99	85.00
34	South Bastian (Flowing Well)	--	-121.00	-16.20	-6.8	34.7
35	Unnamed north of shoshone	--	-111.00	-15.10	-6.4	46.8
36	Unnamed east of peirmont creek	--	-121.00	-16.10	-13.7	--
37	Unnamed Spring #16	--	-122.90	-16.57	-14.3	72.42
38	Unnamed Spring #17	--	-117.60	-15.89	--	--
39	Unnamed Spring #19	--	-116.00	-15.37	-7.5	37.11
40	Shoshone Ponds (average)	0 - 0.4	-108.21	-14.82	-10.74	64.95
41	South Fox	0 - 0.8	-111.86	-14.81	(-5.5/-6.74)	29.66 / 12.80
42	Spring valley well ET1	--	-113.00	-15.00	-2.8	95.79
43	Willow Springs	--	-122.70	-16.17	9.6	69.88
44	Elderidge Well	--	-124.30	-16.10	-6.1	48.29
45	MX Well 24bdd	4.4	-83.00	-11.80	--	--
46	LAP&W Spring Vly Well 1 (156)	--	-125.00	-16.40	--	--
47	184 N23 E66 31AB 2	--	-126.00	-16.50	--	--
48	Rock Spring	2.3	-113.44	-14.82	-9.40	--
49	Swallow Canyon	7.5	-109.57	-15.04	-8.73	--
50	Murphy's Wash (Average)	1.8	-109.05	-14.21	-10.61	--

Table 4. Isotope Chemistry (cont.)						
Sample No.	Name	^3H (TU)	δ^2H (‰)	$\delta^{18}O$ (‰)	$\delta^{13}C$ (‰)	^{14}C (pmc)
51	Fourmile Spring	0.4	-122.13	-16.02	--	--
52	Rock/Pipe	1.1	-121.66	-15.35	-7.20	--
53	Row land Spring	6.9	-112.93	-14.88	-12.56	--
54	Snake Creek River	8.8	-113.59	-15.04	-8.24	--
55	Snake Campsite #2	7.4	-114.53	-15.02	-11.20	--
56	Cedar Cabin (Average)	--	-106.87	-13.90	--	--
57	Decatalon Spring	6.7	-107.63	-14.41	-11.05	--
58	South Baker River	9.6	-114.01	-15.23	-6.60	--
59	Baker Spring	7.3	-96.66	-13.05	-7.23	--
60	Marmot Spring	4.8	-115.87	-15.33	-15.03	--
61	Unnamed Spring #1	--	-107.20	-14.25	--	--
62	Unnamed Spring #2	--	-108.40	-14.40	--	--
63	Mustang Spring	--	-111.10	-15.20	--	--
64	South Spring	--	-107.80	-14.65	--	--
65	Spring Creek Spring	--	-112.95	-15.31	--	--
66	Unnamed Spring #4	--	-106.95	-14.57	--	--
67	Unnamed Spring #5	--	-106.05	-13.93	--	--
68	Cain Springs	--	-98.20	-10.81	--	--
69	Unnamed Spring #11	--	-117.00	-15.58	--	--
70	Eight Mile Spring	--	-116.20	-15.40	--	--
71	Unnamed Spring #12	--	-117.20	-15.82	--	--
72	Mud Spring	--	-116.35	-15.39	--	--
73	Unnamed Spring #13	--	-114.00	-14.70	--	--
74	Raised Spring	--	-107.65	-14.95	--	--
75	Granite Spring	--	-116.00	-15.31	--	--
76	Mike's Spring	--	-121.80	-15.85	--	--
77	Unnamed Spring #7	--	-119.50	-15.73	--	--
78	Grass Valley Springs	--	-124.50	-16.67	-16	89.96
79	Cedar Spring	--	-121.05	-15.43	--	--
80	Tippet Spring	--	-122.60	-16.17	-8.4	41.46
81	Unnamed Spring #8	--	-121.20	-15.79	--	--
82	Unnamed Spring #9	--	-122.90	-16.31	--	--
83	Unnamed Spring #10	--	-121.95	-15.89	--	--
84	Dipping Tank Spring	--	-120.65	-15.67	--	--
85	Rock Springs	--	-118.75	-15.16	--	--
86	Unnamed Spring #15 (Kalamazoo)	--	-120.10	-16.07	-9.6	48.01
87	Unnamed Spring #18	--	-118.20	-16.11	-11.1	87.18
88	Bastian	--	-113.40	-15.40	-9.5	82.91
89	spring	--	-105.60	-14.01	-9.3	82.05
90	Indian Springs	--	-105.95	-14.09	--	--
91	Cobb Spring	--	-103.70	-13.81	--	--
92	Unnamed Spring #14	--	-121	-16.22	-7.8	48.01
93	MX Well 19 dc	1.7	-105	-13.7	--	--
94	Unnamed #10	--	-15.28	-115.40	--	--

Table 5. Summary of the geochemical composition of Initial and Final Waters

Local Flow Paths			Temp (°C)	pH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	TDS	$\delta 13C$
#1	Initial Water	Carbonate Bedrock	10.44	7.18	63.01	14.16	6.46	0.87	251.24	10.37	5.48	351.67	-9.40
	Final Water	Cluster 11	15.00	7.11	54.14	24.39	29.33	2.49	261.00	38.07	33.18	442.98	-10.27
#2	Initial Water	Siliciclastic Bedrock	10.85	7.01	11.88	2.27	6.02	0.77	51.82	4.38	3.00	80.18	-11.48
	Final Water	Cluster 9	14.52	7.42	43.07	12.22	14.88	2.58	167.57	18.82	19.62	278.94	-11.12
#3	Initial Waters	Siliciclastic Bedrock	10.85	7.01	11.88	2.27	6.02	0.77	51.82	4.38	3.00	80.18	-11.48
		Carbonate Bedrock	10.44	7.18	63.01	14.16	6.46	0.87	251.24	10.37	5.48	351.67	-9.40
	Final Water	Cluster 6	12.64	7.70	39.07	12.71	3.48	0.98	186.08	5.82	1.93	250.14	-8.04
#4	Initial Water	Carbonate Bedrock	10.44	7.18	63.01	14.16	6.46	0.87	251.24	10.37	5.48	351.67	-9.40
	Final Water	Cluster 10	19.83	6.90	63.28	26.83	50.34	5.54	296.48	57.87	55.27	556.08	-5.52
#5	Initial Water	Carbonate Bedrock	10.44	7.18	63.01	14.16	6.46	0.87	251.24	10.37	5.48	351.67	-9.40
	Final Water	Cluster 8	13.05	7.82	31.34	19.66	4.90	1.88	195.10	9.97	6.25	269.36	-6.53
#6	Initial Waters	Carbonate Bedrock	10.44	7.18	63.01	14.16	6.46	0.87	251.24	10.37	5.48	351.67	-9.40
		Siliciclastic Bedrock	10.85	7.01	11.88	2.27	6.02	0.77	51.82	4.38	3.00	80.18	-11.48
		Monte Neva Hot Spring	76.00	7.70	66.10	19.50	16.70	6.25	322.00	24.50	3.40	458.45	-1.18
		McGill Spring	26.00		51.00	16.00	8.20	2.30	220.00	19.00	3.20	319.70	-7.57
	Final Waters	Gandy Spring	27.00	7.08	52.29	16.82	28.28	4.79	253.20	22.08	25.56	403.02	(-4.33 to -7.0)
		Big Spring	17.10	7.35	47.94	19.88	4.94	1.09	238.20	8.39	6.85	327.44	-8.09
		USGS-MX (Hamblin Valley South)	17.80	7.76	35.18	16.40	26.48	6.91	215.00	28.00	19.82	348.50	-8.51

Table 5 (cont.) Summary of the geochemical composition of Initial and Final Waters

Interbasin Flow Paths													
#7	Initial Water	Cluster 9 (representing Elderidge well	14.52	7.42	43.07	12.22	14.88	2.58	167.57	18.82	19.62	278.94	-11.12
Modern Recharg		Carbonate Bedrock water	10.44	7.18	63.01	14.16	6.46	0.87	251.24	10.37	5.48	351.67	-9.40
	Final Water	Gandy Spring	27.0	7.08	52.29	16.82	28.28	4.79	253.20	22.08	25.56	403.02	(-4.33 to -7)
#8	Initial #1	South Fox/South	13.05	7.82	31.34	19.66	4.90	1.88	195.10	9.97	6.25	269.36	-6.53
	Initial #2	North/MX well	14.65	7.48	46.24	19.17	5.99	2.30	239.05	17.15	5.99	336.09	-6.50
Modern Recharg		Carbonate Bedrock water	10.44	7.18	63.01	14.16	6.46	0.87	251.24	10.37	5.48	351.67	-9.40
	Final Waters	Big Spring	17.10	7.35	49.33	20.58	5.21	1.34	238.30	8.51	6.72	329.99	-8.09
		USGS-MX (Hamblin Valley South)	17.80	7.76	35.18	16.40	26.48	6.91	215.00	28.00	19.82	348.50	-8.51

Table 6. Model computed isotopic values for NETPATH mass balance models			
Flow Path	Computed δ13C	Observed δ13C	Mixing Ratio
#1	-7.95	-10.27	
#2	-11.82	-11.12	
#3	-8.22	-8.04	30 to 60% Siliciclastic water
#4	-6.23	-6.95	
#5	-10.8	-5.52	
#6 Gandy spring	-9.4	(-4.33 to -7)	
#6 Big Spring	-7.88	-8.09	
#6 Hamblin Valley S.	-8.03	-8.51	
#7 Southern #1 to Big Springs	-8.09	-8.09	92 % Initial #1 and 8% Carbonate water
#7 Southern #2 to Big Springs	-7.63	-8.09	20 % Initial #2 and 80% Carbonate water
#7 Southern #1 to Hamblin Valley S	8.2	8.51	43 % Initial #1 and 57% Carbonate water
#7 Southern #1 to Hamblin Valley S	-7.9	-8.51	25 % Initial #1 and 75% Carbonate water
#8 Northern to Gandy	-10.11	(-4.33 to -7)	59% Spring Valley initial and 41 % Carbonate
Monte Neva+modern water to Gandy	(-5.6 to -6.74)	(-4.33 to -7)	60-70% Carbonate and 40-30% Monte Neva

APPENDIX A

Appendix A-1. Description of Sampling Sites and Field Parameters

Agencies – BYU =1, USGS-DRI =2 (Hershey et al.,2007) and DRI=3 (Hershey, 1995)

Sample No.	Name	Sample Date	Agency	Easting	Northing	Zone	Elevation (m)	Water Source	Temp (°C)	pH	Cond (µS/cm)
1	Big Spring	8/3/06 -6/19/92	1,2,3	749547	4287148	11	1695.34	Spring	17.1	7.35	413
2	Davies Well	6/14/06	1	238930	4298474	12	1651.27	Well	15.4	7.51	608
3	Shell Baker	6/14/06	1	238264	4326306	12	1549.56	Well	15.2	7.39	355
4	Twin Spring	6/14/06 -8/2/06	1	253513	4365465	12	1468.7	Spring	19.8	7.065	405
5	West Buckskin	6/14/06	1	245666	4331266	12	1520.9	Flowing Well	14.5	7.09	744
6	Knoll Spring	8/2/06	1	251588	4347329	12	1488.4	Spring	19.9	6.74	689
7	Gandy Spring	8/2/06	1	238412	4372128	12	1596.5	Spring	27.0	7.08	483
8	Cold Spring	8/2/06	1	245666	4371239	12	1482.81	Spring	14.1	7.34	661
9	Caine Spring	8/2/06	1	755088	4336283	11	1534.26	Spring	14.5	7.65	412
10	Clay Spring	8/2/06	1	240336	4305876	12	1658.79	Spring	13.7	7	608
11	Needle Point Spring	8/3/06	1	236709	4294106	12	1665.1	Spring	12.4	7.97	342
12	North Little Spring	8/3/06	1	229085	4286926	12	1695.91	Spring	12.6	7.27	330
13	MX-100	9/1/06	1	233543	4296930	12	1684.1	Well	12.7	7.94	330
14	USGS-MX (Hamblin Valley South)	9/1/06	1	221090	4266791	12	1761.31	Well	17.8	7.76	404
15	Kious	6/18/92	3	746304	4319026	11	1820.29	Spring	14.2	7.56	440
16	BARCASS 2A	7/14/05	3	754185	4290351	11	1,674.30	Well	16	8.1	391
17	BARCASS 3A	7/14/05	3	753476	4288322	11	1,679.10	Well	12	7.6	449
18	USGS-MX (Snake Valley S.)	7/16/05	3	747485	4331249	11	1,678.20	Well	18	6.9	474
19	Hyde Well	8/31/05	3	741543	4271101	11	1,747.70	Well	14.8	7	413
20	Needle Springs Well	9/1/05	3	753980	4293739	11	1,660.20	Well	15.2	8	383
21	MX well 36bd	9/1/05	3	753876	4297007	11	1,706.90	Well	20.4	7.7	412
22	Monument Well	10/5/05	3	746992	4275125	11	1,731.30	Well	12.1	8	350
23	Sec 14 well	10/5/05	3	753566	4280917	11	1,717.20	Well	13	7.8	382
24	Layton Spring	8/3/06	1	201025	4334432	12	1732.8	Spring	18.5	7.25	315
25	South Spring (north fox)	8/11/06	1	195561	4306291	12	1766.01	Flowing Well	11.5	7.74	323
26	North Spring	8/11/06	1	197873	4312226	12	1755.29	Spring	12.6	7.69	410
27	North Millick	8/12/06	1	208352	4356189	12	1701.99	Spring	13.6	7.3	413
28	South Millick	6/18/92 -8/12/06	1,3	207756	4355817	12	1702.37	Spring	12.7	7.4	438
29	Rustler Spring (Cleveland)	8/12/06	1	201548	4346079	12	1712.51	Spring	12.9	7.55	291
30	North Fourmile (Cleveland)	8/12/06	1	200291	4348414	12	1923.1	Spring	12.7	7.71	241
31	South Bastian	8/12/06	1	197147	4338893	12	1757.58	Spring	12.2	7.45	294
32	USGS-MX (Spring Valley Central)	8/30/06	1	201276	4291621	12	1786.9	Well	16.7	7.27	351
33	MX-28	9/2/06	1	204985	4286310	12	1798	Well	13.2	7.59	349
34	South Bastian (Flowing Well)	6/18/92	3	718417	4333810	11	1730.62	Spring	11.5	8.02	278

Appendix A-1. Description of Sampling Sites and Field Parameters (cont.)											
Sample No.	Name	Sample Date	Agency	Easting	Northing	Zone	Elevation (m)	Water Source	Temp (°C)	pH	Cond (µS/cm)
35	Unnamed north of shoshone	5/27/92	3	725266	4304233	11	1794	Spring	12.3	7.82	269
36	Unnamed east of peirmont creek	6/18/92	3	723814	4312950	11	1749.47	Spring	15.1	6.93	137
37	Unnamed Spring #16	12/14/05	2	714253	4372844	11	1,728.20	Spring	14.6	7	90
38	Unnamed Spring #17	12/14/05	2	716820	4356446	11	1,715.40	Spring	14.1	6.64	132
39	Unnamed Spring #19	9/14/06	2	721790	4349483	11	1,706.90	Spring	11.7	7.7	490
40	Shoshone Ponds (average)	5/27/92 -8/11/06	2	203740	4314725		1,759.71	Flowing Well	23.4	8.0	151
41	South Fox	8/30/05 -8/11/06	1,2	714797	4294404	11	1,763.00	Flowing Well	14.6	7.9	326
42	Spring valley well ET1	9/3/05	2	720019	4295133	11	1,760.50	Well	16.2	7.4	690
43	Willow Springs	10/20/05	2	713758	4397063	11	1,822.70	Spring	12.7	7.2	473
44	Elderidge Well	11/9/05	2	723244	4383963	11	1,738.90	Well	13.2	7.8	353
45	MX Well 24bdd	12/12/05	2	714873	4326895	11	1,772.40	Well	13.3	--	538
46	LAP&W Spring Vly Well 1 (156)	9/16/82	2	715297	4334335	11	1781.13	Well	15.5	8	290
47	184 N23 E66 31AB 2	7/27/83	2	709155	4411770	11	1940.6	Well	28.2	8	330
48	Rock Spring	8/3/06	1,2	726798	4340206	11	1932.33	Spring	12.6	7.06	634
49	Swallow Canyon	8/11/06	1	208016	4304754	12	1866.77	Spring	10.1	7.6	305
50	Murphy's Wash (Average)	7/13/05 -8/11/06	1,2	731793	4290548	11	2,005.90	Spring	12.9	7.0	866
51	Fourmile Spring	8/12/06	1	214885	4356364	12	2096.06	Spring	15.7	7.8	304
52	Rock/Pipe	10/14/06	1	216648	4343771	12	2491.44	Spring	11.9	7.16	430
53	Rowland Spring	10/14/06	1	222212	4322733	12	2004	Spring	10.6	7.01	128
54	Snake Creek River	10/15/06	1	220747	4312972	12	2342.6	Spring	3.5	8	70
55	Snake Campsite #2	10/15/06	1	226608	4311904	12	1985.22	Spring	8.3	7.46	193
56	Cedar Cabin (Average)	7/13/05 -10/15/06	1,2	741138	4297900	11	2,431.20	Spring	7.7	7.6	355
57	Decatalon Spring	7/14/05 -10/15/06	1,2	736287	4298920	11	2520.7	Spring	6.8	7.12	361
58	South Baker River	10/15/06	1	217319	4318238	12	2695.6	Spring	4.1	--	30
59	Baker Spring	10/15/06	1	216275	4319157	12	2866.12	Spring	3.7	--	20
60	Marmot Spring	10/15/06	1	219182	4320423	12	2359.73	Spring	10.0	7.05	90
61	Unnamed Spring #1	7/13/05	2	734755	4296647	11	2,420.70	Spring	9.5	6.82	430
62	Unnamed Spring #2	7/13/05	2	735192	4297225	11	2,399.10	Spring	8.3	7.26	391
63	Mustang Spring	7/14/05	2	736716	4305064	11	3,082.70	Spring	4.3	7.09	329
64	South Spring	7/14/05	2	745240	4298821	11	2,269.50	Spring	9.7	6.87	502
65	Spring Creek Spring	7/16/05	2	750342	4310711	11	1,868.40	Spring	7.26	380	8
66	Unnamed Spring #4	7/28/05	2	743359	4302022	11	2,357.30	Spring	6.1	6.43	713
67	Unnamed Spring #5	7/28/05	2	745556	4304101	11	2,122.30	Spring	11.9	6.97	524
68	Cain Springs	8/26/05	2	738388	4380672	11	2,127.50	Spring	14.9	6.92	1820
69	Unnamed Spring #11	8/26/05	2	731323	4374034	11	2,374.40	Spring	8.9	6.71	390
70	Eight Mile Spring	8/26/05	2	733881	4363392	11	2,477.40	Spring	11.1	7.02	473
71	Unnamed Spring #12	10/25/05	2	740035	4354599	11	2,802.00	Spring	7.6	7.24	222

Appendix A-1. Description of Sampling Sites and Field Parameters (cont.)											
Sample No.	Name	Sample Date	Agency	Easting	Northing	Zone	Elevation (m)	Water Source	Temp (°C)	pH	Cond (µS/cm)
72	Mud Spring	10/25/05	2	735572	4356489	11	2,707.50	Spring	6.9	7.13	441
73	Unnamed Spring #13	10/26/05	2	734364	4340019	11	2,255.50	Spring	9.9	7.48	1249
74	Raised Spring	10/27/05	2	727805	4317029	11	2,161.30	Spring	10.8	6.07	58
75	Granite Spring	7/31/06	2	728271	4343732	11	2,071.70	Spring	14	7.28	513
76	Mike's Spring	8/23/05	2	739842	4391953	11	2,203.70	Spring	10.7	6.77	559
77	Unnamed Spring #7	8/23/05	2	740916	4396100	11	2,398.80	Spring	10.2	6.32	423
78	Grass Valley Springs	8/23/05	2	737192	4399594	11	2,565.50	Spring	9.2	6.35	167
79	Cedar Spring	8/23/05	2	738837	4406299	11	2,083.30	Spring	14.4	7.2	917
80	Tippet Spring	8/24/05	2	724615	4417403	11	1,900.40	Spring	21.4	6.8	495
81	Unnamed Spring #8	8/24/05	2	719135	4429561	11	2,371.00	Spring	9.2	6.13	283
82	Unnamed Spring #9	8/25/05	2	720201	4430242	11	2,417.40	Spring	8.3	6.16	255
83	Unnamed Spring #10	8/25/05	2	725504	4424213	11	2,026.90	Spring	12.9	6.59	894
84	Dipping Tank Spring	8/25/05	2	716241	4405863	11	2,141.20	Spring	12	6.83	358
85	Rock Springs	8/25/05	2	716177	4415256	11	2,279.90	Spring	9.4	6.05	342
86	Unnamed Spring #15 (Kalamazoo)	12/13/05	2	706707	4382375	11	2,130.60	Spring	11.8	7.47	357
87	Unnamed Spring #18	10/6/06	2	703052	4392092	11	2,602.70	Spring	6.4	7.45	359
88	Bastian	7/28/06	2	710106	4336584	11	2,045.50	Spring	10.2	7.48	320
89	spring	8/30/05	2	721465	4286565	11	1,841.60	Spring	19.9	7.3	225
90	Indian Springs	7/29/05	2	721972	4280092	11	1,937.90	Spring	14.1	6.79	220
91	Cobb Spring	7/28/05	2	239707	4270177	12	2294	Spring	11.7	7.31	790
92	Unnamed Spring #14	12/13/05	2	719101	4342418	11	1,721.50	Spring	12.2	7.58	296
93	MX Well 19 dc	12/13/05	2	727555	4297305	11	1,799.80	Well	14.2	--	1171
94	Unnamed #10	9/17/06	2	219314	4373137	12	2502.25	Spring	10.5	6.52	503

Appendix A-2. Samples grouped according to Clusters

Cluster #	Name	Temp (°C)	pH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	Cl^-	TDS	^3H (TU)	δ^2H (‰)	$\delta^{18}O$ (‰)	$\delta^{13}C$ (‰)	^{14}C (pmc)
#1	South Baker River	4.10	--	5.89	0.96	2.53	0.49	28.00	0.60	0.60	39.07	9.60	-114.01	-15.23	-6.60	
	Baker Spring	3.70	--	3.02	0.62	1.00	0.31	6.70	4.29	1.47	17.41	7.30	-96.66	-13.05	-7.23	
	Unnamed Spring #16	14.60	7.00	9.44	2.31	4.18	0.61	44.00	4.10	2.40	67.04	--	-122.90	-16.57	-14.30	72.42
	Raised Spring	10.80	6.07	7.01	1.77	2.38	0.66	31.20	2.40	1.00	46.42		-107.65	-14.95		
	Snake Creek River	3.50	8.00	16.87	3.09	3.19	0.72	69.50	3.00	1.16	97.52	8.80	-113.59	-15.04	-8.24	
	Marmot Spring	10.00	7.05	12.42	2.78	6.38	0.84	62.10	0.79	0.80	86.11	4.80	-115.87	-15.33	-15.03	
	Unnamed east of peirmont creek	15.10	6.93	15.80	3.83	6.08	1.22	54.00	9.50	9.20	99.63		-121.00	-16.10	-13.70	
	Unnamed Spring #17	14.10	6.64	8.66	2.70	14.60	0.85	58.80	10.40	5.40	101.41	--	-117.60	-15.89	--	--
	Grass Valley Springs	9.20	6.35	18.00	3.26	12.30	0.94	81.00	5.10	5.90	126.50		-124.50	-16.67	-16.00	89.96
	Shoshone Ponds (average)	23.43	8.01	21.66	1.34	7.57	1.03	82.85	3.65	2.03	120.13		-108.21	-14.82	-10.74	73.12
	Mean:	10.85	7.01	11.88	2.27	6.02	0.77	51.82	4.38	3.00	80.12					
	SD:	6.28	0.70	6.04	1.06	4.44	0.27	24.44	3.28	2.87	36.28					
#2	Unnamed Spring #9	8.30	6.16	32.80	6.25	8.86	3.03	109.00	14.90	14.80	189.64		-122.90	-16.31		
	Indian Springs	14.10	6.79	26.30	4.10	12.70	4.56	114.00	6.70	9.40	177.76		-105.95	-14.09		
	Row land Spring	10.60	7.01	24.82	4.27	5.86	0.73	98.00	5.49	5.55	144.72	6.90	-112.93	-14.88	-12.56	
	Unnamed Spring #12	7.60	7.24	39.10	3.53	4.78	0.64	130.00	4.20	2.40	184.65		-117.20	-15.82		
	Unnamed Spring #8	9.20	6.13	35.90	6.98	12.80	1.89	130.00	22.10	11.10	220.77		-121.20	-15.79		
	Mean:	9.96	6.67	31.78	5.03	9.00	2.17	116.20	10.68	8.65	183.51					
	SD:	2.57	0.50	6.13	1.50	3.74	1.65	13.86	7.63	4.82	27.22					
#3	Fourmile Spring	15.70	7.80	49.07	7.98	5.62	1.11	196.40	3.81	5.33	269.32	0.37	-122.13	-16.02		
	Rock Springs	9.40	6.05	50.00	8.01	12.50	0.91	188.00	15.70	5.80	280.92		-118.75	-15.16		
	Snake Campsite #2	8.30	7.46	43.07	5.83	8.16	1.16	161.00	8.03	8.93	236.17	7.40	-114.53	-15.02	-11.20	
	Bastian	10.20	7.48	58.50	1.50	2.88	0.56	192.00	4.90	2.00	262.34	--	-113.40	-15.40	-9.50	82.91
	Spring Creek Spring	12.90	7.26	64.20	7.85	6.94	1.22	227.00	12.50	6.70	326.41		-112.95	-15.31		
	Sw allow Canyon	10.10	7.60	57.05	9.64	1.30	0.65	219.50	4.30	1.06	293.49	7.55	-109.57	-15.04	-8.73	
	Mustang Spring	4.30	7.09	68.00	4.58	1.32	0.36	218.00	5.50	0.80	298.56		-111.10	-15.20		
	Unnamed Spring #18	6.40	7.45	60.60	10.50	5.21	0.53	213.00	16.00	2.00	307.84	--	-118.20	-16.11	-11.10	87.18
	Unnamed Spring #11	8.90	6.71	60.10	11.40	11.40	1.56	231.00	11.10	8.30	334.86		-117.00	-15.58		
	Mud Spring	6.90	7.13	73.40	14.50	3.02	0.64	287.00	5.40	2.50	386.46		-116.35	-15.39		
	Unnamed Spring #1	9.50	6.82	83.70	6.73	9.24	0.30	261.00	17.60	7.80	386.37		-107.20	-14.25		
	Unnamed Spring #2	8.30	7.26	83.10	3.37	3.72	0.24	254.00	5.80	2.80	353.03		-108.40	-14.40		
	Mean:	9.64	6.56	34.98	4.82	6.44	1.05	127.53	7.54	4.73	186.51					
	SD:	2.97	0.47	12.77	3.61	3.77	0.42	34.89	5.10	2.97	47.70					

Appendix A-2. Samples grouped according to Clusters (cont.)

#4	Rock Spring	12.60	7.06	73.23	34.89	21.11	2.30	366.20	30.98	25.66	554.37	3.65	-113.44	-14.82	-9.40	
	Rock/Pipe	11.90	7.16	68.84	32.77	10.84	1.87	371.00	17.87	14.06	517.26	3.44	-121.66	-15.35	-7.20	
	Eight Mile Spring	11.10	7.02	77.80	18.30	5.74	0.86	307.00	9.50	4.70	423.90		-116.20	-15.40		
	Granite Spring	14.00	7.28	70.40	23.30	7.50	0.88	310.00	12.70	7.00	431.78	--	-116.00	-15.31		--
	Unnamed Spring #5	11.90	6.97	58.40	30.80	9.34	1.22	322.00	9.20	9.20	440.16		-106.05	-13.93		
	South Spring	9.70	6.87	66.30	28.80	2.23	0.54	343.00	3.40	2.60	446.87		-107.80	-14.65		
	Unnamed Spring #19	11.70	7.70	57.00	25.00	13.70	1.66	277.00	19.80	14.30	408.46	--	-116.00	-15.37	-7.50	37.11
	Cedar Cabin (Average)	7.65	7.62	61.76	20.83	5.30	1.09	287.60	5.81	5.23	387.61		-106.87	-13.90		
	Tippet Spring	21.40	6.80	54.80	30.20	7.65	1.08	279.00	26.00	7.10	405.83		-122.60	-16.17	-8.40	41.46
	Mean:	12.49	7.18	63.78	25.32	7.35	1.05	303.66	12.34	7.16	420.66					
	SD:	4.39	0.36	8.23	4.82	3.59	0.35	24.19	7.99	3.78	21.07					
#5	North Spring	12.60	7.69	47.88	22.53	5.08	1.43	257.40	16.57	6.39	357.28	0.15	-116.02	-15.54	-6.58	20.10
	North Millick	13.60	7.30	49.28	22.99	6.08	1.38	263.00	10.58	7.84	361.15	0.49	-117.00	-15.57	-7.68	53.38
	North Little Spring	12.60	7.27	50.00	18.35	3.51	1.43	244.40	6.54	4.76	328.99	3.63	-110.66	-14.97	-8.17	48.12
	Big Spring	17.10	7.35	47.94	19.88	4.94	1.09	238.20	8.39	6.85	327.28	1.90	-111.35	-14.86	-8.09	35.08
	USGS-MX (Spring Valley Central)	16.70	7.27	44.59	15.80	6.91	3.16	220.70	17.74	5.60	314.49	0.10	-114.17	-14.64	-6.46	
	South Millick (Average)	12.70	7.44	53.54	22.46	8.45	1.50	272.35	13.65	9.25	381.19	5.20	-116.08	-15.27	-8.17	60.05
	Mean:	14.22	7.39	48.87	20.33	5.83	1.67	249.34	12.24	6.78	345.06					
	SD:	2.12	0.16	2.95	2.87	1.72	0.75	18.71	4.50	1.61	25.39					
#6	Unnamed Spring #15 (Kalamazoo)	11.80	7.47	47.30	16.30	3.22	0.69	217.00	12.70	2.10	299.31		-120.10	-16.07	-9.60	48.01
	Rustler Spring (Cleveland)	12.90	7.55	40.63	13.93	2.43	0.93	199.50	4.62	1.72	263.75	1.69	-120.85	-16.26	-7.53	63.29
	North Fourmile (Cleveland)	12.70	7.71	33.63	10.83	2.14	0.87	162.40	3.62	1.46	214.95	5.31	-119.05	-15.93	-8.53	86.54
	Unnamed north of shoshone	12.30	7.82	35.90	11.60	2.60	0.73	172.00	4.08	1.30	228.21	7.19	-111.00	-15.10	-6.40	46.80
	LAP&W Spring Vly Well 1 (156)	15.50	8.00	37.00	13.00	4.70	1.10	180.00	4.00	2.10	241.90		-125.00	-16.40		
	South Bastian	12.20	7.45	45.48	10.30	3.07	0.76	195.70	4.61	2.99	262.90	1.30	-119.91	-15.94	-7.97	82.50
	Unnamed Spring #14	12.20	7.58	38.50	12.90	2.71	0.89	182.00	6.90	2.20	246.10	--	-121.00	-16.22	-7.80	48.01
	South Bastian (Flow ing Well)	11.50	8.02	34.10	12.80	6.99	1.91	180.00	6.07	1.60	243.47	--	-121.00	-16.20	-6.80	34.70
	Mean:	12.64	7.70	39.07	12.71	3.48	0.98	186.08	5.82	1.93	250.07					
	SD:	1.24	0.23	5.07	1.89	1.62	0.40	17.23	2.99	0.54	25.67					
															-6.52	20.10
#7	USGS-MX (Hamblin Valley South)	17.80	7.76	35.18	16.40	26.48	6.91	215.00	28.00	19.82	347.79	0.61	-114.23	-14.82	-8.51	23.00
	Unnamed Spring #7	10.20	6.32	51.50	11.00	25.70	0.82	232.00	14.10	14.90	350.02		-119.50	-15.73		
	MX-28	13.20	7.59	32.84	9.61	29.51	10.01	225.20	7.69	14.75	329.61	2.40	-104.91	-14.03	-10.99	85.00
	Kious	14.20	7.56	52.80	7.69	27.20	1.62	198.00	13.80	34.00	335.11	3.44	-110.00	-14.50	-10.40	83.10
	Mean:	13.85	7.31	43.08	11.17	27.22	4.84	217.55	15.90	20.87	340.63					
	SD:	2.71	0.58	9.12	3.24	1.42	3.79	12.81	7.44	7.85	8.53					
#8	South Fox	14.60	7.90	31.94	19.74	4.70	1.60	195.60	10.12	5.66	269.36		-111.86	-14.81	-6.12	29.66,12.80
	South Spring (north fox)	11.50	7.74	30.73	19.57	5.09	2.16	194.60	9.81	6.83	268.79	0.49	-115.41	-15.07	-6.94	19.03
	MX-100	12.70	7.94	27.08	21.91	8.29	1.86	175.20	11.17	25.89	271.40	0.40	-109.73	-14.38	-7.79	23.60
	Mean:	12.93	7.86	29.92	20.41	6.03	1.87	188.47	10.37	12.79	269.85					
	SD:	1.28	0.09	2.07	1.07	1.61	0.23	9.39	0.58	9.27	1.12					

Appendix A-2. Samples grouped according to Clusters (cont.)

#9	Dipping Tank Spring	12.00	6.83	47.50	8.37	16.20	2.01	167.00	14.60	18.00	273.68		-120.65	-15.67		
	Caine Spring	14.50	7.65	43.84	17.38	16.33	2.17	180.20	22.76	31.44	314.12	1.00	-113.85	-15.17	-8.66	78.79
	Shell Baker	15.19	7.39	45.04	8.59	8.84	0.38	155.40	10.12	23.77	252.12	< 0.2	-112.57	-14.72	-13.55	73.40
	Needle Point Spring	12.40	7.97	30.30	15.16	15.80	3.97	145.50	28.86	25.14	264.74	<0.2	-108.58	-14.32	-9.95	
	Layton Spring	18.50	7.25	42.16	9.45	11.20	2.90	189.30	10.57	8.36	273.94	0.17	-109.90	-15.26	-11.16	98.94
	Mean:	14.52	7.42	41.77	11.79	13.67	2.29	167.48	17.38	21.34	275.72					
	SD:	2.60	0.43	6.70	4.18	3.44	1.32	17.80	8.18	8.69	23.23					
#10	Tw in Spring	19.75	7.07	62.09	27.13	52.33	4.75	290.45	61.00	60.78	558.53	0, 0.3	-107.87	-13.97	-4.91	36.35
	Knoll Spring	19.90	6.74	64.47	26.53	48.35	6.32	302.50	54.73	49.76	552.67	0.40	-108.19	-14.05	-6.13	32.90
	Mean:	19.83	6.90	63.28	26.83	50.34	5.54	296.48	57.87	55.27	555.60					
	SD:	0.11	0.23	1.68	0.42	2.81	1.11	8.52	4.43	7.79	4.15					
#11	Davies Well	15.44	7.51	44.83	33.26	26.20	1.35	270.90	35.45	31.26	443.26	2.03	-108.16	-13.96	-11.14	74.42
	West Buckskin	14.48	7.09	57.53	28.58	31.03	1.99	273.90	59.97	46.69	499.70	0.30	-107.01	-13.49	-9.39	49.27
	Gandy Spring	27.00	7.08	52.29	16.82	28.28	4.79	253.20	22.08	25.56	403.02	4.33	-119.75	-15.68	-4.33/-7.0	52.57, 39.55
	Mike's Spring	10.70	6.77	61.90	18.90	31.80	1.81	246.00	34.80	29.20	424.41		-121.80	-15.85		
	Mean:	16.91	7.11	54.14	24.39	29.33	2.49	261.00	38.07	33.18	442.60					
	SD:	7.03	0.30	7.34	7.83	2.58	1.56	13.54	15.84	9.31	41.47					
#12	Decatalon Spring	6.80	7.12	114.10	8.85	2.24	0.40	396.30	9.86	2.58	534.33	6.70	-107.63	-14.41	-11.05	
	Unnamed Spring #4	6.10	6.43	131.00	22.30	6.06	1.02	474.00	17.90	6.60	658.88		-106.95	-14.57		
	Mean:	6.45	6.78	122.55	15.57	4.15	0.71	435.15	13.88	4.59	596.60					
	SD:	0.49	0.49	11.95	9.51	2.70	0.44	54.94	5.69	2.84	88.07					
#13	Cold Spring	14.10	7.34	59.86	19.81	62.20	6.35	347.30	38.85	34.41	568.78	1.23	-119.19	-15.42	-8.59	
#14	Murphy's Wash (Average)	12.85	6.98	110.75	21.82	45.23	2.43	293.70	72.49	99.42	645.83		-109.05	-14.21	-10.61	
#15	Clay Spring	13.70	7.00	70.31	35.35	8.13	2.29	224.00	131.27	14.03	485.39	0.29	-112.11	-14.79	-5.81	16.00
#16	Unnamed Spring #13	9.90	7.48	79.10	94.70	67.80	1.14	437.00	234.00	83.60	997.34		-114.00	-14.70		

Appendix A-3. Solute Chemisry

Samples that do not charge balance to within 5% are highlighted and were not used in geochemical analysis.

Sample No.	Name	Cations (mg/L)				Anions (mg/L)						Total Cations	Total Anions	Balance Error %
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	Cl^-	F^-	SiO2	TDS	meq/L		
1	Big Spring	47.94	19.88	4.94	1.09	238.20	8.39	6.85	0.16	41.80	327.44	4.3	4.3	-0.1
2	Davies Well	44.83	33.26	26.20	1.35	270.90	35.45	31.26	0.29	--	443.55	6.1	6.1	0.5
3	Shell Baker	45.04	8.59	8.84	0.38	155.40	10.12	23.77	0.24	--	252.37	3.3	3.5	-1.7
4	Tw in Spring	62.09	27.13	52.33	4.75	290.45	61.00	60.78	0.55	--	559.08	7.7	7.8	-0.3
5	West Buckskin	57.53	28.58	31.03	1.99	273.90	59.97	46.69	0.36	--	500.05	6.6	7.1	-3.4
6	Knoll Spring	64.47	26.53	48.35	6.32	302.50	54.73	49.76	0.42	--	553.09	7.7	7.5	0.9
7	Gandy Spring	52.29	16.82	28.28	4.79	253.20	22.08	25.56	0.55	21.70	403.56	5.3	5.4	-0.2
8	Cold Spring	59.86	19.81	62.20	6.35	347.30	38.85	34.41	0.63	--	569.41	7.5	7.5	-0.1
9	Caine Spring	43.84	17.38	16.33	2.17	180.20	22.76	31.44	0.17	--	314.29	4.4	4.3	0.6
10	Clay Spring	70.31	35.35	8.13	2.29	224.00	131.27	14.03	1.53	--	486.92	6.8	6.9	-0.4
11	Needle Point Spring	30.30	15.16	15.80	3.97	145.50	28.86	25.14	0.37	--	265.11	3.5	3.7	-2.5
12	North Little Spring	50.00	18.35	3.51	1.43	244.40	6.54	4.76	0.11	--	329.10	4.2	4.3	-1.0
13	MX-100	27.08	21.91	8.29	1.86	175.20	11.17	25.89	0.23	--	271.62	3.6	3.9	-3.9
14	USGS-MX (Hamblin Valley South)	35.18	16.40	26.48	6.91	215.00	28.00	19.82	0.71	--	348.50	4.4	4.7	-3.2
15	Kious	52.80	7.69	27.20	1.62	198.00	13.80	34.00	0.70	17.50	335.81	4.5	4.5	-0.4
16	BARCASS 2A	21.50	18.90	37.50	6.53	179.00	26.30	5.40	1.12	45.20	296.25	4.4	3.7	9.0
17	BARCASS 3A	56.40	27.00	6.75	1.50	231.00	9.60	19.30	0.10	22.00	351.65	5.4	4.5	8.4
18	USGS-MX (Snake Valley S.)	67.80	22.40	13.50	1.82	222.00	20.50	15.90	0.15	17.10	364.07	5.9	4.5	12.9
19	Hyde Well	43	19	23.8	4.05	198.00	27.00	11.00	0.88	23.90	326.73	4.8	4.2	7.6
20	Needle Springs Well	35.10	19.40	23.00	3.93	128.00	26.50	23.20	0.39	37.40	259.52	4.4	3.3	14.5
21	MX w ell 36bd	51.20	38.10	14.60	1.57	225.00	11.30	22.60	0.06	21.60	364.43	6.4	4.6	16.5
22	Monument Well	43.90	12.20	24.50	4.14	134.00	32.10	16.80	0.50	61.80	268.14	4.4	3.4	13.0
23	Sec 14 w ell	50.80	21.40	12.50	4.21	169.00	17.90	15.90	0.48	54.00	292.19	4.9	3.6	15.5
24	Layton Spring	42.16	9.45	11.20	2.90	189.30	10.57	8.36	0.21	--	274.15	3.4	3.6	-1.8
25	South Spring (north fox)	30.73	19.57	5.09	2.16	194.60	9.81	6.83	0.21	--	269.00	3.4	3.6	-2.6
26	North Spring	47.88	22.53	5.08	1.43	257.40	16.57	6.39	0.12	--	357.40	4.5	4.8	-2.8
27	North Millick	49.28	22.99	6.08	1.38	263.00	10.58	7.84	0.09	--	361.23	4.7	4.8	-1.2
28	South Millick	53.54	22.46	8.45	1.50	272.35	13.65	9.25	0.09	10.50	381.28	4.9	5.0	-0.9
29	Rustler Spring (Cleveland)	40.63	13.93	2.43	0.93	199.50	4.62	1.72	0.09	--	263.85	3.3	3.4	-1.7
30	North Fourmile (Cleveland)	33.63	10.83	2.14	0.87	162.40	3.62	1.46	0.10	--	215.05	2.7	2.8	-1.8
31	South Bastian	45.48	10.30	3.07	0.76	195.70	4.61	2.99	0.03	--	262.93	3.3	3.4	-1.8
32	USGS-MX (Spring Valley Central)	44.59	15.80	6.91	3.16	220.70	17.74	5.60	0.28	--	314.77	3.9	4.2	-3.2
33	MX-28	32.84	9.61	29.51	10.01	225.20	7.69	14.75	0.08	--	329.69	4.0	4.3	-3.8
34	South Bastian (Flow ing Well)	34.10	12.80	6.99	1.91	180.00	6.07	1.60	0.13	20.40	243.60	3.1	3.1	-0.4

Appendix A-3. Solute Chemisry (cont.)

Sample No.	Name	Cations (mg/L)				Anions (mg/L)						Total Cations	Total Anions	Balance Error %
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	F^{-}	SiO2	TDS	meq/L		
35	Unnamed north of shoshone	35.90	11.60	2.60	0.73	172.00	4.08	1.30	0.06	11.80	228.27	2.9	2.9	-1.2
36	Unnamed east of peirmont creek	15.80	3.83	6.08	1.22	54.00	9.50	9.20	0.06	3.70	99.69	1.4	1.3	1.8
37	Unnamed Spring #16	9.44	2.31	4.18	0.61	44.00	4.10	2.40	0.07	13.4	67.11	0.9	0.9	-1.1
38	Unnamed Spring #17	8.66	2.70	14.60	0.85	58.80	10.40	5.40	0.07	10.4	101.48	1.3	1.3	-0.9
39	Unnamed Spring #19	57.00	25.00	13.70	1.66	277.00	19.80	14.30	0.15	18.50	408.61	5.5	5.4	1.6
40	Shoshone Ponds (average)	21.66	1.34	7.57	1.03	82.85	3.65	2.03	0.15	21.00	120.28	1.5	1.5	1.6
41	South Fox	31.94	19.74	4.70	1.60	195.60	10.12	5.66	0.36	15.40	269.72	3.5	3.6	-1.9
42	Spring valley well ET1	95.00	30.80	19.50	8.52	159.00	48.30	97.40	0.27	61.80	458.79	8.3	6.4	13.4
43	Willow Springs	62.9	16.5	25.8	3.43	211	21.8	18	0.13	29.90	359.56	5.7	4.4	12.6
44	Elderidge Well	49.6	14.4	20.9	4.02	168	23	11	0.16	30.20	291.08	4.7	3.6	13.6
45	MX Well 24bdd	--	--	--	--	--	--	--	--	--	--	--	--	--
46	LAP&W Spring Vly Well 1 (156)	37.00	13.00	4.70	1.10	180.00	4.00	2.10	0.10	--	242.00	3.1	3.1	0.8
47	184 N23 E66 31AB 2	41.00	9.70	20.00	6.50	170.00	15.00	25.00	0.60	--	287.80	3.9	3.8	0.6
48	Rock Spring	73.23	34.89	21.11	2.30	366.20	30.98	25.66	0.08	--	554.45	7.5	7.4	0.9
49	Swallow Canyon	57.05	9.64	1.30	0.65	219.50	4.30	1.06	0.10	--	293.59	3.7	3.7	-0.1
50	Murphy's Wash (Average)	110.75	21.82	45.23	2.43	293.70	72.49	99.42	0.23	22.30	646.06	9.4	9.1	1.1
51	Fourmile Spring	49.07	7.98	5.62	1.11	196.40	3.81	5.33	0.03	--	269.35	3.4	3.5	-1.1
52	Rock/Pipe	68.84	32.77	10.84	1.87	371.00	17.87	14.06	0.09	--	517.34	6.7	6.9	-1.6
53	Rowland Spring	24.82	4.27	5.86	0.73	98.00	5.49	5.55	0.07	--	144.79	1.9	1.9	-0.6
54	Snake Creek River	16.87	3.09	3.19	0.72	69.50	3.00	1.16	0.03	--	97.55	1.3	1.2	0.7
55	Snake Campsite #2	43.07	5.83	8.16	1.16	161.00	8.03	8.93	0.09	--	236.27	3.0	3.1	-0.9
56	Cedar Cabin (Average)	61.8	20.8	5.3	1.1	287.6	5.8	5.2	0.1	11.5	387.67	5.1	5.0	0.7
57	Decatalon Spring	114.10	8.85	2.24	0.40	396.30	9.86	2.58	0.05	11.30	534.37	6.5	6.8	-1.9
58	South Baker River	5.89	0.96	2.53	0.49	28.00	0.60	0.60	0.05	--	39.12	0.5	0.5	0.0
59	Baker Spring	3.02	0.62	1.00	0.31	6.70	4.29	1.47		--	17.41	0.3	0.3	0.0
60	Marmot Spring	12.42	2.78	6.38	0.84	62.10	0.79	0.80	0.03	--	86.14	1.2	1.1	4.1
61	Unnamed Spring #1	83.70	6.73	9.24	0.30	261.00	17.60	7.80	0.20	12.90	386.57	5.1	4.9	2.6
62	Unnamed Spring #2	83.10	3.37	3.72	0.24	254.00	5.80	2.80	0.13	9.50	353.16	4.6	4.4	2.5
63	Mustang Spring	68.00	4.58	1.32	0.36	218.00	5.50	0.80	0.04	5.20	298.60	3.8	3.7	1.6
64	South Spring	66.30	28.80	2.23	0.54	343.00	3.40	2.60	0.00	7.40	446.87	5.8	5.8	0.2
65	Spring Creek Spring	64.20	7.85	6.94	1.22	227.00	12.50	6.70	0.11	11.1	326.52	4.2	4.2	0.1
66	Unnamed Spring #4	131.00	22.30	6.06	1.02	474.00	17.90	6.60	0.05	11.5	658.93	8.7	8.3	1.9
67	Unnamed Spring #5	58.40	30.80	9.34	1.22	322.00	9.20	9.20	0.08	10.9	440.24	5.9	5.7	1.3

Appendix A-3. Solute Chemisry (cont.)														
Sample No.	Name	Cations (mg/L)				Anions (mg/L)						Total Cations	Total Anions	Balance Error %
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	Cl^-	F^-	SiO2	TDS	meq/L		
68	Cain Springs	191.00	53.60	117.00	0.85	322.00	162.00	352.00	0.34	34.6	1199	19.1	18.6	1.2
69	Unnamed Spring #11	60.10	11.40	11.40	1.56	231.00	11.10	8.30	0.06	19.3	334.92	4.5	4.3	2.5
70	Eight Mile Spring	77.80	18.30	5.74	0.86	307.00	9.50	4.70	0.00	12.7	423.90	5.7	5.4	2.7
71	Unnamed Spring #12	39.10	3.53	4.78	0.64	130.00	4.20	2.40	0.70	11.9	185.35	2.5	2.3	3.0
72	Mud Spring	73.40	14.50	3.02	0.64	287.00	5.40	2.50	0.00	10.8	386.46	5.0	4.9	1.2
73	Unnamed Spring #13	79.10	94.70	67.80	1.14	437.00	234.00	83.60	0.15	21.3	997.49	14.7	14.4	1.1
74	Raised Spring	7.01	1.77	2.38	0.66	31.20	2.40	1.00	0.05	11.1	46.47	0.6	0.6	2.0
75	Granite Spring	70.40	23.30	7.50	0.88	310.00	12.70	7.00	0.00	11.90	431.78	5.8	5.5	2.1
76	Mike's Spring	61.90	18.90	31.80	1.81	246.00	34.80	29.20	0.35	26.80	424.76	6.1	5.6	4.1
77	Unnamed Spring #7	51.50	11.00	25.70	0.82	232.00	14.10	14.90	0.40	36.00	350.42	4.6	4.5	0.8
78	Grass Valley Springs	18.00	3.26	12.30	0.94	81.00	5.10	5.90	0.09	25.9	126.59	1.7	1.6	3.6
79	Cedar Spring	104.00	50.60	16.50	1.60	208.00	262.00	42.90	0.49	15.1	686.09	10.1	10.1	0.1
80	Tippet Spring	54.80	30.20	7.65	1.08	279.00	26.00	7.10	0.05	11.4	405.88	5.6	5.3	2.4
81	Unnamed Spring #8	35.90	6.98	12.80	1.89	130.00	22.10	11.10	0.13	43.6	220.90	3.0	2.9	1.0
82	Unnamed Spring #9	32.80	6.25	8.86	3.03	109.00	14.90	14.80	0.10	43.3	189.74	2.6	2.5	1.8
83	Unnamed Spring #10	92.00	49.20	34.10	1.19	329.00	175.00	35.50	0.16	19.5	716.15	10.2	10.0	0.5
84	Dipping Tank Spring	47.50	8.37	16.20	2.01	167.00	14.60	18.00	0.10	29.7	273.78	3.8	3.6	3.5
85	Rock Springs	50.00	8.01	12.50	0.91	188.00	15.70	5.80	0.05	36	280.97	3.7	3.6	2.0
86	Unnamed Spring #15 (Kalamazoo)	47.30	16.30	3.22	0.69	217.00	12.70	2.10	0.00	13.40	299.31	3.9	3.9	-0.3
87	Unnamed Spring #18	60.60	10.50	5.21	0.53	213.00	16.00	2.00	0.10	12.60	307.94	4.1	3.9	3.0
88	Bastian	58.50	1.50	2.88	0.56	192.00	4.90	2.00	0.00	8.50	262.34	3.2	3.3	-1.9
89	spring	28.00	4.41	15.40	4.93	104.00	5.90	8.40	0.10	64.80	171.14	2.6	2.1	10.5
90	Indian Springs	26.30	4.10	12.70	4.56	114.00	6.70	9.40	0.10	61.00	177.86	2.3	2.3	0.9
91	Cobb Spring	72.6	53.2	21.1	6.6	502	24.7	14.8	0.12	16.4	695.12	9.1	9.2	-0.4
92	Unnamed Spring #14	38.5	12.9	2.71	0.89	182	6.9	2.2	0	11.5	246.10	3.1	3.2	-1.0
93	MX Well 19 dc	--	--	--	--	--	--	--	--	--	--	--	--	--
94	Unnamed #10	90.5	5.77	14.4	0.73	293	15.5	13.6	--	14.80	433.50	5.6	5.5	1.1