Volume 4

Spring Discharge and Geothermometry Dataset

Presentation to the Office of the Nevada State Engineer

Prepared by

SOUTHERN NEVADA WATER AUTHORITY

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List of Acronyms and Abbreviations

BLM	U.S. Bureau of Land Management
Ca	Calcium
cfs	cubic feet per second
DRI	Desert Research Institute
ft	foot (feet)
gpm	gallons per minute
K	Potassium
km	kilometer
mg/L	milligrams per Liter
Na	Sodium
NBMG	Nevada Bureau of Mines and Geology
NDOW	Nevada Division of Wildlife
SiO_2	Silica
SNWA	Southern Nevada Water Authority
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
°C	Degrees Celsius
°F	Degrees Fahrenheit

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1.0 INTRODUCTION

This study was undertaken to compile background and current information on the physical and chemical characteristics of the springs and groundwater in the study area.
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2.0 PURPOSE AND OBJECTIVES

The purpose of this report is to provide data and documentation of baseline physical and geochemical characteristics of spring flow sources in Spring and Snake Valleys in Lincoln and White Pine Counties, Nevada and parts of Western Utah. The main objectives are:

1. Compilation of historical and current spring flow and spring chemistry data

2. Estimation of reservoir temperature and groundwater circulation depth of the low temperature geothermal springs using geochemistry, and

3. Determination of the source rock for the low temperature geothermal springs.

The data and the results of the geothermometry calculations will be used in the conceptualization, construction, and calibration of a groundwater model in the project area.

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3.0 BACKGROUND

Spring development began in the 1860s, when the population of eastern Nevada increased because of gold and silver discoveries. Since then springs, including their channels and discharge areas, have been modified to facilitate the beneficial use of their waters. Some modifications range from an extensive diversion network such as at Big Springs and Gandy Warm Spring in Snake Valley, to the construction of a simple, small impoundment several yards downstream of their orifice, such as observed at Willow Spring in northern Spring Valley. The conditions of these diversion works vary from a relatively good condition such as at Gandy Warm Spring and Big Springs, to diversion works that appear to be unused and have been long abandoned such as at Swallow Springs. In the past, spring waters have been used as watering places for travelers, municipal and domestic, mining and milling, agricultural, wildlife and recreation. Most of the inventoried springs are currently used for agricultural purposes, such as livestock watering and irrigation. Some of the springs support populations of endangered species, while others such as Shoshone Pond support an expatriated population of Pahrump Pool Fish. Spring Creek Spring in Snake Valley supplies water for the Nevada Division of Wildlife (NDOW) fish rearing station.

The amount of discharge measurement data available is small for most springs. Although Gandy Warm Spring and Big Springs are the two largest springs in the area, they only recently had gaging stations installed for continuous discharge measurements.

Geochemistry of the thermal waters in Nevada has been studied by a number of workers (e.g., Hose and Taylor, 1974; Mariner et al., 1983; Flynn and Buchanan, 1990; Welch and Preissler, 1990). The Desert Research Institute (DRI) studied the mineral content of selected geothermal waters in Nevada as part of a study of geothermal resources in the western United States as a source of minerals (Sanders and Miles, 1974). Most of the geothermal studies in Nevada focused on the use of geothermal resources in electric-power generation mainly in the north and northeastern part of the state. Based on these studies, higher-temperature geothermal reservoirs in the northwestern part of the state are interpreted to be related to the circulation of groundwater to deep levels along faults in a region of higher-than-average heat flow (Hose and Taylor, 1974). The low to moderate temperature geothermal waters in east-central and southern Nevada are observed to be related to regional interbasin groundwater circulation in fractured carbonate-rock aquifer (Winograd and Thordarson 1975; Mifflin, 1968; Garside, 1994). In addition to these studies, datasets of various information on the geothermal resources of Nevada have also been compiled (Garside, 1994; Shevenell et al., 2000; Shevenell and Garside, 2003; NBMG, 2006; SMU, 2006), and a more comprehensive study to geochemically characterize the geothermal systems in Nevada is on going (Arehart et al., 2002) to enhance the exploration and exploitation of the state's geothermal resources.

In their study of geothermal waters of Nevada, Garside and Schilling (1979) used a cutoff value of 21 degrees celsius (°C) (70 degrees Fahrenheit [°F]) as the minimum temperature for geothermal waters. Again, spring and well waters with temperatures greater than 10°C above annual average temperature at the site, and greater than 20°C, have been noted as warm or hot (Shevenell and Garside, 2003). Within the study area, springs and groundwater with temperatures greater than 20°C are considered warm (Thomas et al., 1996) and are believed to have flowed at greater depths on their way from the recharge areas to the discharge points. Mifflin (1968) observed that groundwaters with temperatures ranging from about 16 to 27°C are either associated with lateral flow in moderate to low permeability rock environments several hundred feet (ft) at depth, circulated to moderate depths in a regional flow system, or are associated with localized concentrations of thermal groundwater near major structural features.

4.0 TECHNICAL APPROACH/METHODOLOGY

4.1 Data Collection and Compilation

This report presents spring discharge, water temperature, and silica (SiO_2) concentrations of selected springs and wells. The water chemistry data are mainly for Spring and Snake Valleys. They are part of data compiled from previously published reports by various organizations, published and preliminary data from the U.S. Geological Society (USGS), and from field investigations conducted by the Southern Nevada Water Authority (SNWA) from 2003 to 2005 and are given in Attachment A. The spring discharge data are mainly for Spring and Snake Valleys and adjacent basins and are given in Table 4-1.

Data collection procedures were established to ensure consistent and accurate compilation and collection of data during the spring inventory.

4.1.1 Discharge Measurements

Discharge measurements were made at each spring when conditions allowed using the standard methods outlined by Rantz et al. (1982a and b) and Malone (1931), and the data are given in (Table 4-1). The main condition was accessibility. The locations of the spring sites are given in Figure 4-1. If the spring was inaccessible or other conditions existed that prevented a physical measurement from being made, then the discharge was estimated. Measurements were made upstream of any diversions.

4.2 Water Chemistry

Water-chemistry samples were collected to establish baseline conditions at selected springs. These data were used in the evaluation of the aqueous geochemistry for the estimation of the depths of circulation of groundwater in the area. The water chemistry data have been compiled into the SNWA database, and the appropriate items for this report are given in Attachment A. The field measured temperature and laboratory measured silica concentrations were used to estimate the depths of groundwater circulation of selected springs and wells in Spring and Snake Valleys using geothermometry.

4.2.1 Geothermometry

Geothermometry is a method of estimating the temperature of a fluid at depth prior to cooling en route to the surface because groundwater is commonly temperature-equilibrated with the aquifer

Table 4-1
Spring Miscellaneous Discharge Measurements
(Page 1 of 4)

Spring Name	Date	Discharge (gpm)	Discharge (cfs)	Discharge Measurement Rating	Data Source	Temp °C	Notes
Cherry Creek Hot Springs	08/29/1917	35.9	0.08	--	Clark and Riddell, 1920	47-57	Discharge is combined flow of 3 spring orifice
Cherry Creek Hot Springs	07/14/2004	44.9	0.10	P	SNWA	--	
Cow Trim Spring	06/22/2004	--	0.00	--	SNWA	--	Dry
Monte Neva Hot Springs	08/21/1917	624	1.39	--	Clark and Riddell, 1920	78.8	
Monte Neva Hot Springs	06/22/2004	673	1.50	P	SNWA	76	
Cold Spring	06/22/2004	--	0.00	--	SNWA	--	Dry
Cave Spring	05/24/1966	400	0.89	--	Hess and Mifflin, 1978	--	
Cave Spring	03/01/1980	1,000	2.23	--	Bunch and Harrill, 1984	12	
Cave Spring	06/23/2004	105	0.23	G	SNWA	--	
Cave Spring	07/16/2004	36.4	0.08	E	SNWA	13	
Cave Spring	07/29/2004	9.87	0.02	F	SNWA	--	
Cave Spring	09/14/2004	--	0.00	--	SNWA	--	Dry
Cave Spring	07/26/2005	359	0.80	F	SNWA	12	
Sidehill Spring	08/01/1979	--	--	--	Bunch and Harrill, 1984	17	No discharge reported.
Sidehill Spring	03/01/1980	1.00	0.00	--	Bunch and Harrill, 1984		Discharge is < 1 gpm
Sidehill Spring	06/21/2004	2.69	0.01	P	SNWA	15	
Meloy Spring	05/01/1980	82.0	0.18	--	USGS-NWIS, 2004	--	
Meloy Spring	07/13/1997	44.9	0.10	P	SNWA	19.3	
Bailey Spring	10/18/1912	3.00	0.01	--	Carpenter, 1915	--	
Bailey Spring	05/01/1980	2.00	0.00	--	Bunch and Harrill, 1984	--	Reported as 2-3 gpm
Bailey Spring	06/03/2004	0.03	0.00	E	SNWA	13	Discharge is .03 gpm
Littlefield Spring	05/01/1980	10.0	0.02	--	Bunch and Harrill, 1984	--	
Littlefield Spring	06/03/2004	11.7	0.03	E	SNWA	15	
Littlefield Spring	07/25/2005	59.7	0.13	E	SNWA	17.9	
Geyser Spring	10/24/1912	449	1.00	--	Hardman and Miller, 1934	12.2	
Geyser Spring	08/04/1963	67.3	0.15	--	USGS, 1963	--	Discharge measured at 17:58
Geyser Spring	08/04/1963	471	1.05	--	USGS, 1963	--	Discharge measured at 15:28
Geyser Spring	08/04/1963	1,150	2.57	--	USGS, 1963	--	Discharge measured at 18:26

Table 4-1
Spring Miscellaneous Discharge Measurements
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Spring Name	Date	Discharge (gpm)	Discharge (cfs)	Discharge Measurement Rating	Data Source	Temp °C	Notes
Geyser Spring	08/04/1963	673	1.50	--	USGS, 1963	--	Discharge measured at 18:12 (discharge was a field estimate)
Geyser Spring	08/04/1963	449	1.00	--	USGS, 1963	--	Discharge measured at 18:08 (discharge was a field estimate)
Geyser Spring	08/04/1963	144	0.32	--	USGS, 1963	--	Discharge measured at 17:09
Geyser Spring	08/04/1963	736	1.64	--	USGS, 1963	--	Discharge measured at 14:52
Geyser Spring	08/04/1963	323	0.72	--	USGS, 1963	--	Discharge measured at 16:08
Geyser Spring	08/04/1963	197	0.44	--	USGS, 1963	--	Discharge measured at 16:39
Geyser Spring	08/04/1963	94.2	0.21	--	USGS, 1963	--	Discharge measured at 17:35
Geyser Spring	07/27/1982	633	1.41	--	USGS, 1982	--	
Geyser Spring	03/23/1985	633	1.41	--	USGS, 1985	--	
Geyser Spring	01/31/1986	426	0.95	--	USGS, 1986	--	
Geyser Spring	02/12/1987	323	0.72	--	USGS, 1987	--	
Geyser Spring	08/11/1987	444	0.99	--	USGS, 1987	--	
Geyser Spring	02/25/1988	301	0.67	--	USGS, 1988	--	
Geyser Spring	03/16/1989	579	1.29	--	USGS, 1989	--	
Geyser Spring	03/21/1990	310	0.69	--	USGS, 1990	--	
Geyser Spring	11/07/1990	229	0.51	--	USGS, 1991	--	
Geyser Spring	03/02/1991	180	0.40	--	USGS, 1991	--	
Geyser Spring	10/21/1991	171	0.38	--	USGS, 1992	--	
Geyser Spring	10/16/1992	197	0.44	--	USGS, 1993	--	
Geyser Spring	04/07/1993	2,420	5.40	--	USGS, 1993	--	
Geyser Spring	09/21/1993	283	0.63	--	USGS, 1993	--	
Geyser Spring	03/25/1994	435	0.97	--	USGS, 1994	--	
Geyser Spring	09/09/1994	449	1.00	--	USGS, 1994	--	
Geyser Spring	06/23/2004	414	0.92	G	SNWA	10.8	
Willow Spring	07/14/2004	1.80	0.00	E	SNWA	--	
North Millick Spring	06/24/2004	196	0.44	G	SNWA	15.5	
North Millick Spring	07/28/2005	328	0.73	G	SNWA		
South Millick Spring	07/12/1966	200	0.45	--	Hess and Mifflin, 1978	12.7	Reported by Mifflin as So. Mulick Spr. Data more closely matches the discharge for N. Millick Spring

Table 4-1
Spring Miscellaneous Discharge Measurements
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Spring Name	Date	Discharge (gpm)	Discharge (cfs)	Discharge Measurement Rating	Data Source	Temp °C	Notes
South Millick Spring	07/15/2004	458	1.02	F	SNWA	13.4	
South Millick Spring	07/28/2005	624	1.39	G	SNWA	--	
South Bastian Spring	07/15/2004	3.91	0.01	G	SNWA	12.9	
South Bastian Spring	08/03/2005	4.76	0.01	G	SNWA	12.0	
Willard Spring	07/15/2004	--	--	--	SNWA	--	Spring is stagnant water. Could not measure discharge.
Layton Spring	07/14/2004	--	0.00	--	SNWA	--	Dry
Layton Spring	08/03/2005	--	0.00	--	SNWA	--	Dry pond and water trough
North Spring	06/22/2004	10.0	0.02	P	SNWA	22.7	Spring flows about 150 yards through heavy aquatic plant growth, could not measure, estimated flow
The Cedars	07/28/2004	74.5	0.17	P	SNWA	23.8	Discharge is estimated. Only half the flow from Cedar #2 could be measured, (.018 cfs +(2 x .074 cfs))=.166 cfs
Swallow Springs	07/12/1966	275.0	0.61	--	Hess and Mifflin, 1978	9.4	
Swallow Springs	06/15/1980	360.0	0.80	--	USGS-NWIS, 2004	--	
Swallow Springs	07/28/2004	340.0	0.76	G	SNWA	10	North=.117 cfs, South=.641 cfs
Swallow Springs	07/27/2005	511.0	1.14	G	SNWA	--	North=.277 cfs, South=.866 cfs
Blind Spring	07/28/2004	--	--	--	SNWA	--	Pool of water, possibly water table spring, water does not discharge from pool, could not make measurement. No discharge measured.
Big Springs	11/03/1964	3,600	8.00	--	Rush and Kazmi, 1965	17.7	
Big Springs	09/30/1965	4,000	8.91	--	Hess and Mifflin, 1978	16	Reported flows up to 25 cfs (Mifflin, 1968)
Big Springs	11/18/1972	4,000	8.92	--	Walker, 1972	--	
Big Springs	10/28/2004	4,800	10.70	G	SNWA	--	
Big Springs	04/06/2005	3,840	8.55	--	USGS-NWIS, 2006	--	
Big Springs	05/10/2005	4,000	8.90	--	USGS-NWIS, 2006	--	
Big Springs	05/26/2005	4,160	9.27	--	USGS-NWIS, 2006	--	
Big Springs	08/03/2005	4,120	9.20	F	SNWA	--	
Big Springs	08/04/2005	3,990	8.88	--	USGS-NWIS, 2006	--	

Table 4-1
Spring Miscellaneous Discharge Measurements
(Page 4 of 4)

Spring Name	Date	Discharge (gpm)	Discharge (cfs)	Discharge Measurement Rating	Data Source	Temp °C	Notes
Big Springs	09/14/2005	4,140	9.23	--	USGS-NWIS, 2006	--	
Big Springs	11/29/2005	4,580	10.20	--	USGS-NWIS, 2006	--	
Big Springs	01/05/2006	4,620	10.30	--	USGS-NWIS, 2006	--	
Big Springs	03/09/2006	3,940	8.78	--	USGS-NWIS, 2006	--	
Caine Spring	07/14/2004	5.00	0.01	P	SNWA	14.4	
Warm Springs	11/04/1964	3,600	8.00	--	Rush and Kazmi, 1965	27.2	May have been measured near the main orifice, suspected partial discharge
Warm Springs	06/22/2004	3,780	8.42	F	SNWA	27	25 ft DS of orifice this is ~10 ft above swimmers dam
Warm Springs	10/30/2004	6,730	15.00	F	SNWA	--	At diversion
Warm Springs	08/04/2005	6,960	15.50	G	SNWA	--	75 ft DS of orifice this is below swimmers dam
Warm Springs	08/04/2005	7,990	17.80	F	SNWA	--	At diversion
Warm Springs	08/23/2005	8,710	19.40	--	USGS-NWIS, 2006	--	
Warm Springs	08/31/2005	8,080	18.00	--	USGS-NWIS, 2006	--	
Warm Springs	08/31/2005	7,680	17.10	--	USGS-NWIS, 2006	--	
Warm Springs	10/04/2005	8,260	18.40	--	USGS-NWIS, 2006	--	
Warm Springs	10/14/2005	7,630	17.00	--	USGS-NWIS, 2006	--	
Warm Springs	11/17/2005	8,030	17.90	--	USGS-NWIS, 2006	--	
Warm Springs	12/01/2005	7,540	16.80	--	USGS-NWIS, 2006	--	
Warm Springs	12/01/2005	7,320	16.30	--	USGS-NWIS, 2006	--	
Warm Springs	12/29/2005	7,810	17.40	--	USGS-NWIS, 2006	--	
Warm Springs	01/31/2006	7,760	17.30	--	USGS-NWIS, 2006	--	
Warm Springs	04/13/2006	7,450	16.60	--	USGS-NWIS, 2006	--	
Spring Creek Spring	08/04/2005	2,060	4.59	F	SNWA	--	
Spring Creek Spring	10/05/2005	2,060	4.59	G	SNWA	--	
Rowland Spring	08/04/2005	1,560	3.48	F	SNWA	--	

E = Excellent
G = Good
F = Fair
P = Poor
gpm = gallons per minute
cfs = cubic feet per second

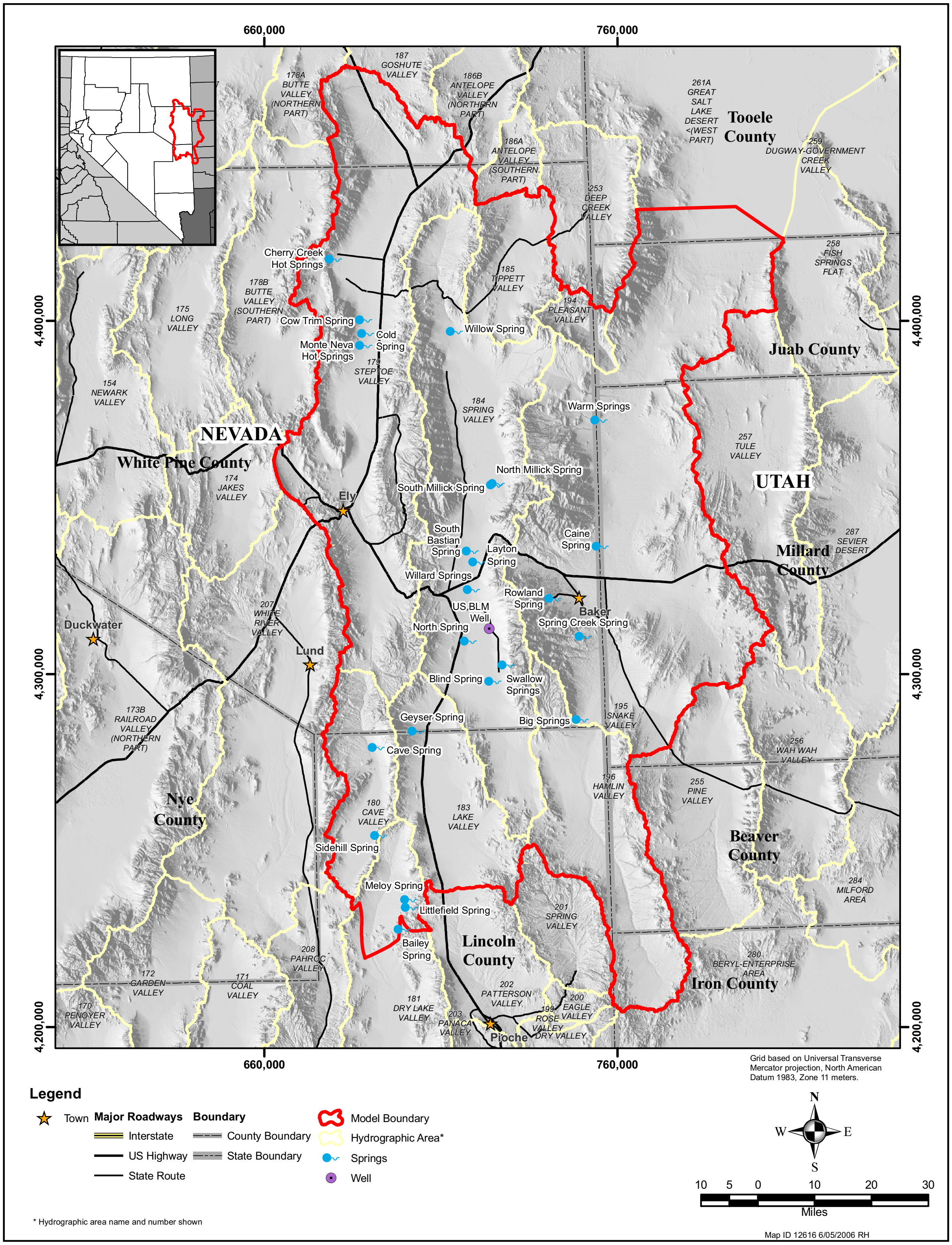

Figure 4-1
Locations of Springs and Wells Used for This Study

materials. Equilibrium thermodynamics assume that (1) the chemical signature of a fluid does not change during its ascent to the surface because of fast travel time of the vertical rising fluid and slow horizontal component of fluid flow; and (2) reequilibration does not occur during ascent and discharge. Thus chemical analysis of geothermal fluids can be used to estimate the groundwater (reservoir) temperature (Gemici et al., 2004). The estimated temperature reflects the depth of groundwater circulation based on an understanding of the regional tectonics and geothermal gradients.

There are two general types of geothermometers: (1) those based on absolute concentrations of constituents in solution (e.g., silica [SiO_2]); and (2) those based on ratios of two or more constituents in solution (e.g., Na-K [sodium-potassium] or Na-K-Ca [sodium-potassium-calcium]). Solubility of these minerals generally changes as a function of temperature and pressure.

The increased solubility of quartz and other silica polymorphs has been used extensively as an indicator of geothermal temperatures (Truesdell and Hulston, 1980; Fournier and Potter, 1982) and is widely used to estimate subsurface temperatures. The silica mineral that constitutes the controlling phase for aqueous silica concentrations depends on two counteracting processes: dissolution of the primary silicate minerals of the rock, and precipitation of a silica mineral (D'Amore and Arnórsson, 2000). The rate of dissolution of the primary rock minerals is largely controlled by the pH of the water.

The temperature of groundwater increases as the depth of burial of aquifers increases because of the geothermal gradient, which is the natural increase in the temperature of the earth as depth increases. These temperature gradients vary widely over the earth and sometimes increase dramatically around volcanic areas. Although the geothermal gradient varies from place to place, it averages about 3°C/100 meters (30°C/kilometer [km]) (Mazor, 1991). Temperatures of over 300°C occur in groundwaters in geothermal wells. The large range in temperatures in groundwater is formed by a variety of discharge mechanisms and, to a large extent, by differences in the depths of circulation and local heat gradients. Thus, temperatures measured in springs and wells reflect the temperatures attained at depth and therefore provide information on the depth of circulation.

4.2.2 Geothermometer Calculations

Geothermometer equations are usually expressed in the form:

$$T°C = \frac{a}{b - \log(X)} - 273.15 \qquad (4\text{-}1)$$

where X is SiO_2 concentration or Na/K, etc., a and b are constants. Most of the geothermometer equations are derived from empirical data, so different coefficient values are found in the literature.

Fournier (1977) and Gendenjamts (2003) observed that in geothermal reservoirs with temperatures ranging from about 120 to 180°C, the solubility of quartz appears to control dissolved silica. At lower temperatures, other silica phases such as chalcedony control the concentration of dissolved silica. When calculating temperatures from the silica content of natural water, assuming equilibrium with either quartz or chalcedony, the temperatures are termed “quartz equilibrium” and “chalcedony equilibrium” temperatures respectively. In aqueous systems, Na, K, and Ca concentrations are controlled by temperature-dependent equilibrium reactions with feldspars, mica, and calcite (Fournier and Truesdell, 1973).

5.0 DATA EVALUATION AND ANALYSIS

Discharge, temperature, and major ions concentration data described in the preceding section were evaluated to determine their quality and limitations. Data were filtered to remove poor quality and erroneous records. The resultant datasets were applied in data analysis completed in support of a series of geologic, hydrologic, and geochemical investigations to assess the water resources of the Project Basins and adjacent basins. The results of these investigations were used to support development of conceptual models of the Project Basins and the groundwater flow systems in which they occur.

5.1 Data Accuracy and Limitations

5.1.1 Discharge Measurements

The accuracy of all discharge measurements made by SNWA have been rated using the same excellent (2% error), good (5%), fair (8%) and poor (over 8%). The rating of the measurement is based on the description of the flow, cross sectional characteristics, and channel control at the time of the measurement. Discharge measurements used in this report ranged from excellent, when a flume was used, to poor, when discharge values were estimated.

Limiting factors of the data include the temporal distribution of the miscellaneous measurements, the areal distribution of the measurements, and the conditions in which the data were collected. Continuous records are only available for two springs, Big Springs Creek South Channel near Baker, NV (10243224) and Warm Creek near Gandy, UT (10172860). Each station has a record of less than one year in length. The accuracy of the annual records (continuous) depends on the stability of the stage-discharge relationship, the frequency of discharge measurements, the accuracy of the measurement of stage, the accuracy of the discharge measurement and calculation of the records (Table 5-1). The hydrographs for Gandy Warm Spring and Big Springs are shown in Figure 5-1 to illustrate this point. Continuous records are rated as excellent if about 95 percent of their daily discharges are within 5 percent of their true values; good if their daily discharges are within 10 percent; fair if their daily discharges are within 15 percent; and poor if more than 95 percent of the daily discharge values are more that 15 percent of their true value. At Big Springs the record published for water year 2005 indicates the record as fair except for periods of estimated record which are rated as poor (USGS, 2005a and b). Gandy Warm Spring was not published in the Utah 2005 data report and is therefore considered preliminary.

Table 5-1
Summary of Spring Discharge Measurements

Site Name	UTM Easting	UTM Northing	Elevation	Number of Discharge Measurements	Minimum Discharge (cfs)	Maximum Discharge (cfs)	Average Discharge (cfs)	Standard Deviation	Discharge Magnitude	Temperature
Cherry Creek Hot Springs	679565	4417460	6,797	2	0.080	0.100	0.090	0.01	5	Warm
Cow Trim Spring	688200	4400350	5,971	1	Dry	Dry	Dry	Dry	--	--
Monte Neva Hot Springs	688116	4393119	6,011	2	1.39	1.50	1.45	0.08	3	Warm
Cold Spring	688748	4396434	5,458	1	Dry	Dry	Dry	Dry	--	--
Cave Spring	691760	4279249	6,488	8	Dry	2.228	0.608	0.80	4	Cold
Sidehill Spring	692407	4254280	6,527	3	0.002	0.006	0.004	0.00	6	Cold
Meloy Spring	700888	4236201	6,174	2	0.100	0.183	0.142	0.06	5	Cold
Bailey Spring	699080	4227795	6,086	3	Dry	0.007	0.004	0.00	6	Cold
Littlefield Spring	701112	4233949	6,146	3	0.022	0.133	0.060	0.06	5	Cold
Geyser Spring	702990	4283851	6,494	28	0.150	5.40	1.05	1.00	3	Cold
Willow Spring	713830	4397068	5,982	1	0.004	0.004	0.004	--	6	Cold
North Millick Spring	725760	4353981	5,590	2	0.436	0.732	0.584	0.21	4	Cold
South Millick Spring	725201	4353599	5,592	3	0.446	1.390	0.952	0.48	4	Cold
South Bastian Spring	718388	4334865	5,660	2	0.009	0.011	0.010	0.00	6	Cold
Willard Springs	718691	4323976	5,755	1	Dry	Dry	Dry	Dry	--	--
Layton Spring	720204	4331794	5,698	2	Dry	Dry	Dry	Dry	--	--
North Spring	717768	4309388	5,763	1	0.022	0.022	0.022	--	6	Warm
The Cedars	723712	4312911	5,783	1	0.166	0.166	0.166	--	--	Warm
Swallow Springs	728571	4302589	6,080	4	0.613	1.1	0.828	0.22	4	Cold
Blind Spring	724792	4297977	5,773	1	--	--	--	--	8	--
Big Springs (Misc. measurements)	749475	4287141	5,568	13	8.00	10.7	9.22	0.76	3	Cold
Big Springs (Mean Daily Values)	--	--	--	--	7.60	10.0	9.13	0.63	--	--
Caine Spring	755138	4336186	5,028	1	0.011	0.011	0.011	--	6	Cold
Warm Springs (Misc. measurements)	754812	4371945	5,248	16	15.0	19.4	17.2	1.14	2	Warm
Warm Springs (Mean Daily Values)	--	--	--	--	16.0	21.0	17.4	1.39	--	--
Spring Creek Spring	750334	4310691	6,087	2	4.59	4.59	4.59	0.00	3	Cold
Rowland Spring	741775	4321436	6,580	1	3.48	3.48	3.48	--	3	Cold

UTM - Universal Transverse Mercator

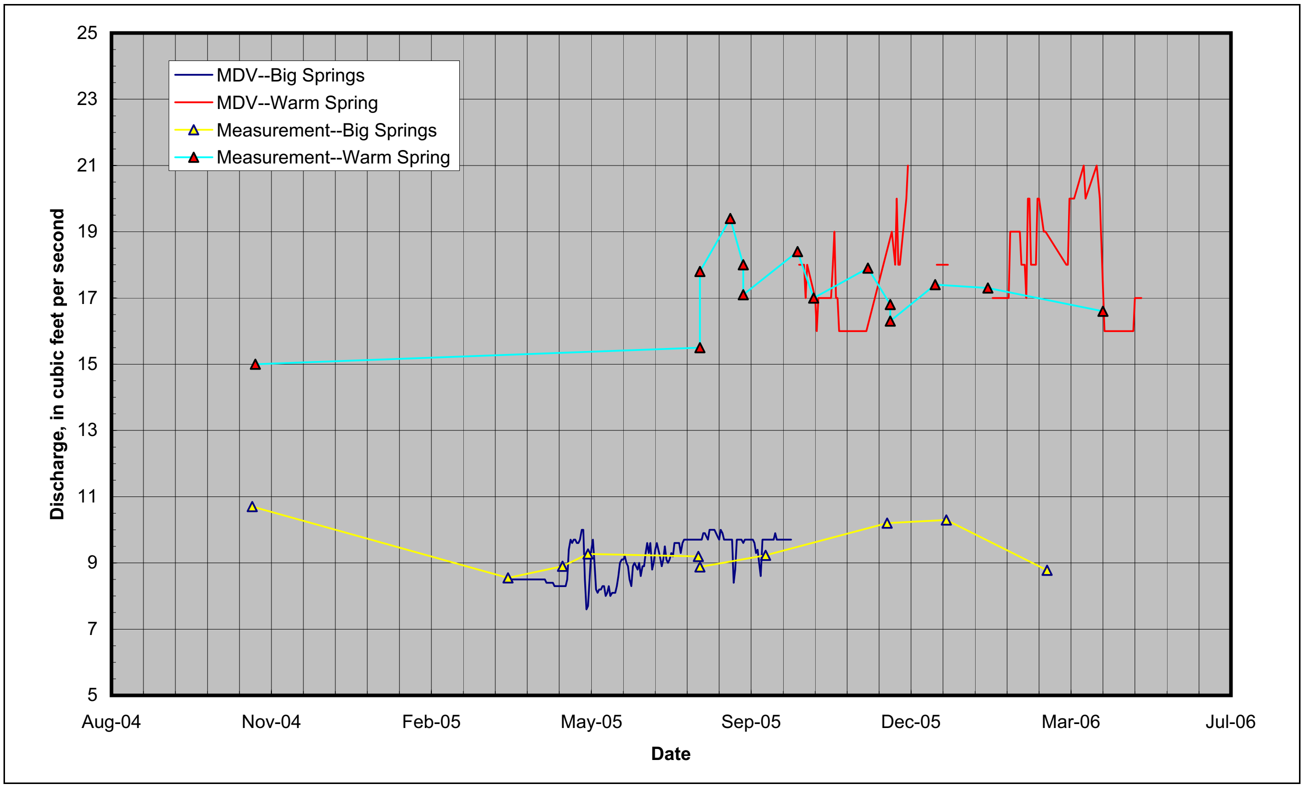

Figure 5-1
Hydrograph of Big Springs and Warm Spring, Snake Valley, Nevada-Utah

5.1.2 Chemistry Data

As stated earlier, numerous sources of geochemical data were used for this study. Data from each source were originally collected for specific studies. Generally, there is a paucity of wells tapping the carbonate-rock aquifer, and the spatial distribution of sample sites is limited. Therefore, the majority of the samples are from springs, and these samples complement the well samples in representing groundwater resources in the study area. There were incomplete sample analyses in some instances, and there was generally no discussion of analytical and sampling procedures because most of the data collected from the web sites were in a tabular form.

A great effort was made to evaluate most of these data for completeness and quality; however, the precision and accuracy of all the data could not be ascertained. At a minimum, reaction error calculations were made to assess the quality of the data. Reaction errors occur because of the analytical errors of the individual parameters or the fact that not all possible ions are commonly measured. Reaction error determination is based on the assumption that the sum of cations in a solution is equal to the sum of anions and is given by the equation:

$$Reaction\ Error = \frac{(\sum cations - \sum anions)}{\sum ions} \times 100\% \qquad (5\text{-}1)$$

Positive reaction errors indicate excess of cations and negative errors indicate anion excess. Normally, cut-off percentages of between 2 and 5 percent are commonly used (Mazor, 1991). However, due to the varied nature of the data sources, a cut-off value of 10 percent was used for some of the analyses. In some cases up to 15 percent was used. This evaluation however, did not apply to the SiO_2 concentrations since silica has no charge. Silica concentrations of samples with complete analysis and temperatures of 20°C or more were used for calculations. Mean silica concentrations were used in cases where there were multiple samples for a site; otherwise, the only available values were used for single measurements.

5.2 Estimation of Temperature and Depth of Groundwater Circulation

Samples from mountain-block and valley floor springs, with discharges ranging from about 0.01 cubic feet per second (cfs) for Caine Spring to about 15 cfs for Gandy Warm Spring in Snake Valley, Utah, on the Utah-Nevada border, were collected and analyzed for this study. However, depths of groundwater circulation for only three springs, and two wells with water temperatures greater than or equal to 20°C were estimated. Groundwater circulation depth of Big Springs in Snake Valley was also estimated, though its mean temperature of 19°C was less than the cut off value of 20°C. Available measurements indicate that temperatures of Big Springs fluctuate from 18 to 22°C, so a mean value of 19°C was used to estimate the depth of circulation. Data for the wells and springs for which depths of circulation were estimated are given in Table 5-2. The warm temperature of Gandy Warm Spring suggests that the waters are likely heated by deep circulation.

Temperature-dependent mineral solubilities (geothermometry), geothermal gradients and water chemistry were used to estimate the average flow depth of water discharging from the thermal waters of the regional springs and wells that are represented in the groundwater flow model. Temperatures and depths of circulation of groundwater were estimated for low temperature geothermal waters with measured surface temperatures of 20°C or more (Thomas et al., 1996).

Using the empirical equation of Fournier (1977):

$$T°C = \frac{1032}{4.69 - \log(SiO_2)} - 273.15 \qquad (5\text{-}2)$$

for chalcedony for temperatures ranging from 0 to 250°C, the temperatures at depth were estimated.

The estimated groundwater temperatures were then used to estimate the mean depths of circulation at each spring and well site using the formula below (Waterloo Hydrogeologic, Inc., 2003):

$$(T_z) = T_{ravg} + (\partial T / \partial Z) \times D \qquad (5\text{-}3)$$

where,

T_z = the mean subsurface temperature (°C),

Table 5-2
Lithology and Estimated Circulation Depths of Some Springs and Moderately Deep Wells in Parts of Clark, Lincoln, and White Pine Counties, Nevada

Site Name	Hydrographic Area	UTM_X	UTM_Y	Water Temp. (°C)	Mean Recharge Temp (°C)	Mean Site Geothermal Gradient (°C/km)	SiO_2 (mg/L)	Chalcedony Temp (°C)	Mean Chalcedony Temperature Difference	Mean Chalcedony Depth (km)	Mean Chalcedony Depth (ft)	Lithology at Groundwater Circulation Depth
Gandy Warm Spring	Snake Valley	754811.80	4371944.86	27.0	9.0	20.0	23.0	36.9	27.9	1.396	4580	Carbonate[a]
Caine Spring	Snake Valley	755137.90	4336185.71	21.2	9.0	20.0	20.0	31.4	22.4	1.118	3,669	Carbonate[a]
Big Spring	Snake Valley	749537.06	4287482.00	19.0	9.0	20.0	12.0	12.7	3.7	0.183	600	Carbonate/Valley Fill[a]
Cedars Flowing Well	Spring Valley	723712.30	4312910.58	21.2	9.0	20.0	22.0	35.1	26.1	1.307	4,287	Carbonate/Quartzite?[a]
US BLM Well	Spring Valley	723718.88	4312880.00	23.5	9.0	20.0	22.0	35.1	26.1	1.307	4,287	Carbonate[a]

[a]Southern Nevada Water Authority (SNWA)
BLM - U.S. Bureau of Land Management
mg/L - milligrams per Liter

T_{ravg} = the mean recharge or surface temperature (°C),
$\partial T/\partial Z$ = the mean geothermal gradient (°C/km), and
D = the mean depth (km).

Estimated mean recharge temperature of 9°C was used based on current on-going recharge studies by the DRI within the White River Flow System (Thomas, 2004). The mean recharge temperature was determined by finding the average between the minimum and maximum recharge temperatures of 6°C and 12°C, respectively, measured by the DRI in parts of the study area. This value seems reasonable considering that recharge water often has a temperature that differs significantly from the aquifer temperature (Mazor, 1991) and the fact that the mean annual air temperature in Nevada varies from about 7°C to over 18°C (Houghton et al., 1975).

The mean chalcedony equilibrium temperatures at depth were estimated by subtracting the mean recharge temperatures from the calculated chalcedony equilibrium temperatures. Due to the lack of geothermal gradients at the various spring and well sites, geothermal gradients from existing data in parts of east-central Nevada were used. Using the mean for the minimum and maximum geothermal gradients of 15°C/km and 25°C/km respectively in Nevada (NBMG, 2006; SMU, 2006), mean depths of groundwater circulation were estimated using the mean chalcedony and recharge temperatures. Davisson et al. (1994) reported geothermal gradients of between 10°C/km and 70°C/km at the Nevada Test Site using measurements from a drilling project, so the mean gradient of 20°C/km used for the calculation is quite appropriate.

6.0 RESULTS AND DISCUSSION

Using the methodology discussed in Section 4.0 and the data given in Section 5.0, the mean depths of groundwater circulation were estimated for low-temperature thermal springs and moderately deep wells in Spring and Snake Valleys, Nevada, and the results are given in Table 5-2. The relatively low observed measured temperatures suggest that the warm waters might have cooled down during their ascent to the surface. All the springs and well water samples correspond to immature waters (Giggenbach, 1988) and were not suitable for the evaluation by K/Na and K/Mg equilibrium geothermometers. Maturity index values of the wells and springs are generally less than 1 and are given in Table 6-1. Cation geothermometers are not considered for waters with maturity index values of less than 2 (Giggenbach, 1988; Gemici et al., 2004). Chalcedony was chosen as the preferred geothermometer because it was observed from the low measured temperatures and the calculated saturation indices to control the silica concentration in the thermal waters in the study area. Quartz is known to be kinetically unreactive at relatively low temperatures similar to the ones measured in the springs and wells (Drever, 1988).

Table 6-1
Maturity Index Values for Low Temperature Geothermal Waters in Spring and Snake Valleys, Nevada

Sample ID	Sample Date	Na meq/L	K meq/L	Ca meq/L	Mg meq/L	Cl meq/L	SO4 meq/L	NO3 meq/L	HCO3 meq/L	MI
Gandy Warm Spring	6/22/2004	1.26	0.102	2.3	1.4	0.68	0.48	0.01	3.36	0.47
Caine Spring	7/14/2004	0.78	0.026	1.8	1.4	1.02	0.46	0.01	2.43	0.69
Big Springs	6/22/2004	0.24	0.026	2.05	1.65	0.16	0.16	0.01	3.21	0.74
Cedars Flowing Well	7/28/2004	0.3	0.026	0.8	0.41	0.14	0.1	0	1.16	0.32
USBLM	7/6/1983	0.38	0.026	1.1	0.06	0.06	0.1	0	1.39	-0.25

MI = Maturity Index

All the calculated chalcedony equilibrium reservoir temperatures are generally low (less than or equal to 100°C) but are relatively higher than the measured temperatures in the springs and wells. The low reservoir temperatures are consistent with the observation by Garside (1994), who concluded that maximum reservoir temperatures of the low to moderate geothermal resources in the fractured carbonate-rock aquifer in east-central and southern Nevada were generally less than 100°C and could be 100 to 150°C (Garside et al., 2002). These low reservoir temperatures suggest that deep circulation along normal geothermal gradients is more important than heating in a geothermal reservoir (Schaefer et al., 2006).

The springs and groundwaters might have circulated to several hundreds or thousands of feet deep. With the exception of outliers like Big Springs, the mean depths of circulation range from about 3,600 ft to about 6,200 ft. In the case of Caine Spring with very low discharge, even the mean depth may be considered as minimum depth value because of the very low fluxes. The larger the flux, the less cooling the water undergoes as it rises to the surface. The estimated depths compare very well with the depths at which water was encountered during the drilling of oil and gas wells in parts of southeastern Nevada (Hess and Mifflin, 1978). Depths at which water was encountered in the oil and gas wells in parts of southeastern Nevada range from 200 to over 9,000 ft (Garside et al., 1988) and are given in Table 6-2. Garside et al. (2002) stated that temperatures slightly higher than 150°C had been encountered in some deep oil wells in eastern Nevada and that groundwater circulation depths of 19,600 ft (6 km) were likely assuming a gradient of 25°C/km. Given that the deepest well drilled in the valley fill in Snake Valley was completed at a depth of 4,200 ft (Hood and Rush, 1965), the depths of groundwater circulation estimated from the chalcedony equilibrium temperatures appear very reasonable. Mifflin (1968) estimated that groundwaters with temperatures of between 18 and 27°C might have circulated up to 4,000 ft in depth to obtain those temperatures.

The estimated depths were used with geological cross-sections of the study area prepared as part of the general study (SNWA, 2006) to classify the aquifer types on the basis of the dominant rock type at the depth of circulation for each of the springs and wells. Lithologies at the depths of groundwater circulation are also given in Table 5-2.

Table 6-2
Depths at Which Water was Encountered in Oil and Gas Wells Drilled in Parts of Clark, Lincoln, and White Pine Counties, Nevada

Owner/Site Name	Location	Permit No.	API Number	Total Depth (ft)	Date Completed	County	Water Zone (ft)
American Quasar Petroleum of NM, Adobe Federal No. 19-1	NE1/4 SW1/4 sec 19 T2N R60E	270	27-017-05203	7,706	Oct. 14, 1979	Lincoln	4,605-4,767
Brent Energy, Inc. Shogrin Federal No.1	SW1/4 NE1/4 SE1/4 sec 16 T6N R66E	424	27-017-05205	9,178	Sep. 24, 1985	Lincoln	8,730-9,178
Gulf Oil Corporation, Cave Valley Unit Federal No. 1	NE1/4 SE1/4 SE1/4 sec 19 T7N R64E	100	27-017-05001	7,024	July 6, 1966	Lincoln	250-260; 1,160-1,270
Gulf Oil Corporation, Nevada-Federal CM No. 1	Center NW1/4 NW1/4 sec 17 T1S R60E	95	27-017-05002	2,434	Mar. 7, 1966	Lincoln	660-800
Amoco Production Co. Stage Line Unit 1-A	SE1/4 SW1/4 sec 22 T23N R56E	427	27-033-05252	8,500	May 24, 1985	White Pine	2,696; 2,992
Gulf Refining Co. Dennison-Federal No.1	NE1/4 NW1/4 SW1/4 sec 20 T26N R70E	2	27-033-05007	4,498	---	---	3,540-3,675, 4,135-4,353
Black Gold Oil and Gas Exploration Co. (Intermountain Assoc) No. 1	S1/2 SW1/4 SW1/4 sec 23 T23S R59E	CL26	27-003-05052	1,670	Sept. 1953	Clark	200-300
Brown, Joe W. Wilson No. 1	Center NW1/4 NW1/4 sec 24 T21S R61E	33	27-003-05008	8,508	Mar. 1, 1957	Clark	6,050
Grimm, Jack F. Wilson No. 1	Center NW 1/4 SE1/4 sec 9 T22S R60E	91	27-003-05070	5,686	Dec. 28, 1965	Clark	650-680; 1,800-1,856; 4,033-4,091
Lightenwalter, SJ & Turpin, C.M. Turpin No. 1	NW1/4 SE1/4 NE1/4 sec 4 T20S R59E	51	27-003-05001	1,725	July 14, 1961	Clark	1,668-1,678
Rosen Oil Co. Muddy Dome No.1	SW1/4 NW1/4 sec 7 T20S R65E	87	27-003-05003	5,666	Oct. 28, 1965	Clark	3,930-4,030; 5,030-5,060

Source: Garside et al. (1988)

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7.0 SUMMARY

Using standardized data collection techniques, a large variety of springs were inventoried in eastern Nevada and western Utah. To supplement the field observations, an extensive literature search was conducted. From the field observations, it has been determined that the vast majority of springs have been modified to some extent since settlers first arrived in the area.

Springs were selected for inventory based on their topographic location, spatial distribution, discharge, geologic conditions, and data availability. Data regarding discharge, geologic setting, and diversions and water use were collected in the field when possible. Detailed geologic maps were prepared at selected springs based on topographic and geologic setting.

The amount of data available is small for most springs. Although Gandy Warm Spring and Big Springs are the two largest springs in the area, they only recently had gaging stations installed. Spring development began in the 1860s when the population of eastern Nevada increased because of gold and silver discoveries. Since then, springs, including their channels and discharge areas, have been modified to facilitate the beneficial use of their waters. Some modifications range from an extensive diversion network such as at Big Springs and Warm Springs, to the construction of a simple, small impoundment several yards downstream of their orifice, such as Willow Spring in northern Spring Valley. The condition of these diversion works varies from good condition such Warm Spring and Big Spring to diversion works that appear to be unused and have been long abandoned such as at Swallow Springs. Most of the inventoried springs are currently used for agricultural purposes, such as livestock water supply and irrigation for crops. In the past, spring waters have been used as watering places for travelers, municipal and domestic, mining and milling, agricultural, wildlife and recreation. Other springs support populations of endangered species, while Shoshone Pond supports an expatriated population of Pahrump Pool Fish. Spring Creek Spring in Snake Valley supplies water for the NDOW fish rearing station.

The temperature of springs and wells reflects the rock-water interaction in the subsurface. Specifically, because solubility, exchange and isotopic fractionation are temperature dependent, the temperature of water-rock equilibration at depth can be estimated. Geothermometry calculations using chalcedony saturation as the control on temperature have been used to estimate the groundwater (reservoir) temperatures at depth and the mean depths of circulation of thermal waters in Spring and Snake Valleys, Nevada. With the exception of an outlier, the mean estimated circulation depths of groundwater range between about 3,600 and 6,200 ft and are comparable to the depths at which water was encountered in the drilling and subsequent drill-stem tests of oil and gas wells in east-central and southern Nevada. Knowledge of these depths is essential in the conceptualization, construction and calibration of a groundwater model in assessing the effects of large-scale groundwater development on the various water sources.

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Attachment A

Gross Chemistry Data

Table A.1-1
Gross Chemistry Data for Springs and Wells in Spring and Snake Valleys, Nevada
(Page 1 of 2)

Reference	Sample ID	HA	Location	Sampling Date	pH	EC µS/cm	Temperature °C	DO	Hardness	TDS	Na	K	Ca	Mg	F	Cl	HCO_3	NO_3	SO_4	Br	SiO_2	Percent Error
								mg/L														
SNWA_13	Bastian Spring Well	Spring Valley	-	10/24/1991	8	269	10.7	-	141	-	-	-	34.2	13.5	-	-	144	-	-	-	-	9.0
SNWA04	Big Springs	Snake Valley	384158114075201	6/22/2004	8	389	20	-	184.5	202	5.6	<1	41	20	0.15	5.6	196	0.44	7.9	<0.05	12	5.0
SNWA04	Caine Spring	Snake Valley	N10 E70 32A 1	7/14/2004	8.15	314	14.4	-	-	246	18	1	36	17	0.18	36	148	0.53	22	-	20	0.8
SNWA04	Cedars #2	Spring Valley	-	7/28/2004	8.18	150	23.8	-	-	106	6.9	1	16	3	0.12	<5	71	0.23	5	-	22	3.1
SNWA04	Cedars Flowing Well	Spring Valley	385613114250401	7/28/2004	7.8	135	23.8	-	41	106	6.9	<1	16	<5	0.12	<5	71	0.23	<5	0.086	22	-3.9
SNWA05	Federal 1-20	Spring Valley	184 N12 E67 20BD	8/2/2005	8.1	295	12.3	-	132	-	10	2.9	20	20	0.9	4.2	149	0.69	12	0.039	55	4.2
SNWA04	Gandy Warm Springs	Snake Valley	392737114021201	6/22/2004	7.5	529	27	10.1	185	268	29	4	46	17	0.69	24	205	0.52	23	0.098	23	5.0
SNWA_13	N. Shoshone Spring	Spring Valley	-	10/22/1991	8.1	269	13	-	144	-	-	-	37.9	12.1	-	-	159	-	-	-	-	5.2
SNWA04	North Millick	Spring Valley	184 N17 E67 25DB 1	6/24/2004	7.8	367	15.5	11.3	218	244	10	<1	46	25	0.081	8.5	221	0.29	14	0.063	13	7.0
SNWA04	North Swallow Spring	Spring Valley	-	7/28/2004	8.01	335	21.2	-	-	289	<5	<1	46	9	<0.05	5	184	0.23	5.4	-	5.5	-4.1
SNWA_13	Piermont Creek	Spring Valley	10243760	5/28/1992	7.5	53	0	-	22	0	2.65	0.57	6.23	1.54	0	1	25.3	0.04	3.75	-	8.1	3.7
SNWA04	South Bastian Spring	Spring Valley	184 N15 E67 29DB 1	7/15/2004	8.1	203	12.9	-	118	164	5.1	<1	26	13	0.074	<5	155	0.26	<5	<0.05	21	0.5
SNWA_13	South Millick Spring	Spring Valley	184 N17 E67 25CD 1	10/24/1991	7.7	431	13.5	-	223	-	-	-	49.3	24.4	-	-	219	-	-	-	-	11.1
SNWA04	South Millick Spring	Spring Valley	184 N17 E67 25CD 1	7/15/2004	7.2	309	13.4	-	175	244	7.2	<1	39	19	0.1	8.9	218	0.58	15	0.08	12	-4.6
SNWA_13	Stone House	Spring Valley	-	10/23/1991	8.2	1655	6.8	-	506	-	-	-	102	61.1	-	-	584	-	-	-	-	2.9
SNWA04	Swallow Canyon Spring	Spring Valley	385026114205701	7/28/2004	8	335	10	-	152	289	<5	<1	46	9	<0.05	<5	184	0.23	5.4	0.071	5.5	-1.8
SNWA03	Swallow Canyon Spring	Spring Valley	385026114205701	8/7/2003	8	339	10	-	185	174	<3	<3	56	11	0.09	<5	173	0.17	<10	<0.05	5.6	13.2
SNWA03	Swallow Creek	Spring Valley	385033114205201	8/7/2003	8	339	10	-	185	174	<3	<3	56	11	0.09	<5	173	0.17	<10	<0.5	5.6	13.2
SNWA04	Swallow Spring	Spring Valley	385040114213901	7/28/2004	8	335	10	-	152	289	<5	<1	46	9	<0.05	<5	184	0.23	5.4	0.071	5.5	-1.8
SNWA_13	The Cedars	Spring Valley	184 N12 E67 02AB 1	5/27/1992	8.2	146	21	-	58	-	9.03	1.03	22.3	0.67	-	1.9	86.1	0.62	4.03	-	22.3	-0.2

Table A.1-1
Gross Chemistry Data for Springs and Wells in Spring and Snake Valleys, Nevada
(Page 2 of 2)

Reference	Sample ID	HA	Location	Sampling Date	pH	EC µS/cm	Temperature °C	DO	Hardness	TDS	Na	K	Ca	Mg	F	Cl	HCO_3	NO_3	SO_4	Br	SiO_2	Percent Error
								mg/L														
USGS1	Unknown Spring	Spring Valley	391516114292001	7/16/1964	7.8	287	12.8	-	127	-	15	-	38	7.8	-	4.7	172	-	12	-	-	-0.2
USGS1	USBLM	Spring Valley	390420114313901	7/15/1964	7.8	499	11.7	-	227	-	22	-	48	26	-	19	220	-	63	-	-	0.4
USGS2	USBLM	Spring Valley	385613114250401	7/6/1983	8.1	168	23.5	6.8	58	-	8.8	1	22	0.7	0.1	2.2	85	-	5	-	22	0.2
USGS1	USBLM	Spring Valley	385659114280301	7/14/1964	8.5	750	13.9	-	210	-	82	-	61	14	-	80	239	-	52	-	-	3.5
SNWA_13	Willard	Spring Valley	-	10/24/1991	7.6	238	13.6	-	93	-	0	-	28.5	5.29	-	-	108	-	-	-	-	2.4
SNWA_13	Willow	Spring Valley	-	10/23/1991	7.8	434	11.8	-	190	-	0	-	54.3	13.3	-	-	194	-	-	-	-	9.1
SNWA04	Willow Spring	Spring Valley	184 N21 E66 15BC 1	7/14/2004	8.2	383	11.9	-	185	270	20	<1	51	14	0.17	18	193	0.085	20	0.12	29	5.6

References
SNWA-13 - CWP Report 13 1994
SNWA03 - SNWA sampling done in 2004
SNWA04 - SNWA sampling done in 2004
SNWA05 - SNWA sampling done in 2005
NBMG - Nevada Bureau of Mines and Geology
USGS1 - Reconnaissance Series Report #33
USGS2 - USGS NWIS Database