Temperature Profiles of Groundwater Monitor Wells in Western Juab and Millard Counties, Utah

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ABSTRACT

The Utah Geological Survey (UGS) established a network of 68 groundwater monitoring wells at 27 well sites in several western Utah valleys, primarily in Millard and Juab Counties, from 2007 through 2009. In support of the UGS Snake Valley groundwater monitoring project, temperature logs were acquired from wells at 23 of these monitoring well sites using high-precision temperature logging gear. Wells were completed in a variety of geologic formations to test groundwater conditions within a Pliocene-Pleistocene basin-fill aquifer and a deep carbonate-rock aquifer consisting mainly of fractured Paleozoic limestone and dolomite strata. Well depths ranged from 67 ft (20 m) at Fish Springs to 1840 ft (561 m) near the community of Garrison. Bottom-hole temperatures ranged from about 53°F (12°C) in a shallow, 180-ft (55 m) well completed in valley-fill deposits near Needle Point Spring on the south end of Snake Valley, to 117°F (47°C) measured in a 1000-ft (305-m) deep well on the northwest side of the Middle Range (Juab County), completed in the Devonian Guillmette Formation. Thermal gradients range from near zero (isothermal conditions) at the well site near Garrison (UGS PW03) to a high of 6.72°F/100 ft (122.5°C/km) at the well site northwest of the Middle Range (UGS PW18).

Introduction

In 2007 the Utah State Legislature funded the UGS to establish a groundwater monitoring-well network in and around Snake Valley of Utah's west desert. The Snake Valley Groundwater Monitoring Well Project was established in response to proposed water-development projects in east-central Nevada that could affect groundwater resources in west-central Utah (Utah Geological Survey, 2010). Objectives of the Snake Valley Groundwater Monitoring Well Project are to improve the understanding of the groundwater flow systems and resources, characterize baseline groundwater levels and chemistry, and measure future changes in these parameters.

The Snake Valley Groundwater Monitoring Well Project is located in west-central Utah and east-central Nevada. Kirby and Hurlow (2005) describe the study region as a north-south trending hydrologic basin straddling the Nevada-Utah state line for 135 miles (217 km) in the east-central part of the Great Basin.

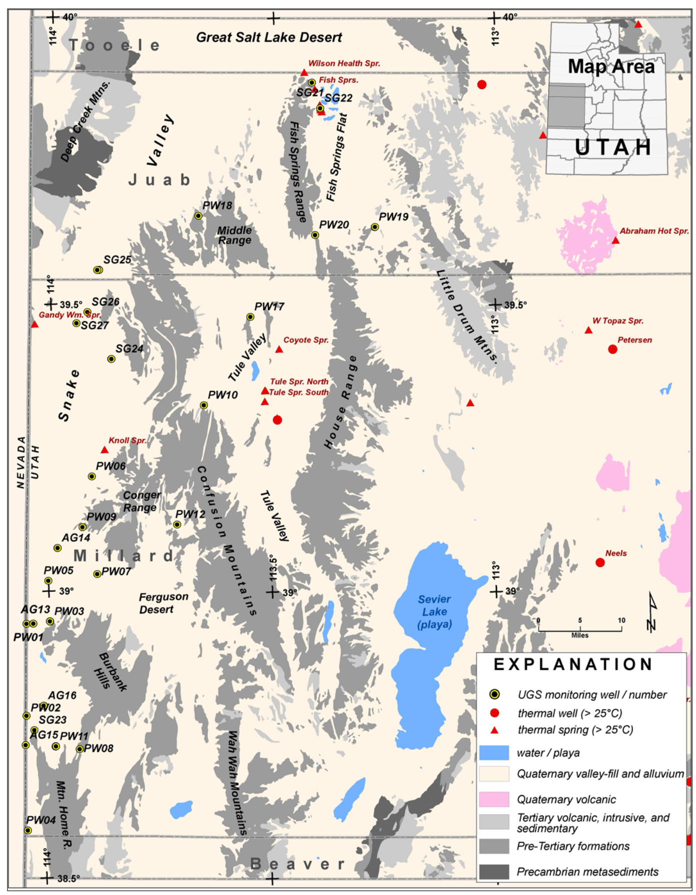

Figure 1. Location of monitoring wells, Snake Valley groundwater monitoring project (geology from Hintze and others, 2000).

Situated within the Basin and Range Province (BRP), Snake Valley is bounded by several north-south trending mountain ranges including the Snake Range and Deep Creek Range on the west, and the Confusion Range, Burbank Hills, and Mountain Home Range to the east-southeast. Snake Valley also extends northeastward, merging with the Great Salt Lake Desert and is bounded on the northeast by the Middle Range and the Fish Springs Range. Several monitoring wells were also installed northeast of Snake Valley in Tule Valley and Fish Springs Flat (figure 1).

The first phase of monitor-well drilling occurred from early July to early December 2007. The second phase occurred from late March to late May 2008. The third phase commenced in early June and ended in December 2008. The fourth and final phase of drilling ended in April of 2009. Standard geophysical logs were recorded from each well site, and lithologic descriptions were prepared from cutting samples. Monitoring wells were installed at 27 sites and included 51 boreholes with a total of 68 piezometers screened to test the various water-bearing units. This paper, summarizing down-hole temperature measurements in 23 of these wells, is a synthesis of a more detailed report (Blackett, 2011).

Geology and Geohydrology

Regional Setting

Kirby and Hurlow (2005) described geologic units of the Snake Valley study area and surrounding region, paraphrased in this section and illustrated on figure 2. Bedrock units primarily consist of Neoproterozoic to early Mesozoic strata up to 33,000 feet (10,058 m) thick (Gans and Miller, 1983). Paleozoic-age shelf carbonates dominate the middle and upper part of the sequence, whereas quartzites and clastic rocks of Early Cambrian and Proterozoic age dominate the lower part of the section.

Contraction of these rocks began in the Late Jurassic and continued through early Tertiary as east-directed thrust faults and north-south trending folds of the Sevier fold and thrust belt. Lower- and mid-crustal metamorphism occurred during the emplacement of plutons in the Mesozoic and early Cenozoic as seen in the northern and southern Snake Range (Gans and Miller, 1983; McGrew, 1993; Miller and others, 1999).

Extension, widespread volcanism, and crustal thinning began during the latest Eocene and early Oligocene (Axen and others, 1993; Miller and others, 1999). Crustal thinning was accommodated along the Snake Range decollement (SRD), a regional, shallow, east-dipping fault (low-angle detachment), imaged in the subsurface with estimated extension between 5 and 15 miles (8 and 24 km) east-southeastward across the southern Snake Range and adjacent Snake Valley (Allmendinger and others, 1983; Gans and Miller, 1983; Bartley and Wernicke, 1984; Shah Alam, 1990; McGrew, 1993). Footwall rocks (of the SRD) were thinned and metamorphosed to greenschist facies during extension (Miller and others, 1983; McGrew, 1993). A later period of extension involving slip on both the low-angle SRD and other high-angle faults to the north and south occurred in the Miocene; volcanic rocks and clastic basin fill were deposited and regional doming of the Snake Range occurred (Miller and others, 1999). Various aspects of the SRD have received much debate (Gans and Miller, 1983; Bartley and Wernicke, 1984).

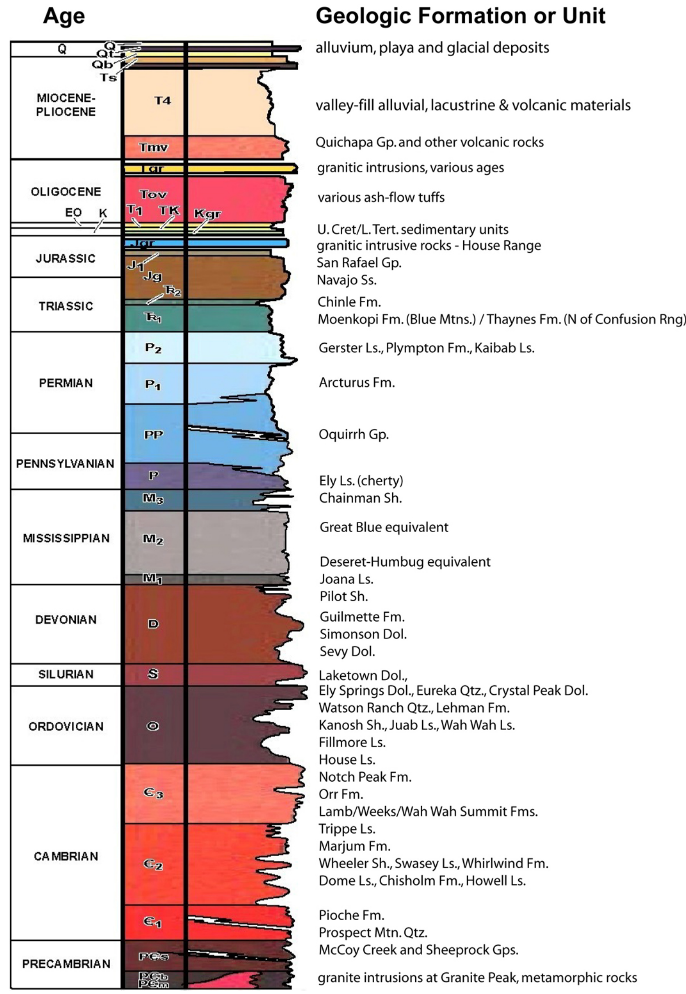

Figure 2. Generalized stratigraphic column for west-central Utah. From Kirby and Hurlow (2005), modified from Hintze and others (2000).

Welch and others (2007) described the groundwater resources of the region as contained in three general categories of aquifers– shallow basin-fill aquifers, a deeper volcanic-rock aquifer, and an underlying carbonate-rock aquifer that forms the base of the regional groundwater flow system. Two aquifers in the Snake Valley hydrologic basin are important to this project: the regionally extensive carbonate-rock aquifer, and the overlying basin-fill aquifer (Gates, 1987; Plume, 1996; Harrill and Prudic, 1998). Locally important aquifers may exist in the Early Cambrian and upper Proterozoic clastic parts of the section. Important aquitards include the Mesozoic to Tertiary-aged igneous and metamorphic rocks of the lower plate of the SRD (Plume, 1996).

Paleozoic Carbonate-rock Aquifer

The Paleozoic shelf carbonate rocks throughout the region form an important aquifer underlying much of the eastern and southern parts of the Great Basin, referred to as the "Great Basin Carbonate-Rock Aquifer System." Permeability in the carbonate-rock aquifer is dominated by secondary dissolution along joints, fractures, and faults (fracture permeability). Kirby and Hurlow (2005) cited data from oil and gas well drill-stem tests indicating a wide variance in horizontal hydraulic conductivity, likely representing fluid flow in highly fractured carbonate rocks versus un-fractured rocks. They also assumed that vertical hydraulic conductivity is equal to or less than horizontal hydraulic conductivity, depending on lithology, bedding, and fracture relationships.

Quaternary-Tertiary Basin-Fill Aquifer

Most groundwater is developed from the basin-fill aquifers that, in the Snake Valley study area, comprise mostly clastic, fine-grained deposits derived from the surrounding mountain ranges. Total thickness of basin fill modeled from gravity and well data ranges between 0 and 2.4 miles (0 – 3.8 km) (Kirby and Hurlow, 2005). Seismic and gravity data, and well data show asymmetric basins with basin-fill deposits generally thickening westward toward the Snake Range (Allmendinger and others, 1983; Shah Alam, 1990; McGrew, 1993). Basin-fill geometry is irregular north to south, defining several distinct pockets of thick basin fill. Primary permeability in the basin-fill aquifer is due to connected voids of the aquifer matrix (matrix permeability).

Groundwater Monitoring Wells

Well Drilling Summary

Monitor-well drilling was conducted in four phases beginning in December 2007 and ending in April 2009. Fifty-one boreholes with 68 piezometers were installed at 27 well sites (temperature profiles were measured at 23 of these well sites) (Figure 1, Table 1). (A piezometer is a 1.0-inch [2.5-cm], 2.0-inch [5.1-cm], or 2.5-inch- [6.4-cm] diameter PVC pipe, slotted [or screened] and therefore open to the aquifer over a limited depth range, but isolated from the rest of the aquifer by cement or “bentonite” grout.) Pressure transducers were installed in most of the wells to monitor long-term water levels. The U.S. Geological Survey’s (USGS) Western Region Research Drilling Program (RDP) and Central Region RDP drilled the majority of the wells using mud rotary and direct-air techniques. “Geoprobe” and auger drilling methods were used by the USGS Central Region RDP at some shallow well sites near areas of groundwater discharge or “up-welling.” Several wells installed near agricultural areas were drilled by a private contractor (Hurlow and Kirby, 2007). Data from these wells, along with other project information, can be accessed through an Internet website at http://geology.utah.gov/esp/snake_valley_project/index.htm.

Temperature Profiles

Temperature-depth profiles were recorded at 23 monitor-well sites throughout the Snake Valley project area using a high-precision thermistor probe and temperature logging equipment. The equipment consists of a thermistor probe linked to four-conductor cable on a cable reel with electrical connection to a volt-ohm meter. Probe resistance is read from the volt-ohm meter, manually recorded and, converted to temperature using a probe-specific, polynomial expression determined by the manufacturer (Natural Progression Instruments, Olympia, Washington). Instrument characteristics and periodic calibrations result in a temperature measurement precision of 0.02°F (0.01°C). Temperatures were recorded at 23 monitoring well sites with a total of 15,519 ft (4730 m) of borehole length recorded. Bottom-hole temperatures ranged from 52.7 to 117°F (11.5 to 47°C) in boreholes ranging from 67 to 1840 ft (20 to 561 m) deep, completed in various geologic units ranging in age from Cambrian to Quaternary (Table 1 and Figure 2).

Table 1. Summary of wells used for temperature-depth profiles, Snake Valley groundwater monitoring project.

Map ID	Site Name	Tsp, Rng, Sec	Longitude	Latitude	Screened Unit*	Water Depth (m)	BHT** (°C)	PD*** (m)	Gradient °C/km
PW01	Garrison	T21S R20W 36	-114.049200	38.941208	QTs	37.8	19.7	490.0	19.2
PW02	Burbank	T23S R20W 25	-114.047470	38.780888	PlPMe	9.0	17.3	192.8	24.7
PW03	NE of Garrison	T21S R19W 32	-113.996220	38.945457	Ds	59.3	13.3	263.0	ISO
PW04	N. Hamlin Valley	T26S R20W 02	-114.042730	38.581146	Tv	180.8	15.9	278.0	8.8
PW05	SW of Eskdale	T20S R19W 32	-114.001230	39.016315	QTs	10.8	16.3	294.2	12.6
PW06	NE of Eskdale	T18S R18W 32	-113.905270	39.198845	Pa	33.1	18.6	168.0	23.3
PW07	NW Ferguson Valley	T20S R18W 32	-113.891770	39.028576	QTs	14.6	17.0	390.0	11.1
PW08	Mormon Gap	T24S R19W 13	-113.928840	38.723457	PlPMe	30.1	14.9	121.0	18.8
PW09	East of Eskdale	T19S R19W 36	-113.925410	39.110268	Sl	53.6	19.4	267.5	15.9
PW10	E. of Cowboy Pass	T17S R16W 16	-113.655075	39.323803	PlPMe	165.4	15.7	200.0	16.5
PW11	The Cove	T24S R19W 16	-113.981760	38.728310	PlPMe	64.1	18.8	350.8	16.7
PW12	Little Valley	T19S R17W 36	-113.714040	39.115450	Dg	435.4	35.1	495.0	60.8
AG13	Garrison Ag	T21S R20W 36	-114.033770	38.947560	QTs	22.4	12.5	96.0	ISO
AG14	Eskdale Ag	T20S R19W 16	-113.980930	39.073790	QTs	6.3	14.2	96.5	4.0
AG15	GPR Ag	T24S R20W 14	-114.049020	38.729767	QTs	25.0	11.5	54.6	ISO
AG16	Davies Ranch Ag	T23S R19W 20	-114.009346	38.798737	QTs	4.7	13.5	95.0	27.6
PW17	Coyote Knolls	T15S R15W 32	-113.551010	39.477930	Oes	25.7	19.1	175.0	21.5
PW18	NW Middle Range	T13S R16W 32	-113.668570	39.653854	Dg	230.8	47.0	302.0	122.5
PW19	Table Knoll	T14S R13W 02	-113.271225	39.634266	Co	60.4	35.1	139.0	86.3
PW20	Sand Pass	T14S R14W 10	-113.405600	39.620647	Cpm	89.4	25.4	172.0	33.3
SG21	Fish Springs	T11S R14W 03	-113.413370	39.886540	Sl?	1.2	23.1	19.6	ISO
SG24	Twin Springs	T16S R18W 22	-113.863014	39.403480	QTs	0.7	16.4	34.7	43.5
SG25	Leland Harris Sprgs. N	T14S R18W 32	-113.891720	39.558666	QTs	0.7	14.7	35.5	51.0

* Screened unit refers to geologic unit/formation at maximum probe depth where piezometer is open as follows: QTs - valley fill; Tv – Tertiary volcanics; Pa - Arcturus Fm; PIPMe - Ely Ls; Dg - Guillmette Fm; Ds - Simonson Dol; Sl - Laketown Dol; Oes - Ely Springs Dol; Co - Orr Fm; Cpm - Prospect Mtn. Quartzite; **BHT - Bottom-Hole Temperature; ***PD - Probe Depth. The code “ISO” indicates isothermal gradient.

Summary

In support of the UGS’s Snake Valley groundwater monitoring project, high-precision temperature profiles were acquired from 23 of 27 monitoring well sites throughout the Snake Valley project area. Well depths ranged from 67 ft (20 m) at Fish Springs to 1840 ft (561 m) near the community of Garrison. Maximum temperatures (usually bottom-hole temperatures) ranged from about 53°F (12°C) in a shallow, 180-ft (55-m) well completed in valley-fill deposits near Needle Point Spring on the south end of Snake Valley, to 117°F (47°C) measured in a 1000-ft (305-m) deep well on the northwest side of the Middle Range (Juab County), completed in the Devonian Guillmette Formation. Among other factors, thermal gradients vary with depth, water saturation, and the thermal conductivity of geologic material penetrated by the well. Variations in thermal gradients are summarized in temperature-depth plots (figures 3 and 4). The gradients range from near zero (isothermal conditions) to an overall high of 6.72°F/100 ft (122.5°C/km), considerably above typical values for the BRP, at well PW18 (NW Middle Range).

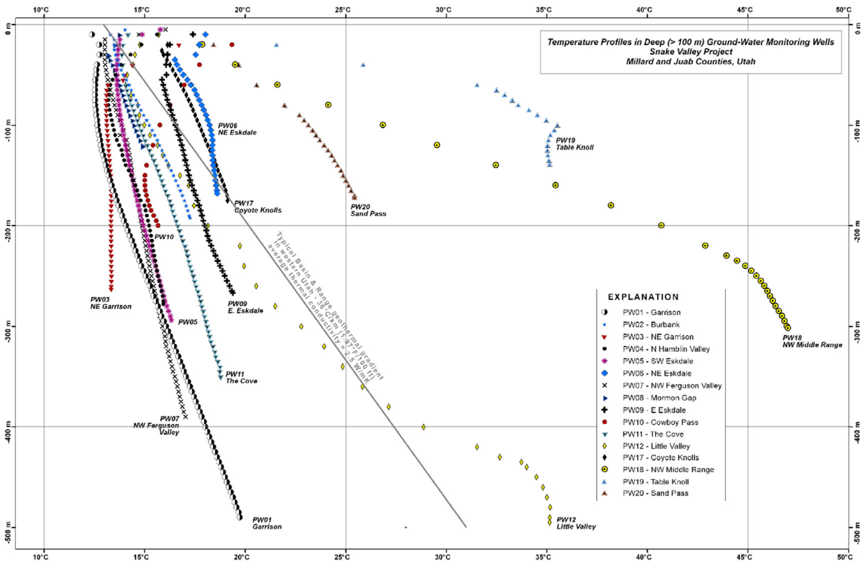

Figure 3. Comparison of temperature (°C) vs. depth (meters) of deep (> 100 m) groundwater monitoring wells, Snake Valley Project (see figure 1 for well locations; typical BRP geothermal gradient [36°C/km] assumes a heat flow of 91 mWm^{-2} [from Henrikson, 2000] and an average thermal conductivity of 2.5 $Wm^{-1}K$).

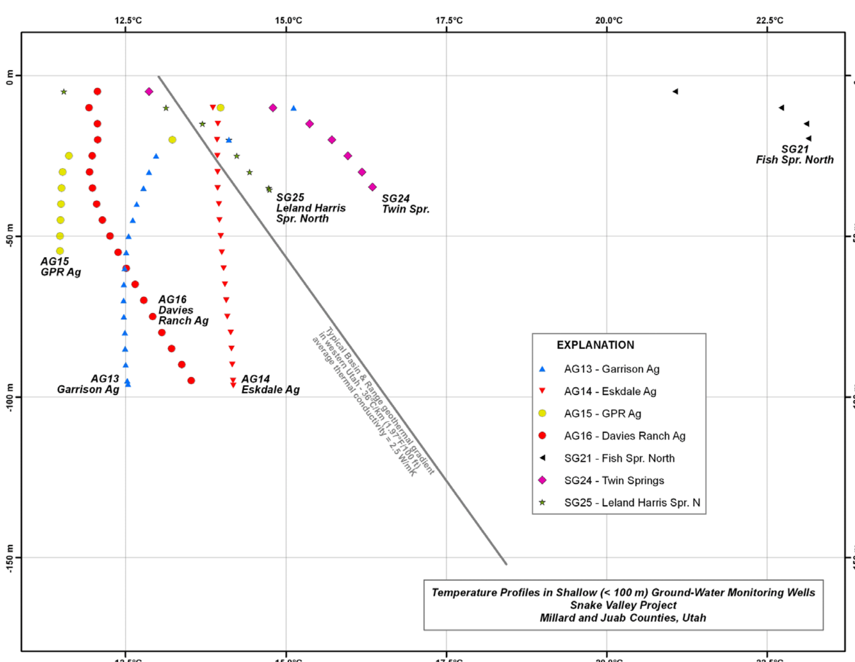

Figure 4. Comparison of temperature (°C) vs. depth (meters) of shallow (< 100 m) groundwater monitoring wells, Snake Valley Project (see figure 1 for well locations; typical BRP geothermal gradient [36°C/km] assumes a heat flow of 91 mWm^{-2} [from Henrikson, 2000] and an average thermal conductivity of 2.5 $Wm^{-1}K$).

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