Thermal-Water Discharge from Steamboat Hills Geothermal System

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ABSTRACT

Measurements of the flux of chloride in Steamboat Creek are used to estimate the rate at which thermal water (Cl = 820 mg/L) discharges from the geothermal system at Steamboat Hills, Nevada. Past studies of thermal-water discharge between 1955 and 1989 yielded estimates of 660-1,200 gallons per minute (gpm). In this study, 4 repeated sets of Cl flux measurements over the period April 2007 to March 2008 yielded estimates for this discharge of 730–1,214 gpm. These results are based on Cl flux measurements in SB Creek at Bella Vista Road (in the Huffaker Hills at the northern end of the system) and at Rhodes Road (at the southern end of the system). Alternative computations based on Cl flux measurements in Steamboat Creek and the Crane Ditch tributary at Steamboat Parkway and at Steamboat Creek at Rhodes Road yielded discharge estimates of 250-580 gpm. Differences between these estimates for each measurement set reflect the additions of thermal water to Steamboat Creek as it flows through the meadows north of Steamboat Parkway. Estimates based on the Huffaker Hills gaging site are considered more accurate indicators of present-day thermal-water discharge. Our results are consistent with those of previous investigations which involved similar uses of chloride-flux measurements or estimates, along with estimates of hot spring discharge. This indicates that there has been little if any change in the total rate of discharge from the geothermal system despite a significant increase in the rates of geothermal fluid production and cessation of hot-spring discharge from the silica terraces at the base of Steamboat Hills.

Introduction

The Steamboat Hills geothermal system is situated south of Reno and includes the Steamboat Hills and surrounding South Truckee Meadows (STM). The Steamboat Hills are comprised of the 1.1 m.y. old Steamboat Hills Rhyolite and 2.5 m.y old basaltic andesite flows. One of the unique features of the Steamboat Hills is the extensive deposits of silica sinter surrounding the NE end of the Hills, formed by precipitation from hot-spring discharge and thermal groundwater. Hot spring and geyser discharge was notable from the main silica terrace overlooking Highway 395 until the late 1980's when spring discharge ceased and water levels fell to depths of ≥10 ft in the linear conduits crossing the terrace. The cessation of thermal-water discharge from the silica terraces has been attributed to a combination of thermal reservoir pressure declines following the initiation of sustained geothermal

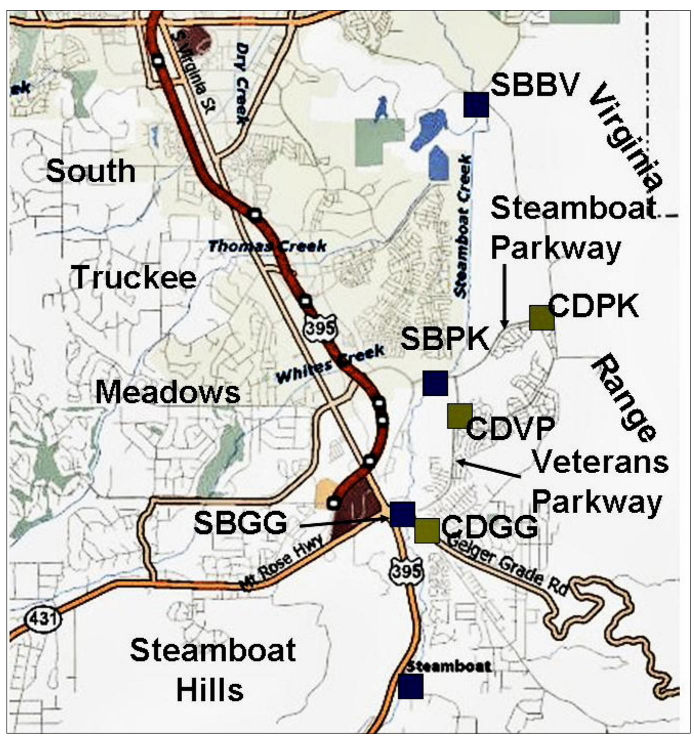

Figure 1. Map of Steamboat Creek study area for Cl flux determinations. Abbreviations for sampling sites on Steamboat Creek and Crane Ditch are explained in Table 1.

Table 1. Results of Chloride Flux Measurements in 2007-2008.

Steamboat Creek	Date	Flow cfs	Web site Q**	Cl Mg/L	Cl Flux cfs x mg/L	Thermal W. Discharge GPM
Rhodes	4/11/2007	4.48		18.7	84	46
Road	4/26/2007	NM	3.4	NM		
(aka SBRR)	5/19/2007	NM	3.9	15	59**	32**
	6/29/2007	NM	1.6	NM		30 est
	10/03/2007*	8		6	48	26
	11/11/2007	3.88		20	78	43
	3/30/2008	2.35		26	61	34
Geiger	4/11/2007	0.3	2	231	69	39
Grade	4/26/2007	NM	2	NM		
(aka SBGG)	5/19/2007	NM	0.66	300	198**	109**
	6/29/2007	0.1	0.04	380	38	21
	10/3/2007	NM	0.03	NM		
	11/11/2007	0.19	0.12	340	65	36
	3/30/2008	NM	2.1	NM	ND	ND
Steamboat	4/11/2007	2.26		229	517	285
Parkway	4/26/2007	NM		NM		
(aka SBPK)	5/19/2007	NM		NM		
	6/29/2007	2.05		200	410	226
	10/3/2007	NM		NM		
	11/10/2007	2.22		230	511	282
	3/29/2008	1.1		220	242	133
Bella Vista	4/11/2007	NM	7.2	322	2120**	1275**
Road	4/26/2007	NM	4.9	NM		
(aka SBBV)	5/19/2007	NM	2.5	NM		
	6/29/2007	NM	1.6	NM		
	10/3/2007	6.4	7.9	270	2133	1170**
	11/11/2007	NM	7.7	260	2000**	1100**
	3/29/2008	3.55	4.6	300	1380**	760**
Crane Ditch						
Geiger Grade	4/11/2007	4.43		66	292	161
(akd CDGG)	4/26/2007	NM		NM		
	5/19/2007	NM		NM		
	6/29/2007	0.1		200	20	11
	10/3/2007	NM		NM		
	11/11/2007	2.67		93	248	137
	3/30/2008	2.55		82	210	115
Veterans PK	4/11/2007	NM		NM		
(aka CDVP)	4/26/2007	3.9		79	308	169
	5/19/2007	NM		NM		
	6/29/2007	0.1		220	22	12
	10/3/2007	4.1		40	164	90
	11/10/2007	2.51		110	276	152
	3/29/2008	0		NM	0	0
Steamboat PK	4/11/2007	NM		NM		340est
(aka CDSB)	4/26/2007	NM		NM		340est
	5/19/2007	NM		NM		
	6/29/2007	1.1		240	264	145
	10/3/2007	>4		NM		
	11/10/2007	3.73		160	597	328
	3/29/2008	1		280	280	154

Totals – 4/11/07	1275 - 46 = 1230 gpm (SBBV-SBRR)	4/11/07	286 + 340 - 46 = 580 gpm (SBPK + CDSP-SBRR
10/3/07	950 - 26 = 924 gpm (SBBV-SBRR)	6/29/07	226 + 145 - 30 = 340 gpm (SBPK + CDSP-SBRR
11/11/07	1100 - 43 = 1057 gpm (SBBV-SBRR)	11/11/07	282 + 328 - 43 = 570 gpm (SBPK + CDSP-SBRR
3/29/08	760 - 34 = 730 gpm (SBBV-SBRR)	3/29/08	133 + 154 - 34 = 253 gpm (SBPK + CDSP-SBRR

*Steamboat Creek gaged and sampled downstream of SB Ditch inflow
**Measurements taken from rating curve published on USGS Web site
***Thermal -water discharge in Crane Ditch at Steamboat Parkway - estimated at twice the value for Crane Ditch at Veterans Parkway based on visual comparisons and measurements at both sites on 11/10/2007

well production, a multiyear period of decline in water levels in the groundwater system in the South Truckee Meadows resulting from below normal precipitation, and increasing pumpage of groundwater for domestic consumption (Sorey and Colvard, 1992).

In spite of the decline of hot-spring discharge both at the base of the Steamboat Hills and within the STM, thermal water has continued to discharge in Steamboat Creek between the upstream gaging site at Rhodes Road and the downstream gaging site at Bella Vista Road (also known as Short Lane) (Figure 1). In addition to the present study, five previous investigations utilizing the chloride-flux technique yielded values of total thermal-water discharge between these two streamflow sites (Table 1). At the downstream site, Steamboat Creek passes through a narrow channel in the basaltic rocks of Huffaker Hills. Just below the upstream site at Rhodes Road, water enters Steamboat Creek in the Steamboat Ditch, which transports water some 100 km from the point of diversion from the Truckee River near Verdi, along the western edge of the STM, around the northeastern edge of SB Hills, and finally crossing Highway 395 some 50 m north of Rhodes Road. Flow in Steamboat Ditch occurs from spring until early fall of each year and contributes a small amount of chloride to Steamboat Creek at seasonally variable rates.

Measurement Techniques

The chloride-flux technique used in this and previous studies involves determinations of the rate of thermal-water flow at sites where streamflow and chloride concentration are determined simultaneously. The presence of water from the Steamboat geothermal system is recognized in Steamboat Creek by the concentrations of thermal-water ions Cl and B in the same proportion found in reservoir water beneath the Steamboat Hills. Typical concentrations of Cl = 820 mg/L and B = 35 mg/L yield ratios near 23. Similar values for Cl in thermal waters were assumed in each of the previous studies. In this study, chloride-flux determinations were made at 4 sites in Steamboat Creek and 3 sites in Crane Ditch (Figure 1), an irrigation ditch that diverts water from Steamboat Creek between Rhodes Road and Geiger Grade (aka Mt Rose Highway).

Chloride flux is determined from the product of streamflow and average chloride concentration in the stream. For each Cl flux determination, the associated thermal-water flow is computed by dividing the flux by the assumed Cl concentration in thermal water flowing beneath Steamboat Hills. As indicated in Table 1, values for the total rate of thermal water input to SB Creek can then be computed from the difference between thermal water flow in Steamboat Creek at Bella Vista Road and Rhodes Road (subtracting out as necessary any Cl inputs from Steamboat Ditch).

Results from Previous Studies

Similar computational techniques were utilized in five previous studies over the 1955-1989 period (Table 2). In the studies by White (1968), measurements were made of chloride flux in Steamboat Creek, and in the discharge of hot springs and hot-water wells located on the silica terraces over the period 1945-1955 and in 1964. For the April 1955 and April 1964 computations, the measured hot spring flows were adjusted to represent the components of high-chloride reservoir water in each vent (820 mg/L). White's values of total seepage into Steamboat Creek were 1,100 and 1,385 gpm, respectively. It is not known whether wells on the silica terraces were discharging in April 1964, as they were in April 1955.

Bateman and Scheibach (1975) report on Cl flux measurements made by the Nevada Center for Water Resources Research, Desert Research Institute that yielded values near 900 gpm for thermal-water discharge in Steamboat Creek. Although the actual measurements were never published, it is assumed here that the data were collected at various times over the period 1970-1974.

Shump (1985) used averages for the 1981-1982 period of streamflow and specific conductivity measurements to compute chloride flux values, assuming a relationship between conductivity and Cl concentration for water in Steamboat Creek. Although average values of streamflow and specific conductivity for the period of study were used, the resultant estimate of 1,300 gpm for thermal-water discharge is in reasonable agreement with previous results of White (1968). Shump's study in the mid-1980's was conducted during a time when geothermal wells on the silica terraces had been abandoned, but hot springs were still flowing on the main terrace.

Collar (1990) presents a detailed set of measurements of chloride flux made in March 1989 along Steamboat Creek and various outflows (irrigation ditches) and inflows (cold creeks) between Rhodes Road and Bella Vista Road. This author computed that a total of 380 gpm of hot water was lost to evaporation in the cooling tower atop Steamboat Hills running a maximum capacity (i.e. net production, adjusted to a volumetric flow rate at 90ºC), while at the base of the hills in the binary geothermal field all produced water was reinjection on site. Collar's computed thermal-water inflow to Steamboat Creek, based on the 820 mg/L Cl value attributed to the deep geothermal reservoir, was 663 gpm. A summary of these results are presented and discussed by Sorey and Colvard (1990).

Results of This Study

Significant changes have been made to the flow of Steamboat Creek and its tributaries in the South Truckee Meadows since the studies of Collar (1990) and Sorey and Colvard (1990). The stream channel itself has been rerouted and enlarged north of Steamboat Parkway to accommodate a walkway/bikeway with catchment basins to hold excess flow during flood periods. Another significant change has occurred where a housing development was built along the course of Rio Wrangler Parkway between Veterans Parkway and Steamboat Parkway (Figure 1). A former irrigation ditch channel was deepened and widened to effectively drain groundwater from the area of new housing. The flow in this drainage channel (referred to here as Crane Ditch), is then channeled beneath Steamboat Parkway and eventually enters Steamboat Creek between Steamboat Parkway and Bella Vista Road. Crane Ditch itself drains into a catchment basin just south of Steamboat Parkway. Water seepage from this basin is then diverted beneath Veterans Parkway and into the drainage channel that meanders through the housing development. Note also that during winter, most of the flow from Crane Ditch is diverted back into Steamboat Creek just below Geiger Grade.

In order to account for these changes in flow channels, chloride-flux measurements were made on numerous occasions at 7 sites indicated in Figure 1, including three sites on Crane Ditch, and four on Steamboat Creek. Streamflow and chloride concentration data were collected at key sites on seven different occasions between April 2007 and March 2008 (Table 1). Mean-daily streamflow values are published on the USGS web site for the Steamboat Creek at Rhodes Road, Steamboat Creek at Bella Vista Road (aka Short

Table 2. Results of Previous Studies of Thermal Water Discharge from the SB Geothermal System.

Date	Author	Conditions	TW Discharge Estimate	Explanation
Apr 1955	White	300 gpm well flow	1100 gpm	Includes 65 gpm from hot springs
Apr 1964	White	No well flow	1385 gpm	Springs not measured
1970-1974	Bateman & Schiebach	No well flow	900 gpm	Springs not measured
1981/82	Shump	No well flow	1300 gpm	Springs not measured
Mar 1989	Collar	Net well flow 380 gpm	663 gpm	No flowing springs
Apr 2007	This study	Net well flow 380 gpm	1230 gpm	No flowing springs, SB Hill plants off line for ~3 months
Oct 2007	This study	Net well flow 380 gpm	924 gpm	No springs, all plants on line
Nov 2007	This study	Net well flow 380 gpm	1057 gpm	No springs, all plants on line
Mar 2008	This study	Net well flow 380 gpm	730 gpm	No springs, all plants on line

Lane), and Steamboat Creek at Geiger Grade sites. These web site values were used in cases where a streamflow measurement was not made or where streamflow was measured but the web-site value was considered to be more accurate. The web site flow data are determined from a combination of periodic wading measurements, a rating curve for discharge versus stream gage height, and continuous records of gage height. At one site (Steamboat Creek at Geiger Grade), streamflow records are inaccurate under low flow conditions (<140 gpm) when a stagnant pool forms around the gage-house intake.

The entire data set of streamflow and chloride concentration determinations is listed in Table 1, along with computed values of chloride flux and thermal-water discharge. Total thermal water input to Steamboat Creek upstream of Bella Vista Road has been computed by two methods: (1) from the difference in thermal-water flow at SBBV and SBRR, and (2) from the sum of thermal water flow at SBPK and CDPK minus SBRR. These two methods yield consistent differences reflecting the inflow of thermal water to Steamboat Creek north of Steamboat Parkway – a region of meadowland where Steamboat Creek has been reworked to create the scenic walk and bikeway. To obtain four sets of results by each method, it was necessary to estimate the thermal-water discharge value for Crane Ditch at Steamboat Parkway in April 2007, based on comparisons of results at this site and the Crane Ditch at Veterans Parkway site on later occasions where both sites were measured.

During 2007, the flow of Steamboat Creek at Bella Vista Road varied from a high of 3,300 gpm (7 cfs in the early spring and late fall to lows near 2 cfs in the summer. Brief periods of even higher flows were recorded during and following storms and snowfalls. The results for four sets of measurements of total thermal-water discharge are listed at the bottom of the table, showing ranges of 730-1230 gpm using method (1) and 250-580 gpm using method (2). Differences between each method reflect the input of thermal water from groundwater seepage into the meadowland region of Steamboat Creek between Steamboat Parkway and Bella Vista Road. The average value for total thermal water inflow above Bella Vista Road would be ~985 gpm.

Previous studies that determined total thermal water inflow to Steamboat Creek yielded values of 660– 1385 gpm (Table 2), a range that includes or is comparable with the results of this study. The estimate made in 1955 included the flow of springs (85 gpm) and wells on the silica terraces (300 gpm), whereas for later measurements made before 1989 there were no significant flows from springs or wells. In contrast, the results of Collar (1990) and those from this study apply to conditions of continuous power production from geothermal developments in the Steamboat Hills. Although total production and injection rates are higher now than during the Collar (1990) study, the net mass consumption of hot water has not changed, given that there is only one cooling tower (with a fixed upper limit on fluid throughflow) in operation in the Steamboat Hills; the increased production over the years has been kept under single phase conditions and run through binary power plants before being reinjected. So for both studies, the consumptive use of geothermal flow (production minus injection) was computed to be 380 gpm. For the binary development on the lower silica terrace at the base of the hills, total fluid production is about twice that for the hills development, but with a binary development scheme in place, all of this flow in injected back into the geothermal reservoir. It should also be pointed out that the process of evaporation used to cool geothermal fluid and to provide cooling water to steam condensation does not actually result in removal of thermal ions (Cl and B) from the geothermal system – these ions remain in the cooled liquid or the liquid fraction separated from steam and hence are returned to the geothermal system to ultimately discharge in Steamboat Creek.

In conclusion then we find that the computed total thermal-water discharge from the Steamboat geothermal system does not appear to have changed significantly over the past 60 years, despite (1) significant increase in geothermal development and (2) groundwater development for domestic consumption, and (3) large-scale reworking of the course and geometry of Steamboat Creek and Crane Ditch. Our measurements over the 2007-2008 period suggest an average discharge of 1,030 gpm with a variablility of ± 25%. We also find that approximately half of this total flow reaches Steamboat Creek and Crane Ditch before it crosses Steamboat Parkway, the remainder enters Steamboat Creek from groundwater seepage between the Parkway and Bella Vista Road in the Huffaker Hills.

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