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BASELINE WATER-QUALITY INVESTIGATION, EMIGRANT CREEK WATERSHED, SOUTH-CENTRAL MONTANA

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Cover image: Emigrant Peak, south-central Montana.

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ABSTRACT

The Montana Bureau of Mines and Geology collected water samples from 17 sites in the Emigrant Creek watershed in south-central Montana to establish baseline water-quality conditions. Samples were collected from three boreholes, seven springs, six stream locations, and one adit discharge. They were analyzed for major ions, trace metals, stable-water isotopes of oxygen and hydrogen, and tritium.

The total dissolved solids concentrations for the groundwater and surface-water samples ranged from 59 to 271 mg/L. Acidic (field pH < 3.0), metal-rich, SO_4-type water was observed in the Allison Tunnel adit discharge and two nearby springs. Moderately acidic (pH 5.8–6.1), Ca-Mg-SO_4-HCO_3-type water was observed in two samples from the East Fork of Emigrant Creek and in samples from two springs in the East Fork drainage near the St. Julian Mine. Surface-water samples from Emigrant Creek, and spring and groundwater samples from the Emigrant Creek drainage, had neutral pH's (7.2–7.8) and Ca-Mg-HCO_3-SO_4-type water. Based on the geologic, hydrologic, and geochemical data, it is unlikely that water from the Emigrant Creek watershed is connected to the geothermal system that feeds Chico Hot Springs.

INTRODUCTION

In June 2015, Lucky Minerals, Inc. submitted a mineral exploration plan to assess the presence of base and precious metals in the Emigrant Creek watershed, approximately 7 mi SE of Emigrant, Montana (fig. 1). The plan called for exploratory drilling in two areas on unpatented claims on U.S. Forest Service lands (DUV and Emigrant), and on private land of the St. Julian patented claims (fig. 2). In December 2015, Lucky Minerals withdrew its permit application for drilling on U.S. Forest Service lands.

The purpose of this investigation was to characterize the water quality in the Emigrant Creek and East Fork of Emigrant Creek drainages prior to the proposed drilling. This report describes the baseline water-quality and stable isotope data collected during this investigation, and evaluates potential impacts that the drilling may have on nearby geothermal features.

STUDY AREA

The Emigrant Creek watershed is located in Park County along the western edge of the Absaroka Mountains in the Gallatin National Forest. Emigrant Creek is tributary to the Yellowstone River and drains rugged mountainous terrain covering about 13,400 acres. The climate includes warm summers and cold winters, with a mean average annual temperature of 35°F; the watershed receives 25 to 35 in of precipitation annually, mostly in the form of snow (PRISM, http://www.prism.oregonstate.edu/). Within the watershed, the elevation ranges from 5,500 ft near Old Chico to 10,915 ft at Emigrant Peak. The East Fork of Emigrant Creek separates the DUV and St. Julian exploration areas (fig. 2).

An Eocene intrusive complex forms Emigrant Peak, underlies much of the Emigrant Creek drainage, and is the host rock for the Emigrant–Mill Creek mining district. The Emigrant Stock is principally dacitic and has intruded Precambrian gneiss and schist, Paleozoic sedimentary rocks, and Tertiary volcanic rocks. Pyritic mineralization and intense hydrothermal alteration are prevalent within the Emigrant complex (Van Gosen and others, 1993; Elliot and others, 1983). A granodiorite porphyry intrudes the dacite and is exposed near the Allison Tunnel on the north side of the East Fork of Emigrant Creek (fig. 2); veins of quartz containing sulfide mineralization were noted at the tunnel (Elliot

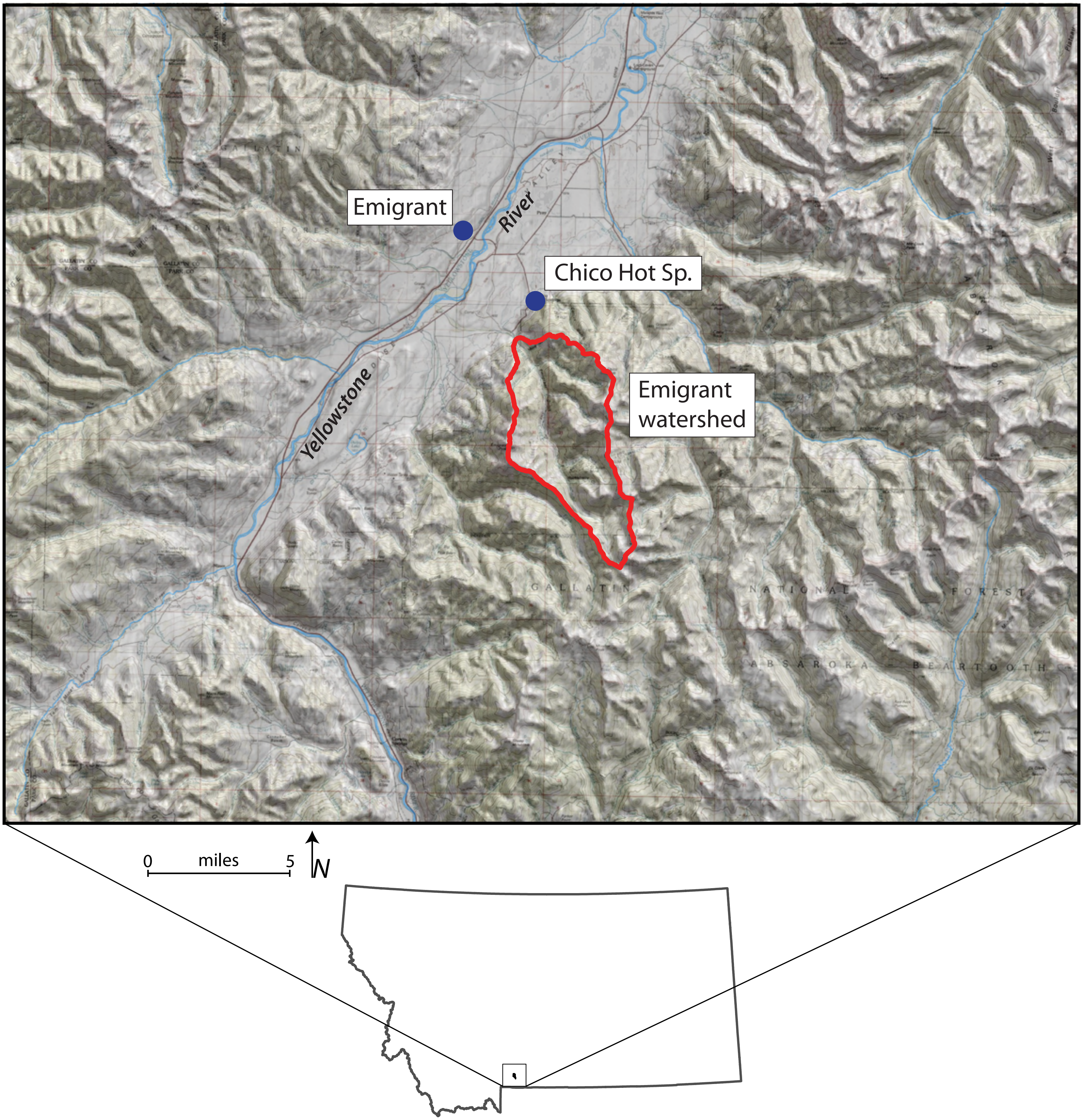

Figure 1. Location map. Emigrant Creek is a small northward flowing tributary to the Yellowstone River.

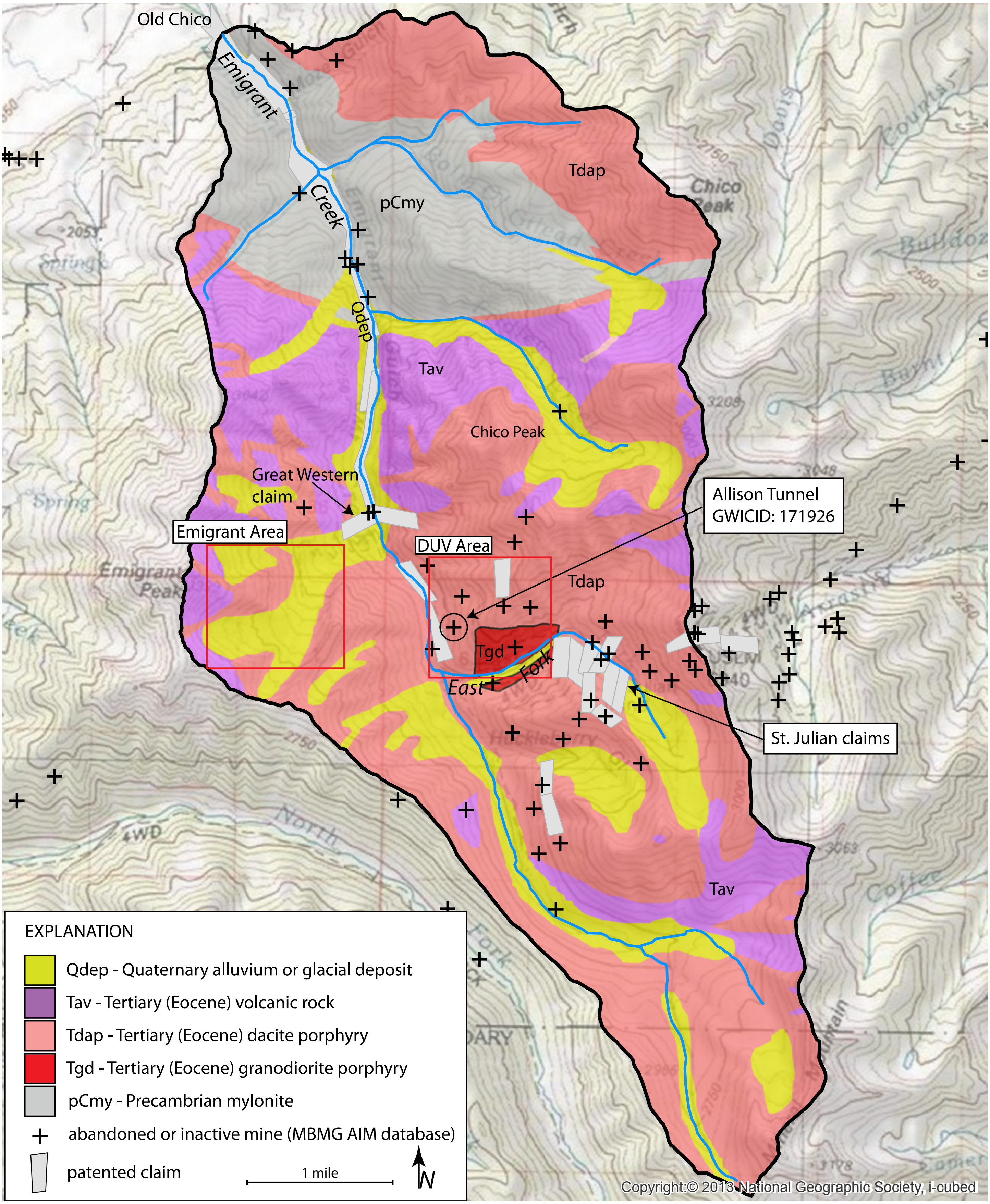

Figure 2. Site map, Geology modified from Berg and others (1999).

and others, 1983). The Allison Tunnel was driven into Tertiary dacite to intercept a copper–molybdenum-bearing breccia pipe, and is associated with an area of “strong pyrite alteration” (Hargrave and others, 2000). Detailed descriptions of the geology, alteration, and mineralization are in Elliot and others (1983).

The Emigrant Creek mining district has a long history of placer and hard rock mining (Stotelmeyer and others, 1983). Mineral deposits associated with the Emigrant Stock consist of stockwork, breccia-pipe, and vein-type deposits; peripheral to the stock, mineralization is mostly vein and replacement types (Hargrave and others, 2000). There are records of 48 abandoned or inactive mines in the Emigrant watershed (fig. 2) and 83 boreholes from prior exploration activity (Geologic Systems, 2015; MBMG Abandoned Mines Database). Patented placer claims lie along most of lower Emigrant Creek below the East Fork confluence. Most abandoned lode claims are in the East Fork and upper part of Emigrant Creek, and their locations suggest an overall northeast-trending structural control on mineralization (fig 2). More information on the abandoned and inactive mines in the watershed is in Hargrave and others (2000) and USGS (1993).

METHODS

Investigators from the Montana Bureau of Mines and Geology (MBMG) selected surface water and spring sites that bracketed areas of potential mineral exploration. The MBMG collected water samples at six stream sites along the East Fork and main stem of Emigrant Creek during baseflow conditions on October 23–30, 2015, and from seven springs. The spring sites were selected because of their proximity to the proposed drilling. In addition to the streams and springs, the MBMG sampled three flowing artesian boreholes, and the discharge from the Allison Tunnel (fig. 3). Although Hargrave and others (2000) reported three flowing boreholes near the St. Julian Mine, only two were flowing in the fall of 2015. Iron staining around the third borehole suggested recent flow. The third borehole was blocked and there was no access for sampling and water-level measurement. A borehole near the Great Western claim adjacent to FS Road 3272 below the Emigrant exploration area provided the third borehole sample.

The sample locations were grouped by their proximity to the proposed exploration areas. Three sites (two springs and the Allison Tunnel discharge) were sampled in the DUV area; six sites (two boreholes, two springs, and two surface-water sites) were sampled in the St. Julian claims area; and eight sites (one borehole, three springs, and four surface-water sites) were sampled in the Emigrant area.

At each site measurements of pH, specific conductance, temperature, redox potential, and dissolved oxygen were obtained; at the surface-water sites stream discharge was also measured. Samples were collected by pumping water through a 0.45-µm canister filter into pre-cleaned polyethylene bottles. Samples bottled for metals analysis were acidified using concentrated nitric acid, and samples for nitrate analysis were preserved using sulfuric acid; samples for anions, alkalinity, and isotopes were unpreserved.

All samples were analyzed for major ions, nutrients, and trace elements by the MBMG Analytical Laboratory (EPA methods 200.7, 200.8, and 300.0), and results are reported as “dissolved.” Hydrogen (^{2}H and ^{3}H) and oxygen (^{18}O) isotope samples were analyzed at the University of Waterloo Environmental Isotope Laboratory.

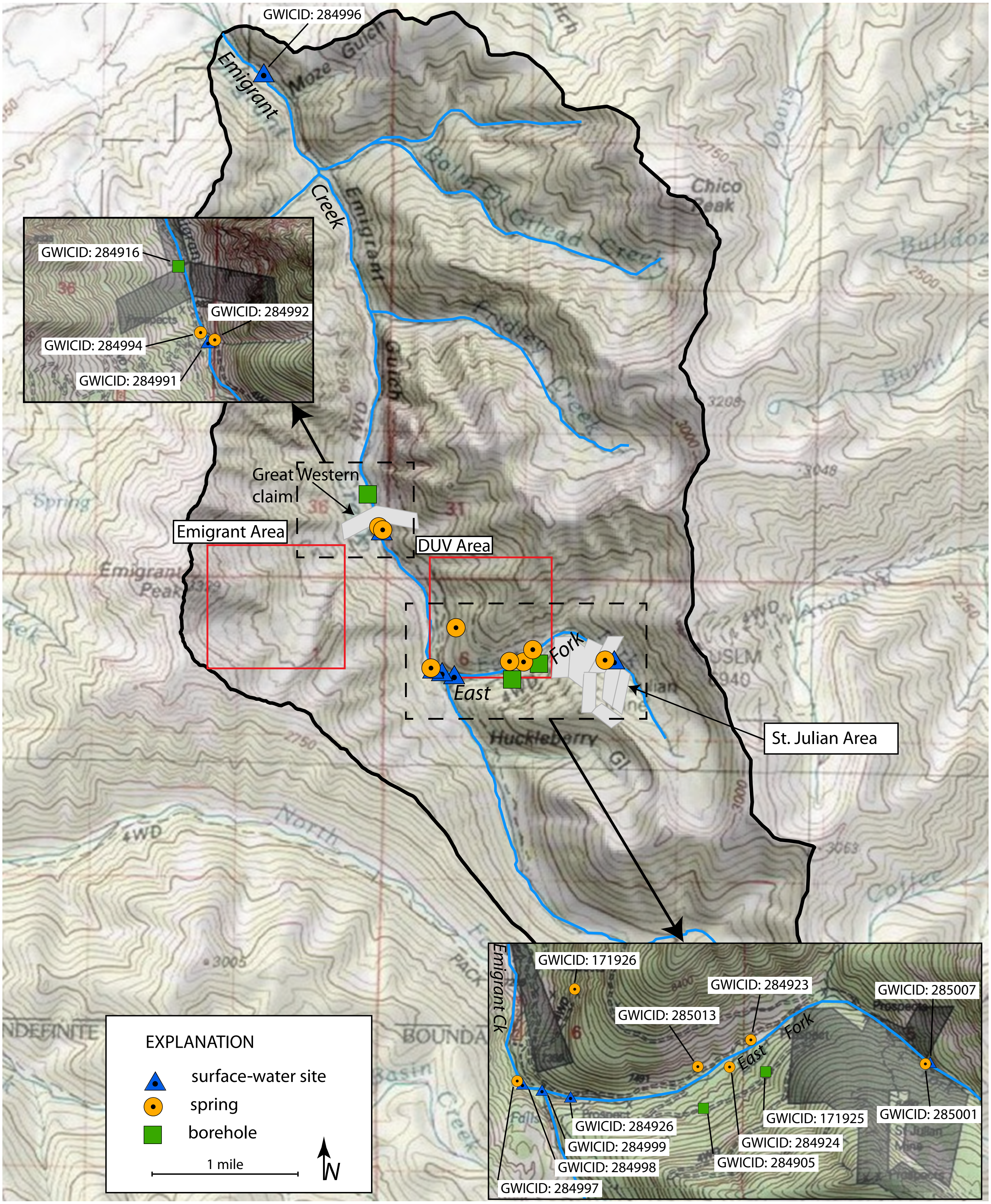

Figure 3. Sample sites. See table 1 to relate GWIC ID to site name. The Allison Tunnel is GWIC ID 171926.

RESULTS

The major ion and trace metal results for the surface-water, groundwater, and spring sites are presented in table 1. Most of the water is a Ca-Mg- HCO_3- SO_4-type; however, at three sites nearly the entire anionic charge was derived from SO_4 (fig. 4). Water from these sites also had pH < 3.0, and elevated concentrations of aluminum (Al), cadmium (Cd), copper (Cu), and zinc (Zn). For the surface-water, groundwater, and spring samples, total dissolved solids concentrations (TDS) ranged from 59 to 271 mg/L, and pH ranged from 2.8 to 7.8 (fig. 5). Although the TDS concentrations in water from all sites were < 300 mg/L, the water quality varies based on source (surface water or groundwater) and geographic area/geology.

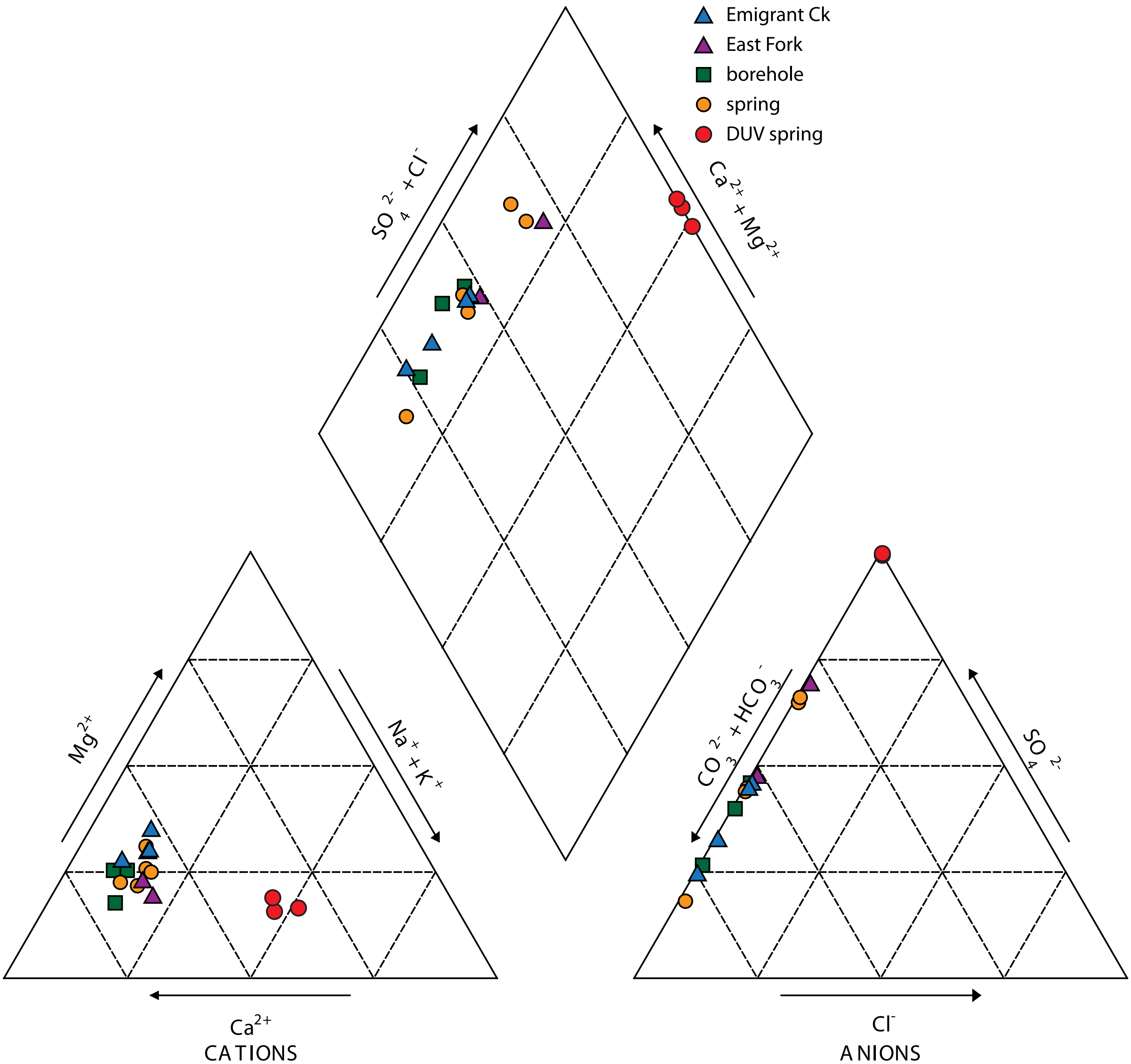

Figure 4. Piper plot showing relative percentage of major ions (in milliequivalents per liter) in water samples from the Emigrant Creek drainage.

Table 1A. Site data.

GWIC ID	Sample ID	Sample Date	Site Name	Site Type	Area	Latitude	Longitude	Altitude	Township	Range	Section	Qsection
171925	210336	10/23/2015	EMIGRANT MINING DISTRICT -DUV UPPER BOREHOLE	BOREHOLE	SJ - BH	45.2550	-110.6565	7799	07S	09E	5	CBBC
171926	210330	10/28/2015	ALLISON TUNNEL	MINE DRAINAGE	DUV	45.2585	-110.6683	7650	07S	09E	6	BDAD
284905	210332	10/23/2015	EMIGRANT MINING DISTRICT DUV- MIDDLE BOREHOLE	BOREHOLE	SJ - BH	45.2534	-110.6603	7642	07S	09E	6	
284916	210331	10/23/2015	GE/GW BOREHOLE	BOREHOLE	E - BH	45.2716	-110.6811	6800	06S	08E	36	AD
284923	210334	10/23/2015	EMIGRANT MINING DISTRICT EAST FORK NORTH GROUNDWATER	SPRING	DUV	45.2564	-110.6575	7595	07S	09E	5	BC
284924	210333	10/23/2015	EMIGRANT MINING DISTRICT EAST FORK SOUTH GROUNDWATER	SPRING	SJ	45.2552	-110.6588	7559	07S	09E	6	DA
284926	210335	10/23/2015	EAST FORK EMIGRANT CREEK ABOVE CONFLUENCE	STREAM	SJ	45.2538	-110.6685	7360	07S	09E	6	CA
284991	210327	10/29/2015	EMIGRANT CREEK ABOVE GREAT WESTERN	STREAM	E	45.2680	-110.6790	6857	06S	08E	36	D
284992	210329	10/29/2015	EAST SPRING SOUTH OF GREAT WESTERN #2	SPRING	E	45.2681	-110.6789	6874	06S	08E	36	D
284994	210323	10/29/2015	WEST SPRING SOUTH OF GREAT WESTERN #1	SPRING	E	45.2685	-110.6795	6864	06S	08E	36	D
284996	210324	10/30/2015	EMIGRANT CREEK AT PRIVATE BRIDGE	STREAM	E	45.3136	-110.6967	5561	06S	08E	13	CB
284997	210321	10/29/2015	SOUTH SPRING BELOW CONFLUENCE	SPRING	E	45.2544	-110.6718	7269	07S	09E	6	C
284998	210328	10/29/2015	EMIGRANT CREEK BELOW EAST FORK CONFLUENCE	STREAM	E	45.2543	-110.6715	7256	07S	09E	6	C
284999	210325	10/29/2015	EMIGRANT CREEK ABOVE EAST FORK	STREAM	E	45.2541	-110.6703	7282	07S	09E	6	C
285001	210322	10/28/2015	SAINT JULIAN #1	SPRING	SJ	45.2555	-110.6467	8082	07S	09E	5	D
285007	210326	10/28/2015	EAST FORK EMIGRANT CREEK ABOVE SAINT JULIAN	STREAM	SJ	45.2555	-110.6465	8066	07S	09E	5	D
285013	210320	10/28/2015	EAST FORK EMIGRANT CREEK ROAD SPRING	SPRING	DUV	45.2552	-110.6607	7557	07S	09E	6	D

Note. SJ, St. Julian; E, Emigrant.

Table 1B. Field parameters, isotopes, and major ions

Sample ID	GWIC ID	Sample Date	Site Name	Site Type	Area	Field Parameters: Water Temp °C	Field pH	Field SC µmhos	Field Redox mV	Dissolved Oxygen mg/L	Isotopes: δ18O	δ2H	3H (TU)
210336	171925	10/23/2015	EMIGRANT MINING DISTRICT -DUV UPPER BOREHOLE	BOREHOLE	SJ	4.6	7.3	283.6	-75.2	2.4	-19.882587	-149.786515	8.5
210330	171926	10/28/2015	ALLISON TUNNEL	MINE DRAINAGE	DUV	3.5	2.9	262.6	446	8.64	-19.418997	-146.138914	11.9
210332	284905	10/23/2015	EMIGRANT MINING DISTRICT DUV- MIDDLE BOREHOLE	BOREHOLE	SJ	4.8	7.2	315.6	-60.8	0.36	-19.838568	-149.590546	5.8
210331	284916	10/23/2015	GE/GW BOREHOLE	BOREHOLE	E	4.7	7.5	289.3	-118.9	0.69	-19.508288	-145.112706	4
210334	284923	10/23/2015	EMIGRANT MINING DISTRICT EAST FORK NORTH GROUNDWATER	SPRING	DUV	5.5	2.9	279.3	487.2	8.55	-19.191116	-145.370516	9.8
210333	284924	10/23/2015	EMIGRANT MINING DISTRICT EAST FORK SOUTH GROUNDWATER	SPRING	SJ	6	5.8	127.1	243.9	7.35	-19.187933	-143.898716	9.7
210335	284926	10/23/2015	EAST FORK EMIGRANT CREEK ABOVE CONFLUENCE	STREAM	SJ	3.4	6.1	99.6	99.5	9.49	-18.994347	-143.029284	NA
210327	284991	10/29/2015	EMIGRANT CREEK ABOVE GREAT WESTERN	STREAM	E	3.1	7.8	125.1	123	9.48	-18.923329	-142.136686	NA
210329	284992	10/29/2015	EAST SPRING SOUTH OF GREAT WESTERN #2	SPRING	E	4.1	7.8	89.2	117.7	9.47	-18.111449	-135.901517	10.6
210323	284994	10/29/2015	WEST SPRING SOUTH OF GREAT WESTERN #1	SPRING	E	2.2	7.5	102.4	123.9	9.78	-18.416823	-136.894332	8.6
210324	284996	10/30/2015	EMIGRANT CREEK AT PRIVATE BRIDGE	STREAM	E	3.7	7.1	142.6	137.4	10.36	-18.392619	-138.928941	9.4
210321	284997	10/29/2015	SOUTH SPRING BELOW CONFLUENCE	SPRING	E	2.3	7.4	128.8	106.6	9.68	-18.468591	-138.642108	8
210328	284998	10/29/2015	EMIGRANT CREEK BELOW EAST FORK CONFLUENCE	STREAM	E	2.9	7.2	143.1	74.5	9.64	-18.938673	-142.459295	NA
210325	284999	10/29/2015	EMIGRANT CREEK ABOVE EAST FORK	STREAM	E	1.8	7.2	132.5	122.9	9.88	-18.913833	-141.244158	8.2
210322	285001	10/28/2015	SAINT JULIAN #1	SPRING	SJ	2.1	5.9	176.4	356	9.13	-19.34459	-144.731448	6.5
210326	285007	10/28/2015	EAST FORK EMIGRANT CREEK ABOVE SAINT JULIAN	STREAM	SJ	1.6	6.0	84	344.7	9.11	-18.829676	-140.905537	9.6
210320	285013	10/28/2015	EAST FORK EMIGRANT CREEK ROAD SPRING	SPRING	DUV	5.7	2.8	285.7	486.2	5.84	-19.295876	-146.912915	11

Sample ID	GWIC ID	Major Ions (mg/L): Ca	Mg	Na	K	Fe	Mn	SiO_2	HCO_3	CO_3	Cl	SO_4	NO_3_n	F	OPO_4	TDS	Hardness as $CaCO_3$	Alkalinity as $CaCO_3$
210336	171925	37.56	8.79	5.91	0.82	0.393	0.467	19.03	112.07	0	0.490 J	58.7	<0.010 U	0.49	<0.020 U	186.5	130.0	91.9
210330	171926	5.55	1.76	6.84	1.84	5.124	5.409	49.96	0	0	0.73	189	<0.010 U	0.13	<0.020 U	270.8	21.1	0.0
210332	284905	39.15	9.56	8.25	0.86	0.42	0.514	19.68	109.99	0	0.65	74.28	<0.010 U	0.78	<0.020 U	208.9	137.1	90.2
210331	284916	37.13	5.82	8.33	0.53	0.233	0.256	15.48	138.55	0	0.63	39.58	<0.010 U	1.29	<0.020 U	177.4	116.7	114.0
210334	284923	4.82	1.21	5.46	2.53	0.295	0.313	52.54	0	0	0.57	172.3	0.14	0.17	<0.020 U	247.4	17.0	0.0
210333	284924	13.18	3.44	4.06	0.82	<0.015 U	0.005 J	20.17	25.38	0	0.450 J	39.73	0.2	0.14	<0.020 U	94.1	47.1	20.5
210335	284926	9.87	1.89	3.4	0.83	0.185	0.212	17.67	18.84	0	0.480 J	33.77	0.09	0.19	<0.020 U	77.4	32.4	15.6
210327	284991	12.63	3.98	3.38	0.66	0.038 J	0.029 J	15.88	40.82	0	0.480 J	27.3	0.08	0.1	<0.020 U	83.9	47.9	33.6
210329	284992	10.53	2.79	3.05	0.41	<0.015 U	0.015 J	11.94	45.09	0	0.490 J	8.04	0.29	0.23	<0.020 U	58.5	37.8	36.9
210323	284994	11.82	2.5	2.31	0.46	<0.015 U	<0.002 U	10.25	20.33	0	0.360 J	29.97	0.28	0.09	<0.020 U	66.2	39.8	16.4
210324	284996	18.11	4.77	3.05	0.64	<0.015 U	0.015 J	11.61	68.01	0	0.480 J	17.08	0.16	0.13	<0.020 U	89.4	64.9	55.8
210321	284997	12.46	4.22	3.15	0.4	<0.015 U	0.006 J	11.15	42.65	0	0.400 J	27.25	0.2	0.18	<0.020 U	78.9	48.5	35.3
210328	284998	13.27	4.26	3.54	0.74	0.055 J	0.055	16.83	42.4	0	0.490 J	27.06	0.07	0.07	<0.020 U	87.3	50.7	34.4
210325	284999	13.5	5.32	3.36	0.62	0.050 J	0.032 J	15.4	56.1	0	0.500 J	21.3	0.06	0.07	<0.020 U	86.5	55.6	45.9
210322	285001	21.21	4.52	5.92	0.67	<0.015 U	0.004 J	21.21	59.57	0	0.450 J	36.87	<0.010 U	0.51	<0.020 U	121.3	71.6	49.2
210326	285007	8.83	1.99	2.57	0.41	<0.015 U	0.007 J	12.61	26.15	0	0.410 J	18.78	0.13	0.06	<0.020 U	58.7	30.2	21.3
210320	285013	4.76	1.46	7.4	2.25	0.458	0.46	51.6	0	0	0.75	131.5	0.08	0.2	<0.020 U	206.6	17.9	0.0

Note. J, estimated quantity above detection limit but below reporting limit; U, undetected quantity below detection limit; mg/L, milligrams per Liter; SJ, St. Julian; E, Emigrant.

Table 1C. Trace metals.

Trace Metals (µg/L)

Sample ID	GWIC ID	Al	Sb	As	Ba	Be	B	Br	Cd	Cr	Co	Cu	Pb	Li	Mo	Ni	Se	Ag	Sr
210336	171925	8.880 J	<0.100 U	3	19.66	<0.100 U	<0.500 U	<10.000 U	<0.100 U	<0.100 U	0.67	<0.500 U	1.5	4.980 J	<0.100 U	<0.100 U	<0.100 U	<0.100 U	314.29
210330	171926	3099.53	<0.100 U	1.34	8.27	0.62	<0.500 U	<10.000 U	3.08	<0.100 U	8.5	175.11	2.07	<2.000 U	<0.100 U	7.25	<0.100 U	<0.100 U	30.87
210332	284905	9.230 J	<0.100 U	3.53	10.31	<0.100 U	<0.500 U	<10.000 U	<0.100 U	<0.100 U	0.410 J	<0.500 U	0.43	6.100 J	<0.100 U	<0.100 U	<0.100 U	<0.100 U	283.32
210331	284916	8.960 J	<0.100 U	6.96	21.23	<0.100 U	<0.500 U	<10.000 U	<0.100 U	<0.100 U	<0.100 U	<0.500 U	<0.060 U	9.460 J	1.66	<0.100 U	<0.100 U	<0.100 U	361.31
210334	284923	6422.76	<0.100 U	<0.100 U	23.73	0.380 J	<0.500 U	<10.000 U	2.69	<0.100 U	3.84	346.04	2.46	<2.000 U	<0.100 U	3.67	<0.100 U	0.260 J	32.87
210333	284924	13.02	<0.100 U	0.240 J	30.44	<0.100 U	<0.500 U	<10.000 U	0.360 J	<0.100 U	<0.100 U	1.610 J	<0.060 U	<2.000 U	<0.100 U	0.88	<0.100 U	<0.100 U	80.25
210335	284926	151.12	<0.100 U	0.45	21.8	<0.100 U	<0.500 U	<10.000 U	0.47	<0.100 U	0.71	17.11	<0.060 U	<2.000 U	<0.100 U	0.7	<0.100 U	<0.100 U	53.29
210327	284991	46.64	<0.100 U	<0.100 U	52.4	<0.100 U	<0.500 U	<10.000 U	0.280 J	<0.100 U	0.260 J	5.74	<0.060 U	<2.000 U	<0.100 U	0.420 J	<0.100 U	<0.100 U	124.37
210329	284992	20.56	<0.100 U	0.47	12.37	<0.100 U	<0.500 U	<10.000 U	<0.100 U	<0.100 U	<0.100 U	<0.500 U	<0.060 U	2.690 J	1.03	<0.100 U	<0.100 U	<0.100 U	90.89
210323	284994	11.03	<0.100 U	0.280 J	28.57	<0.100 U	<0.500 U	<10.000 U	<0.100 U	<0.100 U	<0.100 U	4.08	<0.060 U	<2.000 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	61.26
210324	284996	23.06	<0.100 U	0.47	45.35	<0.100 U	<0.500 U	<10.000 U	<0.100 U	<0.100 U	<0.100 U	1.460 J	<0.060 U	<2.000 U	1.17	<0.100 U	<0.100 U	<0.100 U	161.34
210321	284997	9.060 J	<0.100 U	<0.100 U	33.72	<0.100 U	<0.500 U	<10.000 U	<0.100 U	<0.100 U	<0.100 U	<0.500 U	<0.060 U	<2.000 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	85.23
210328	284998	52.21	<0.100 U	<0.100 U	62.93	<0.100 U	<0.500 U	<10.000 U	0.370 J	<0.100 U	0.410 J	4.17	<0.060 U	<2.000 U	<0.100 U	0.6	<0.100 U	<0.100 U	145.9
210325	284999	92.11	<0.100 U	<0.100 U	88.21	<0.100 U	<0.500 U	<10.000 U	0.240 J	<0.100 U	0.270 J	0.960 J	<0.060 U	<2.000 U	<0.100 U	0.250 J	<0.100 U	<0.100 U	178.74
210322	285001	12.29	<0.100 U	0.44	26.09	<0.100 U	<0.500 U	<10.000 U	<0.100 U	<0.100 U	<0.100 U	<0.500 U	<0.060 U	2.820 J	<0.100 U	<0.100 U	<0.100 U	<0.100 U	212.19
210326	285007	10.53	<0.100 U	0.210 J	37.89	<0.100 U	<0.500 U	<10.000 U	<0.100 U	<0.100 U	<0.100 U	<0.500 U	<0.060 U	<2.000 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	46.24
210320	285013	5003.29	<0.100 U	<0.100 U	19.74	0.300 J	<0.500 U	<10.000 U	2.8	<0.100 U	6.26	555.6	0.58	<2.000 U	<0.100 U	5	0.410 J	<0.100 U	22.56

Sample ID	GWIC ID	Tl	Sn	Ti	V	Zn	Zr	Ce	Cs	Ga	La	Nd	Nb	Pd	Pr	Rb	Th	W	U
210336	171925	<0.100 U	<0.100 U	30.64	<0.100 U	26.07	<0.100 U	0.350 J	0.260 J	0.72	<0.100 U	0.230 J	<0.100 U	0.120 J	<0.100 U	1.67	<0.100 U	<0.100 U	1.56
210330	171926	<0.100 U	<0.100 U	2.68	<0.100 U	1182.9	<0.100 U	1.95	0.64	0.310 J	0.74	2.04	<0.100 U	0.210 J	0.310 J	11.26	<0.100 U	<0.100 U	1.76
210332	284905	<0.100 U	<0.100 U	27.59	<0.100 U	6.81	<0.100 U	<0.100 U	0.230 J	0.350 J	<0.100 U	<0.100 U	<0.100 U	0.220 J	<0.100 U	1.85	<0.100 U	0.240 J	0.97
210331	284916	<0.100 U	<0.100 U	24.86	<0.100 U	1.490 J	<0.100 U	<0.100 U	<0.100 U	0.77	<0.100 U	<0.100 U	<0.100 U	0.250 J	<0.100 U	1.17	<0.100 U	1.19	1.11
210334	284923	0.280 J	<0.100 U	2.03	<0.100 U	629.65	<0.100 U	8.64	0.69	1.02	3.84	5.19	<0.100 U	<0.100 U	1.17	12.75	<0.100 U	<0.100 U	0.85
210333	284924	<0.100 U	<0.100 U	10.24	<0.100 U	109.77	<0.100 U	<0.100 U	<0.100 U	1.3	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	2.16	<0.100 U	<0.100 U	<0.100 U
210335	284926	<0.100 U	<0.100 U	1.92	<0.100 U	117.99	<0.100 U	<0.100 U	<0.100 U	0.95	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	3	<0.100 U	<0.100 U	<0.100 U
210327	284991	<0.100 U	<0.100 U	9.64	<0.100 U	49.9	<0.100 U	<0.100 U	<0.100 U	2.15	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	1.72	<0.100 U	<0.100 U	<0.100 U
210329	284992	<0.100 U	<0.100 U	1.24	<0.100 U	3.8	<0.100 U	<0.100 U	<0.100 U	0.53	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	0.92	<0.100 U	<0.100 U	0.280 J
210323	284994	<0.100 U	<0.100 U	9.38	<0.100 U	14.37	<0.100 U	<0.100 U	<0.100 U	1.2	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	1.55	<0.100 U	<0.100 U	<0.100 U
210324	284996	<0.100 U	<0.100 U	16.16	<0.100 U	14.42	<0.100 U	<0.100 U	<0.100 U	1.93	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	1.13	<0.100 U	<0.100 U	0.72
210321	284997	<0.100 U	<0.100 U	10.93	<0.100 U	4.3	<0.100 U	<0.100 U	<0.100 U	1.34	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	0.65	<0.100 U	<0.100 U	<0.100 U
210328	284998	<0.100 U	<0.100 U	11.16	<0.100 U	68.29	<0.100 U	<0.100 U	<0.100 U	2.64	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	2.21	<0.100 U	<0.100 U	<0.100 U
210325	284999	<0.100 U	<0.100 U	11.17	<0.100 U	35.38	<0.100 U	0.360 J	<0.100 U	3.69	0.250 J	<0.100 U	<0.100 U	<0.100 U	<0.100 U	1.53	<0.100 U	<0.100 U	<0.100 U
210322	285001	<0.100 U	<0.100 U	15.69	<0.100 U	8.62	<0.100 U	<0.100 U	<0.100 U	1.09	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	2.29	<0.100 U	<0.100 U	<0.100 U
210326	285007	<0.100 U	<0.100 U	2.43	<0.100 U	22.05	<0.100 U	<0.100 U	<0.100 U	1.49	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	1.04	<0.100 U	<0.100 U	<0.100 U
210320	285013	0.250 J	<0.100 U	2.54	<0.100 U	818.49	<0.100 U	5.67	0.440 J	0.77	2.53	3.98	<0.100 U	<0.100 U	0.86	10.75	<0.100 U	<0.100 U	1.35

Note. J, estimated quantity above detection limit but below reporting limit; U, undetected quantity below detection limit; µg/L, micrograms per liter. Pink shaded cells, exceedance of acute aquatic-life standard (DEQ-7); yellow shaded cells, exceedance of chronic aquatic-life standard (DEQ-7).

Table 1D. Gauging data.

GWIC ID	Site Name	Site Type	Latitude	Longitude	Altitude	Date Measured	Discharge (cfs)
285009	EAST FORK EMIGRANT CREEK Below SAINT JULIAN	STREAM	45.25801	-110.65315	7769	10/28/2015	0.8
284926	EAST FORK EMIGRANT CREEK ABOVE CONFLUENCE	STREAM	45.2538	-110.6685	7360	10/23/2015	1.42
284999	EMIGRANT CREEK ABOVE EAST FORK	STREAM	45.25407	-110.67025	7282	10/29/2015	3.01
284998	EMIGRANT CREEK BELOW EAST FORK CONFLUENCE	STREAM	45.25434	-110.67149	7256	10/29/2015	4.21
284991	EMIGRANT CREEK ABOVE GREAT WESTERN	STREAM	45.26803	-110.679	6857	10/29/2015	5.43
284996	EMIGRANT CREEK AT PRIVATE BRIDGE	STREAM	45.313576	-110.696697	5561	10/30/2015	14.41

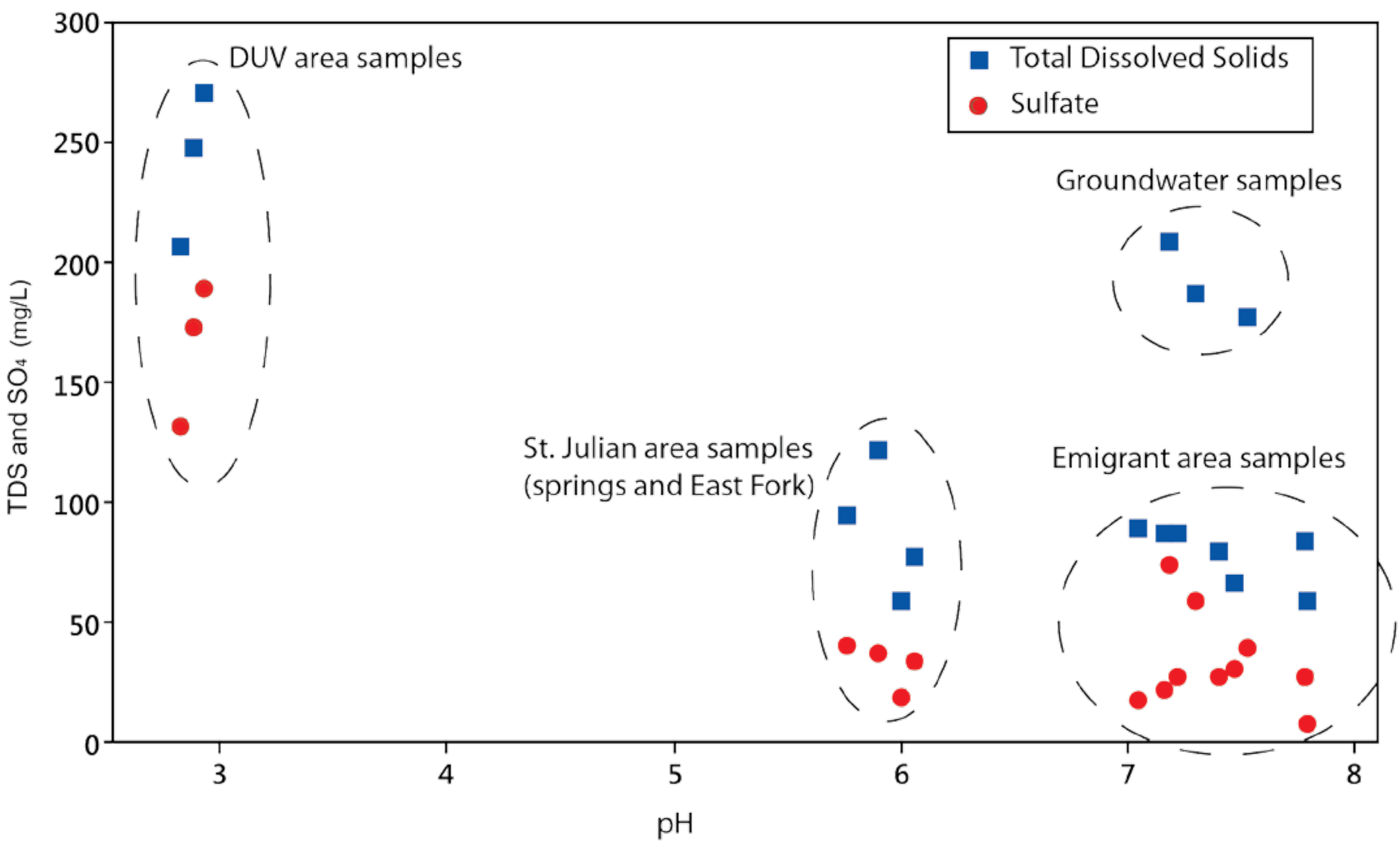

Figure 5. Individual value plot of total dissolved solids and sulfate versus pH.

SURFACE WATER

Surface water was sampled at six locations, two on the East Fork and four on the main stem of Emigrant Creek. TDS concentrations ranged from 59 to 89 mg/L, and generally increased downstream (fig. 6). All of the surface-water samples contained dissolved oxygen > 9 mg/L; pH in the two East Fork samples (6.0 and 6.1) was lower than those in the Emigrant Creek samples (range 7.1 to 7.8). Alkalinity concentrations in the East Fork samples were 15.58 and 21.32 mg/L as HCO_3, and lower than alkalinities in the Emigrant Creek samples (34 to 58 mg/L). Sulfate was relatively enriched in the East Fork samples (fig. 7); in the sample from above the East Fork's confluence with the main stem of Emigrant Creek (GWIC ID: 284926), Cu and Zn concentrations exceeded acute aquatic-life standards (MDEQ, 2012) and Al and Cd exceeded the chronic aquatic-life standards (table 1). The relatively low pH, enriched sulfate, and elevated metals concentrations in samples from the East Fork are likely related to acidic drainage from the north side (DUV area) of the East Fork of Emigrant Creek (fig. 2).

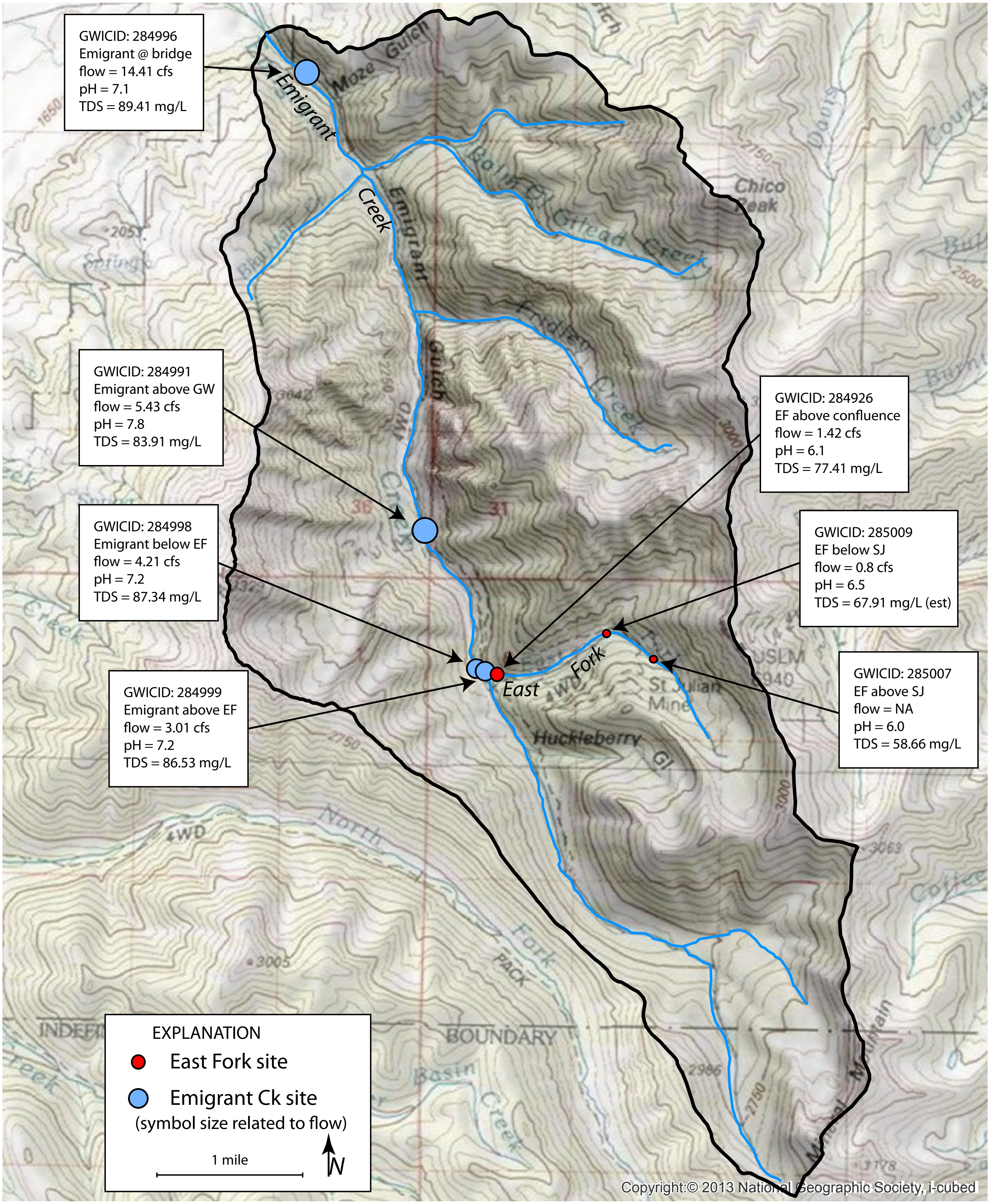

Figure 6. Surface-water sites: with total dissolved solids, pH, and discharge in cubic feet per second (cfs).

Samples from the main stem of Emigrant Creek had pH values between 7.1 and 7.8, low TDS concentrations (84 to 89 mg/L), and were of a Ca-Mg- HCO_3-type water (fig. 4). The Zn concentration in the sample below the East Fork confluence (GWIC ID: 284998, fig. 3) exceeded the acute aquatic-life standard; however, concentrations of Al, Cu, and Zn generally decreased downstream.

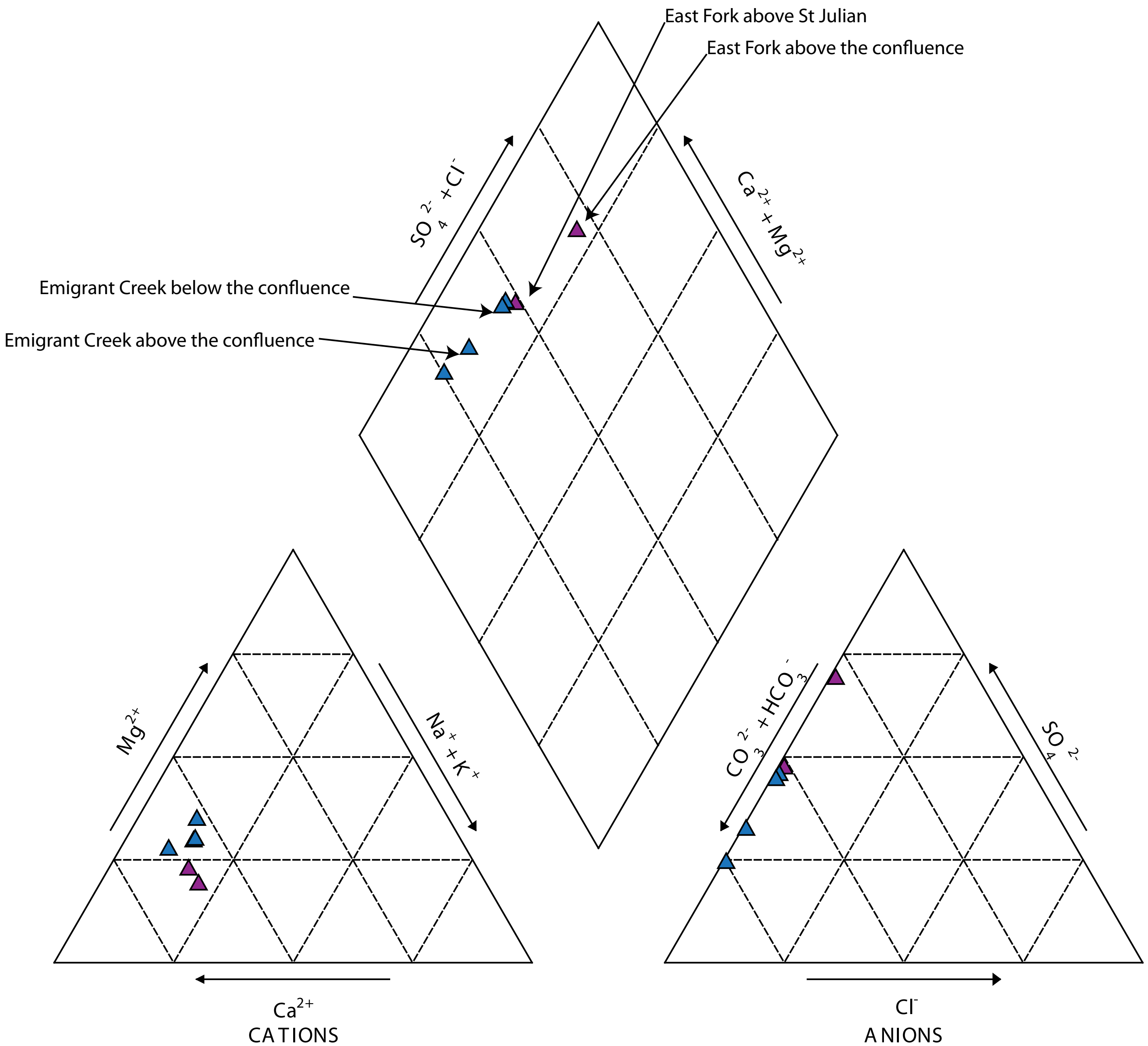

Figure 7. Surface-water Piper plot showing relative percent of major ions based on milliequivalents per liter. Purple, East Fork samples; blue, Emigrant Creek samples.

SPRINGS

Springs occur throughout the watershed, typically in close proximity to streams (fig. 3). Seven springs and the Allison Tunnel discharge were sampled. Two springs and the tunnel discharge occur north of the East Fork in the DUV area; two other springs occur south of the East Fork in the St. Julian area. Three springs occur in the Emigrant area, one below the confluence of the East Fork and Emigrant Creeks, and two above the Great Western Claim on the north and south sides of Emigrant Creek (fig. 3).

Water from the three sites in the DUV area had distinctly low pH values (< 3.0); elevated TDS, SO_4, Al, Cd, Cu, and Zn concentrations; and no detectable alkalinity. The TDS concentrations ranged from 207 to 271 mg/L, and the Al concentrations ranged from 3,100 to 6,423 µg/L. The discharge from the Allison Tunnel had iron (Fe) and manganese (Mn) concentrations of 5.1 and 5.4 mg/L, respectively—more than an order of magnitude greater than the other two springs in the DUV area. All three sites exceeded the acute aquatic-life standards for Al, Cd, Cu, and Zn; the lead concentrations exceeded the chronic aquatic-life standard. These sites are near the granodiorite intrusive (Tgd on fig. 2) that contains pyrite and other sulfide mineralization. The analytical results suggest pyrite oxidation and other sulfides in the host rock are the source of the acidity, elevated SO_4, and trace metals.

Samples from the two springs in the St. Julian area were moderately acidic (pH 5.8 and 5.9) and had TDS concentrations of 94 and 121 mg/L. Water from both springs was a Ca-Mg- HCO_3- SO_4–type (fig. 4); the zinc concentration in the spring south of the East Fork (GWIC ID: 284924, fig. 3, table 1), across from the DUV area, exceeded the acute aquatic-life standard.

Water from the springs in the Emigrant drainage had neutral pH values (7.4–7.8), low TDS concentrations (59–79 mg/L), and was a Ca-Mg- HCO_3-type.

GROUNDWATER

Groundwater samples were collected from three flowing exploratory boreholes: two located in the St. Julian area and one in the Emigrant area above the Great Western claim next to FS Road 3272. The depths of the boreholes are unknown. The water quality is consistent among the borehole samples; it had neutral pH values (7.2–7.5), the highest measured alkalinity values in the watershed (90–114 mg/L as HCO_3), low dissolved oxygen concentrations (0.36–2.4 mg/L), relatively elevated TDS concentrations (177–209 mg/L, fig. 5) and was a Ca-Mg- HCO_3-type (fig. 4).

ISOTOPES

The $\delta^{18}O$ and $\delta^{2}H$ results are shown in figure 8; $\delta^{18}O$ values ranged from -19.88 to -18.11 per mille (‰), and the $\delta^{2}H$ values ranged from -152 to -134 ‰. The results plot along the meteoric water line, indicating the meteoric origin of the water; however, the isotopic values vary by source. The borehole groundwater samples have the smallest (lightest) values, followed by the spring samples from the DUV and St. Julian areas. The surface-water values from the East Fork and Emigrant Creek (upstream from the Great Western claim) were consistent and showed the well mixed condition of the surface water; the stream samples were slightly heavier than the groundwater and DUV/St. Julian spring samples. The three spring samples from the Emigrant Creek drainage (GWIC IDs: 284997, 284994, 284992, fig. 3) and the farthest downstream surface water sample (GWIC ID: 284996, fig. 3) are distinct and heavier than the other surface-water and spring samples.

The stable-isotope values can suggest the altitude and temperature of precipitation, as well as dif-

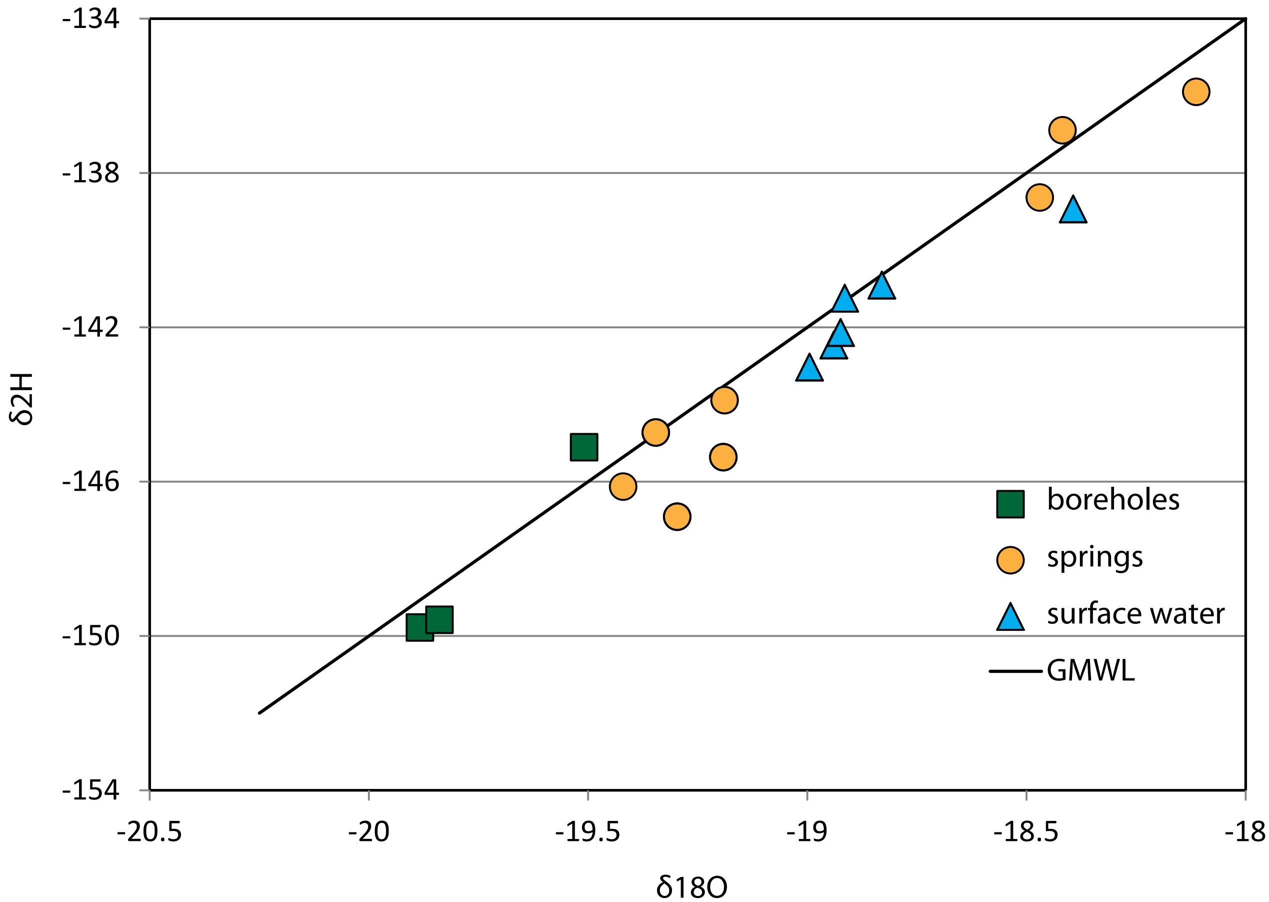

Figure 8. Stable isotope composition of groundwater, surface water, and springs.

ferent sources of groundwater recharge. The observed differences in values among the groundwater samples, springs in the upper watershed, springs in the lower watershed, and the surface-water samples highlight the variability of the groundwater flow system.

Tritium is a naturally occurring radioactive isotope of hydrogen that has a half life of 12.3 years. It is produced in the upper atmosphere, where it is incorporated into water molecules and therefore is present in precipitation that becomes groundwater recharge. Atmospheric testing of nuclear weapons between 1952 and 1963 released large amounts of tritium into the atmosphere, overwhelming the natural production. Because of its short half-life, tritium is an ideal marker of “recent” groundwater recharge; groundwater recharged prior to 1952 will not have detectable tritium. Groundwater recharged after the advent of above-ground nuclear testing will have detectable tritium. Tritium concentrations ranged from 4.0 to 11.90 tritium units (TU) (table 1 and fig. 9). The lowest values (between 4 and 6.5 TU) suggest that the oldest of the sampled waters were from two of the borehole samples and the St. Julian spring (GWIC ID: 285001). The remainder of the samples had values between 8 and 12 TU, which is consistent with recent precipitation and suggests that the water is very young.

GEOTHERMAL IMPACTS

Geothermal springs typically occur along faults that provide a pathway for deep circulating water. Chico Hot Springs occurs along the northeast-trending Emigrant fault zone along the western edge of the Beartooth uplift (fig. 10). The downthrown side of the fault is to the northwest and forms the Paradise Valley. Precambrian and Tertiary volcanic rocks of the Absaroka Mountains are on the upthrown side. Near Chico Hot Springs there is a localized occurrence of sedimentary rocks, including an outcrop of the Madison Limestone. The Madison Limestone could be important as it is a potential

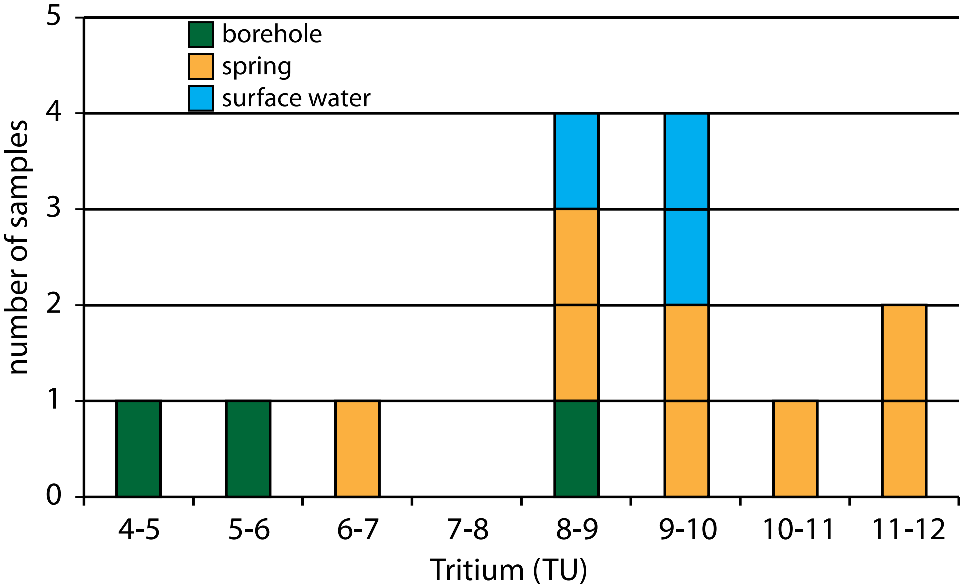

Figure 9. Histogram of tritium values from groundwater, surface water, and spring samples.

source of recharge water to other geothermal springs, such as Mammoth Hot Springs in Yellowstone National Park and Bear Creek Springs in the Corwin Springs Known Geothermal Resources Area (KGRA) about 14 mi south–southwest of Chico (Rye and Truesdell, 1993; Sorey, 1991). In the Corwin Springs KGRA, geothermal water discharged at Bear Creek is heated by deep circulation within zones of high geothermal gradient through sedimentary-rock aquifers. The presence of sedimentary rocks along the fault near Chico suggests a similar process may be responsible for the occurrence of Chico Hot Springs.

The proposed exploratory drilling raises questions about the location and configuration of the recharge area for Chico Hot Springs and the potential that deep boreholes might intercept or disrupt water that would otherwise reach the hot springs.

In the St. Julian area, angle or vertical drill holes up to 2,000 ft deep are proposed at 23 sites across the north-facing slope of the mountain that underlies the claims. The surface elevation of the proposed drill sites ranges from about 7,600 to 9,000 ft (DEQ Plan of Operations for Drilling on Private Land, April 2015). The drill sites are approximately 6 mi south–southeast of Chico Hot Springs, which lies at an elevation of 5,264 ft (fig. 10).

For the Emigrant Creek watershed to be a recharge area for Chico Hot Springs, the following geologic and hydrologic conditions must be met: (1) a sufficient source of water, (2) a permeability pathway to allow deep groundwater circulation between the recharge area and the springs, (3) a hydraulic gradient to drive water deep into the subsurface from the recharge area to the springs, and (4) a geothermal heat source.

The watershed receives 25–35 in of precipitation annually, mostly in the form of snow, and this precipitation is the source of surface flow and groundwater recharge. The large topographic relief of the watershed, about 5,000 ft, creates a steep topographic gradient between the upper catchment area and Chico Hot Springs. Groundwater flow in alpine watersheds most often occurs in near-surface, relatively high-permeability zones (active zones) that generally overlie deep zones of low permeability. The relatively high near-surface permeability is typically due to weathering and fracturing (Manning and Caine, 2008).

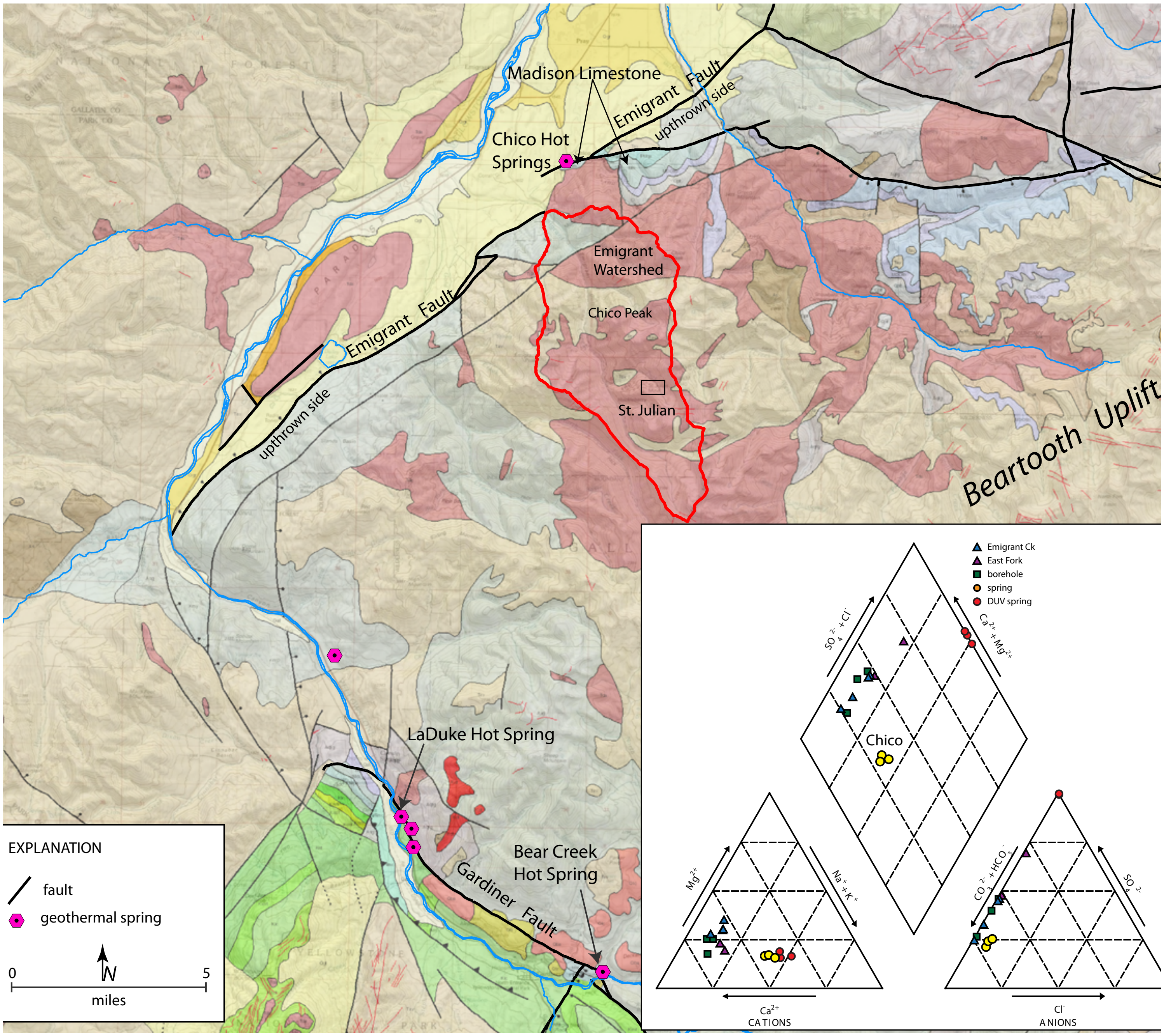

Figure 10. Regional geologic map modified from Berg and others (1999) with geothermal sites and Chico Hot Springs water quality.

The Emigrant Creek watershed is underlain by fractured crystalline bedrock. The near-surface bedrock is sufficiently fractured to host a groundwater flow system, as shown by the artesian boreholes that discharge cool (4.6–4.8°C), tritiated water. The steep topography creates hydraulic gradients that drive groundwater toward the topographic lows (valley bottoms). The measured increased flow in the East Fork and main stem of Emigrant Creek going downstream indicates that groundwater accounts for a significant component of surface-water flow.

Geologic evidence of a deep permeability pathway that could produce geothermal water is sparse. The prominent regional fault orientations trend northeast, normal to the watershed topographic profile, and there are no sedimentary rock units in the watershed (fig. 10). The basin contains only crystalline rocks that typically exhibit decreasing permeability with depth (Manning and Caine, 2008).

There is speculative evidence of a geothermal heat source beneath the watershed. Zilka (1983) reported that gravity and aeromagnetic surveys indicated a coincident gravity low and magnetic high near Chico Peak. Zilka speculates that these anomalies may indicate an eruptive center, consistent with the thick accumulation of volcanic rocks in the area and an area of anomalous geothermal heat flow. However, the cool water discharged from the artesian boreholes and the lack of geothermal features within the watershed suggests either no geothermal heat source or insufficient permeability to allow deep circulation and subsequent surface expression of geothermal water.

Water-quality data gathered during this investigation do not suggest connections between Emigrant Creek groundwater and the geothermal system feeding Chico Hot Springs. The water sampled in fall 2015 is chemically distinct from Chico Hot Springs water (fig. 10). Chico Hot Springs water is enriched in sodium and bicarbonate relative to the non-acidic waters in the Emigrant watershed; the stable isotope composition of Chico Hot Springs is shifted off the global meteoric water line and is relatively depleted compared to the Emigrant water samples (fig. 11). The distinct chemical and isotopic differences show that the geothermal system at Chico is separate from groundwater in the Emigrant drainage. It is unlikely that Chico Hot Springs receives significant recharge from the Emigrant Creek watershed.

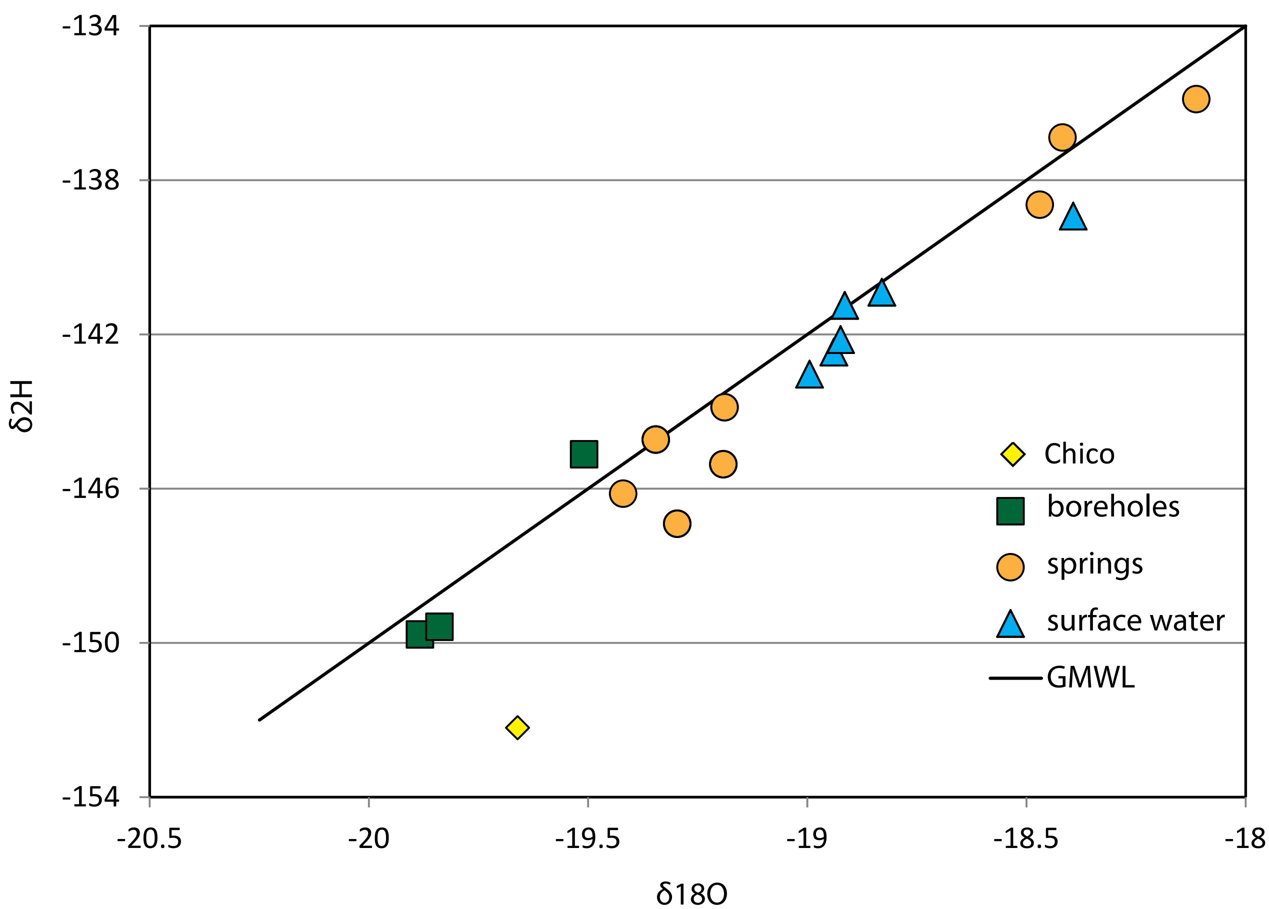

Figure 11. Stable isotope composition of Emigrant water and Chico Hot Springs.

SUMMARY

Groundwater and surface water were sampled in the Emigrant Creek watershed to establish baseline conditions. Samples were collected during the last week of October 2015 during base-flow conditions. Although all the sampled water had <300 mg/L total dissolved solids, dissolved constituents concentrations and the pH varied. Three samples from the DUV area had pH <3.0 and were dominated by sulfate and aluminum; concentrations of copper and zinc were also elevated. The local altered bedrock, associated with a granodiorite intrusive, appears to provide the conditions necessary to produce natural acid rock drainage from the DUV area that may cause the moderately low pH values observed in the East Fork of Emigrant Creek. Dilution and buffering result in more neutral pH's observed downstream in Emigrant Creek. Springs and groundwater samples from the St. Julian and Emigrant areas were characterized by low TDS concentrations, neutral pH values, and Ca-Mg- HCO_3-type water.

The proposed exploratory drilling in the St. Julian area, in the upper catchment of Emigrant Creek, is about 6 miles southeast of Chico Hot Springs, and about 2,500 feet higher in elevation. High elevation catchments can be important sources of groundwater recharge to adjacent lowland areas. However, there is no clear hydrogeologic or geochemical evidence to suggest that water from the Emigrant Creek watershed is connected to the geothermal system that feeds Chico Hot Springs.

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