

Principal Locations of Major-Ion, Trace-Element, Nitrate, and *Escherichia coli* Loading to Emigration Creek, Salt Lake County, Utah, October 2005



Prepared in cooperation with the
Salt Lake County Department of Public Works, Engineering Division

Scientific Investigations Report 2008–5043

Cover photo: Panorama of Emigration Canyon showing generally older homes along the road and newer developments on the side drainages. Photograph taken looking southeast from Mt. Wire, near the mouth of the canyon in June 2006 by Briant A. Kimball, U.S. Geological Survey.

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By Briant A. Kimball, Robert L. Runkel, and Katherine Walton-Day

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**U.S. Department of the Interior
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Conversion Factors, Datums, and Abbreviated Water-Quality Units

Multiply	By	To obtain
Length		
meter (m)	3.281	foot (ft)
micrometer (μm)	0.000003281	foot (ft)
kilometer (km)	0.6214	mile (mi)
Area		
square kilometer (km^2)	247.1	acre
Volume		
milliliter (mL)	0.000264	gallon (gal)
Flow rate		
milliliter per minute (mL/min)	0.000264	gallon per minute (gal/min)
liter per second (L/s)	0.03534	cubic foot per second (ft^3/sec)
Mass flow		
kilogram per day (kg/day)	2.205	pound avoirdupois per day (lb/day)

Temperature in degrees Celsius ($^{\circ}\text{C}$) may be converted to degrees Fahrenheit ($^{\circ}\text{F}$) as follows:

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32.$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). Altitude, as used in this report, refers to distance above the vertical datum. Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83). Universal Transverse Mercator locations are given in easting and northing, in meters, for zone 12 North.

Specific conductance is reported in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25°C). Concentrations of chemical constituents in water are reported either in milligrams per liter (mg/L), micrograms per liter ($\mu\text{g}/\text{L}$), or millimoles per liter (mM/L).

Principal Locations of Major-Ion, Trace-Element, Nitrate, and *Escherichia coli* Loading to Emigration Creek, Salt Lake County, Utah, October 2005

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Abstract

Housing development and recreational activity in Emigration Canyon have increased substantially since 1980, perhaps causing an observed decrease in water quality of this northern Utah stream located near Salt Lake City. To identify reaches of the stream that contribute to water-quality degradation, a tracer-injection and synoptic-sampling study was done to quantify mass loading of major ions, trace elements, nitrate, and *Escherichia coli* (*E. coli*) to the stream. The resulting mass-loading profiles for major ions and trace elements indicate both geologic and anthropogenic inputs to the stream, principally from tributary and spring inflows to the stream at Brigham Fork, Burr Fork, Wagner Spring, Emigration Tunnel Spring, Blacksmith Hollow, and Killyon Canyon. The pattern of nitrate loading does not correspond to the major-ion and trace-element loading patterns. Nitrate levels in the stream did not exceed water-quality standards at the time of synoptic sampling. The majority of nitrate mass loading can be considered related to anthropogenic input, based on the field settings and trends in stable isotope ratios of nitrogen. The pattern of *E. coli* loading does not correspond to the major-ion, trace-element, or nitrate loading patterns. The majority of *E. coli* loading was related to anthropogenic sources based on field setting, but a considerable part of the loading also comes from possible animal sources in Killyon Canyon, in Perkins Flat, and in Rotary Park. In this late summer sampling, *E. coli* concentrations only exceeded water-quality standards in limited sections of the study reach. The mass-loading approach used in this study provides a means to design future studies and to evaluate the loading on a catchment scale.

Introduction

Over a period of several decades, Emigration Canyon, near Salt Lake City, Utah, has been developed as a residential area. Since 1980, the population in the canyon has doubled (Jensen and others, 2003). More than 440 out of 1,136

registered building lots have been developed. Despite this development, the canyon remains without a sewer system, and wastewater is disposed into septic systems. To identify reaches of the stream that may contribute to water-quality degradation, the U.S. Geological Survey, in cooperation with the Salt Lake County Department of Public Works, Engineering Division, conducted a tracer-injection and synoptic-sampling study with the purpose of quantifying the mass loading of major ions, trace elements, nitrate, and *Escherichia coli* (*E. coli*) to the stream. Tracer-injection studies have been used to provide a watershed context for the quantification of metal loads from abandoned and inactive mines (Kimball and others, 2002), but these methods can be applied to other constituent loads like those of nitrate and *E. coli*.

Some limited water-quality comparisons have been reported between Emigration Creek and Red Butte Creek (Giddings, 2000; Willden, 2006). Concentrations of chloride, dissolved phosphorus, and nitrate plus nitrite all were higher in Emigration Creek than in Red Butte Creek, and concentrations generally were higher in the lower reaches of the creek than in the upper reaches. High counts of coliform bacteria in the stream water of Emigration Canyon have been reported in a Salt Lake County study (Jensen and others, 2003). Possible sources include the septic systems throughout the canyon, as well as waste from livestock and pets. Temporal data indicate that the counts of *E. coli* could be increasing with continued development, and thus, the water quality poses concern for human health (Jensen and others, 2003). Basic information must be obtained to formulate a plan to address the water-quality concerns. First, it is necessary to determine the location and magnitude of nitrate and *E. coli* loading to the creek. Second, it is necessary to distinguish whether the high concentrations of nitrate and *E. coli* result from human or animal waste. Finally, the general patterns of major-ion and trace-element loading are needed to distinguish anthropogenic from geologic sources of loading.

Purpose and Scope

This report (1) determines the principal locations and amount of loading of nitrate, *E. coli*, and other constituents to Emigration Creek along the study reach under the given conditions and season, and (2) determines and interprets the isotopic signature of nitrogen in the stream with respect to other studies of stable nitrogen isotopes in human and animal waste. Mass-loading and isotopic data collected during the spatially detailed study will provide information for science-based decisions about improving the water quality of Emigration Creek, for understanding the possible risk to human health posed by input from septic systems, and for understanding the degradation of water quality in Emigration Creek.

Description of Study Area

Emigration Canyon is east of Salt Lake City, Utah (fig. 1), and Emigration Creek eventually discharges to the Jordan River, which discharges to Great Salt Lake. With construction, conditions in the canyon can change. Thus, the conditions present at the time of the study are described here. Synoptic sampling began upstream from all the homes in Killyon Canyon. This allowed samples to reflect the upstream conditions and to include discharge from Burr Fork, the first major tributary. New homes are located throughout the canyon, but the majority of new housing developments are situated on the north side of the canyon between Brigham Fork and Pioneer Fork (fig. 2a). This area mostly drains to Brigham Fork, Freeze Creek, and Pioneer Fork. Some new homes also have been built to the south of Emigration Creek in the vicinity of Perkins Flat. Along most of the stream, homes are relatively old (fig. 2b), although newer homes have been built among the older homes (fig. 2c). Perkins Flat (fig. 2e) is an area that has been preserved as green space. At the lower end of Perkins Flat is the development of Camp Kostopolos, which contains horse stables. Most of the homes downstream from Rattlesnake Point to near Rattlesnake Hollow are relatively old. At the time of the study, a reservoir in Rotary Park was drained (fig. 2d). On the day of synoptic sampling, heavy equipment was being used in that area and large amounts of sediment were being added to the stream. Because this affected the concentrations of almost all constituents, the samples collected from 10,910 to 11,174 m are not included in the discussion of this study.

Acknowledgments

This work was supported by a cooperative agreement between Salt Lake County and the U.S. Geological Survey, through support from the Toxic Substances Hydrology Program. Steven Jensen of Salt Lake County Department of Public Works, Engineering Division helped at all stages of the study, including the planning, sampling, and interpretation of

results. Judy Steiger of the U.S. Geological Survey helped in the processing and analysis of samples. Several volunteers helped with the synoptic sampling in Emigration Canyon. Garrick Willden and Steven Burian of the University of Utah collected and analyzed the bacterial samples. William Moellmer of the Utah Division of Water Quality and Rhonda Theile of Salt Lake Valley Health Department helped with sample processing.

Methods and Approach

The mass-loading approach used here addresses the problem of solute source determination (Kimball and others, 2002). The approach is based on two well-established techniques: the tracer-dilution method (Kilpatrick and Cobb, 1985) and synoptic sampling (Bencala and McKnight, 1987). The tracer-dilution method provides estimates of stream discharge that are in turn used to quantify the amount of water entering the stream in a given stream segment through tributary and ground-water inflow. Synoptic sampling of stream and inflow chemistry provides a spatially detailed ‘snapshot’ of water quality in the stream and the inflows that influence changes in the stream. When used together, these techniques provide a description of a watershed that includes both discharge and concentration that may then be used to determine mass loading of chemical constituents and *E. coli* associated with various sources of surface and ground water. The resulting longitudinal loading profiles can help distinguish anthropogenic contributions to Emigration Creek.

This study was undertaken during low-flow conditions in October 2005 because low-flow conditions provide the best opportunity to detect small contributions of ground water to the stream. These potential ground-water contributions most likely vary throughout the day as domestic water use varies. The amount of constituent loading from this study may not represent a load that can be used to engineer a remediation solution, but the pattern of loading should help guide further investigation. Typically, the entire study reach is evaluated to identify all the inflows and to choose stream sampling sites to bracket the inflows, enabling mass-balance calculations. Because of thick vegetation and problems with access to private property in a heavily populated area, the entire study reach in Emigration Canyon was not available for sampling. In the sections that were not available, stream sampling sites were located about 160 m apart at locations that had access from the road. This design resulted in fewer inflow samples than are normally collected for a synoptic sampling such that the study must rely on instream changes to evaluate the effects of inflows.

A downstream metric, with the injection point being 0 m, provided an ordinate for the study and for future computer simulation studies that might be conducted to better understand loading and geochemical reactions (Kimball and others, 2003; Runkel and Kimball, 2002; Runkel and others,

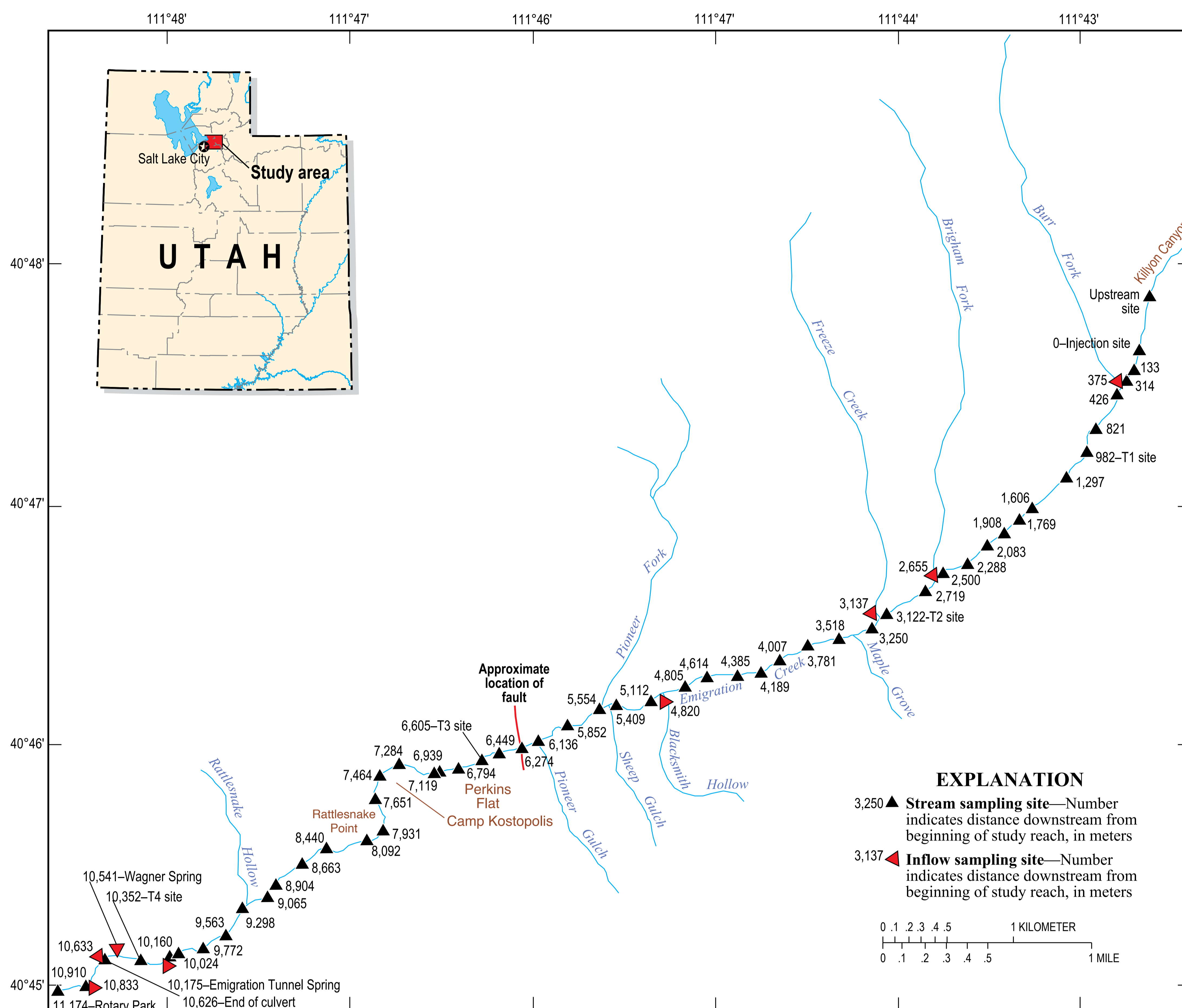


Figure 1. Location of sampling sites along the study reach in Emigration Creek, Utah.

2007). Downstream distances were determined marking detailed waypoints to represent the path of the stream by using a handheld receiver using the Global Positioning System and summing the point-to-point Euclidian distances. This procedure involved many more waypoints than just the sampling site locations. Each stream sampling site represents the downstream end of a stream segment, and the stream segments divide the watershed into increments to account for changes in loads. At this level of spatial detail, changes in stream chemistry and discharge between stream sampling sites reflect a net change in load for each segment. Specific sources that are responsible for the loading within specific stream segments, however, cannot always be identified at this stream reach scale.

Tracer Injections and Stream Discharge

Tracer-injection methods have been used in numerous catchments throughout the Rocky Mountain region, and the tracer-injection and discharge methods used in this study are the same as those described in the report for Questa, New Mexico (Kimball and others, 2006). Sodium bromide was injected as the tracer 375 m upstream from Burr Fork (fig. 1). The injection began at 12:40 on October 10, 2005, but the injection pump stopped at 19:22 that evening. The pump was restarted at 8:23 on October 11, 2006, and functioned well throughout the remaining injection period. Samples of the injectate solution were collected several times throughout the injection period to measure the injection rate and injectate concentration. These samples indicated a reasonably uniform mass flux of sodium bromide to the stream, with the median injection rate of 90 mL/min and the median injectate concentration of 174,850 mg/L as

4 Principal Locations of Major-Ion, Trace-Element, Nitrate, and *Escherichia coli* Loading to Emigration Creek

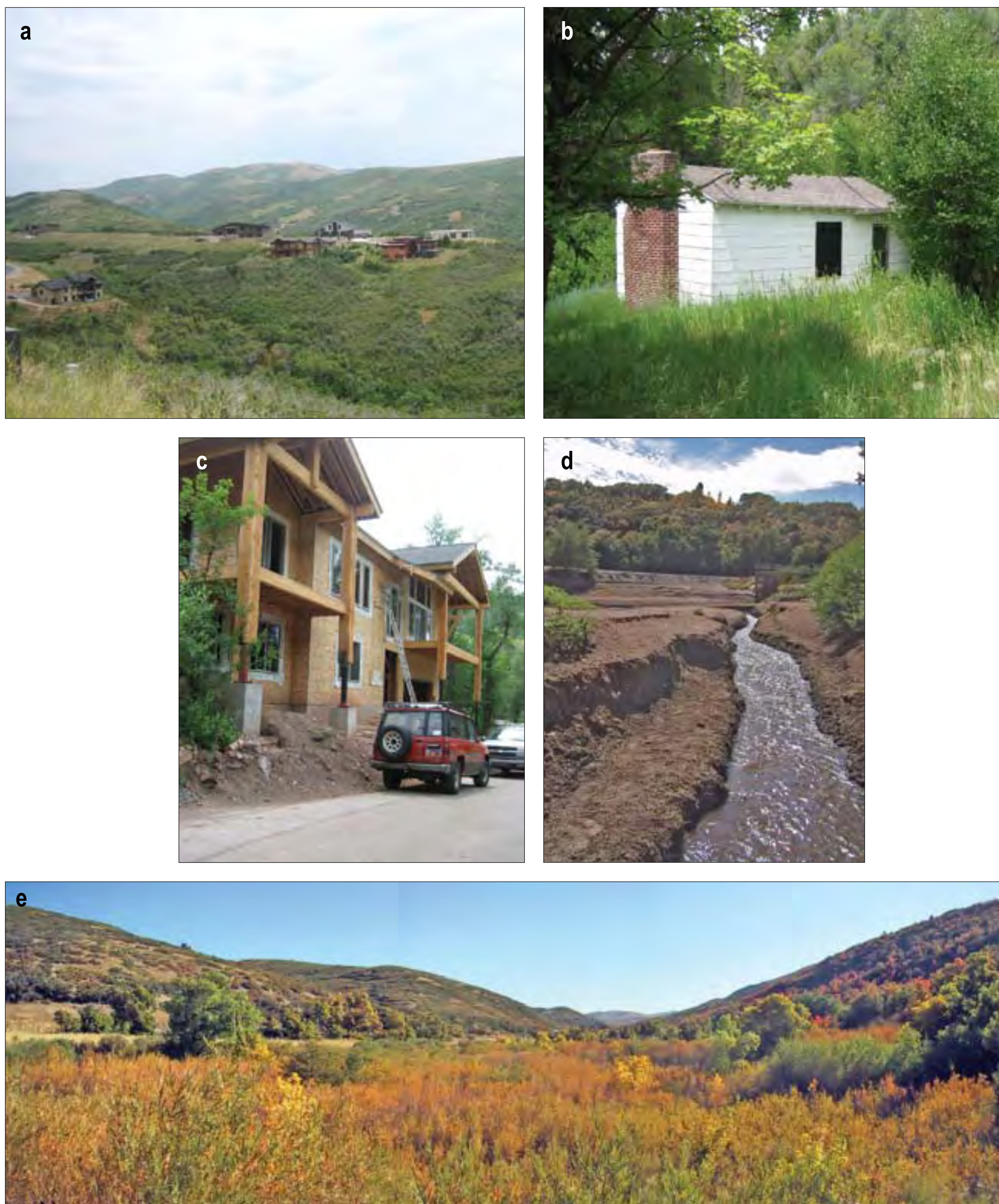


Figure 2. Photographs of settings along Emigration Creek in northern Utah showing (a) new home construction in the upper reaches of Brigham Fork, (b) old home along the stream, (c) new construction near the stream, (d) drained reservoir area where construction activity on the day of synoptic sampling affected samples, and (e) Perkins Flat area.

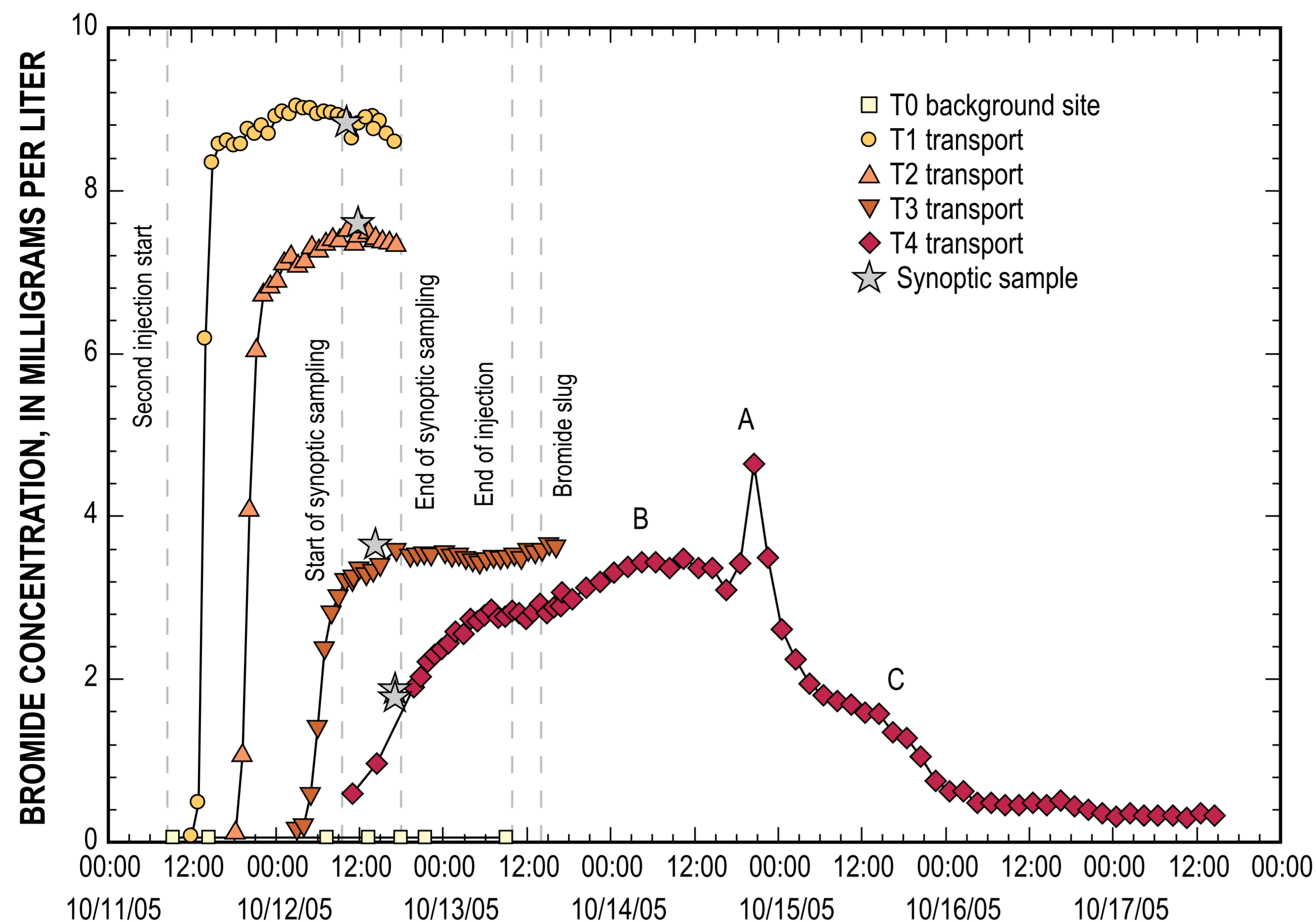


Figure 3. Variation of bromide concentration with time at transport sites, Emigration Canyon, Utah. The spike in bromide concentration at A represents the arrival of a slug injection at site T4. Increase of bromide concentration at site T4 (point B) may be from longer flow paths of ground water. Point C may represent the tail of the spike in bromide concentration at A.

bromide. The variation of bromide in the stream with time was followed at four “transport” sites along the study reach (fig. 3). This temporal view only shows the tracer concentration history for the period after the pumps were started the second time. For the T4 site, the bromide concentration had not gone back down to background levels before the increase started again (fig. 3). Vertical lines indicate the period of synoptic sampling, and the bromide concentration of the corresponding synoptic samples at each transport site also are indicated. A plateau condition of bromide had been achieved at transport sites T1 and T2 and was achieved by the latter part of synoptic sampling at T3 (fig. 3). Bromide concentration at site T4 clearly had not reached a plateau.

To account for the lack of a plateau, a sampling sweep of stream sites was made at the end of the synoptic sampling period to get a bromide concentration profile closer to a plateau condition. The bromide profile used for calculating discharge was a combination of results from the synoptic sampling at upstream sites and the bromide sweep at downstream sites (fig. 4). During the tracer injection, injected bromide concentrations were substantially higher than ambient background concentrations (fig. 4). With only eight inflow samples (the sample near 1,600 m is a domestic well), there were few values of C_I (see equation 1), and all but one inflow sample had a bromide concentration less than the method detection limit of 0.20 mg/L bromide. A value of 0.2 mg/L was used for the

background bromide concentration in discharge calculations.

Discharge was estimated by using an area-velocity measurement at 4,007 m, which was considered the best of those measurements made during the synoptic sampling. From 4,007 to 5,112 m, discharge was calculated by using the dilution of the bromide tracer according to the equation:

$$Q_B = Q_A \left(\frac{C_A - C_I}{C_B - C_I} \right) \quad (1)$$

where Q_B is the downstream discharge, in L/s,
 Q_A is the upstream discharge from the measurement, in L/s,
 C_A is the upstream tracer concentration, in mg/L,
 C_I is the inflow tracer concentration, in mg/L, and
 C_B is the downstream tracer concentration, in mg/L.

For stream sites from 0 to 4,007 m, discharge was calculated by using bromide concentrations and rearranging equation 1 to solve for Q_A at each successive site upstream from 4,007 m.

Downstream from the transport site T3 (6,605 m), discharge was adjusted to measured values because the tracer had not reached plateau concentration. Discharge was interpolated between the measured values. Thus, discharge values downstream from site T3 have greater uncertainty and the loads calculated for those sites are more qualitative than quantitative. The load profiles downstream from site T3 are still valuable for indicating trends. The variation of calculated discharge along the study reach is indicated in figure 4.

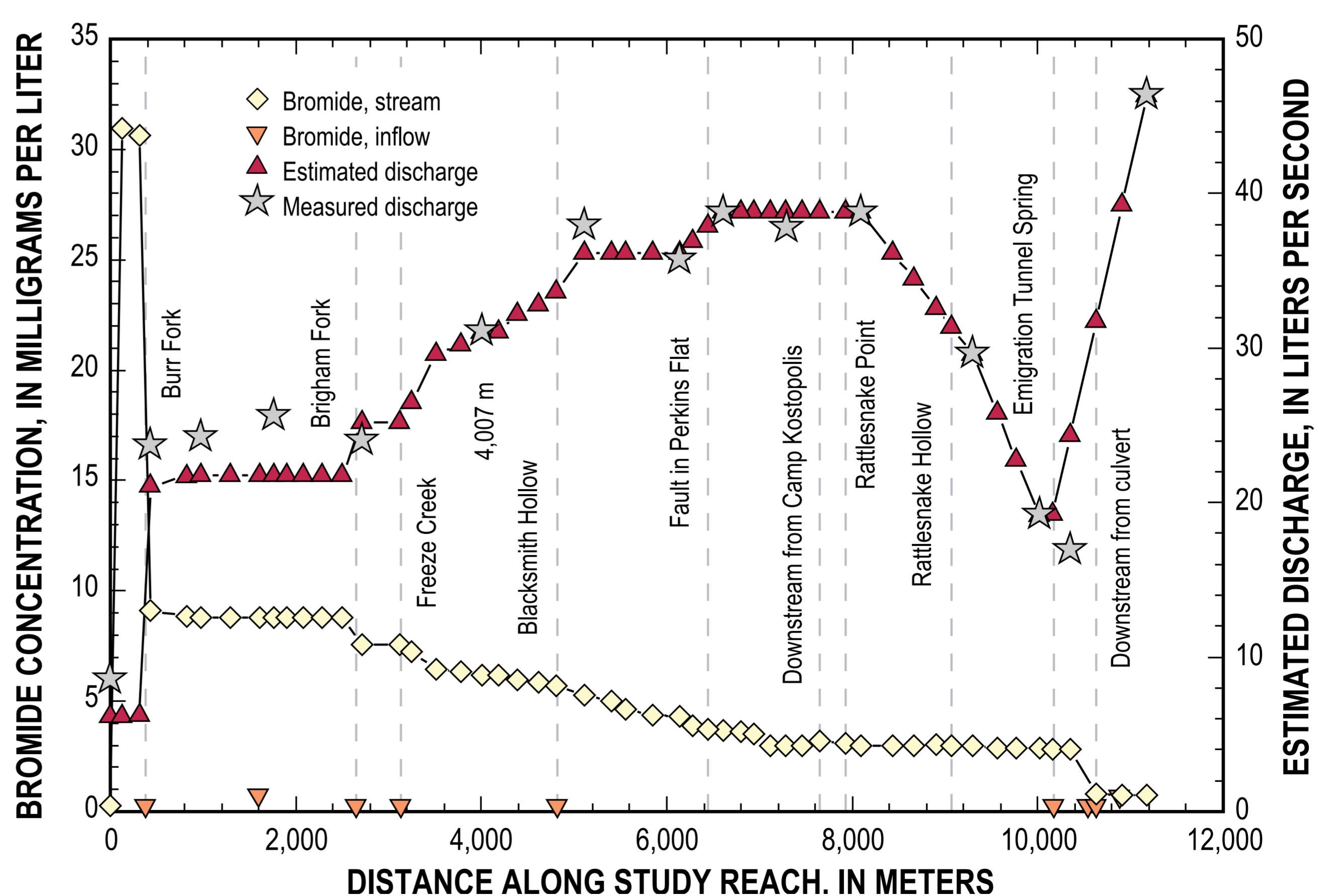


Figure 4. Variation of bromide concentration and estimated discharge with distance along the study reach, Emigration Creek, Utah, October 12, 2005.

6 Principal Locations of Major-Ion, Trace-Element, Nitrate, and *Escherichia coli* Loading to Emigration Creek

Discharge of inflows was assigned as the difference in discharge between the downstream and upstream stream sites around the particular inflow:

$$Q_I = Q_B - Q_A \quad (2)$$

where Q_I is the inflow discharge, in L/s, and Q_B and Q_A are defined in equation 1.

Dilution by an inflow can arise in several ways. If no visible inflow occurs in a stream segment, the change in stream discharge comes from dispersed, subsurface inflow. If a tributary inflow occurs, the change includes both the surface-water tributary inflow and any dispersed, subsurface inflow that is associated with the tributary or with other sources of subsurface inflow. Individual measurements of tributary surface-water inflow were not made.

Additional information on the application of tracer-dilution for mass-loading studies is published elsewhere (Kimball and others, 2002; Kimball and others, 2000). At higher concentrations than were used in this study, bromide has been shown to be toxic (Flury and Papritz, 1993), but no effects have been identified at these lower instream concentrations.

Synoptic Sampling and Analytical Methods

The spatial distribution of nitrate and *E. coli* sources may be characterized by synoptic sampling. Under ideal conditions, samples at all of the sampling locations would be collected simultaneously, providing an instantaneous description of stream-water quality along the study reach. Personnel limitations generally preclude simultaneous sample collection, but samples were collected over an 8.5-hour period to minimize the effect of transient conditions such as diurnal discharge variations.

Stream and inflow sampling sites were chosen during a reconnaissance of the stream reach. Stream sampling sites defined 53 stream segments along Emigration Creek. These segments are referenced by the upstream and downstream distances at the beginning and end of the segment. For example, the segment from 314 to 426 m includes the inflow of Burr Fork at 375 m (table 1). The experiment only included eight inflow samples, as noted, because access to inflow sampling sites was limited by vegetation and private property. The influence of additional inflows can only be quantified by their influence on instream concentrations. Details of the sampling sites are listed in table 1. Many site descriptions in table 1 reference street addresses along Emigration Canyon Road that are near the access points to stream sampling sites.

Although synoptic sampling typically goes from downstream to upstream to prevent sampling of colloidal material from the streambed, the order was reversed for Emigration Creek for two reasons. First, access to the stream

sampling sites was mostly from the road, and so sampling did not stir up the streambed by walking downstream. Second, the long study reach and slow travel time along the reach ensured that the sampling could stay ahead of any effects from sampling at upstream sites. Inflow and stream sites that were considered well mixed were sampled by using grab techniques. Water temperature was measured on site, and water samples were transported to a central location for further processing. Samples were divided into several 125-mL bottles with different treatments at the central processing location: a raw (unfiltered) unacidified sample (RU), a raw acidified sample (RA), a filtered unacidified sample (FU), and a filtered acidified sample (FA).

Specific conductance and pH were determined from the RU sample within hours of sample collection. In-line 0.45- μ m capsule filters were used to obtain the FU and FA samples. Metal concentrations for the RA and FA treatments were determined by inductively coupled plasma-atomic emission spectrometry-mass spectrometry at the University of Southern Mississippi (Lichte and others, 1987). Anion concentrations were determined from FU samples by using ion chromatography (Brinton and others, 1996; Kimball and others, 1999), and total alkalinity was determined by titration from the FU sample at the U.S. Geological Survey Utah Water Science Center.

Use of both filtered and unfiltered treatments provides two operationally defined concentrations for each metal. Metal concentration from the unfiltered sample (RA) is a measure of the total-recoverable concentration (dissolved plus colloidal) and the filtered concentration (FA) is an operational measure of the dissolved metal concentration. Colloidal metal concentrations are defined operationally for this study as the difference between the total-recoverable (RA) and the filtered metal concentrations (FA) for stream samples (Kimball and others, 1995).

Constituent Loads

Mass load was calculated for each stream sampling site along the study reach as:

$$M_A = C_A Q_A (0.0864) \quad (3)$$

where M_A is the total constituent load, or mass flux, at location A , in kg/day,
 C_A is the total-recoverable concentration at location A , in mg/L,
 Q_A is the discharge at location A , in L/s, and
0.0864 is the conversion factor from mg/s to kg/day.

This sampled instream load was calculated from the total-recoverable concentration of the constituent; dissolved and colloidal loads were calculated individually from the filtered and total-recoverable concentrations for metals. The longitudinal profiles of sampled instream loads (total or

Table 1. Characteristics of synoptic sampling sites, Emigration Creek, Utah, October 12, 2005.

[Distance, in meters downstream from beginning of study reach; Sample source: S, stream; RBI, right-bank inflow; LBI, left-bank inflow; Easting and Northing, in meters; pH, in standard units; $\mu\text{S}/\text{cm}$, microsiemens per centimeter; mg/L, milligrams per liter; L/s, liters per second; NM, not measured]

Distance	Sample source	Site description	Easting	Northing	Time	pH	Conduc-tance ($\mu\text{S}/\text{cm}$)	Bromide (mg/L)	Discharge (L/s)
0	S	Killyon Canyon baseline upstream from homes	440080	4516545	9:25	8.22	254	<0.2	6.19
0	S	T0 - Injection site at end of paved road	439986	4516128	9:35	8.39	254	< .2	6.19
					13:15	8.34	254	< .2	6.19
133	S	First site downstream from injection	439959	4516014	9:40	8.38	408	30.93	6.19
314	S	Upstream from Burr Fork inflow	439869	4515892	9:47	8.48	431	30.64	6.25
375	RBI	Burr Fork	439789	4515914	9:55	8.48	694	< .2	NM
426	S	Downstream from Burr Fork	439823	4515791	10:00	8.45	635	9.09	21.0
821	S	Downstream from ponds at Pinecrest B&B	439594	4515499	10:08	8.51	645	8.82	21.7
982	S	T1 site - At concrete flume	439574	4515357	10:14	8.57	655	8.82	21.8
					14:05	8.46	655	8.75	21.8
					17:08	8.52	655	8.59	21.8
1,297	S	Downstream from turn to Little Mountain	439386	4515123	10:24	8.53	655	8.79	21.8
1,590	RBI	Water supply well for home	NM	NM	10:40	7.17	NM	.77	NM
1,606	S	Upstream end of culvert for canyon road	439161	4514918	10:55	8.52	653	8.79	21.8
1,769	S	Upstream from 5611 East	439040	4514836	11:05	8.46	648	8.79	21.8
1,908	S	At culverts by yellow side rail	438937	4514745	11:09	8.48	649	8.79	21.8
2,083	S	Downstream from 5424 East	438807	4514637	11:17	8.48	637	8.79	21.8
2,288	S	Driveway bridge downstream from stone home	438657	4514509	11:25	8.40	647	8.79	21.8
2,500	S	At driveway to 5220 East; upstream from Brigham Fork	438473	4514432	11:30	8.49	649	8.79	21.8
2,655	RBI	Brigham Fork	438356	4514336	11:35	8.39	809	<.2	NM
2,719	S	Downstream from confluence with Brigham Fork	438325	4514281	11:40	8.35	706	7.59	25.2
3,122	S	T2 site - Upstream from Freeze Creek	437976	4514089	11:50	8.43	711	7.45	25.2
					14:12	8.35	711	7.39	25.2
					17:15	8.43	711	7.33	25.2
3,137	RBI	Freeze Creek	437927	4514111	11:55	8.23	1,403	.2	NM
3,250	S	Downstream from Freeze Creek	437906	4514009	12:08	8.43	725	7.24	26.4
					12:10	8.44	725	7.24	26.4
3,518	S	Downstream from Maple Grove; upstream from driveway culvert at 4444 East	437660	4513925	12:22	8.24	828	6.47	29.6
3,781	S	At condemned house at 4422 East	437412	4513862	12:30	8.33	836	6.33	30.2
4,007	S	Dirt road across stream at 4301 East	437209	4513777	12:37	8.38	847	6.16	31.1
4,189	S	Downstream from 4231 East	437064	4513669	12:43	8.36	869	6.16	31.1
4,385	S	Sampled near pipeline marker "170" at road	436870	4513652	12:50	8.40	866	5.95	32.2
4,614	S	Downstream from culvert across from 3988 East	436643	4513641	12:56	8.46	878	5.84	32.8
4,805	S	Upstream from bridge at 3843 East	436472	4513573	13:00	8.41	906	5.69	33.6
4,820	LBI	Discharge from Blacksmith Hollow	436316	4513503	13:10	8.38	561	<.2	NM
5,112	S	Downstream from Blacksmith Hollow and 3690 East driveway	436212	4513458	13:20	8.19	962	5.29	36.2
5,409	S	Upstream from road to houses	435940	4513439	13:28	8.24	967	5.02	36.2
5,554	S	At vacant lot between houses, upstream from 3350 East	435807	4513408	13:37	8.10	974	4.65	36.2
5,852	S	Away from road between houses	435563	4513284	13:48	8.24	995	4.38	36.2
6,136	S	Downstream from Pioneer Gulch	435335	4513166	13:58	8.28	993	4.30	36.2
6,274	S	At fault upstream from Perkins Flat	435208	4513114	14:04	8.14	1,109	3.87	36.9

8 Principal Locations of Major-Ion, Trace-Element, Nitrate, and *Escherichia coli* Loading to Emigration Creek

Table 1. Characteristics of synoptic sampling sites, Emigration Creek, Utah, October 12, 2005.—Continued.

Distance	Sample source	Site description	Easting	Northing	Time	pH	Conductance (μS/cm)	Bromide (mg/L)	Discharge (L/s)
6,449	S	Into middle meadow upstream from marsh area	435037	4513076	14:13	8.10	1,133	3.74	37.9
6,605	S	T3 site - Upstream from thick cattails in Perkins Flat	434895	4513019	11:08	8.22	1,134	3.27	38.8
					14:20	8.18	1,134	3.63	38.8
					17:22	8.29	1,134	3.59	38.8
6,794	S	Downstream from marsh area in Perkins Flat	434720	4512958	14:30	8.18	1,149	3.62	38.8
6,939	S	Upstream end of culvert at road to housing development	434577	4512937	14:40	8.19	1,152	3.53	38.8
7,119	S	Downstream from culvert and bridge	434410	4512933	14:50	8.27	1,153	3.00	38.8
7,284	S	Downstream from culvert at upstream entrance to Camp Kostopolis	434264	4513002	14:58	8.29	1,152	3.00	38.8
7,464	S	Under walking bridge to Camp Kostopolis	434114	4512910	15:07	8.33	1,148	3.00	38.8
7,651	S	Downstream from Camp Kostopolis	434082	4512732	15:13	8.36	1,122	3.21	38.8
					15:15	8.39	1,122	3.21	38.8
7,931	S	Downstream from Ruth's Dinner	434134	4512483	15:22	8.41	1,113	3.09	38.8
8,092	S	At lower end of 1960 East property	434006	4512409	15:32	8.46	1,111	3.00	38.8
8,440	S	Downstream from bridge to 1720 East	433697	4512360	15:42	8.45	1,098	2.98	36.1
8,663	S	Downstream from 1620 East	433514	4512243	15:49	8.45	1,092	2.96	34.4
8,904	S	At downstream end of guard rail upstream from 1522 East	433314	4512112	15:58	8.39	1,082	3.02	32.6
9,065	S	Near west end of Sunnysdale Lane	433238	4512000	16:13	8.44	1,073	3.01	31.4
9,298	S	Near road west of "Cabin safety" sign on north side of road	433052	4511899	16:23	8.28	1,060	2.99	29.6
9,563	S	Down from "Warning" sign on thick wood post along concrete guard rail	432910	4511683	16:32	8.23	1,044	2.89	25.8
9,772	S	Across road from vertically dipping strata - nice ripple marks	432755	4511605	16:40	8.22	1,035	2.89	22.8
10,024	S	Down from "pipeline" warning signs on south of road	432544	4511558	16:48	8.26	1,020	2.86	19.2
10,160	S	Stream at cased spring; upstream from Donner Party marker	432426	4511494	16:58	8.35	1,011	2.85	19.2
10,175	LBI	Discharge from Emigration Tunnel Spring	432418	4511483	17:00	7.52	1,022	.08	NM
10,352	S	T4 site - Downstream from stream reach flowing on bedrock	432265	4511501	17:08	8.35	1,015	2.83	24.4
					17:10	8.34	1,015	2.83	24.4
10,541	RBI	Wagner Spring on north side of canyon road	432082	4511547	17:20	8.30	580	<.2	NM
10,626	S	Downstream from exit of long culvert	431991	4511505	17:32	8.01	938	.79	31.7
10,633	RBI	Just downstream from stream site, spring covered with vine	431985	4511508	17:35	7.53	505	<.2	NM
10,883	LBI	Discharge from sand boils near stream in reservoir at Rotary Park dog run	431888	4511333	17:50	7.34	1,303	.70	NM
10,910	S	Before entering reservoir drain	431865	4511331	17:56	8.06	946	.76	39.3
11,174	S	At gage in Rotary Park	431611	4511273	18:00	8.23	938	.76	46.4

dissolved plus colloidal) constitute the basic data from the mass-loading study.

For each stream segment, the change in load between a pair of stream sites accounts for the gain or loss of constituent load for that segment. The change in load for the segment starting at location *A* and ending at location *B* is:

$$\Delta M_S = (M_B - M_A) \quad (4)$$

where ΔM_S is the change in sampled instream load from locations *A* to *B*, in kg/day,
 M_B is the constituent load at location *B*, in kg/day, and
 M_A is defined in equation 3.

Gains in constituent load (ΔM_S is greater than zero) imply that there is a source that contributes to the stream between the two stream sites. However, there could be instream processes that reduce the net gain; thus, the measured change may not indicate the total magnitude of the load that enters in a particular stream segment. Instream load also can decrease within a stream segment (ΔM_S is less than zero), meaning that there is a net loss of the constituent as a result of physical, chemical, or biological processes. A net loss does not preclude the presence of a source of loading for a particular stream segment, but it does preclude quantifying the magnitude of that source. The sum of all the increases in load between sampling sites along the study reach (positive values of ΔM_S) is the cumulative instream load. At the end of the study reach, the cumulative instream load is the best estimate of the total load added to the stream but is likely a minimum estimate because it only measures the net loading between sites and does not account for metal loads added to and then lost from the water column within individual stream segments.

Although few inflows were sampled in this study, the loads they represent can be evaluated by calculation of an inflow load:

$$\Delta M_I = C_I (Q_B - Q_A)(0.0864) \quad (5)$$

where ΔM_I is the load attributed to the inflow, I , in kg/day,
 C_I is the inflow concentration, in mg/L, and
 Q_B , Q_A , and 0.0864 are defined in equations 1 and 3.

This calculated inflow load assumes that the actual volume-weighted inflow concentration is adequately represented by the sampled inflow concentration. The inflow load, however, often varies from the calculated value of ΔM_S for the stream segment containing the inflow. If ΔM_S is greater than ΔM_I , an unsampled inflow load is calculated:

$$\Delta M_U = \Delta M_S - \Delta M_I \quad (6)$$

where ΔM_U is unsampled inflow load, in kg/day, and
 ΔM_S and ΔM_I are defined in equations 4 and 5.

In considering estimates of stream discharge and metal concentration at each stream site, it is possible to predict an error for the change in load along a stream segment. The error is determined by the precision of both discharge and chemical measurements (Taylor, 1997), according to the equation (McKinnon, 2002):

$$\text{Load error} = \left(\sqrt{Q_A^2 \Delta C_A^2 + C_A^2 \Delta Q_A^2} \right) (0.0864) \quad (7)$$

where ΔC_A is the concentration error at site A , in mg/L,
 ΔQ_A is the discharge error at site A , in L/s, and
 Q_A , C_A , and 0.0864 are defined in equation 3.

The value of ΔC_A is based on the single operator precision (Friedman and Erdmann, 1982), calculated from repeated analysis of reference samples collected at transport sites to cover the range in concentration. The value of ΔQ_A is based on the variation of the tracer concentration at the transport sites, where hourly samples were collected during the period of synoptic sampling. This results in an estimate of variation as a function of discharge so that a value can be calculated for each stream site. Load error is calculated for the upstream sampling site of each stream segment and compared to the change in load for the stream segment, ΔM_S . If the absolute value of ΔM_S is greater than the load error, then there has been a significant change in load. Only the values of ΔM_S that are greater than the load error are included in the longitudinal profiles of cumulative instream load.

Cluster Analysis

An important objective of synoptic sampling is to recognize patterns or chemical characteristics among samples that can indicate the various sources of solutes. As water interacts with different mineral assemblages or is affected by domestic uses, it obtains a distinct chemical signature. A method of cluster analysis called partitioning around medoids was used to evaluate distinctions among the samples (Kaufman and Rousseeuw, 1990). The method operates on a dissimilarity index by choosing the number of representative objects (medoids) specified by the user. Then the Euclidian distance between samples is used as a measure of similarity, and each sample is assigned to the cluster of the nearest medoid. Selection of the number of groups for inflows and stream sites was guided by the ability to explain a grouping in terms of geologic, hydrologic, or geochemical information. Clusters that represented small portions of the total variance and that could not be explained in relatively simple physical or chemical terms were not included.

Concentrations were standardized for the cluster analysis to give an equal weighting to major and trace elements. The differences between dissolved and total-recoverable concentrations were small for most constituents (see "Chemical Characterization of Synoptic Samples" section of this report); therefore, dissolved concentrations were used in the cluster analysis. Too few inflow samples were collected to allow a meaningful analysis of inflows, so the cluster analysis was done only for stream samples.

Field-Scale Experiment

The field-scale experiment provided estimates of discharge, a chemical characterization of the stream and a limited number of inflows, loading profiles for many constituents, and an indication of changes in nitrogen isotopes.

Discharge

The hydrologic setting of the field experiment is established by using a tracer injection to estimate a detailed spatial profile of stream discharge. During the study, discharge increased along Emigration Creek from 6.2 L/s at the injection site to a maximum of 46 L/s at the end of the study reach (fig. 4). Along the first 8,092 m of the study reach, Emigration Creek displayed the characteristics of a typical gaining stream. Four tributaries discharged to Emigration Creek along this section. Burr Fork added 15 L/s, Brigham Fork added 3.4 L/s, Freeze Creek added 1.2 L/s, and Blacksmith Hollow added 2.5 L/s. The area at Maple Grove added 3.1 L/s and the area near the fault in Perkins Flat (fig. 1) added 2.6 L/s, but there was no visible inflow to the stream. Although tracer-dilution methods do not allow the quantification of decreases in discharge with only one injection site, the area-velocity measurements clearly indicated that discharge decreased from 39 L/s at 8,092 m to 19 L/s at 10,024 m (fig. 4). The loss of 20 L/s corresponds to the downstream geologic change from the Preuss Sandstone to the Twin Creek Limestone (Bryant, 1990). The limestone is highly fractured, suggesting that water could be moving into the formation. Downstream from 10,024 m there was a substantial gain in discharge. In the segment containing the Emigration Tunnel Spring, from 10,160 to 10,352 m, discharge increased by 5.1 L/s. Although most of the water from the Emigration Tunnel Spring is piped to the Salt Lake City water supply, a pipe at 10,175 m discharges excess water from the tunnel to the stream. From 10,352 to 10,626 m, Emigration Creek flows through a culvert. Discharge increased by 7.3 L/s in that segment. Wagner Spring, at 10,541 m, which is cased on the north side of the road and piped to the stream, is the likely source of that increase. Discharge increased by 7.6 L/s downstream from the culvert where two unnamed springs were sampled, and discharge increased by 7.1 L/s in the last stream segment. Samples were collected at the T4 site (10,352 m) for an extra 4 days (fig. 3). Although these gains in discharge from 10,160 m to the end of the study reach occurred, the values of discharge are less quantitative than values upstream from 8,092 m.

Chemical Characterization of Synoptic Samples

Results of chemical analyses for all of the synoptic samples are listed for major ions (table 2, at back of report) and for trace elements (table 3, at back of report). For stream samples the data include the analysis for the filtered samples (FA and FU) and the total-recoverable sample (RA). For some inflow samples only the FA treatment was analyzed because the RA treatment may have been contaminated with mud during sample collection. Inflow samples with both FA and RA concentrations generally were free flowing to the stream, and not bailed from pits. Colloidal concentrations that are plotted in figures and used in the loading calculations were calculated for stream samples from the difference between

the RA and the FA concentrations. The FA concentration was greater than the RA concentration for some samples, but the two concentrations always were within analytical precision. When this occurred, the FA concentration was used for both the filtered and total-recoverable concentrations and the colloidal concentration was considered less than detection.

Precision and method detection limits (MDL) are provided in table 4. Variation from sampling and chemical analysis must be sufficiently low to allow the observation of environmental change. Both analytical and sampling variability are included in the coefficient of variation in this report (Davis, 2002). Stream standard reference samples and sampling replicates were collected at the transport sites along the study reach (locations provided in table 1). These samples, along with certified standard reference samples, represented the range of concentrations for each constituent and were analyzed at regular intervals throughout the analytical work (Kimball and others, 1999). For each stream and certified reference sample, both the mean and the coefficient of variation (CV) were calculated for each constituent, and all the values were combined to calculate a power equation expressing CV as a function of the mean concentration. This is similar to the single operator precision of Friedman and Erdman (1982) but also includes the sampling variability. Thus, for an individual sample, precision is calculated by using the power equation:

$$CV = aC_A^b \quad (8)$$

where CV is precision calculated as the coefficient of variation for a reference sample,
 a is the empirical coefficient from regression,
 b is the empirical exponent from regression, and
 C_A is the sample concentration, in mg/L.

This form for the calculation fits the data better than a linear regression because, in general, the CV increases at lower concentrations in a non-linear pattern. This power equation was used to calculate the ΔC term in the load error calculation (see equation 8), where ΔC was the indicated percentage of the measured concentration for the given sample.

Major Ions

Synoptic sampling along Emigration Creek provided detailed spatial information about chemical changes in the stream that were classified into six groups. The groups generally followed an upstream to downstream sequence (fig. 5). The samples farthest upstream in Killyon Canyon were a calcium bicarbonate type water (fig. 5a and b), which is typical of water influenced by the weathering of limestone and sandstone that crop out in the headwaters (Bryant, 1990). Concentrations of most constituents were relatively low among the four samples of this group (table 5). A change

Table 4. Precision and method detection limits for chemical analyses.

[Coefficient and Exponent, for power equation giving the coefficient of variation; Units: mg/L, milligrams per liter; MPN/100 mL, count per 100 milliliters; $\mu\text{g/L}$, micrograms per liter; NC, not calculated]

Constituent	Unit	Coefficient	Exponent	Method detection limit
Calcium	mg/L	2.1265	-0.0777	0.431
Magnesium	mg/L	1.6681	.0415	.025
Sodium	mg/L	.0001	1.1435	.194
Potassium	mg/L	3.6002	.1914	.01
Alkalinity	mg/L	10.325	-.1423	1
Sulfate	mg/L	0.0000	10.363	150
Chloride	mg/L	21.874	-.8525	NC
Bromide	mg/L	4.20	0	.2
Silica	mg/L	2.7082	-.3983	.049
Nitrate	mg/L	.2022	1.3009	.01
<i>E. coli</i>	MPN/100 mL	.0500	0	NC
Aluminum	$\mu\text{g/L}$.0564	-1.1279	1.54
Arsenic	$\mu\text{g/L}$	NC	NC	.030
Barium	$\mu\text{g/L}$	1.0377	.0557	.058
Cadmium	$\mu\text{g/L}$	NC	NC	.019
Cobalt	$\mu\text{g/L}$	NC	NC	.006
Chromium	$\mu\text{g/L}$	3.0914	-.1740	.007
Copper	$\mu\text{g/L}$	4.3850	-.4419	.055
Iron	$\mu\text{g/L}$	140.87	-1.0259	1.48
Lead	$\mu\text{g/L}$	NC	NC	.005
Lithium	$\mu\text{g/L}$	2.3737	.0015	.143
Manganese	$\mu\text{g/L}$	1.0251	-.2214	1.35
Molybdenum	$\mu\text{g/L}$	NC	NC	.177
Nickel	$\mu\text{g/L}$	NC	NC	.023
Silver	$\mu\text{g/L}$	NC	NC	.022
Strontium	$\mu\text{g/L}$	1.1765	.0746	1.35
Uranium	$\mu\text{g/L}$	NC	NC	.002
Vanadium	$\mu\text{g/L}$	NC	NC	.002
Zinc	$\mu\text{g/L}$	NC	NC	.185

occurred as Burr Fork contributed magnesium, sodium, chloride (fig. 5c), and sulfate (fig. 5d), and this group of samples continued downstream to Blacksmith Hollow. The sodium to chloride mole ratio almost went to a value of 1 (fig. 5c), indicating a common source of those constituents. No geologic source of sodium chloride is present in the canyon, but halite is used to melt snow on the roads during the winter and could be a likely source. The ratio of sodium to chloride gradually decreased to less than 1 downstream from Freeze Creek, indicating that an additional source of

chloride is present (fig. 5c). A possible cause could be the addition of chloride salts of calcium and magnesium, which also are used for melting snow, both at homes and for road maintenance during the winter. Concentrations of most constituents progressively increased from Burr Fork to Blacksmith Hollow, similar to the increases shown for calcium and alkalinity (group 2; fig. 5). The trend of increasing concentration continued for major ions in samples from Blacksmith Hollow to Perkins Flat (group 3; table 5), but those samples were sufficiently distinct to be grouped separately. Most constituents reached a peak concentration downstream from where a fault crosses the stream near Perkins Flat (fig. 1). Stream samples collected from the area of the fault in Perkins Flat to Rattlesnake Hollow were chemically similar, making up a separate group (table 5). In the vicinity of Rattlesnake Hollow, concentrations of calcium and alkalinity decreased, but the concentration of most constituents remained nearly constant (fig. 5a and b). One cause of this decrease could be the precipitation of calcite to the streambed, which might be favored as the stream entered this area where the Twin Creek Limestone crops out. Calculations using WATEQ4F (Ball and Nordstrom, 1991) indicate that samples of stream water were supersaturated along the entire study reach with respect to the calcite equilibrium constant used in WATEQ4F. In this section where concentrations of calcium and alkalinity decreased, the state of saturation was relatively greater, which would be consistent with calcite precipitation.

Finally, the chemical character of stream water changed substantially downstream from the culvert from 10,352 to 10,626 m (fig. 5d). Concentrations of calcium and sulfate increased, but concentrations of sodium, chloride, and silica decreased. Each of these changes near the end of the study reach closely reflects the chemistry of four

inflows. Among these four springs, the Emigration Tunnel Spring (10,175 m) and an unnamed spring at 10,883 m, within the drained reservoir of Rotary Park, were on the south side of the canyon and were similar. Wagner Spring and an unnamed spring at 10,633 m were on the north side of the canyon and were similar to each other, but different from the springs on the south side of the stream (fig. 5).

The pattern of sulfate concentration differed from that of all the other major ions. Sulfate concentration increased downstream from Burr Fork, but then remained essentially

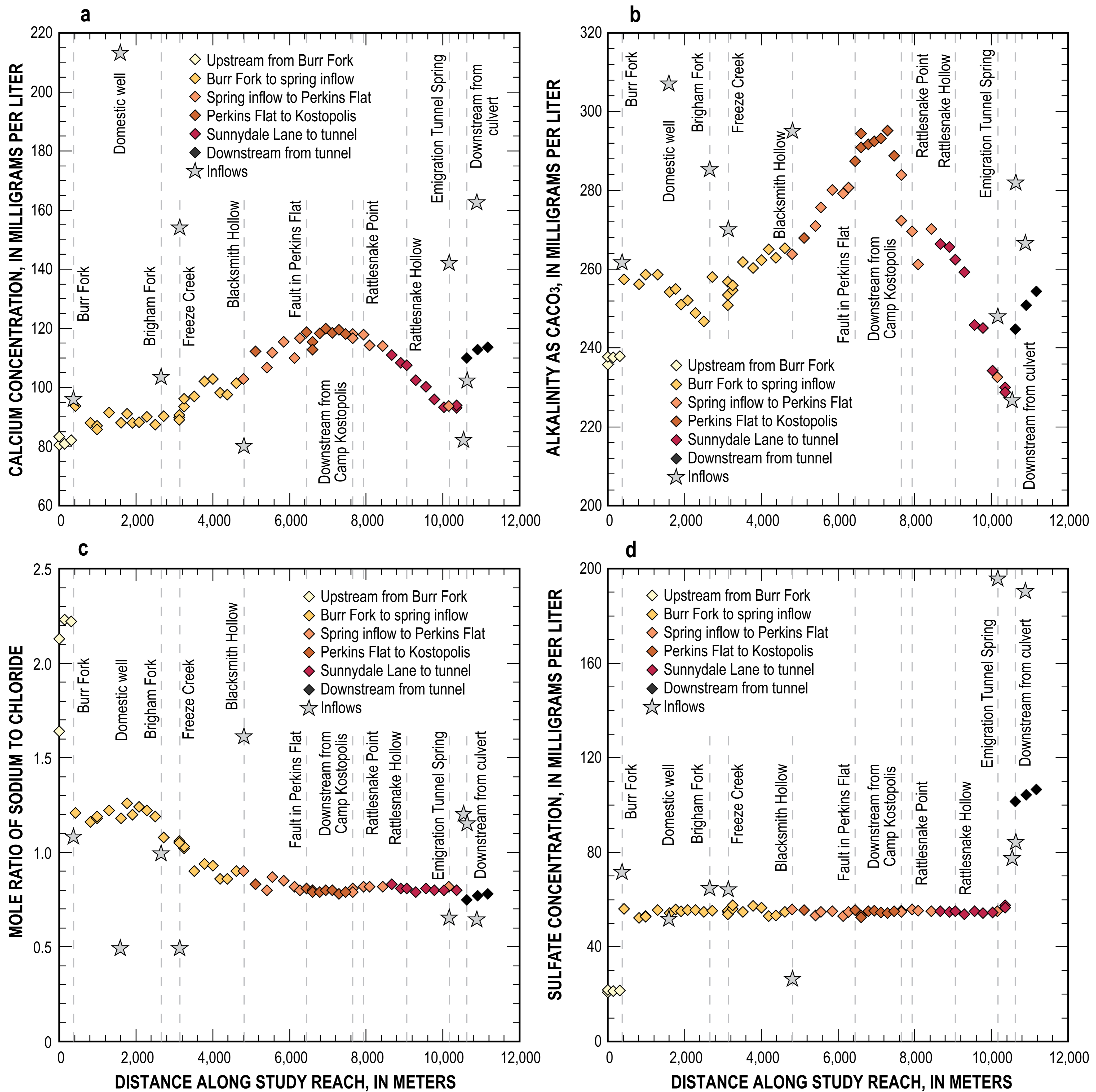


Figure 5. Variation of (a) calcium and (b) alkalinity concentration, (c) sodium to chloride mole ratio, and (d) sulfate concentration with distance along the study reach, Emigration Creek, Utah, October 12, 2005.

constant along the entire study reach as far as the inflows starting at Emigration Tunnel Spring (fig. 5d). Concentrations of other major ions varied along the study reach in response to inflow concentrations. For sulfate concentration to remain constant, all the inflows, not just the sampled inflows, had to have essentially the same sulfate concentration. Such an atypical situation could be the result of the particular geology along Emigration Creek because the stream lies almost at the axis of a syncline. This makes the geology similar for streams draining both the north and south sides of Emigration Canyon (Bryant, 1990). Sulfate concentrations from Killyon Canyon and Burr Fork differ and there are different geologic

formations in the Killyon Canyon drainage (Bryant, 1990). In summary, sulfate, like most of the major ions, is principally influenced by weathering of the bedrock geology. Among the major ions, only sodium and chloride concentrations appear to have an anthropogenic source from road salt.

Trace Elements

Analysis of trace-element concentrations in synoptic samples was done to provide indications of domestic water inflow to Emigration Creek. Most trace-element concentrations had the same general pattern as calcium,

magnesium, and sodium (fig. 5), but a few notable exceptions occurred. Patterns of some trace-element concentrations cannot be explained by geologic sources, but instead are a result of anthropogenic influence. None of the trace-element concentrations measured in Emigration Creek (table 3) exceed water-quality standards, but they are very useful for interpretation because of their indications of domestic water use.

Three patterns of trace-element concentration are indicated by the variation of lithium, strontium, manganese, and chromium along the study reach. Patterns of lithium (fig. 6a) and strontium (fig. 6b) are similar to patterns of most of the major ions. Lithium, however, has no likely geologic source in Emigration Canyon and probably results from its use in lubricants, alloys, batteries, and possibly medication (Winter, 1993). In the Boulder Creek watershed of the Colorado front range, lithium was identified as an indicator of anthropogenic input, possibly related to the medicinal

uses of lithium carbonate (Barber and others, 2006). Lithium concentration doubled in the stream reach beginning one site upstream from Brigham Fork to Blacksmith Hollow (fig. 6a), indicating input from anthropogenic sources. This increase corresponds to a substantial increase in discharge (fig. 4). Strontium, unlike lithium, does have a natural source from the weathering of limestone, and the variation of strontium indicates a non-anthropogenic pattern (fig. 6b). The substantial increase in strontium concentration in the area of the fault in Perkins Flat is similar to the increase in alkalinity (fig. 5b) and suggests that water entering the stream from the fault likely contains products resulting from weathering, rather than products resulting from anthropogenic input.

Concentrations of manganese (fig. 6c) and chromium (fig. 6d) represent completely different patterns. Manganese concentration had maxima along the study reach at 982, 5,112, 6,939, and 10,910 m. Iron concentration had the same pattern suggesting a common source, but the exact source is not

Table 5. Median filtered concentrations of constituents in stream and inflow groups defined by cluster analysis, Emigration Creek, Utah.

[mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Constituent	Group						Inflows
	Killyon Canyon	Burr Fork to Blacksmith Hollow	Blacksmith Hollow to fault in Perkins Flat	Fault in Perkins Flat to Rattlesnake Hollow	Rattlesnake Hollow to Emigration Tunnel	Downstream from Emigration Tunnel	
Number of samples	4	23	12	9	9	3	9
Calcium, in mg/L	81.5	90.7	114	118	100	113	103
Magnesium, in mg/L	11.5	19.2	25.5	26.8	27.1	27.8	27.4
Sodium, in mg/L	19.4	49.4	83.4	85.0	85.6	57.2	37.2
Alkalinity as CaCO ₃ , in mg/L	238	257	272	291	245	251	270
Sulfate, in mg/L	21.4	55.0	55.1	55.1	55.0	104	71.4
Chloride, in mg/L	13.7	63.0	159	165	163	114	60.1
Silica as SiO ₂ , in mg/L	12.1	12.0	15.4	15.6	15.3	14.6	15.6
Aluminum, in µg/L	11.5	14.2	14.7	15.5	14.9	18.8	13.4
Arsenic, in µg/L	.585	.73	.93	.97	.89	.77	.65
Barium, in µg/L	66.7	86.8	151	160	150	97.1	82.3
Cadmium, in µg/L	< .019	< .019	< .019	< .019	< .019	< .019	< .019
Chromium, in µg/L	.03	.16	.10	.10	.28	.25	.19
Cobalt, in µg/L	.02	.04	.06	.07	.05	.54	.04
Copper, in µg/L	.26	.48	.59	.58	.58	.27	.30
Iron, in µg/L	10.2	11.3	14.3	24.5	8.58	9.4	10.6
Lead, in µg/L	.035	.04	.04	.04	.04	.05	.04
Lithium, in µg/L	6.9	9.2	15.5	15.7	15.8	14.7	14.4
Manganese, in µg/L	7.91	5.02	7.41	14.6	.72	83.3	2.38
Molybdenum, in µg/L	.08	.29	.44	.45	.43	1.13	.21
Nickel, in µg/L	.15	.23	.33	.33	.33	.34	.22
Strontium, in µg/L	316	467	741	789	778	1,180	973
Uranium, in µg/L	.45	.75	.97	.97	.94	.77	.83
Vanadium, in µg/L	.67	.98	1.52	1.61	1.5	1.55	.93
Zinc, in µg/L	.92	.42	1.41	2.88	.94	.81	.60

clear. At the high pH of Emigration Creek, both manganese and iron tend to be removed from the stream through the formation and settling of colloidal solids (Kimball and others, 2001). As these solids become buried in the streambed, reducing conditions could cause the dissolution of the solids. The increases in iron and manganese could be from such dissolved concentrations re-entering the stream or even from the discharge of reduced ground water to the stream at the particular areas suggested by the maxima of manganese concentration in figure 6c. The maximum of manganese concentration downstream from the fault in Perkins Flat (6,939 m) is near a marsh-like area. This setting would be

consistent with the release of manganese by a reducing zone. Relatively high manganese concentrations occurred in samples from the inflow at 10,883 m and from the last two stream sites at 10,910 and 11,174 m (fig. 6c). The high concentrations at the last two stream sites most likely are the result of reservoir construction on the day of the synoptic sampling.

The pattern of chromium concentration differs from all the other trace-element patterns (fig. 6d). It is characterized by a substantial increase downstream from Burr Fork; then a steady decline to 8,440 m, which is downstream from Rattlesnake Point; and finally another substantial increase at 8,663 m. At both locations where chromium concentration

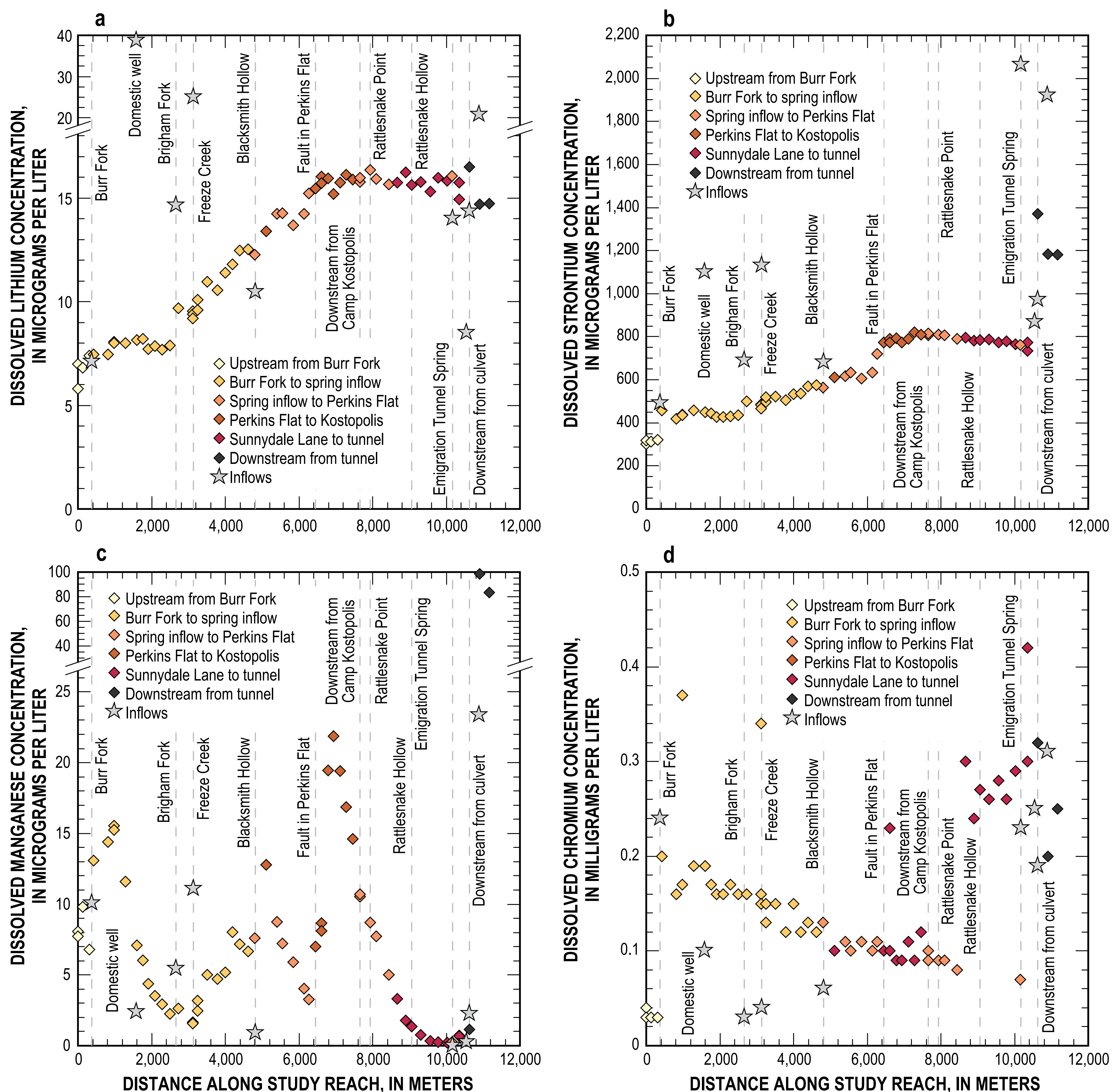


Figure 6. Variation of concentration of (a) lithium, (b) strontium, (c) manganese, (d) and chromium with distance along the study reach, Emigration Creek, Utah, October 12, 2005.

increased, the substantial increase was likely anthropogenic. Such sources could include chrome plating, hardened steel, oxidizing agent, or yellow paint pigment (Winter, 1993).

Nitrate, Nitrogen Isotopes, and *E. coli*

Nitrate concentration varied between <0.01 and 0.83 mg/L along the study reach, with the higher concentrations occurring at three locations (fig. 7a). First, the stream sample at 4,189 m had a value of 0.15 mg/L, but values upstream and downstream from there were only 0.01 mg/L, which is near the lower detection limit. Second, instream nitrate increased to 0.08 mg/L at 6,274 and 6,449 m, which is the location of the fault in Perkins Flat. Fault discharge would not be related

to anthropogenic sources (fig. 7b). Downstream from that increase, nitrate concentrations gradually decreased back to the limit of detection.

Differences in the ratios of stable isotopes of nitrogen can result from physical, chemical, and biological processes. These differences have been used to identify and distinguish sources of nitrogen in catchments (Kendall, 1998). The range of nitrogen isotope ratios ($\delta^{15}\text{N}$) that have been measured in septic and animal waste, including wildlife and domestic animals, is from -10 to 32 permil. Measurements of $\delta^{15}\text{N}$ from these two sources overlap, but the septic values are more commonly from about 4 to 8 permil and the animal values are mostly from 8 to 24 permil. Thus, values of $\delta^{15}\text{N}$ in the stream may help indicate the source of the nitrate, whether from septic or animal waste.

Seven inflow samples and 17 stream samples were analyzed for $\delta^{15}\text{N}$ (fig. 7b). Because the analysis for $\delta^{15}\text{N}$ requires a nitrate concentration of at least 0.03 mg/L as N, not all the sampling sites were available for analysis (fig. 7a). Results for inflow samples varied from 4.25 to 12.13 permil. Six of the inflow samples were in the range suggested for septic values (Kendall, 1998), and only the sample from Burr Fork (375 m) was in the range suggested for animal waste. Results for stream samples ranged from 6.43 to 14.12 permil, and only two samples collected at the end of the study reach had ratios of less than 8 permil, the upper limit suggested for septic systems. Stream samples fall into three groups based on $\delta^{15}\text{N}$. A first group, between Brigham Fork and Blacksmith Hollow, progressively increased from 12.8 to 14.12 permil. A second group from 5,554 to 8,663 m also progressively increased from 10.63 to 13.09 permil. This pattern from light to heavy isotope ratios could result from an inflow of lighter nitrogen from septic systems, followed by a progressive inflow of heavier nitrogen that could represent the catchment background more reflective of animal and plant nitrogen. Values also decreased in the area from 7,651 to 8,440 m, perhaps indicating additional anthropogenic or septic input. Thus, the nitrogen isotopes could be consistent with the influence of septic nitrogen, but these values do not give definitive evidence of that influence. A more extensive sampling that might include so called “emerging contaminants” could be useful to verify this pattern (Barber and others, 2006).

Concentrations of *E. coli* and total coliform were obtained at the time of the synoptic sampling by researchers from the University of Utah (fig. 8). The concentration patterns of both bacterial indicators are very similar. Two locations had concentrations of *E. coli* that exceeded the water-quality standard of 200 organisms per 100 mL

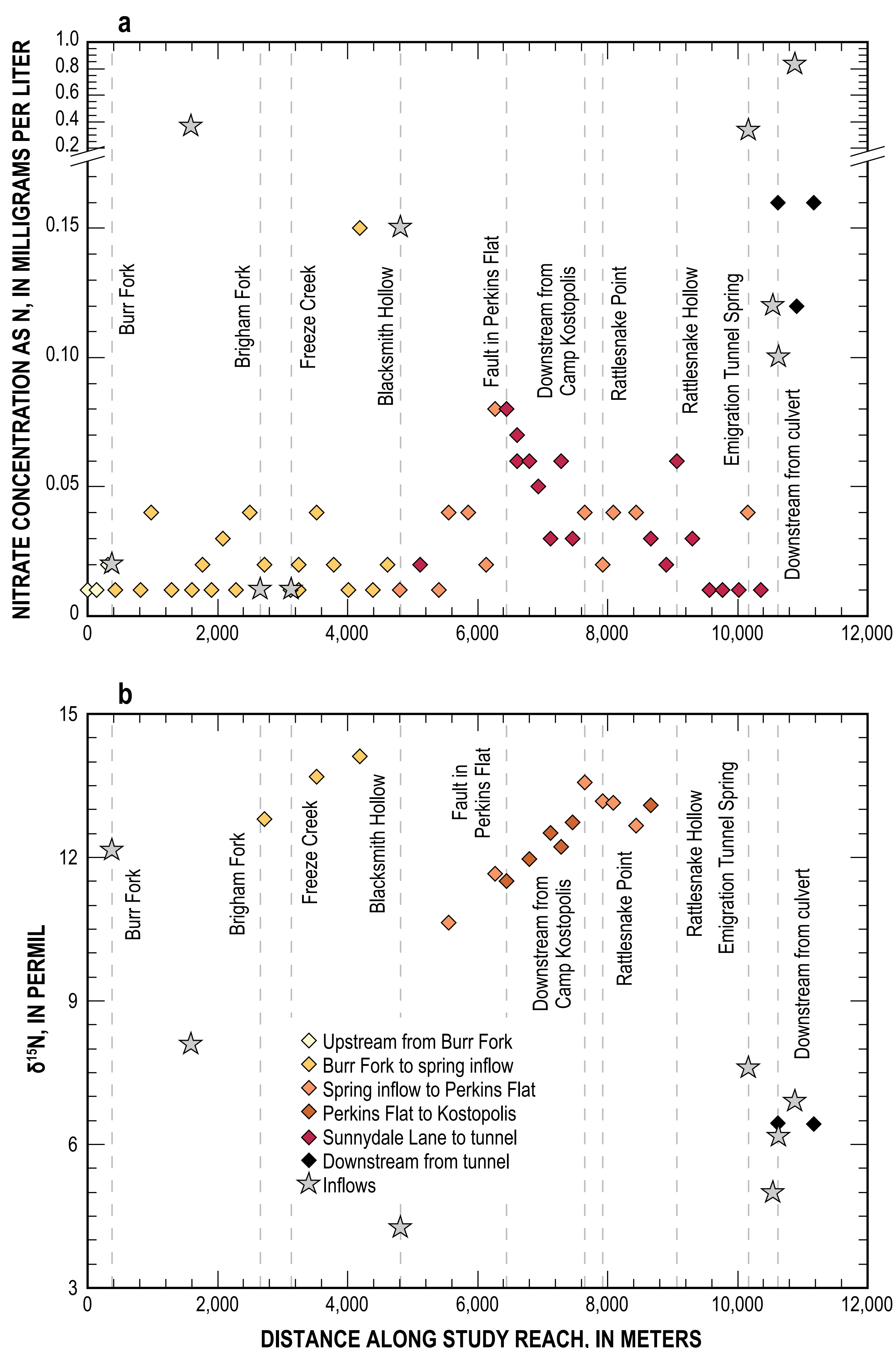


Figure 7. Variation of (a) nitrate concentration and (b) $\delta^{15}\text{N}$ ratio with distance along the study reach, Emigration Creek, Utah, October 12, 2005.

(Utah Department of Administrative Services, 2005); the area upstream from houses in Killyon Canyon and far downstream at 8,092 m. Willden (2006) also measured relatively high concentrations in Killyon Canyon, but the sampling sites in that study were too far apart to observe an increase near 8,092 m. Relatively higher *E. coli* concentrations occurred downstream from Burr Fork, upstream from Freeze Creek, near Pioneer Gulch, in Perkins Flat, and in Rotary Park (fig. 8). Three of these areas correspond to where $\delta^{15}\text{N}$ values decreased, including downstream from Brigham Fork, near Pioneer Gulch, and downstream from 7,651 to 8,440 m (fig. 7b), and thus the relative increases in *E. coli* could be consistent with the input of septic nitrogen.

Data from Willden (2006) on *E. coli* concentrations include seasonal variation for the months of June through September. All but one of the sampling sites in that study

exceeded water-quality standards for *E. coli*. Concentrations were substantially higher in July and August, the warmest months, than in September. Relatively lower concentrations might be expected from these synoptic samples in October because of lower temperatures, fewer daylight hours, and less hiking traffic.

Quantification of Mass Loading

Mass-loading profiles provide a framework, or hydrologic context, to discuss the changes in the chemical character of stream water that result from physical, chemical, and biological processes on the catchment scale. Because the absolute value of loading can vary over orders of magnitude for different constituents, comparison among the solutes

and recognition of patterns is easiest using a normalized cumulative instream load. The normalization for each constituent is accomplished by dividing the cumulative sum at each point along the study reach by the cumulative sum at the end (10,626 m, not 11,174 m), resulting in values from 0 to 1. Comparison of normalized profiles indicates common locations where loading occurs (fig. 9). Distinctions among profiles characterize three groups, although many constituents have some of the distinctions of each group. The first group includes most of the major ions and some trace elements (fig. 9a). The general characteristics of the loading for these constituents include the substantial loading at Burr Fork and Brigham Fork, a gradual loading from Brigham Fork to the fault in Perkins Flat, and then 10 to 20 percent of the loading from the Emigration Tunnel to the culvert at 10,626 m. The second group includes sulfate, chromium, copper, lithium, and strontium (fig. 9b). Although loading at Burr Fork and Brigham Fork also was important for these constituents, it was not as great as for the first group. Loading at the end of the study reach was greater for these constituents than for the first group. The third group includes aluminum, iron, and manganese (fig. 9c). The major characteristic of these constituents is the substantial loading near the fault in Perkins Flat.

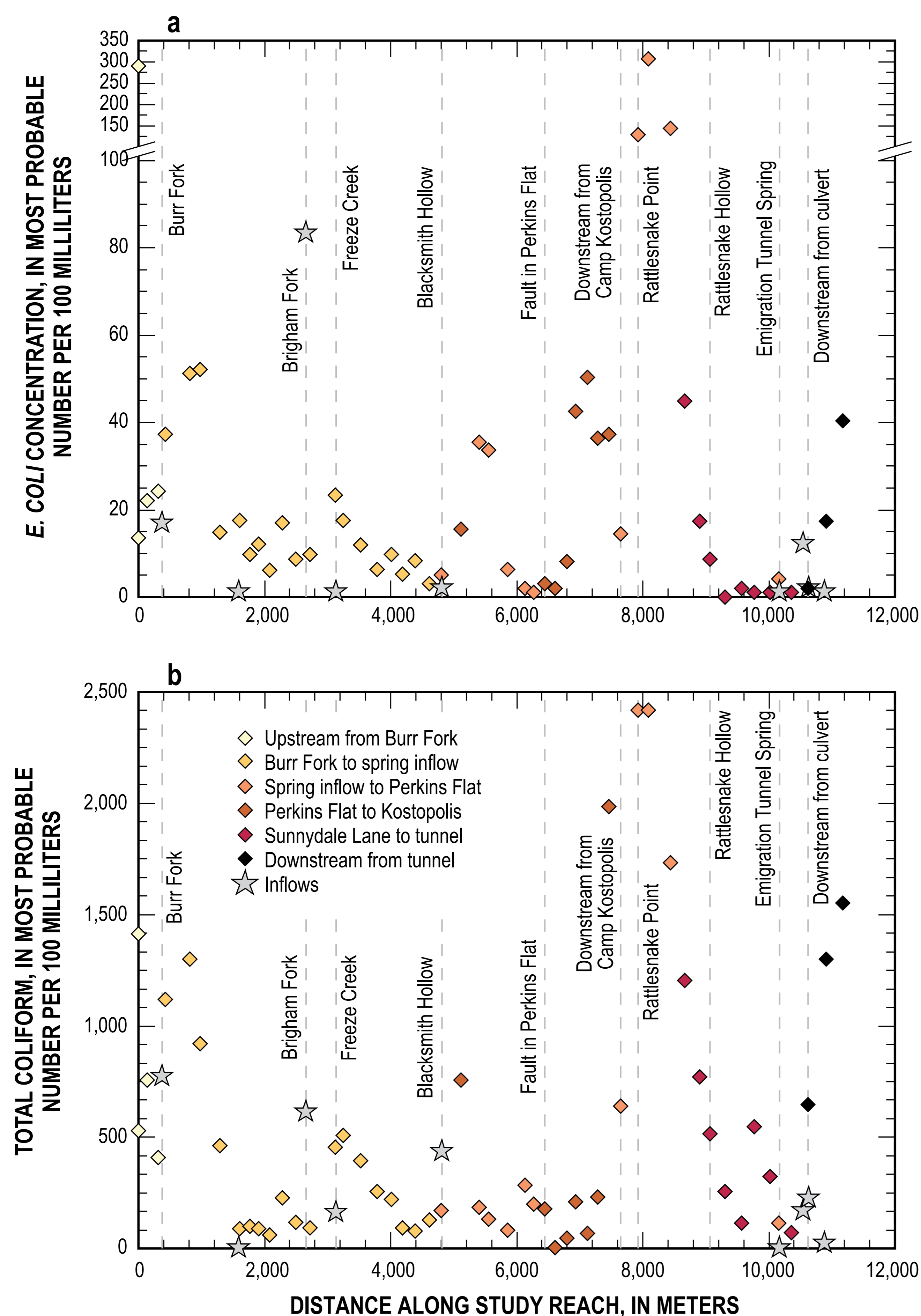


Figure 8. Variation of (a) *E. coli* and (b) total coliform concentration with distance along the study reach, Emigration Creek, Utah, October 12, 2005.

Loading Pattern of Major Ions and Selected Trace Elements

The loading profile of calcium represents the first group of loading patterns (fig. 10a). A detailed loading profile for calcium indicates two different calculations of loading, the sampled instream load and the cumulative instream load.

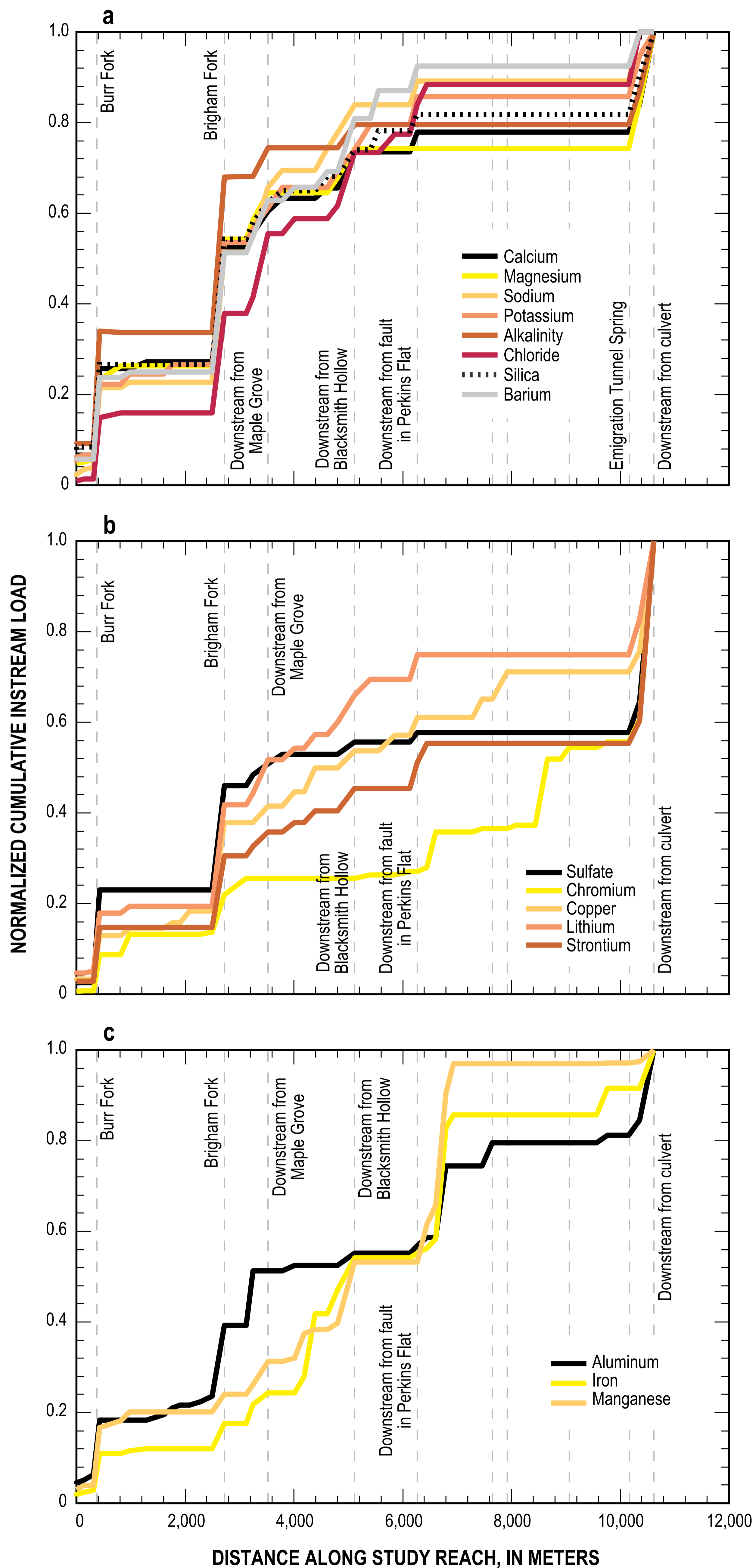


Figure 9. Variation of normalized cumulative instream load with distance along the study reach for (a) calcium, magnesium, sodium, potassium, alkalinity, chloride, silica, and barium, (b) sulfate, chromium, copper, lithium, and strontium, and (c) aluminum, iron, and manganese, Emigration Creek, Utah, October 12, 2005.

In this, and subsequent loading figures for metals, the total instream load is divided into the dissolved and colloidal instream loads. For calcium the total is essentially equal to the dissolved instream load (fig. 10a). Unlike the normalized cumulative instream load in figure 9a, these instream loads indicate both increases and decreases in loading along the study reach. The cumulative instream load has the same pattern as the normalized version in figure 9a, but shows the actual load in kilograms per day.

Calcium loading principally occurred at Burr Fork (314 to 426 m), Brigham Fork (2,500 to 2,719 m), and two stream segments downstream from the Emigration Tunnel Spring (10,160 through 10,626 m). The relative height of the bars in figure 10b and in subsequent figures illustrates the relative magnitude of loading from each of the stream segments. These last two segments indicate more qualitative than quantitative results. Loading from Burr and Brigham Forks likely resulted from weathering of bedrock for the major ion constituents, but also could reflect some septic input (see lithium discussion below). A gradual increase in calcium load occurred between 3,250 and 5,409 m, a reach that includes Freeze Creek, Maple Grove, and Blacksmith Hollow. The concentration of all of these constituents, except magnesium, increased between 6,136 and 6,274 m in a stream segment that is near a fault that crosses Perkins Flat (fig. 1). Discharge from the fault might account for the increase in load, particularly for these major ions. Although the patterns of normalized cumulative instream load (fig. 9a) do not indicate where load may decrease, most of these constituents had a decrease in load between 7,931 and 10,024 m, similar to the decrease illustrated for calcium (fig. 10). For calcium and alkalinity, some of this decrease likely resulted from precipitation of carbonate minerals from the water column, but the greatest part of the decrease was from the loss of water along that particular reach.

The pattern of lithium load had an important difference from that of calcium (fig. 11). The difference was the important, gradual increase in load in the reach from Brigham Fork to the stream site upstream from the fault in Perkins Flat. The gradual increase of lithium load in this section indicates that the increase had anthropogenic contribution because this is a reach of the stream with many homes and because lithium has no geologic source in the canyon. The similarity between lithium and calcium loading at Burr Fork and Brigham Fork also could be an indication of anthropogenic input. For both constituents, Burr Fork and Brigham Fork were the greatest sources of loading (figs. 10b and 11b).

The patterns of aluminum, iron, and manganese differed from the patterns of other trace elements. The variation of manganese loading illustrates the general pattern of these three metals and indicates several locations where manganese load substantially increased and decreased along the study reach (fig. 12). The three greatest increases of loading occurred at Burr Fork (314 to 426 m), Blacksmith Hollow (4,805 to 5,112 m), and in four stream segments in Perkins Flat (from 6,274 to 6,939 m). Manganese concentrations were high at 982, 5,125, and 6,939 m, but in the context of loading, the loading in Perkins Flat (6,939 m) was substantially greater than at the other locations (fig. 12b). Despite these distinctive increases in load, the source of the manganese, iron, and aluminum is not known. As noted, one possibility could be the release

of reduced ground water with higher concentrations of iron and manganese to the stream, and this is consistent with the Perkins Flat loading because of the marshy character of the stream through that area. However, the reduced ground water would not necessarily account for the loading of aluminum. A greater portion of the manganese loading was unsampled load rather than sampled load like some of the trace elements that only have anthropogenic sources (fig. 12b). This observation and the locations of loading for these elements suggest that their loading is not related to anthropogenic sources.

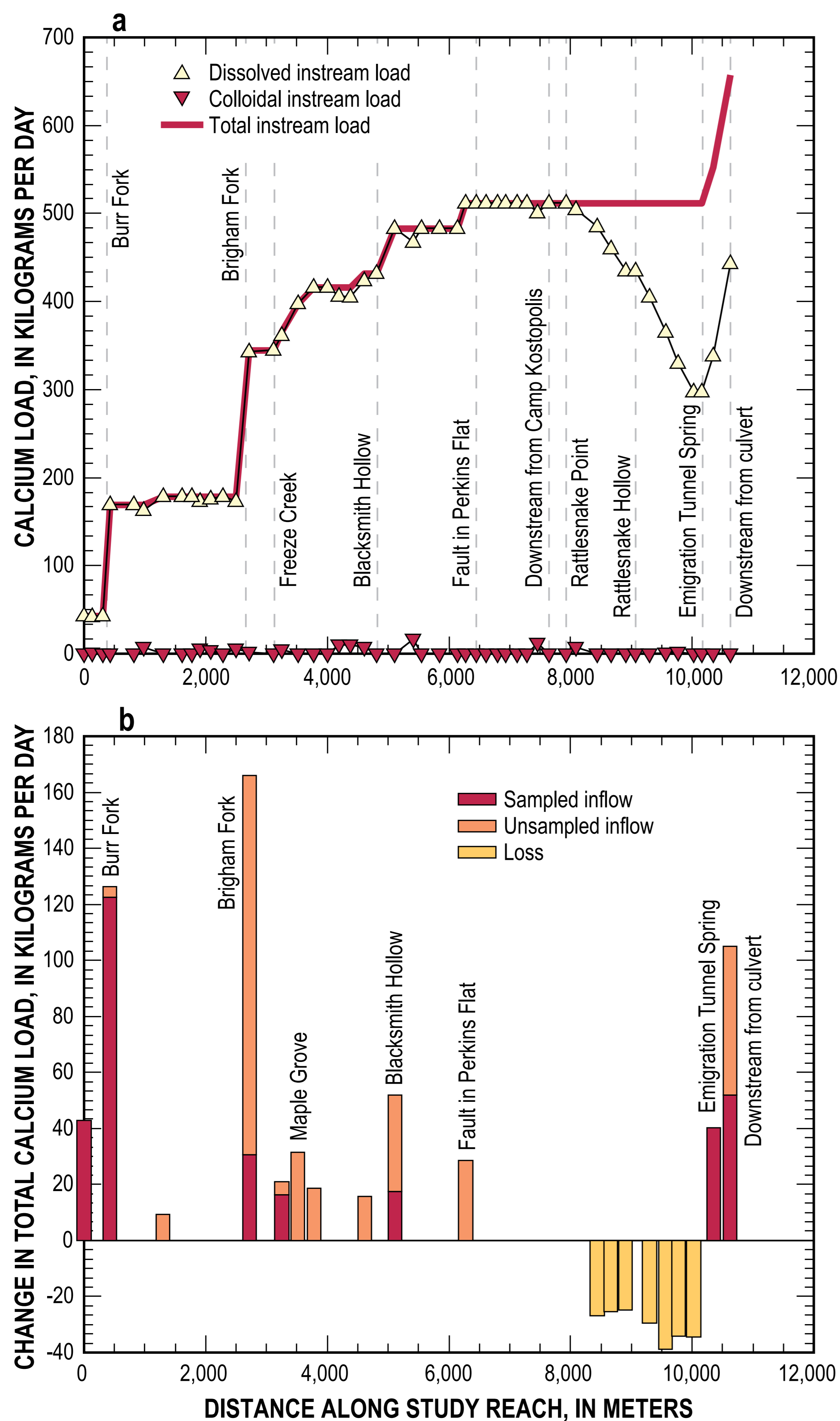


Figure 10. Variation of (a) dissolved and colloidal calcium load and (b) change in calcium load for individual stream segments with distance along the study reach, Emigration Creek, Utah, October 12, 2005.

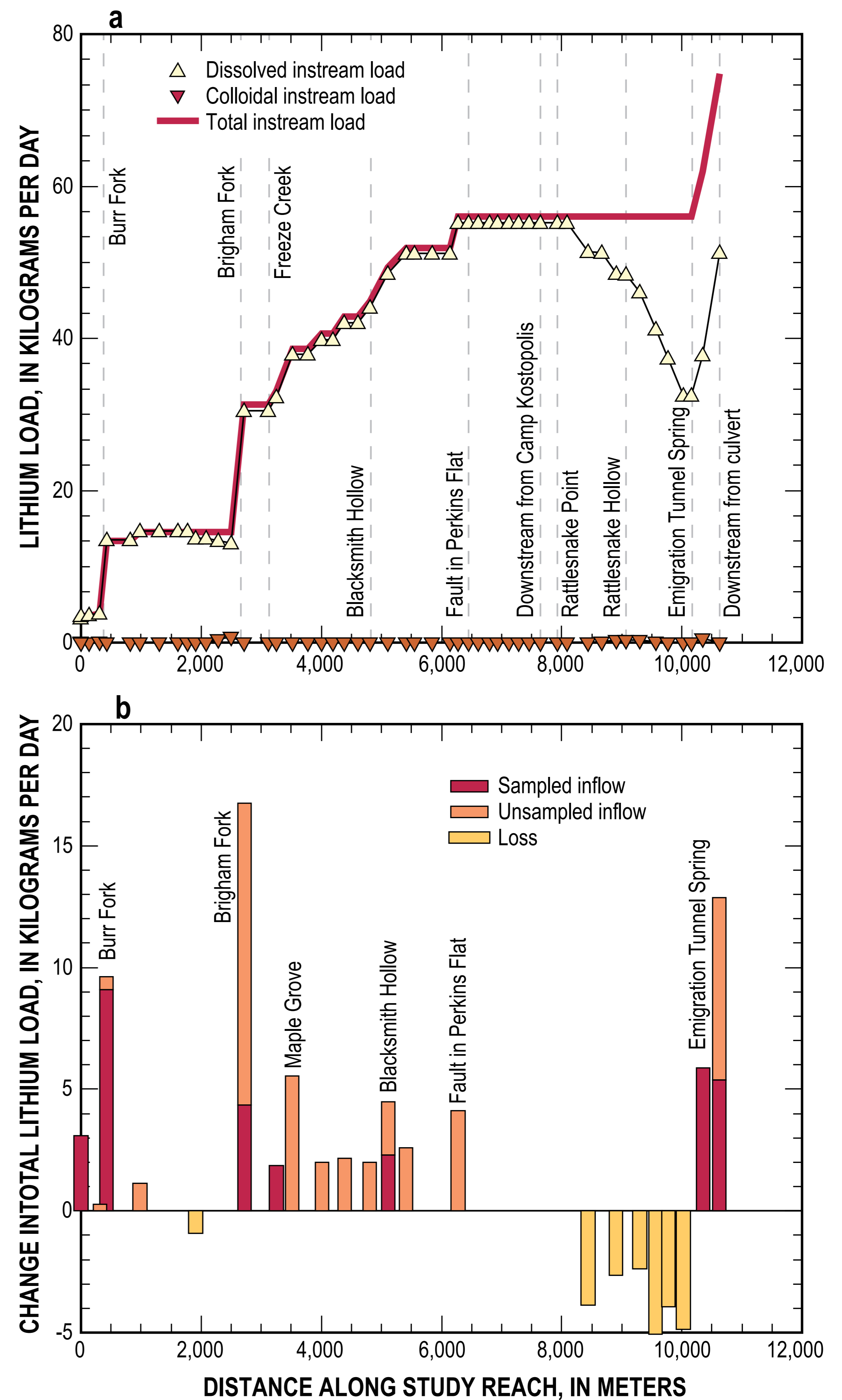


Figure 11. Variation of (a) dissolved and colloidal lithium load and (b) change in total lithium load for individual stream segments with distance along the study reach, Emigration Creek, Utah, October 12, 2005.

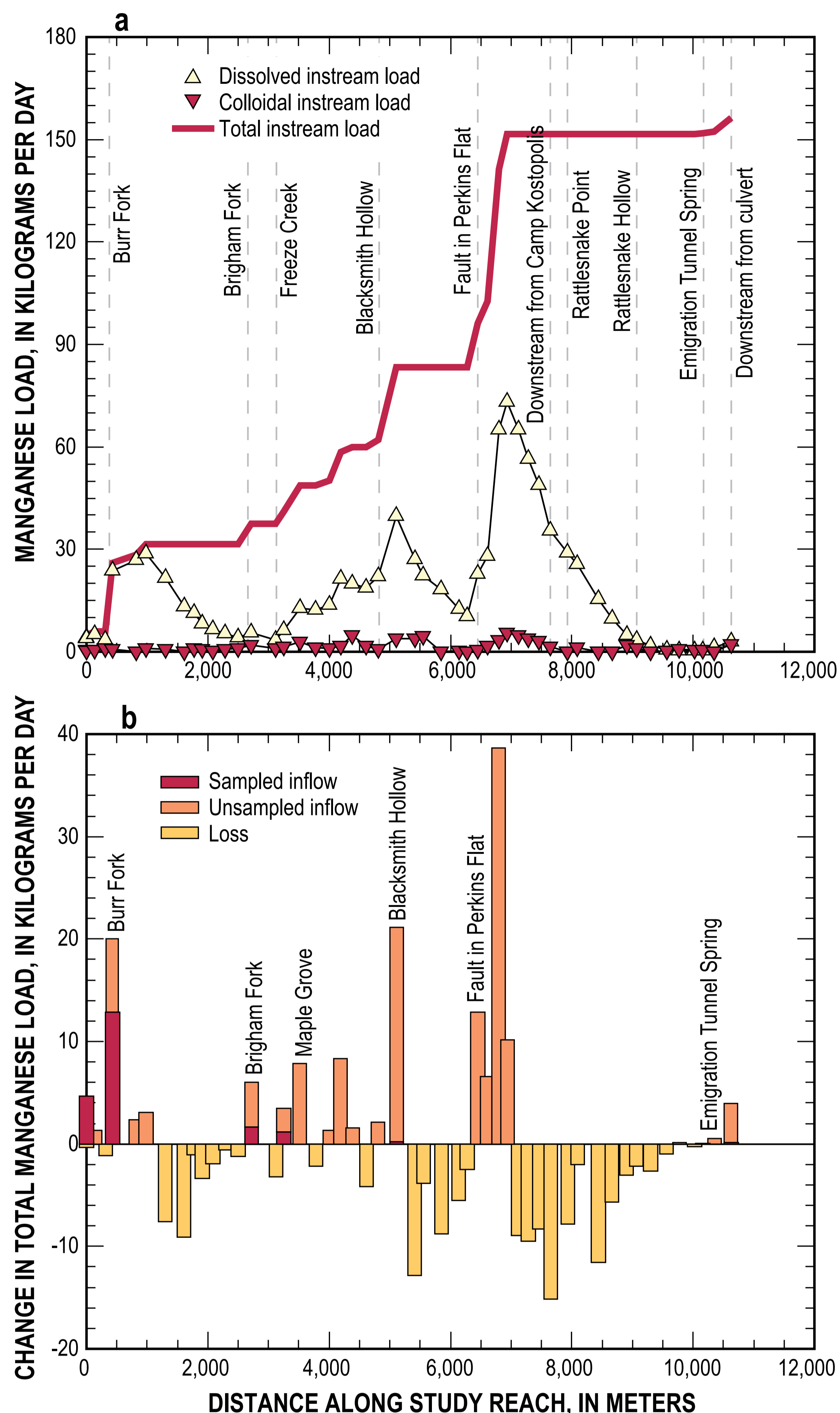


Figure 12. Variation of (a) dissolved and colloidal manganese load and (b) change in manganese load for individual stream segments with distance along the study reach, Emigration Creek, Utah, October 12, 2005.

Loading Pattern of Sulfate

The majority of trace elements had loading profiles that were similar to that of calcium (fig. 10), but patterns of sulfate, chromium, copper, lithium, and strontium were distinguished from the main pattern because the greatest loading for these constituents occurred at the end of the study reach, downstream from 10,160 m (fig. 9b). If the increase in loads for these downstream segments were a result of water re-emerging after being lost upstream (fig. 4), then one would expect the concentrations of most constituents to be similar to stream-water concentrations between 8,092 and 10,024 m (fig. 5). On the time scale of this experiment, no bromide

would have occurred in any of those downstream inflow samples. But concentrations of sulfate and the trace elements were much higher in samples from inflows at 10,175, 10,541, and 10,633 m than in samples of stream water from 8,092 to 10,024 m (tables 2 and 3), suggesting that discharge from the downstream inflows was not from re-emergent stream water. The stream segment from 10,160 to 10,352 m contained loading from the Emigration Tunnel Spring. The segment from 10,352 to 10,626 m flowed in the culvert, and discharge from Wagner Spring (10,541 m), which is located on the north side of the road across from the culvert, is piped into the culvert (Jeff Nermeier, Salt Lake City Public Utilities, oral commun., 2006). The sulfate concentration in the sample from Wagner Spring, however, accounts for less than half of the sulfate loading in the stream segment (fig. 13b), suggesting that there could be additional sources of loading that discharge into the culvert. Downstream from 10,626 m, stream samples were affected by construction and no loading was calculated.

The loading of sulfate has characteristics of the major ions but also illustrates the pattern for this second group of constituents (fig. 13). Although sulfate concentration was nearly constant along most of the study reach, the loading profile indicated distinct locations where sulfate loading occurred. Sulfate concentration in samples from Burr Fork, Brigham Fork, and Freeze Creek was comparable (fig. 5d) because all three tributaries drain the same sequence of geologic formations along the north flank of the syncline (Bryant, 1990). Because those inflows account for the great majority of loading along the study reach down to the Emigration Tunnel Spring, the sulfate concentration remained nearly constant (fig. 5d). Sulfate load decreased between 7,931 and 10,024 m as a result of the decrease in discharge through that reach (fig. 4), and not as a result of a chemical or biological process because sulfate concentration did not decrease (fig. 5b).

Loading Patterns of Nitrate and *E. coli*

Loading patterns for nitrate and *E. coli* had little in common with the loading patterns of the major ions or trace elements. Nitrate load increased and decreased at many locations along the study reach, suggesting a dynamic system for nitrate, with uptake of nitrate keeping pace with nitrate loading (fig. 14). Nitrate load increased substantially between 4,007 and 4,189 m, but no particular source was observed there. Between 6,136 and 6,274 m nitrate load also increased, and this nitrate loading could be associated with the fault in Perkins Flat, similar to loading of other elements already noted (fig. 1). If so, this source would not be associated with septic or animal influences. A second location with substantial loading that has no apparent connection to septic systems is in the segment from 10,352 to 10,626 m, within the culvert. All the inflows that were sampled downstream from 10,160 m had $\delta^{15}\text{N}$ values that are in the range reported for septic systems, but occur in a part of the study reach with no homes (fig. 7b).

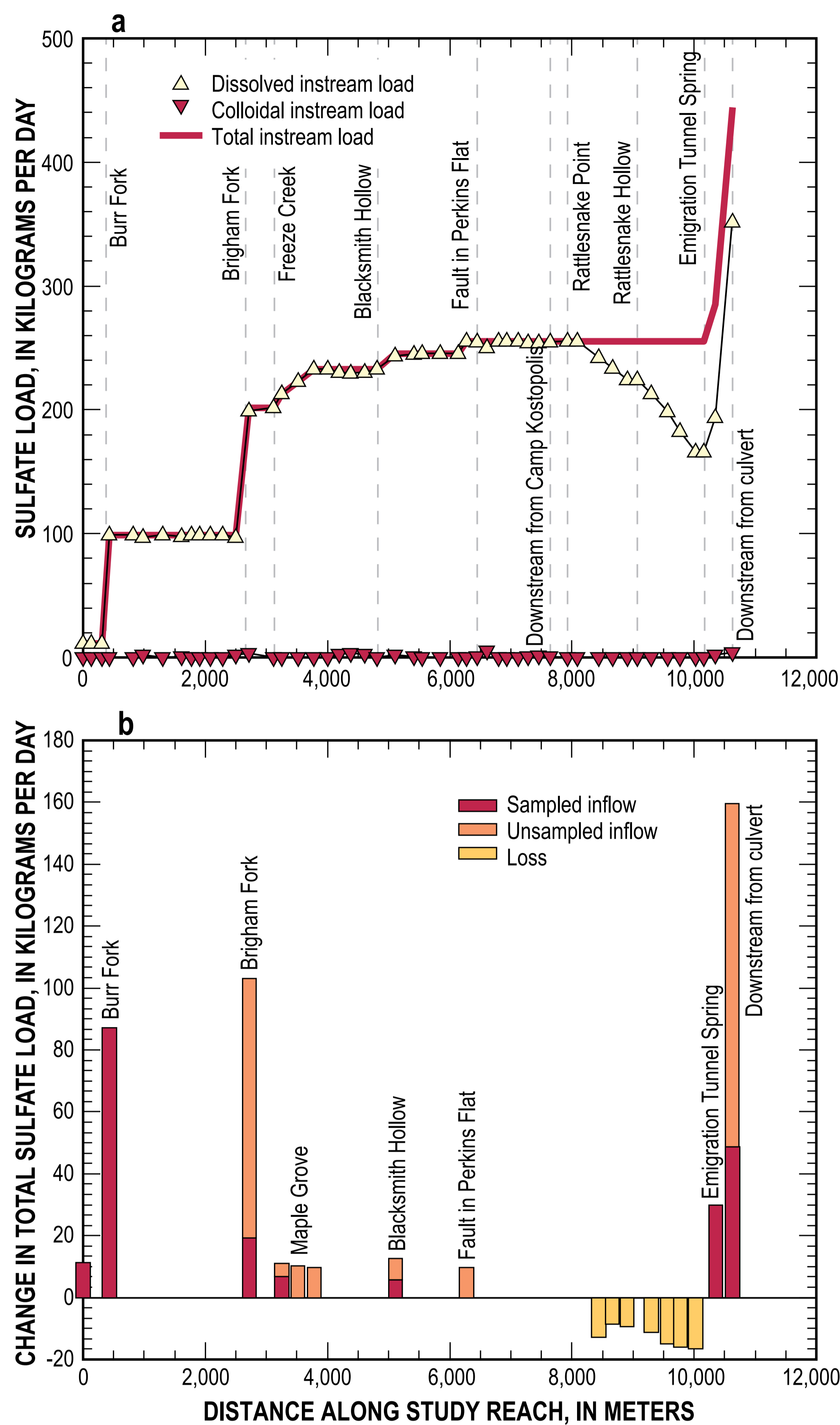


Figure 13. Variation of (a) sulfate load and (b) change in sulfate load for individual stream segments with distance along the study reach, Emigration Creek, Utah, October 12, 2005.

The pattern of loading for *E. coli* is notable for two stream segments that had relatively large contributions between 7,651 and 8,092 m (fig. 15). Downstream from 8,092 m, the *E. coli* load decreased to low levels that had been present along most of the study reach. This decrease in load is likely a result of bacterial attenuation (Willden, 2006), but it occurs in the part of the study reach where stream discharge decreased, making the detection of attenuation difficult. A few locations contributed small, but measurable loads including the segment that represents upstream sources at 0 m, the segment with Burr Fork (314 to 426 m), the segment from 5,112 to 5,409 m near Pioneer Gulch, and the segment from 6,794 to 6,939 m within Perkins Flat. These same stream segments correspond to the locations where substantial

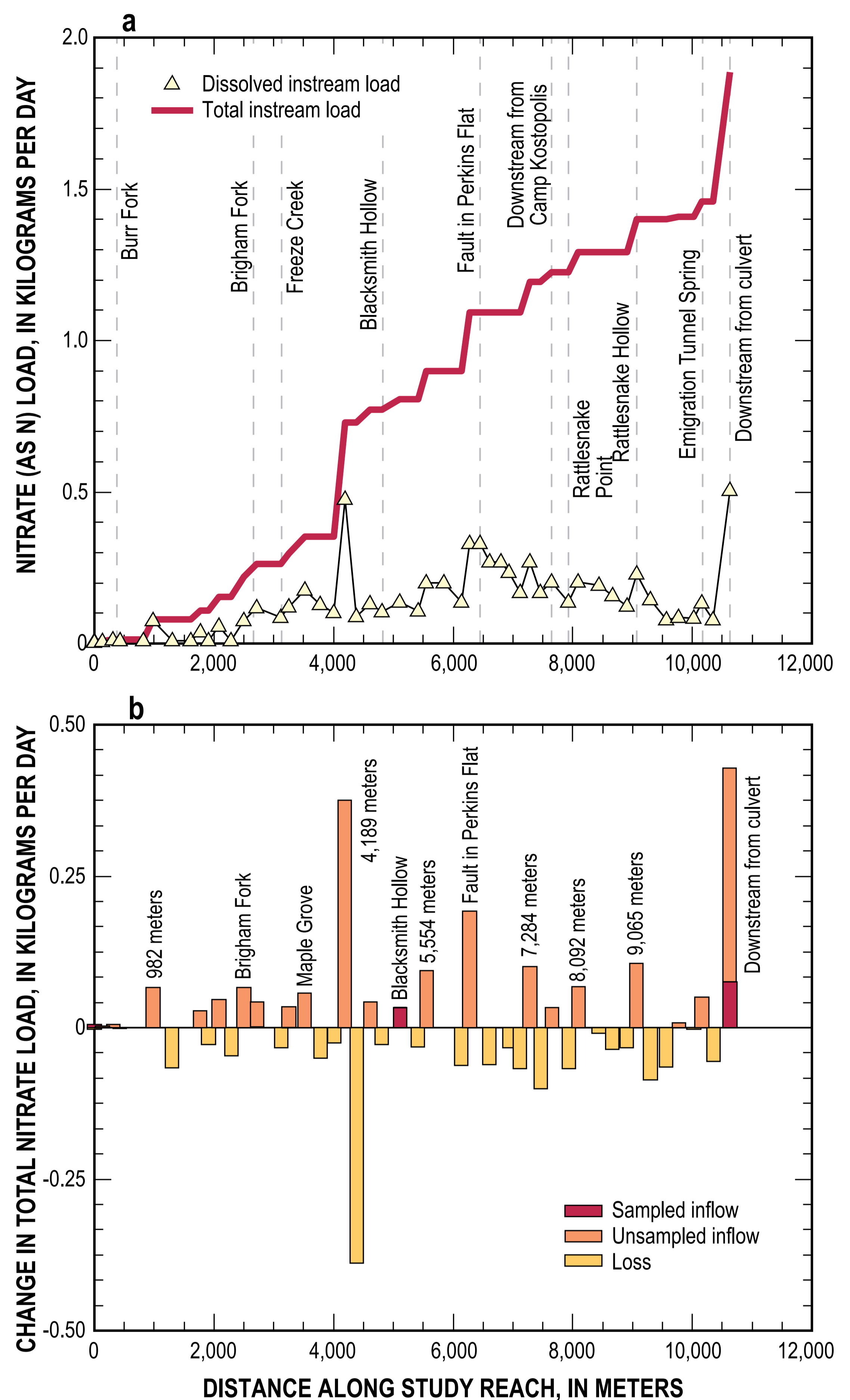


Figure 14. Variation of (a) nitrate (as N) load and (b) change in nitrate load for individual stream segments with distance along the study reach, Emigration Creek, Utah, October 12, 2005.

loading of aluminum, manganese, and iron occurred (fig. 12). If manganese and iron loading represent aging septic systems, then the correspondence could be explained as faulty systems, but these data only point to the covariance, not to the cause.

The loading patterns of nitrate and *E. coli* were compared to a map of wastewater facility status and age presented in Jensen and others (2003). The two largest increases in nitrate load occurred where there were no septic systems at all. Others locations of loading were not associated with relatively older septic systems. The greatest loading of *E. coli* occurred downstream from septic systems that date from the 70s and 80s, one of which has been upgraded since then. Thus, no clear tie to old systems is apparent for nitrate or *E. coli* loads.

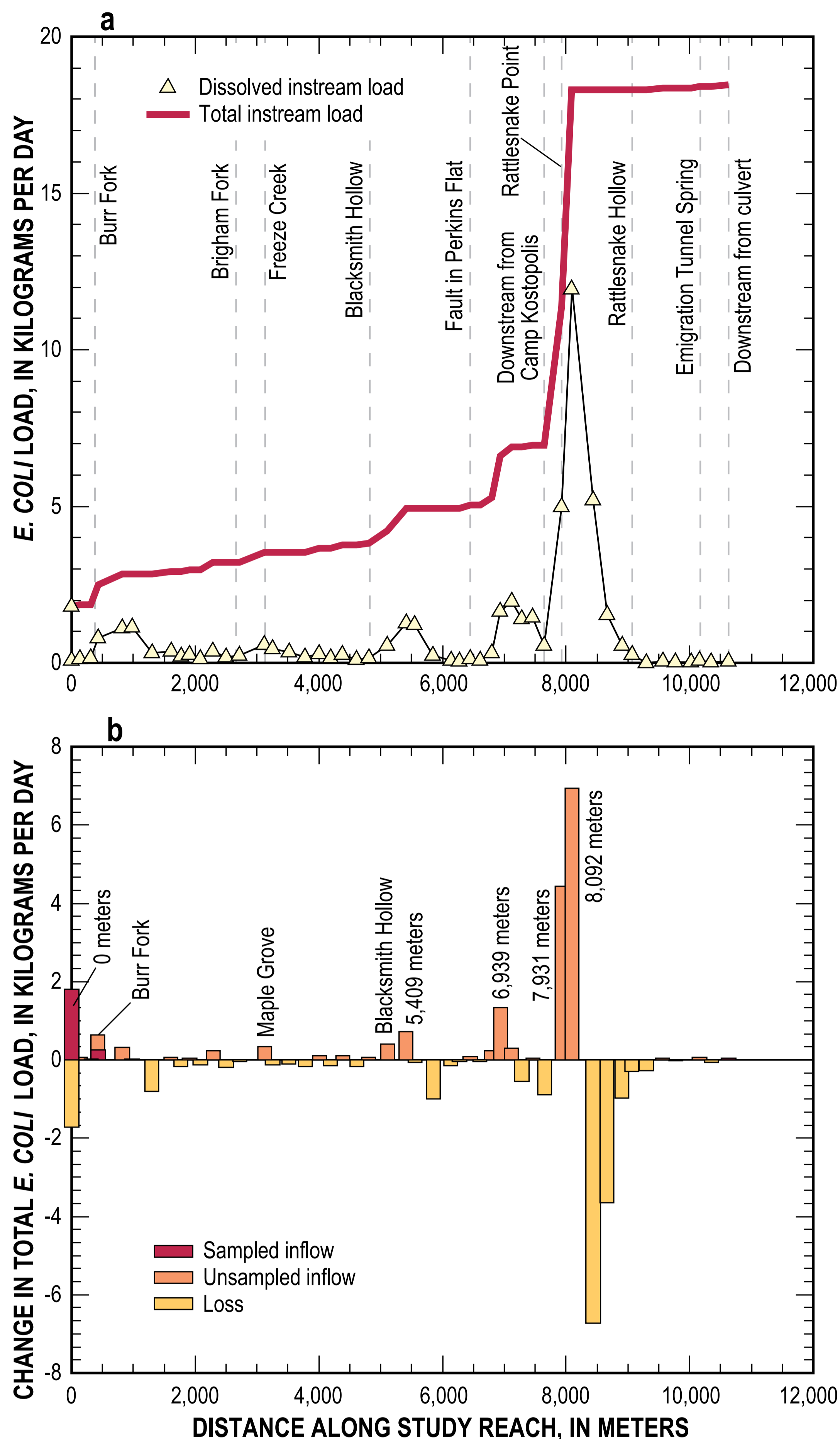


Figure 15. Variation of (a) *E. coli* load and (b) change in *E. coli* load for individual stream segments with distance along the study reach, Emigration Creek, Utah, October 12, 2005.

Summary and Conclusions

The U.S. Geological Survey, in cooperation with the Salt Lake County Department of Public Works, Engineering Division, carried out a mass-loading study in Emigration Creek in northern Utah to identify locations of mass loading for major ions, trace elements, nitrate, and *E. coli*. The study was accomplished during low-flow conditions when inflows from residential septic systems could most easily be identified. Detailed indications of the loading profiles can help guide planning for improved water quality in Emigration Creek. The mass-loading study successfully indicated locations of major ion, trace element, nitrate, and *E. coli* loading by using a tracer injection for discharge estimates and synoptic sampling

for spatially detailed concentrations profiles. Loading for most constituents was greatest from Brigham Fork, followed by Burr Fork. At the end of the study reach, loading was substantial in the stream segment within a culvert where discharge from Wagner Spring (and possibly other sources) is added to the stream and also in the stream segment that contains discharge from the Emigration Tunnel Spring. Lesser, but relatively important amounts of loading were noted for Freeze Creek, Maple Grove, and Blacksmith Hollow.

Dilution of the tracer indicated locations with the greatest increases in stream discharge. Upstream from Rattlesnake Point, the greatest increases of stream discharge occurred at Burr Fork, Killyon Canyon, Brigham Fork, Maple Grove, Blacksmith Hollow, and Freeze Creek. Increases at Maple Grove, Blacksmith Hollow, and a fault area in Perkins Flat were mostly from diffuse inflow to the stream. A substantial amount of stream discharge was lost downstream from Rattlesnake Point. Near the mouth of the canyon, discharge increased substantially as a result of contributions from the Emigration Tunnel Spring, Wagner Spring, and two unnamed springs in the same area.

Downstream changes in chemical character and loading correspond to several of these locations where stream discharge increased, indicating which of the inflows had the greatest effect on the stream. Geologic sources of solutes are indicated by the loading of most major ions. The most distinct increases from geologic sources occurred at Burr Fork, Brigham Fork, Freeze Creek, Blacksmith Hollow, the fault in Perkins Flat, Emigration Tunnel Spring, and Wagner Spring (within the culvert). A gradual increase in major ion loading occurred between Freeze Creek and Pioneer Gulch. Anthropogenic sources of solutes are indicated by the loading of particular trace elements, and two distinct patterns occurred. Loading of lithium, which should only have anthropogenic sources in Emigration Canyon, indicated that Burr Fork, Brigham Fork, Maple Grove, Blacksmith Hollow, and the Emigration Tunnel Spring were the greatest contributors. The area of gradual increase between Freeze Creek and Pioneer Gulch also contributed substantial loads of lithium. Higher instream chromium concentration also indicated possible anthropogenic sources from Burr Fork and between 8,440 and 8,663 m, downstream from Rattlesnake Point. The loading pattern of manganese differed from that of lithium. Some locations like Blacksmith Hollow and Burr Fork were in common, but other locations were distinct for manganese loading in Perkins Flat.

Loading of nitrate indicated multiple sources, but each increase was followed by a decrease that likely occurred through reactive uptake. The pattern of nitrate loading did not correspond to the patterns of major ions or trace elements. Variation of $\delta^{15}\text{N}$ was consistent, but not definitive with the influence of septic sources of nitrogen. The greatest loading of *E. coli* occurred in the downstream part of the study reach, near Rattlesnake Point, but smaller loads also occurred in Killyon Canyon, at Burr Fork, and in Perkins Flat. A gradual increase in load occurred from Brigham Fork through Pioneer

Gulch. These locations corresponded to some, but not all, of the observed loading of nitrate.

Considering the detailed loading profiles of major ions, trace elements, nitrate, and *E. coli* together helps indicate many sources along the study reach. Loading of nitrate and *E. coli* occurred independently from the loading of major ions and most trace elements so it most likely does not represent the well defined geologic inputs. However, no clear tie to older septic systems was indicated by the results.

References Cited

- Ball, J.W., and Nordstrom, D.K., 1991, User's manual for WATEQ4F, with revised thermodynamic data base and test cases for calculating speciation of major, trace, and redox elements in natural waters: U.S. Geological Survey Open-File Report 91-183, 189 p.
- Barber, L.B., Murphy, S.F., Verplanck, P.L., Sandstrom, M.W., Taylor, H.E., and Furlong, E.T., 2006, Chemical loading into surface water along a hydrological, biogeochemical, and land use gradient: A holistic watershed approach: *Environmental Science & Technology*, v. 40, no. 2, p. 475-486.
- Bencala, K.E., and McKnight, D.M., 1987, Identifying instream variability: Sampling iron in an acidic stream, *in* Averett, R.C. and McKnight, D.M., eds., *Chemical Quality of Water and the Hydrologic Cycle*: Chelsea, Mich., Lewis Publishers, Inc., p. 255-269.
- Brinton, T.I., Antweiler, R.C., and Taylor, H.E., 1996, Method for the determination of dissolved chloride, nitrate, and sulfate in natural water using ion chromatography: U.S. Geological Survey Open-File Report 95-426A, 16 p.
- Bryant, B., 1990, Geologic map of the Salt Lake City 30' x 60' quadrangle, north-central Utah, and Uinta County, Wyoming: U.S. Geological Survey IMAP 1944, scale 1:100,000.
- Davis, J.C., 2002, *Statistics and data analysis in geology* (3d ed.): New York, John Wiley & Sons, Inc., 638 p.
- Flury, M., and Papritz, A., 1993, Bromide in the natural environment: Occurrence and toxicity: *Journal of Environmental Quality*, v. 22, no. 4, p. 747-758.
- Friedman, L.C., and Erdmann, D.E., 1982, Quality assurance practices for the chemical and biological analyses of water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations book 5, chap. A6, 181 p.
- Giddings, E.M., 2000, Water quality and macroinvertebrate communities of Emigration and Red Butte Creeks, Salt Lake County, Utah: U.S. Geological Survey Fact Sheet 161-00, 6 p.
- Jensen, S.F., Norton, C., and Collings, K.J., 2003, Emigration watershed non-point pollution assessment: Coliform bacteria water quality analysis: Salt Lake City, Utah, Salt Lake County Department of Public Works, Engineering Division, 28 p.
- Kaufman, L., and Rousseeuw, P.J., 1990, *Finding groups in data: An introduction to cluster analysis*: New York, Wiley, 368 p.
- Kendall, C., 1998, Tracing nitrogen sources and cycling in catchments, *in* Kendall, C., and McDonnell, J.J., eds., *Isotope tracers in catchment hydrology*: New York, Elsevier, p. 519-576.
- Kilpatrick, F.A., and Cobb, E.D., 1985, Measurement of discharge using tracers: U.S. Geological Survey Techniques of Water-Resources Investigations Report, book 3, chap. A16, 27 p.
- Kimball, B.A., Bencala, K.E., and Runkel, R.L., 2000, Quantifying effects of metal loading from mine drainage, *in* International Conference on Acid Rock Drainage, 5th, Englewood, Colo., May 13-15, 2000, Proceedings: Englewood, Colo., Society for Mining, Metallurgy, and Exploration, Inc., p. 1381-1389.
- Kimball, B.A., Callender, E., and Axtmann, E.V., 1995, Effects of colloids on metal transport in a river receiving acid mine drainage, upper Arkansas River, Colorado, U.S.A.: *Applied Geochemistry*, v. 10, p. 285-306.
- Kimball, B.A., Nimick, D.A., Gerner, L.J., and Runkel, R.L., 1999, Quantification of metal loading in Fisher Creek by tracer injection and synoptic sampling, Park County, Montana, August 1997: U.S. Geological Survey Water-Resources Investigations Report 99-4119, 40 p.
- Kimball, B.A., Nordstrom, D.K., Runkel, R.L., Vincent, K.R., and Verplanck, P.L., 2006, Questa baseline and pre-mining ground-water quality investigation. 23. Quantification of mass loading from mined and unmined areas along the Red River, New Mexico: U.S. Geological Survey Scientific Investigations Report 2006-5004, 53 p.
- Kimball, B.A., Runkel, R.L., and Gerner, L.J., 2001, Quantification of mine-drainage inflows to Little Cottonwood Creek, Utah, using a tracer-injection and synoptic-sampling study: *Environmental Geology*, v. 40, p. 1390-1404.
- Kimball, B.A., Runkel, R.L., and Walton-Day, K., 2003, Use of field-scale experiments and reactive solute-transport modelling to evaluate remediation alternatives in streams affected by acid mine drainage, *in* Jambor, J.L., Blowes, D.W., and Ritchie, A.I.M., eds., *Environmental aspects of mine wastes*: Vancouver, British Columbia, Mineralogical Association of Canada, p. 261-282.

- Kimball, B.A., Runkel, R.L., Walton-Day, K., and Bencala, K.E., 2002, Assessment of metal loads in watersheds affected by acid mine drainage by using tracer injection and synoptic sampling: Cement Creek, Colorado, U.S.A.: *Applied Geochemistry*, v. 17, no. 9, p. 1183-1207.
- Lichte, F.E., Golightly, D.W., and Lamothe, P.J., 1987, Inductively coupled plasma-atomic emission spectrometry, *in* Baedecker, P.A., ed., *Methods for geochemical analysis: U.S. Geological Survey Bulletin 1770*, p. B1-B10.
- McKinnon, T.E., 2002, Sources and seasonal variability of metal and arsenic concentrations in the surface water of the Clark Fork River Basin, Montana: Missoula, University of Montana, Master of Science thesis, 115 p.
- Runkel, R.L., and Kimball, B.A., 2002, Evaluating remedial alternatives for an acid mine drainage stream: Application of a reactive transport model: *Environmental Science & Technology*, v. 36, no. 5, p. 1093-1101.
- Runkel, R.L., Kimball, B.A., Walton-Day, K., and Verplanck, P.L., 2007, A simulation-based approach for estimating premining water quality: Red Mountain Creek, Colorado: *Applied Geochemistry*, v. 22, p. 1899-1918.
- Taylor, J.R., 1997, *An introduction to error analysis: The study of uncertainties in physical measurements (2d ed.)*: Sausalito, Calif., University Science Books, 327 p.
- Utah Department of Administrative Services, 2005, Standards of quality for waters of the state: Division of Administrative Rules, Rule R317-2, accessed April 7, 2005, at <http://www.rules.utah.gov/publicat/code/r317/r317-002.htm>
- Willden, G.D., 2006, Loading and attenuation of fecal indicator bacteria in Emigration Creek: Salt Lake City, University of Utah, Master of Science thesis, 105 p.
- Winter, M., 1993, Webelements Periodic Table, accessed on October 24, 2006, at <http://webelements.com/>

24 Principal Locations of Major-Ion, Trace-Element, Nitrate, and *Escherichia coli* Loading to Emigration Creek

Table 2. Concentration of major ions in stream and inflow samples collected from Emigration Creek, Utah, October 12, 2005.

[Distance, in meters downstream from beginning of study reach; Sample source: S, stream; RBI, right-bank inflow; LBI: left-bank inflow; QA, quality-assurance blank; Filter: F, filtered, both acidified for metals and unacidified for anions; RA, unfiltered, acidified; pH, in standard units; all chemical concentrations reported in milligrams per liter; <, less than; MDL, method detection limit]

Distance	Sample source	Sample time	Filter	pH	Calcium	Magnesium	Sodium	Potassium	Alkalinity as CaCO ₃	Sulfate	Chloride	Nitrate	Silica
0	S	9:25	F	8.22	80.4	10.7	11.8	0.84	236	20.8	11.1	0.01	11.5
0	S	9:25	RA		80.5	10.5	11.8	.84		21.2			11.6
1	S	9:35	F	8.39	83.3	11.5	15.3	1.08	238	21.8		< .01	12.4
1	S	13:15	RA	8.34	81.3	11.2	15.2	1.05		21.7		.12	12.2
133	S	9:40	F	8.38	80.8	11.5	23.6	1.14	238	21.3	16.3	.01	12.2
133	S	9:40	RA		82.4	11.8	23.4	1.13		21.5			12.2
314	S	9:47	F	8.48	82.1	11.5	24.1	1.15	238	21.5	16.7	.02	12.0
314	S	9:47	RA		80.5	11.3	23.9	1.18		21.6			11.9
375	RBI	9:55	F	8.48	95.8	21.8	42.0	.98	261	71.4	60.1	.02	10.6
375	RBI	9:55	RA		93.9	21.9	41.1	.99		70.3			10.2
426	S	10:00	F	8.45	93.8	19.3	39.8	1.14	257	56.1	50.6	< .01	11.4
426	S	10:00	RA		93.8	19.8	39.3	1.10		52.7			10.8
821	S	10:08	F	8.51	88.0	17.2	39.6	1.05	256	52.4	52.7	< .01	10.9
982	S	14:05	F	8.46	87.1	17.1	41.8	1.25	259	53.1	54.5	.04	11.1
982	S	14:05	RA		90.9	19.2	42.8	1.09		55.2			11.4
982	S	17:08	F	8.52	85.8	17.2	41.6	1.23	259	52.8	54.2	.04	11.0
1,297	S	10:24	F	8.53	91.4	19.2	42.8	1.15	259	55.5	54.2	< .01	11.1
1,297	S	10:24	RA		89.3	18.8	42.7	1.15		55.3			11.4
1,590	RBI	10:40	F	7.17	213	45.2	155	2.30	307	51.6	488	.36	12.9
1,590	RBI	10:40	RA		216	44.3	156	2.24		52.0			12.8
1,606	S	10:55	F	8.52	88.0	18.8	41.5	1.09	254	54.3	54.4	< .01	11.2
1,769	S	11:05	F	8.46	91.0	19.2	43.7	1.24	255	55.8	53.7	.02	11.0
1,769	S	11:05	RA		88.8	18.7	42.8	1.16		55.2			11.3
1,908	S	11:09	F	8.48	87.9	19.1	42.2	1.22	251	55.0	54.1	< .01	11.4
1,908	S	11:09	RA		90.7	20.0	43.3	1.07		49.9			10.1
2,083	S	11:17	F	8.48	88.2	19.1	43.5	1.23	252	55.6	54.1	.03	11.6
2,083	S	11:17	RA		90.0	18.9	43.4	1.29		55.8			11.5
2,288	S	11:25	F	8.40	90.0	19.2	43.1	1.27	249	55.7	54.7	< .01	11.2
2,288	S	11:25	RA		87.2	18.6	42.7	1.23		54.6			11.2
2,500	S	11:30	F	8.49	87.3	18.9	43.2	1.25	247	54.8	55.8	.04	11.4
2,500	S	11:30	RA		90.2	19.6	44.5	1.28		55.9			11.5
2,655	RBI	11:35	F	8.39	103	25.0	37.2	1.67	285	64.6	58.1	< .01	20.4
2,655	RBI	11:35	RA		102	24.2	36.7	1.67		64.1			20.3
2,719	S	11:40	F	8.35	90.3	18.8	49.4	1.33	258	55.4	70.3	< .01	12.2
2,719	S	11:40	RA		90.9	19.5	50.1	1.45		56.2			12.8
3,122	S	11:50	F	8.43	89.8	18.7	50.5	1.45	257	54.7	74.4	< .01	12.0
3,122	S	11:50	RA		88.1	18.1	48.9	1.41		53.2			11.8
3,122	S	14:12	F	8.35	90.7	19.6	50.5	1.34	253	55.3	73.1	< .01	12.3
3,122	S	17:15	F	8.43	89.0	18.4	50.3	1.47	251	53.8	73.6	< .01	12.0
3,122	S	17:15	RA		88.1	18.5	49.2	1.45		54.2			12.0
3,137	RBI	11:55	F	8.23	154	38.5	91.4	2.21	270	64.0	286	< .01	23.0
3,137	RBI	11:55	RA		157	37.5	93.1	2.22		64.3			23.0
3,250	S	12:08	F	8.43	93.5	20.4	52.8	1.42	255	56.0	79.6	.02	12.6
3,250	S	12:08	RA		94.7	19.8	52.7	1.49		56.7			12.8
3,250	S	12:10	F	8.44	96.2	20.9	53.8	1.54	256	57.7	80.7	.01	13.0
3,250	S	12:10	RA		92.9	20.2	52.4	1.41		56.7			13.0

Table 2. Concentration of major ions in stream and inflow samples collected from Emigration Creek, Utah, October 12, 2005—Continued.

Distance	Sample source	Sample time	Filter	pH	Calcium	Magnesium	Sodium	Potassium	Alkalinity as CaCO ₃	Sulfate	Chloride	Nitrate	Silica
3,518	S	12:22	F	8.24	97.0	20.3	61.8	1.48	262	54.8	105	< .01	12.8
3,518	S	12:22	RA		96.6	20.8	62.5	1.43		54.8			12.5
3,781	S	12:30	RA		98.5	21.1	64.1	1.47		56.2			13.0
4,007	S	12:37	F	8.38	103	22.3	67.2	1.66	262	56.7	112	.01	13.3
4,007	S	12:37	RA		100	21.7	65.5	1.57		55.9			12.6
4,189	S	12:43	F	8.36	98.1	20.5	65.2	1.59	265	53.0	117	.03	12.6
4,189	S	12:43	RA		101	21.6	67.2	1.61		54.5			12.8
4,385	S	12:50	F	8.40	97.7	20.6	65.2	1.64	263	53.2	117	< .01	12.6
4,385	S	12:50	RA		100	21.8	67.6	1.60		54.8			12.2
4,614	S	12:56	F	8.46	101	21.3	69.9	1.53	265	54.8	120	.02	13.1
4,614	S	12:56	RA		103	22.0	70.2	1.64		55.7			13.2
4,805	S	13:00	F	8.41	103	22.6	72.2	1.71	264	55.9	123	.01	13.4
4,805	S	13:00	RA		102	22.3	69.7	1.73		55.2			12.9
4,820	LBI	13:10	F	8.38	79.8	24.2	22.9	1.59	295	26.2	21.9	.15	17.4
4,820	LBI	13:10	RA		87.7	24.8	24.2	2.23		27.2			29.9
5,112	S	13:20	F	8.19	112	24.0	74.0	1.73	268	55.6	138	.02	13.8
5,112	S	13:20	RA		110	23.4	73.7	1.70		56.0			13.9
5,409	S	13:28	F	8.24	107	23.0	72.2	1.89	271	53.4	139	.01	13.6
5,409	S	13:28	RA		112	23.4	74.3	1.85		55.5			14.0
5,554	S	13:37	F	8.10	112	24.6	77.1	1.89	276	54.8	137	.04	15.1
5,554	S	13:37	RA		108	23.9	74.7	1.74		53.4			14.6
5,852	S	13:48	F	8.24	116	24.9	79.8	1.93	280	55.1	145	.04	15.5
6,136	S	13:58	F	8.28	110	23.8	77.4	1.84	279	53.0	146	.02	15.1
6,136	S	13:58	RA		107	23.8	75.9	1.74		51.6			14.5
6,274	S	14:04	F	8.14	117	26.0	81.3	1.98	281	54.9	156	.08	15.7
6,449	S	14:13	F	8.10	119	26.8	85.7	2.11	287	55.6	164		16.0
6,449	S	14:13	RA		116	24.8	84.0	2.00		54.4			15.8
6,605	S	11:08	F	8.22	115	27.1	83.2	2.01	291	53.2	160	.06	15.4
6,605	S	17:22	F	8.29	113	26.4	81.7	1.95	294	52.4	160	.07	15.2
6,605	S	17:22	RA		117	25.1	85.4	1.97		54.7			15.8
6,794	S	14:30	F	8.18	118	27.4	84.6	2.06	292	55.2	166	.06	15.9
6,794	S	14:30	RA		116	26.9	83.8	1.97		53.8			15.3
6,939	S	14:40	F	8.19	120	27.3	86.2	2.13	292	55.2	167	.05	16.2
6,939	S	14:40	RA		118	25.4	84.2	1.98		55.2			15.9
7,119	S	14:50	F	8.27	118	26.4	85.9	2.07	293	54.6	166	.03	15.6
7,119	S	14:50	RA		117	25.6	84.2	2.04		54.0			15.5
7,284	S	14:58	F	8.29	120	27.1	85.0	2.04	295	54.2	167	.06	15.6
7,284	S	14:58	RA		118	25.4	85.6	2.01		55.2			15.6
7,464	S	15:07	F	8.33	118	26.4	85.7	1.98	289	55.1	167	.03	15.7
7,464	S	15:07	RA		121	27.4	87.2	2.14		55.3			16.1
7,651	S	15:13	F	8.36	118	27.2	86.8	2.13	272	54.7	166	.04	15.7
7,651	S	15:13	RA		116	25.4	85.3	1.99		55.0			15.4
7,651	S	15:15	F	8.39	117	27.0	85.6	2.03	284	55.4	166	.04	15.5
7,651	S	15:15	RA		117	27.5	85.5	2.18		55.3			15.8
7,931	S	15:22	F	8.41	118	27.7	86.8	2.18	270	55.8	162	.02	15.8
8,092	S	15:32	F	8.46	114	25.1	86.3	2.08	261	55.2	163	.04	15.3
8,092	S	15:32	RA		116	27.4	86.0	2.16		55.2			15.8
8,440	S	15:42	F	8.45	114	27.4	86.8	2.25	270	55.2	163	.04	15.4

Table 2. Concentration of major ions in stream and inflow samples collected from Emigration Creek, Utah, October 12, 2005—Continued.

Distance	Sample source	Sample time	Filter	pH	Calcium	Magnesium	Sodium	Potassium	Alkalinity as CaCO ₃	Sulfate	Chloride	Nitrate	Silica
8,663	S	15:49	F	8.45	111	27.4	87.1	2.29	266	55.0	162	.01	15.5
8,904	S	15:58	F	8.39	108	27.1	85.6	2.19	266	54.8	162	.02	15.4
8,904	S	15:58	RA		108	26.8	85.0	2.21		54.8			15.5
9,065	S	16:13	F	8.44	107	27.1	85.6	2.37	262	55.0	163	.06	15.6
9,065	S	16:13	RA		106	26.9	84.0	2.15		54.5			15.1
9,298	S	16:23	F	8.28	102	26.7	83.1	2.15	259	53.9	163	.03	15.0
9,563	S	16:32	F	8.23	100	27.4	85.9	2.31	246	55.2	163.	< .01	15.4
9,563	S	16:32	RA		100	27.5	85.4	2.19		54.6			15.3
9,772	S	16:40	F	8.22	95.9	25.1	86.0	2.06	245	54.3	165	.01	15.2
9,772	S	16:40	RA		96.5	27.1	85.0	2.14		54.2			15.1
10,024	S	16:48	F	8.26	93.2	26.8	85.7	2.17	234	54.6	165	.01	15.2
10,024	S	16:48	RA		91.8	25.7	84.3	2.10		53.8			15.0
10,160	S	16:58	F	8.35	93.7	26.1	86.8	2.23	233	55.1	164	.04	15.4
10,160	S	16:58	RA		92.3	27.1	85.6	2.20		54.7			15.5
10,175	LBI	17:00	F	7.52	142	35.8	33.6	1.75	248	195	79.5	.33	15.4
10,175	LBI	17:00	RA		139	35.9	32.9	1.64		195			15.4
10,352	S	17:08	F	8.35	93.2	27.6	85.0	2.18	230	57.5	164	< .01	15.2
10,352	S	17:10	F	8.34	94.0	26.3	84.7	2.08	229	56.6	164	.01	15.3
10,352	S	17:10	RA		93.6	27.8	86.7	2.27		57.8			15.4
10,541	RBI	17:20	F	8.30	81.9	24.2	15.1	.99	227	77.2	19.4	.12	14.0
10,541	RBI	17:20	RA		79.8	22.5	14.7	.90		75.7			13.6
10,626	S	17:32	F	8.01	110	28.2	56.0	1.81	245	102	114	.16	14.4
10,626	S	17:32	RA		110	27.6	57.5	1.67		103			14.6
10,633	RBI	17:35	F	7.53	102	27.4	25.4	1.34	282	84.1	34.27	.10	16.2
10,883	LBI	17:50	F	7.34	162	38.4	72.9	1.90	266	190	175	.83	15.6
10,883	LBI	17:50	RA		175	40.4	75.6	2.57		195			28.2
10,910	S	17:56	F	8.06	113	27.2	57.2	1.79	251	104	114	.12	14.6
10,910	S	17:56	RA		155	30.1	59.2	3.38		111			46.1
11,174	S	18:00	F	8.23	114	27.7	58.0	1.79	254	107	115	.16	14.9
11,174	S	18:00	RA		128	29.6	58.7	2.45		107			29.8
	QA	15:00	F		<MDL	<MDL	<MDL	<MDL	3.84	<MDL	<MDL	< .01	<MDL
	QA	15:00	RA		<MDL	<MDL	<MDL	<MDL		<MDL			< MDL

28 Principal Locations of Major-Ion, Trace-Element, Nitrate, and *Escherichia coli* Loading to Emigration Creek

Table 3. Concentration of trace elements in stream and inflow samples collected from Emigration Creek, Utah, October 12, 2005.

[Distance, in meters downstream from beginning of study reach; Sample source: S, stream; RBI, right-bank inflow; LBI, left-bank inflow; QA, quality-assurance blank; Filter: FA, filtered, acidified; RA, unfiltered, acidified; concentrations reported in micrograms per liter; <, less than]

Distance	Sample source	Filter	Time	Aluminum	Arsenic	Barium	Cadmium	Cobalt	Chromium	Copper	Iron	Lead
0	S	FA	9:25	10.7	0.54	61.7	<0.019	0.022	0.043	0.259	8.68	0.046
0	S	RA	9:25	21.7	.52	61.1	<.019	.024	.056	.224	16.2	.042
1	S	FA	9:35	14.1	.61	67.1	<.019	.024	.029	.299	11.6	.032
1	S	RA	13:15	21.1	.56	68.6	<.019	.026	.037	.228	21.5	.044
133	S	FA	9:40	10.2	.56	67.2	<.019	.023	.026	.250	10.8	.042
133	S	RA	9:40	26.5	.60	66.8	<.019	.028	.046	.249	26.9	.061
314	S	FA	9:47	12.2	.66	66.2	<.019	.027	.026	.256	9.60	.030
314	S	RA	9:47	32.1	.66	65.6	<.019	.036	.056	.284	30.8	.078
375	RBI	FA	9:55	11.5	.65	82.3	<.019	.035	.236	.330	13.1	.028
375	RBI	RA	9:55	32.0	.66	83.1	<.019	.045	.287	.379	39.5	.075
426	S	FA	10:00	29.3	.72	80.7	<.019	.032	.202	.594	13.5	.066
426	S	RA	10:00	27.9	.69	79.4	<.019	.041	.206	.337	35.5	.064
821	S	FA	10:08	14.4	.67	76.6	<.019	.032	.163	.355	12.9	.030
982	S	FA	14:05	18.7	.67	79.2	<.019	.036	.172	.390	13.6	.036
982	S	RA	14:05	19.8	.72	78.6	<.019	.040	.188	.401	27.1	.049
982	S	FA	17:08	15.5	.72	81.5	<.019	.034	.366	.397	14.0	.030
1,297	S	FA	10:24	34.2	.71	81.8	<.019	.034	.188	.368	11.3	.057
1,297	S	RA	10:24	21.1	.67	78.6	<.019	.039	.177	.333	28.6	.069
1,590	RBI	FA	10:40	11.2	3.94	396	<.019	.044	.098	14.2	28.5	.034
1,590	RBI	RA	10:40	14.7	2.08	376	<.019	.041	.234	16.7	146	.079
1,606	S	FA	10:55	16.1	.69	80.2	<.019	.033	.186	.367	9.24	.035
1,769	S	FA	11:05	11.9	.67	78.4	<.019	.033	.169	.400	8.71	.032
1,769	S	RA	11:05	25.0	.67	77.8	<.019	.035	.173	.354	21.3	.051
1,908	S	FA	11:09	16.1	.67	77.8	<.019	.029	.164	.369	8.48	.043
1,908	S	RA	11:09	23.4	.73	77.5	<.019	.034	.183	.355	21.1	.060
2,083	S	FA	11:17	18.6	.65	78.9	<.019	.031	.160	.438	9.11	.054
2,083	S	RA	11:17	23.4	.77	78.6	<.019	.034	.191	.374	19.7	.058
2,288	S	FA	11:25	12.9	.64	77.8	<.019	.030	.169	.429	12.0	.051
2,288	S	RA	11:25	23.9	.71	77.9	<.019	.034	.183	.381	19.0	.054
2,500	S	FA	11:30	10.7	.71	78.4	<.019	.030	.162	.413	6.44	.037
2,500	S	RA	11:30	26.0	.72	79.2	<.019	.038	.194	.408	20.1	.057
2,655	RBI	FA	11:35	16.6	1.23	125	<.019	.049	.027	.301	5.98	.038
2,655	RBI	RA	11:35	57.6	1.29	124	<.019	.068	.070	.292	41.7	.069
2,719	S	FA	11:40	17.9	.83	90.7	<.019	.041	.159	.481	7.04	.044
2,719	S	RA	11:40	5,840	.78	87.6	<.019	.047	.177	.453	26.2	.066
3,122	S	FA	11:50	13.9	.79	86.8	<.019	.036	.163	.490	9.80	.041
3,122	S	RA	11:50	30.0	.76	86.8	<.019	.043	.167	.465	23.2	.073
3,122	S	FA	14:12	14.2	.79	88.5	<.019	.038	.147	.517	6.50	.040
3,122	S	FA	17:15	14.1	.73	86.8	<.019	.035	.341	.533	8.06	.041
3,122	S	RA	17:15	26.6	.80	88.1	<.019	.041	.423	.489	19.2	.063
3,137	RBI	FA	11:55	13.4	1.38	232	<.019	.116	.037	.425	7.31	.043
3,137	RBI	RA	11:55	31.2	1.38	234	<.019	.121	.086	.408	23.3	.073
3,250	S	FA	12:08	3.75	.83	92.8	<.019	.038	.129	.452	10.1	.027
3,250	S	RA	12:08	37.0	.76	91.6	<.019	.054	.181	.478	32.3	.100
3,250	S	FA	12:10	592	.82	95.2	<.019	.045	.153	.495	7.73	.041
3,250	S	RA	12:10	34.9	.72	92.1	<.019	.050	.162	.451	28.3	.082
3,518	S	FA	12:22	11.0	.82	103	<.019	.049	.149	.491	12.9	.048
3,518	S	RA	12:22	27.6	.82	102	<.019	.057	.159	.470	33.0	.072
3,781	S	FA	12:30	14.1	.85	99.9	<.019	.045	.123	.483	13.0	.038
3,781	S	RA	12:30	26.1	.86	103	<.019	.055	.160	.498	27.3	.079
4,007	S	FA	12:37	14.2	.90	106	<.019	.050	.146	.542	15.8	.041
4,007	S	RA	12:37	26.5	.81	106	<.019	.056	.163	.472	31.4	.068
4,189	S	FA	12:43	13.7	.92	109	<.019	.052	.124	.477	18.5	.040
4,189	S	RA	12:43	26.8	.79	109	<.019	.058	.156	.486	39.3	.073
4,385	S	FA	12:50	14.0	.85	109	<.019	.055	.127	.564	18.3	.035
4,385	S	RA	12:50	26.2	.90	108	<.019	.059	.160	.500	67.3	.060
4,614	S	FA	12:56	12.8	.93	115	<.019	.052	.121	.548	16.7	.038

Table 3. Concentration of trace elements in stream and inflow samples collected from Emigration Creek, Utah, October 12, 2005—Continued.

Distance	Sample source	Filter	Time	Lithium	Manga-nese	Molybde-num	Nickel	Silver	Strontium	Uranium	Vanadium	Zinc
0	S	FA	9:25	5.80	8.07	<0.177	0.169	<0.022	302	0.430	0.678	1.06
0	S	RA	9:25	5.36	8.75	.183	.101	<.022	303	.441	.688	.687
1	S	FA	9:35	6.98	7.74	.765	.149	.033	317	.451	.732	.783
1	S	RA	13:15	6.66	8.10	<.177	.116	<.022	313	.460	.729	.715
133	S	FA	9:40	6.82	9.83	<.177	.129	<.022	314	.464	.653	1.28
133	S	RA	9:40	6.74	10.7	<.177	.131	<.022	311	.458	.670	1.11
314	S	FA	9:47	7.40	6.80	<.177	.150	<.022	322	.453	.655	.383
314	S	RA	9:47	6.98	8.48	<.177	.149	<.022	317	.447	.691	1.37
375	RBI	FA	9:55	7.11	10.1	.210	.185	<.022	491	.833	.927	.375
375	RBI	RA	9:55	7.07	11.0	.306	.207	<.022	517	.839	1.02	1.37
426	S	FA	10:00	7.46	13.1	.188	.161	<.022	457	.745	.898	.896
426	S	RA	10:00	7.59	13.5	.216	.184	<.022	434	.722	.925	.987
821	S	FA	10:08	7.45	14.4	.191	.159	<.022	419	.687	.832	.200
982	S	FA	14:05	8.06	15.6	.294	.198	<.022	437	.714	.928	1.17
982	S	RA	14:05	7.88	16.7	.303	.182	<.022	438	.673	.944	1.22
982	S	FA	17:08	8.00	15.2	.308	.216	<.022	435	.712	.968	.475
1,297	S	FA	10:24	8.02	11.6	.239	.299	<.022	457	.711	.866	.385
1,297	S	RA	10:24	7.76	11.9	.296	.193	<.022	437	.728	.854	.653
1,590	RBI	FA	10:40	38.7	2.38	<.177	.369	<.022	1,100	2.16	2.84	2.88
1,590	RBI	RA	10:40	37.0	1.65	<.177	.357	<.022	1,060	2.09	2.93	2.51
1,606	S	FA	10:55	8.16	7.09	.447	.201	<.022	450	.717	.885	.791
1,769	S	FA	11:05	8.21	6.05	.291	.212	<.022	445	.713	.873	.722
1,769	S	RA	11:05	7.76	6.54	.282	.181	<.022	434	.722	.863	.618
1,908	S	FA	11:09	7.71	4.39	.223	.189	<.022	426	.712	.818	.471
1,908	S	RA	11:09	7.64	4.73	.270	.190	<.022	435	.742	.856	.599
2,083	S	FA	11:17	7.87	3.52	.235	.217	<.022	426	.729	.846	.310
2,083	S	RA	11:17	7.78	3.70	.319	.192	<.022	443	.733	.858	.935
2,288	S	FA	11:25	7.69	2.94	.231	.211	<.022	431	.724	.846	.532
2,288	S	RA	11:25	7.83	3.38	.281	.201	<.022	437	.707	.852	.823
2,500	S	FA	11:30	7.89	2.25	.290	.194	<.022	436	.730	.866	.310
2,500	S	RA	11:30	8.12	2.74	.322	.192	<.022	442	.736	.881	1.07
2,655	RBI	FA	11:35	14.7	5.45	<.177	.295	<.022	688	.853	.915	.403
2,655	RBI	RA	11:35	14.5	6.41	.217	.307	<.022	710	.862	1.02	.834
2,719	S	FA	11:40	9.69	2.65	.340	.238	<.022	500	.790	.992	.370
2,719	S	RA	11:40	9.07	3.50	.292	.225	<.022	474	.780	.972	1.84
3,122	S	FA	11:50	9.53	1.56	.310	.260	<.022	485	.769	.975	.275
3,122	S	RA	11:50	9.37	2.31	.302	.194	<.022	473	.776	.993	.809
3,122	S	FA	14:12	9.40	1.67	.311	.240	<.022	484	.781	.988	.394
3,122	S	FA	17:15	9.20	1.57	.313	.191	<.022	467	.746	1.01	.302
3,122	S	RA	17:15	9.31	2.08	.322	.208	<.022	472	.766	1.06	.666
3,137	RBI	FA	11:55	25.0	11.1	.241	.875	<.022	1,130	1.46	1.34	.372
3,137	RBI	RA	11:55	25.4	12.2	.260	.877	<.022	1,140	1.39	1.40	1.18
3,250	S	FA	12:08	9.61	2.45	.277	.246	<.022	496	.756	1.00	.274
3,250	S	RA	12:08	9.39	3.31	.316	.240	<.022	505	.817	1.05	.901
3,250	S	FA	12:10	10.1	3.17	.332	.258	<.022	520	.819	1.01	.364
3,250	S	RA	12:10	9.43	3.59	.296	.245	<.022	482	.786	.995	.790
3,518	S	FA	12:22	11.0	5.02	.284	.281	<.022	523	.821	1.07	3.88
3,518	S	RA	12:22	11.0	6.15	.347	.261	<.022	530	.806	1.10	1.20
3,781	S	FA	12:30	10.6	4.71	.258	.232	<.022	505	.803	1.03	.688
3,781	S	RA	12:30	11.0	5.18	1.10	.269	<.022	533	.839	1.08	1.21
4,007	S	FA	12:37	11.4	5.18	.260	.258	<.022	534	.839	1.09	2.87
4,007	S	RA	12:37	10.8	5.54	.415	.271	<.022	527	.828	1.11	.977
4,189	S	FA	12:43	11.8	8.04	.289	.276	<.022	536	.836	1.07	.311
4,189	S	RA	12:43	11.5	8.65	.333	.272	<.022	552	.847	1.13	.996
4,385	S	FA	12:50	12.5	7.18	.395	.300	<.022	570	.810	1.12	.450
4,385	S	RA	12:50	12.2	8.90	.368	.290	<.022	560	.770	1.15	.820
4,614	S	FA	12:56	12.5	6.68	.372	.301	<.022	575	.868	1.13	.423

Table 3. Concentration of trace elements in stream and inflow samples collected from Emigration Creek, Utah, October 12, 2005—Continued.

Distance	Sample source	Filter	Time	Aluminum	Arsenic	Barium	Cadmium	Cobalt	Chromium	Copper	Iron	Lead
4,614	S	RA	12:56	26.0	.82	110	<.019	.056	.147	.479	35.1	.070
4,805	S	FA	13:00	16.4	.91	115	<.019	.055	.132	.512	24.3	.040
4,805	S	RA	13:00	25.2	.83	114	<.019	.060	.141	.520	44.8	.065
4,820	LBI	FA	13:10	13.3	.59	167	<.019	.033	.058	.598	13.1	.125
4,820	LBI	RA	13:10	2,260	1.32	209	.11	1.66	3.34	24.3	2,540	18.0
5,112	S	FA	13:20	15.4	.97	130	<.019	.065	.104	.535	24.5	.036
5,112	S	RA	13:20	25.9	.80	124	<.019	.069	.128	.479	55.0	.066
5,409	S	FA	13:28	14.0	.92	131	<.019	.063	.110	.554	20.7	.037
5,409	S	RA	13:28	23.9	.94	125	<.019	.066	.138	.515	43.4	.064
5,554	S	FA	13:37	14.9	.94	143	<.019	.059	.103	.536	16.9	.036
5,554	S	RA	13:37	23.3	.90	138	<.019	.063	.125	.514	40.9	.068
5,852	S	FA	13:48	14.2	1.00	147	<.019	.060	.115	.590	15.3	.040
6,136	S	FA	13:58	14.5	.84	146	<.019	.059	.102	.588	13.9	.041
6,136	S	RA	13:58	20.7	.89	148	<.019	.062	.127	.569	31.1	.060
6,274	S	FA	14:04	16.4	1.04	155	<.019	.059	.111	.637	13.0	.044
6,449	S	FA	14:13	17.9	1.12	158	<.019	.058	.095	.592	13.2	.041
6,449	S	RA	14:13	22.6	.81	157	<.019	.062	.120	.535	33.4	.082
6,605	S	FA	11:08	18.5	.99	160	<.019	.064	.101	.631	36.3	.055
6,605	S	FA	17:22	15.0	.91	159	<.019	.060	.230	.571	16.4	.037
6,605	S	RA	17:22	22.9	.93	160	<.019	.065	.347	.574	36.6	.063
6,794	S	FA	14:30	17.2	1.43	163	<.019	.071	.091	.621	26.5	.044
6,794	S	RA	14:30	33.7	.95	160	<.019	.085	.134	.601	79.1	.099
6,939	S	FA	14:40	15.5	.94	157	<.019	.072	.092	.578	26.8	.052
6,939	S	RA	14:40	30.6	.92	169	<.019	.080	.131	.564	83.9	.093
7,119	S	FA	14:50	14.7	1.01	160	<.019	.069	.106	.572	21.9	.041
7,119	S	RA	14:50	28.2	.94	162	<.019	.076	.107	.586	73.1	.080
7,284	S	FA	14:58	16.0	.94	167	<.019	.068	.091	.553	20.1	.041
7,284	S	RA	14:58	23.9	.92	162	<.019	.070	.112	.542	65.2	.071
7,464	S	FA	15:07	14.3	.92	164	<.019	.069	.120	.612	29.6	.035
7,464	S	RA	15:07	20.6	.92	164	<.019	.071	.097	.571	58.0	.054
7,651	S	FA	15:13	14.8	.87	162	<.019	.061	.098	.599	15.7	.071
7,651	S	RA	15:13	25.7	.96	160	<.019	.067	.106	.530	49.0	.064
7,651	S	FA	15:15	13.7	.91	163	<.019	.061	.092	.554	13.9	.034
7,651	S	RA	15:15	23.7	.90	161	<.019	.066	.093	.521	50.0	.059
7,931	S	FA	15:22	16.8	.99	162	<.019	.062	.086	.669	14.3	.055
8,092	S	FA	15:32	13.8	1.08	158	<.019	.064	.092	.621	14.3	.035
8,092	S	RA	15:32	22.6	.96	161	<.019	.067	.097	.535	42.8	.059
8,440	S	FA	15:42	14.1	.91	155	<.019	.057	.083	.619	14.0	.042
8,663	S	FA	15:49	14.9	.89	158	<.019	.058	.303	.613	12.5	.074
8,904	S	FA	15:58	15.7	1.06	153	<.019	.056	.236	.559	11.1	.033
8,904	S	RA	15:58	20.5	.97	150	<.019	.056	.260	.551	28.9	.049
9,065	S	FA	16:13	12.9	1.01	150	<.019	.054	.266	.591	8.58	.039
9,065	S	RA	16:13	21.4	.92	152	<.019	.061	.313	.603	29.5	.058
9,298	S	FA	16:23	13.2	.87	152	<.019	.054	.257	.568	7.27	.038
9,563	S	FA	16:32	14.5	.88	150	<.019	.051	.276	.581	9.23	.032
9,563	S	RA	16:32	15.3	.87	145	<.019	.052	.283	.538	17.4	.036
9,772	S	FA	16:40	16.0	1.00	146	<.019	.052	.256	.654	5.46	.051
9,772	S	RA	16:40	39.8	.86	144	<.019	.066	.346	.582	37.4	.089
10,024	S	FA	16:48	14.4	1.13	142	<.019	.052	.292	.561	4.93	.038
10,024	S	RA	16:48	23.1	.72	140	<.019	.054	.324	.548	20.7	.054
10,160	S	FA	16:58	17.8	.98	143	<.019	.053	.074	.562	5.73	.036
10,160	S	RA	16:58	19.9	.88	142	<.019	.058	.300	.558	16.9	.043
10,175	LBI	FA	17:00	14.2	.34	45.0	<.019	.027	.229	.176	8.27	.360
10,175	LBI	RA	17:00	11.6	.49	42.6	<.019	.025	.347	.104	< 10.48	.383
10,352	S	FA	17:08	17.7	.87	135	<.019	.048	.297	.550	3.94	.040
10,352	S	FA	17:10	255	.78	137	<.019	.052	.416	.928	10.7	.333
10,352	S	RA	17:10	65.4	.85	140	<.019	.054	.236	.611	13.4	.082
10,541	RBI	FA	17:20	12.9	.17	46.5	<.019	.009	.250	.129	< 10.48	.025

Table 3. Concentration of trace elements in stream and inflow samples collected from Emigration Creek, Utah, October 12, 2005—Continued.

Distance	Sample source	Filter	Time	Lithium	Manganese	Molybdenum	Nickel	Silver	Strontium	Uranium	Vanadium	Zinc
4,614	S	RA	12:56	11.5	7.28	.348	.284	<.022	548	.842	1.13	.929
4,805	S	FA	13:00	12.3	7.61	.310	.303	<.022	564	.867	1.09	1.20
4,805	S	RA	13:00	12.5	7.82	.406	.284	<.022	550	.853	1.13	.610
4,820	LBI	FA	13:10	10.5	< 10.35	<.177	.129	<.022	680	.662	2.18	.315
4,820	LBI	RA	13:10	13.2	50.4	1.06	2.43	.075	695	.698	5.96	26.9
5,112	S	FA	13:20	13.4	12.8	.303	.270	<.022	611	.909	1.16	3.55
5,112	S	RA	13:20	12.4	14.0	.347	.314	<.022	571	.861	1.15	1.14
5,409	S	FA	13:28	14.2	8.73	.469	.313	<.022	618	.898	1.26	.726
5,409	S	RA	13:28	12.8	9.93	.371	.296	<.022	593	.880	1.24	1.30
5,554	S	FA	13:37	14.3	7.21	.396	.292	<.022	635	.922	1.54	1.19
5,554	S	RA	13:37	13.1	8.70	.419	.286	<.022	606	.896	1.51	1.26
5,852	S	FA	13:48	13.7	5.89	.392	.331	<.022	605	.944	1.53	4.60
6,136	S	FA	13:58	14.2	4.03	.456	.328	<.022	634	.963	1.58	.952
6,136	S	RA	13:58	13.5	4.13	.494	.299	<.022	611	.938	1.59	1.06
6,274	S	FA	14:04	15.2	3.28	.439	.269	<.022	720	.971	1.69	2.44
6,449	S	FA	14:13	15.5	6.99	.393	.556	<.022	773	.993	1.69	3.62
6,449	S	RA	14:13	14.5	7.12	.489	.320	<.022	736	.942	1.69	.989
6,605	S	FA	11:08	16.0	8.68	.459	.377	<.022	790	.959	1.61	1.04
6,605	S	FA	17:22	15.7	8.13	.461	.348	<.022	774	.949	1.68	1.92
6,605	S	RA	17:22	14.8	9.16	.815	.322	<.022	791	.983	1.73	1.18
6,794	S	FA	14:30	15.9	19.5	.387	.327	<.022	794	.979	1.63	2.88
6,794	S	RA	14:30	15.4	20.5	.458	.341	<.022	781	.962	1.67	.900
6,939	S	FA	14:40	15.2	21.9	.517	.293	<.022	774	.968	1.55	3.19
6,939	S	RA	14:40	15.2	23.5	.639	.356	<.022	801	.949	1.70	.702
7,119	S	FA	14:50	15.7	19.4	.475	.330	<.022	789	.985	1.54	2.31
7,119	S	RA	14:50	15.3	20.8	.474	.332	<.022	801	.973	1.67	3.00
7,284	S	FA	14:58	16.1	16.9	.449	.296	<.022	822	.999	1.62	7.01
7,284	S	RA	14:58	15.7	18.0	.473	.315	<.022	786	.966	1.62	2.35
7,464	S	FA	15:07	15.9	14.6	.415	.370	<.022	808	.950	1.57	.700
7,464	S	RA	15:07	15.9	15.5	.423	.313	<.022	819	.977	1.65	2.09
7,651	S	FA	15:13	15.8	10.5	.444	.332	<.022	807	.977	1.52	3.72
7,651	S	RA	15:13	15.6	11.1	.482	.326	<.022	796	.974	1.53	2.43
7,651	S	FA	15:15	16.0	10.7	.428	.339	<.022	816	.975	1.53	1.17
7,651	S	RA	15:15	15.8	11.0	.414	.315	<.022	811	.967	1.56	1.63
7,931	S	FA	15:22	16.4	8.70	.434	.336	<.022	811	.966	1.51	2.25
8,092	S	FA	15:32	15.9	7.72	.443	.549	<.022	806	.974	1.51	1.47
8,092	S	RA	15:32	15.8	8.10	.414	.303	<.022	810	.979	1.56	1.30
8,440	S	FA	15:42	15.7	4.99	.430	.321	<.022	789	.978	1.52	2.63
8,663	S	FA	15:49	15.8	3.32	.408	.335	<.022	795	.961	1.49	.598
8,904	S	FA	15:58	16.2	1.77	.447	.322	<.022	781	.943	1.50	.733
8,904	S	RA	15:58	15.9	2.42	.637	.299	<.022	769	.952	1.48	.648
9,065	S	FA	16:13	15.6	1.35	.609	.382	<.022	785	.968	1.51	.505
9,065	S	RA	16:13	16.3	1.72	.513	.317	<.022	782	.928	1.51	.654
9,298	S	FA	16:23	15.8	< 10.35	.433	.333	<.022	789	.962	1.52	.935
9,563	S	FA	16:32	15.3	< 10.35	.407	.357	<.022	772	.954	1.47	.487
9,563	S	RA	16:32	15.6	< 10.35	1.09	.304	.025	764	.929	1.50	.403
9,772	S	FA	16:40	16.0	< 10.35	.433	.341	<.022	778	.936	1.50	2.40
9,772	S	RA	16:40	15.8	1.60	.412	.311	<.022	756	.939	1.55	.487
10,024	S	FA	16:48	15.8	< 10.35	.457	.309	<.022	766	.942	1.52	1.52
10,024	S	RA	16:48	15.9	< 10.35	.430	.305	<.022	740	.918	1.51	.379
10,160	S	FA	16:58	16.1	< 10.35	.442	.276	<.022	762	.937	1.51	1.35
10,160	S	RA	16:58	16.7	< 10.35	.449	.303	<.022	769	.921	1.52	.437
10,175	LBI	FA	17:00	14.0	< 10.35	.248	.513	<.022	2,060	.486	.623	2.48
10,175	LBI	RA	17:00	13.3	< 10.35	.296	.221	<.022	1,980	.492	.592	1.69
10,352	S	FA	17:08	14.9	< 10.35	.425	.303	<.022	733	.907	1.40	2.43
10,352	S	FA	17:10	15.8	< 10.35	.431	.317	<.022	773	.892	1.49	1.10
10,352	S	RA	17:10	15.7	< 10.35	.408	.312	<.022	790	.935	1.54	.384
10,541	RBI	FA	17:20	8.51	< 10.35	<.177	.206	<.022	868	.393	.538	.597

Table 3. Concentration of trace elements in stream and inflow samples collected from Emigration Creek, Utah, October 12, 2005—Continued.

Distance	Sample source	Filter	Time	Aluminum	Arsenic	Barium	Cadmium	Cobalt	Chromium	Copper	Iron	Lead
10,541	RBI	RA	17:20	22.4	.18	45.4	<.019	.014	.268	.111	10.3	.047
10,626	S	FA	17:32	14.0	.67	99.7	<.019	.039	.324	.862	9.40	.039
10,626	S	RA	17:32	31.0	.49	85.9	<.019	.044	.911	.387	28.3	.085
10,633	RBI	FA	17:35	13.5	.16	52.5	<.019	.051	.188	.139	10.5	.035
10,883	LBI	FA	17:50	15.3	1.34	43.2	<.019	.081	.309	.093	36.6	.040
10,883	LBI	RA	17:50	2,560	1.38	70.7	.12	1.17	2.79	3.97	2,160	5.84
10,910	S	FA	17:56	20.6	.80	97.1	<.019	.538	.202	.260	11.4	.048
10,910	S	RA	17:56	6,370	2.72	180	.29	3.34	6.21	11.3	5,780	14.3
11,174	S	FA	18:00	18.8	.77	94.5	<.019	.739	.245	.266	8.28	.057
11,174	S	RA	18:00	2,790	1.69	130	.14	1.42	3.07	4.95	2,620	6.14
	QA	FA	15:00	14.7	<.03	<.058	<.019	<.006	.180	.068	< 10.48	.025
	QA	RA	15:00	13.1	<.03	<.058	.02	<.006	.207	.173	< 10.48	.036

Table 3. Concentration of trace elements in stream and inflow samples collected from Emigration Creek, Utah, October 12, 2005—Continued.

Distance	Sample source	Filter	Time	Lithium	Manganese	Molybdenum	Nickel	Silver	Strontium	Uranium	Vanadium	Zinc
10,541	RBI	RA	17:20	8.58	< 10.35	.188	.178	<.022	847	.390	.552	.197
10,626	S	FA	17:32	16.5	< 10.35	1.29	.310	<.022	1,370	.888	1.35	2.64
10,626	S	RA	17:32	14.1	1.98	1.07	.192	<.022	1,160	.755	1.16	1.05
10,633	RBI	FA	17:35	14.3	2.24	.310	.186	<.022	973	.633	.654	2.40
10,883	LBI	FA	17:50	20.7	23.4	.430	.223	<.022	1,920	.995	1.21	1.28
10,883	LBI	RA	17:50	24.4	73.9	.237	2.32	<.022	1,980	1.06	5.05	13.8
10,910	S	FA	17:56	14.7	98.6	1.12	.371	<.022	1,180	.763	1.55	.540
10,910	S	RA	17:56	21.9	249	.486	6.52	.039	1,200	.977	11.6	39.6
11,174	S	FA	18:00	14.7	83.2	1.13	.336	<.022	1,180	.767	1.64	.813
11,174	S	RA	18:00	18.3	137	.811	2.97	.217	1,210	.887	5.95	18.1
	QA	FA	15:00	< .143	< 10.35	<.177	.044	<.022	< 10.35	< .002	.002	.996
	QA	RA	15:00	< .143	< 10.35	<.177	.030	<.022	< 10.35	< .002	.002	.574

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