Characterization of Selenium in the Lower Gunnison River Basin, Colorado, 1988–2000

By David L. Butler and Kenneth J. Leib

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.028317	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound avoirdupois (lb avdp)	0.4536	kilogram (kg)
pound per day (lb/d)	0.9072	kilogram per day
pound per year (lb/yr)	0.9072	kilogram per year

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = 9/5\ °C + 32$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Altitude, as used in this report, refers to distance above sea level.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L). Concentrations in milligrams per liter are commonly expressed as parts per million (ppm), and concentrations in micrograms per liter are commonly expressed as parts per billion (ppb).

ADDITIONAL ABBREVIATIONS

g	gram
L	liter
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius
mg/L	milligrams per liter

ACRONYMS

BOR	Bureau of Reclamation
NIWQP	National Irrigation Water Quality Program
USGS	U.S. Geological Survey
MRL	Minimum reporting limit

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Abstract

Selenium concentrations in certain water bodies in the lower Gunnison River Basin, including the lower Gunnison River and lower Uncompahgre River, have exceeded the Colorado water-quality standard of 5 micrograms per liter for selenium. A task force was formed in 1998 that consists of various government agencies, private irrigation companies, and local residents to address the selenium concerns in the lower Gunnison River Basin. The task force, working with the National Irrigation Water Quality Program, needed more detailed information on selenium loading in the basin to develop viable alternatives for remediating selenium in the lower Gunnison River Basin.

In 1999–2000, the U.S. Geological Survey collected selenium data for tributaries of the Gunnison River downstream from the North Fork of the Gunnison and in the North Fork Basin. The largest selenium load in a tributary stream was in the Uncompahgre River, which accounted for about 38 percent of the selenium load in the Gunnison River at Whitewater. The North Fork of the Gunnison River accounted for about 7 percent of the selenium load in the Gunnison River. Two tributaries east of Delta, Sunflower Drain and Bonafide Ditch, consist primarily of irrigation return flows and were other major selenium sources to the Gunnison River.

Some tributaries in the lower North Fork Basin had selenium concentrations exceeding 5 micrograms per liter. Except for several streams draining the Uncompahgre Plateau, many tributaries to the Gunnison River downstream from the North Fork had selenium concentrations exceeding 5 micrograms per liter. Except during occasional rain and snowmelt events, selenium loading from nonirrigated desert areas was minimal.

Detailed characterization studies were done in 1999–2000 on Cedar Creek and Loutzenhizer Arroyo, which contribute the largest tributary selenium loads to the Uncompahgre River. Selenium concentrations in Cedar Creek downstream from Miguel Road ranged from 12 to 28 micrograms per liter in November 1999. Montrose Arroyo was the largest selenium source to Cedar Creek. On an annual basis, about 20 percent of the selenium load in Cedar Creek originates in the basin upstream from Miguel Road.

Selenium concentrations in Loutzenhizer Arroyo ranged from 157 to 347 micrograms per liter in February 2000. A significant increase in selenium concentrations occurred in the stream reach between the Selig Canal and Falcon Road (LZU7). Although selenium concentrations in the west tributary of Loutzenhizer Arroyo were lower than in the main stem, the west tributary contributed about 41 percent of the selenium load. Downstream from the confluence with the west tributary to the mouth, selenium concentrations in the arroyo gradually decreased, and the increase in selenium load in the lower reach was small.

INTRODUCTION

Selenium is a water-quality concern in the Gunnison River Basin. Since 1985, a multiagency program within Department of the Interior, the National Irrigation Water Quality Program (NIWQP), has done investigations at various irrigation projects in the Western United States to determine if irrigation drainage was having adverse effects on water quality and on fish and wildlife. Beginning in 1988, NIWQP studies have been done in the Uncompahgre River Basin, a major tributary of the Gunnison River, and in the Grand Valley in west-central Colorado. High levels of selenium were reported in some water, sediment, and biota samples in both areas (Butler and others, 1996). Selenium concentrations in some fish- and bird-tissue samples were at levels of concern, and in late 1994 NIWQP initiated the planning phase for remediation. One objective of the NIWQP planning phase was to determine what, if any, remediation methods could be used to reduce selenium loading from irrigation sources to the Uncompahgre and Gunnison Rivers (fig. 1).

Prior to 1997, the chronic criterion for aquatic life for dissolved selenium in Colorado was 17 μg/L. In 1997, the State Water Quality Control Commission adopted the 5-μg/L chronic criterion for selenium for surface waters in Colorado (Colorado Department of Public Health and Environment, 1998). Because the criterion is based on the dissolved-selenium concentration, all selenium concentrations and loads discussed in this report are for dissolved selenium. Also in 1997, the triennial review of the water-quality standards for the Gunnison River Basin was completed and the 5-μg/L criterion was applied to streams with aquatic-life classifications in the basin. The more stringent selenium standard caused the lower Uncompahgre River (from Montrose to the mouth) and the lower Gunnison River (downstream from the Uncompahgre River to the mouth), along with some tributary streams to the North Fork of the Gunnison River, to be listed as out of compliance for selenium. Temporary modifications were put in place for the affected water bodies to allow time for measures to be taken at the local level to address the selenium issue. A local watershed initiative began in February 1998 with formation of the Gunnison Basin Selenium Task Force (Task Force). The Task Force is a group of private, local, State, and Federal interests, including NIWQP, whose goal is to examine projects or methods that could be feasible for reducing selenium levels in the Uncompahgre and Gunnison Rivers.

The Task Force needed to examine possible remediation methods to address selenium loading to the Gunnison and Uncompahgre Rivers. Previous NIWQP studies (Butler and others, 1996) indicated that Cedar Creek and Loutzenhizer Arroyo were the largest contributors to the selenium load in the Uncompahgre River and that the Uncompahgre River was the single largest selenium source to the Gunnison River. However, data for determining selenium loading to the lower Gunnison River from tributary streams other than the Uncompahgre River were limited. Selenium data were available only for a few tributaries in the North Fork Basin, and much of this information was for streams in the upper basin where selenium concentrations are low. Few or no data were available for many of the tributaries to the Gunnison River downstream from the North Fork to Whitewater (fig. 1). The Task Force and the NIWQP realized that if selenium load, and subsequently selenium concentration, in the Uncompahgre River was to be significantly reduced, some of the remediation alternatives would need to address selenium loading in the Cedar Creek and Loutzenhizer Arroyo Basins. However, other than general synoptic data collected by NIWQP in these basins (Butler and others, 1994; Butler and Osmundson, 2000), data were lacking to describe areal distribution of selenium concentrations and loads in great detail. More specific data were needed to focus potential remediation efforts in the Cedar Creek and Loutzenhizer Arroyo Basins to areas with the highest selenium loading.

The U.S. Geological Survey (USGS), in cooperation with Delta County and the Shavano Soil Conservation District, developed a characterization study to provide more detailed selenium information for the lower Gunnison River Basin. The selenium characterization study objectives are:

1. To characterize selenium concentrations and loads in tributary streams of the North Fork of the Gunnison and tributaries of the Gunnison River downstream from the Smith Fork to Whitewater.
2. To characterize selenium concentrations and loads in Cedar Creek and Loutzenhizer Arroyo.

This report summarizes selenium data for streams in the North Fork Basin and for tributary streams of the lower Gunnison River. Selenium data were collected in water years 1999–2000 and supplemented with historical data collected since water year

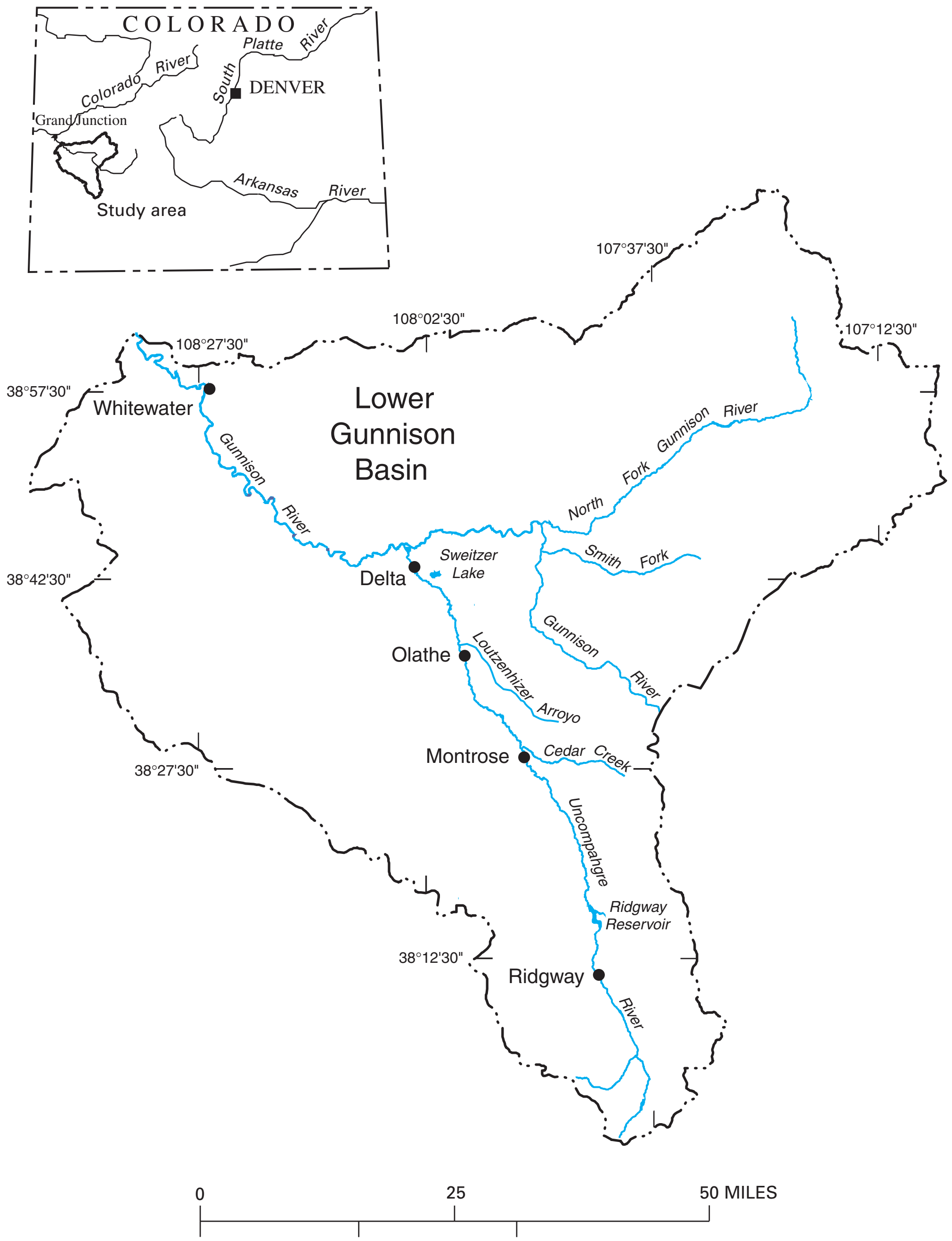


Figure 1. Location of the Lower Gunnison River Basin.

1988, where water year is defined as the period beginning on October 1 and ending on September 30 of the following year. The report also describes results of detailed characterization studies done in 1999 and 2000 in the Cedar Creek and Loutzenhizer Arroyo Basins.

CHARACTERIZATION OF SELENIUM IN THE LOWER GUNNISON RIVER

The characterization of selenium loads in the North Fork Basin and tributary streams to the lower Gunnison River began in the spring of 1999. A list of sampling sites was developed using previous selenium data that had been collected by the USGS and by the Colorado Department of Public Health and Environment (CDPHE). Generally, major tributaries and selected small washes and drainages were sampled. Basins with significant areas of irrigation were included, especially in areas with outcrops of Mancos Shale of Cretaceous age. According to Butler and others (1996), basins that have the highest selenium levels also have extensive outcrops of Mancos Shale. Synoptic sampling was done by the USGS, starting in the North Fork Basin and then sampling downstream to Whitewater. The study area (fig. 1) was separated into three major sections for the synoptic sampling runs: (1) the North Fork Basin, (2) the reach from Smith Fork to the Uncompahgre River, and (3), the reach from the Uncompahgre River to Whitewater. All the sampling sites are listed in table 1. Selenium data also were collected by the CDPHE and USGS in March 1999 from a few tributary streams of the Gunnison River and from the Gunnison River between Delta and Whitewater. The major synoptic sampling runs were done in April and May 1999 (runoff), late August and early September 1999 (late summer, irrigation effects), in November 1999 (nonirrigation season), and in March 2000 (base flow). During the major synoptic sampling runs, all sites that had flowing water were sampled. Additional sampling for this study also was done in June and July 1999 at a limited number of sites. Selenium data and field

Table 1. Summary of selenium data for the lower Gunnison River Basin, 1988–2000

[Selenium concentrations in micrograms per liter, or parts per billion; mean load in pounds per day; <, less than; --, no data; data collected in 1999–2000 unless otherwise noted in remarks; years are in water years (October 1–September 30)]

Site number (figs. 2–4)	Site name (U.S. Geological Survey streamflow-gaging station number)	Number of samples	Selenium concentration		Mean load	Remarks
			Median	Range		
	North Fork Basin					
2	North Fork near Somerset (09132500)	4	<1	<0.7–<1	1.56	
3	Hubbard Creek at mouth	4	<1	<.7–<1	.10	
4	Terror Creek at mouth	4	<1	<.7–<1	.04	
5	Stevens Gulch at Paonia	0	--	--	--	No flow when visited—no samples.
6	Minnesota Creek at Paonia	5	1.3	<1–1.5	.04	
7	Roatcap Creek at Highway 133	4	1.7	<2–5	.06	
8	Reynolds Creek near mouth	4	4.6	<1–8	.02	
9	Bell Creek near mouth	6	4.4	2–7	.19	
10	Jay Creek at Highway 133	4	13	6–19	.06	
11	Cottonwood Creek near mouth	7	7.3	4–13	.33	
12	Short Draw at Hotchkiss	7	11	8–29	.37	
13	Leroux Creek at Highway 92	13	13	1–21	.57	All but one sample from 1990 to 1993.
14	Leroux Creek at mouth	6	7.9	5–9	.29	
15	Alum Gulch at mouth	5	2.4	1–3	.11	
16	Big Gulch at Highway 92	4	7.6	6–9	.13	
17	North Fork at mouth	39	2.5	<1–6	3.93	Data from 1991 to 2000.
	Smith Fork to the Uncompahgre River					
1	Smith Fork at mouth	5	2.7	1–4	.06	
18	Sulphur Gulch at Highway 92	4	11	4–21	.01	

Table 1. Summary of selenium data for the lower Gunnison River Basin, 1988–2000—Continued

[Selenium concentrations in micrograms per liter, or parts per billion; mean load in pounds per day; <, less than; --, no data; data collected in 1999–2000 unless otherwise noted in remarks; years are in water years (October 1–September 30)]

Site number (figs. 2–4)	Site name (U.S. Geological Survey streamflow-gaging station number)	Number of samples	Selenium concentration		Mean load	Remarks
			Median	Range		
		Uncompahgre River to Whitewater—Continued				
19	Lawhead Gulch at Highway 92	4	7.0	5–8	0.01	
20	Oasis Ditch below Oasis Pond	6	9.5	5–15	.30	
21	Currant Creek below Dry Creek	8	19	10–45	.68	
22	Gunnison River at Austin	5	1.2	1–2	9.34	One sample from 1991.
23	Peach Valley Arroyo near mouth	10	6.5	5–95	.39	Includes data from 1991 to 1998.
24	Alfalfa Run at Austin	6	16	11–18	.32	
25	Sunflower Drain at Highway 92	61	20	6–200	3.67	Data from 1992 to 2000.
26	Tongue Creek near Cory	8	4.7	4–10	.70	One sample in 1991.
27	Hartland Ditch diversion	3	2.2	1–3	.35	Diversion on Gunnison River.
28	Bonafide Ditch at Delta	19	12	4–95	4.57	Data from 1992 to 2000.
29	Gunnison River at Delta (09144250)	27	3.8	<1–8	27.2	Data from 1988 to 2000.
		Uncompahgre River to Whitewater				
30	Uncompahgre River at Delta (09149500)	84	12	2–34	21.4	Data from 1988 to 2000.
31	East Ditch at Highway 50, north Delta	4	6.2	5–65	.08	
32	West Ditch at Highway 50, north Delta	4	3.2	2–5	.11	
33	Cummings Gulch at mouth	14	8.7	3–16	.87	Data from 1991 to 1995 and 1999 to 2000.
34	Roubideau Creek at upper site	6	<1	<1–<1	.20	Mean load biased high by 1 sample.
35	Roubideau Creek at mouth	16	3.0	<1–5	.97	Data from 1991 to 1995 and 1999 to 2000.
36	Alkali Creek below Highway 50	11	85	18–150	.04	Data from 1996 to 2000. Additional samples in January 2000.
37	Gunnison River above Escalante Creek	8	5	3–10	48.3	Data for 1987 to 1988 and 1991 included.
38	Escalante Creek at mouth	5	<1	<1–<1	.13	
39, 40	Wells Gulch (2 sites below Highway 50)	8	2.6	<1–10	<.01	Additional runoff samples.
41	Beaver Gulch at Highway 50	0	--	--	--	No flow observed.
42	Dominguez Creek at mouth	3	<1	<1–1.5	.02	
43, 44	Deer Creek (2 sites below Highway 50)	6	7.2	2–11	<.01	Five of six samples snowmelt runoff.
45	Kannah Creek below city diversion	7	<.7	<.7–<1	.05	Background site for Kannah Creek.
46	Kannah Creek below Indian Creek	10	10.5	4–31	.41	
47	East Creek at Highway 141	3	1.3	1–1.5	.01	
48	Brandon Ditch near Whitewater	7	<.7	<.7–1.5	.01	Water from upper Whitewater Creek.
49	Whitewater Creek near mouth	10	27	13–48	.59	
50	Gunnison River at Whitewater (Gunnison River near Grand Junction, 09152500)	103	5.0	<1–11	55.3	Data for 1988 to 2000.
51	Callow Creek at Whitewater	3	11	5–13	<.01	
52	Bangs Canyon at mouth	1	<1	--	.01	

measurements made during each sample collection for the 1999–2000 characterization are published in the USGS annual data report for 2000 (Crowfoot and others, 2001). Much of the selenium data collected for the NIWQP prior to 1999 are published in Butler and others (1994) and in Butler and Osmundson (2000).

For some sites, the data summary in table 1 includes other selenium data that were collected at that site in addition to data collected for the characterization study. A majority of such data were collected for NIWQP studies, but some of the data were collected for several water-quality programs by USGS. Because some sites have much more selenium data than only the samples collected for this study, data for water years 1988–2000 also are included in the summaries in table 1.

Mean selenium load from table 1 is calculated by taking the average of all load values at a given site. Individual selenium loads at each site are calculated using the following equation:

$$L = (28.32 \times Q) \times (C/453{,}600{,}000) \times 86{,}400 \qquad (1)$$

where

L	is selenium load, in pounds per day;
28.32	converts cubic feet to liters;
Q	is streamflow discharge, in cubic feet per second;
C	is selenium concentration, in micrograms per liter; (C/453,600,000) × 86,400
453,600,000	converts pounds to micrograms; and
86,400	converts days to seconds.

Some selenium concentrations in table 1 were reported as less than a minimum reporting limit (MRL) of either 1 µg/L or 0.7 µg/L. For samples with selenium concentrations reported as a "less than" value, a concentration of 0.7 times the MRL was used to compute the selenium load.

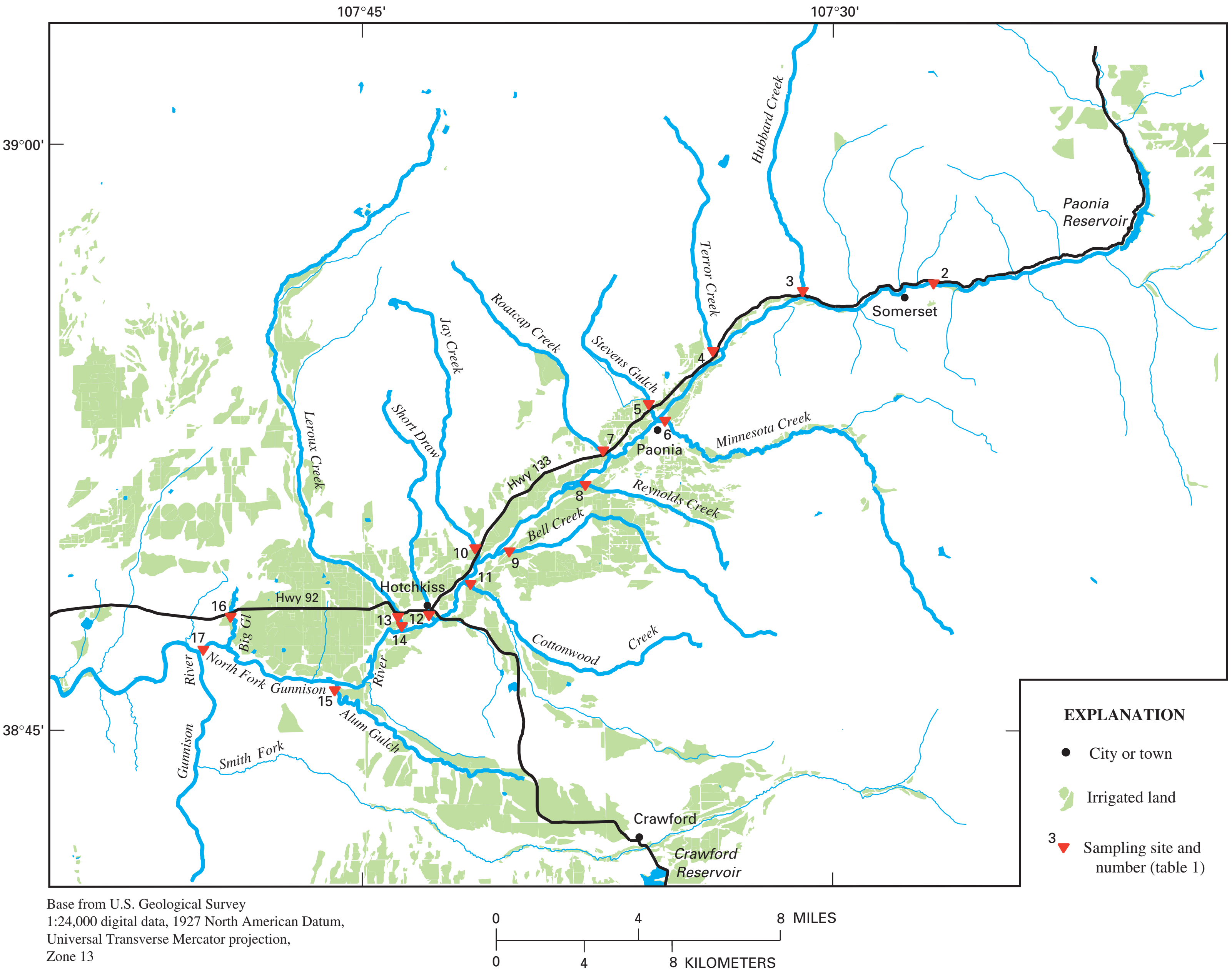
Data interpretation for the characterization study of the lower Gunnison River Basin identified streams that have selenium concentrations that exceed the State standard of 5 µg/L. Tributary basins that are contributing the largest selenium loads to the Gunnison River and, therefore, have the largest effect on selenium concentrations at the Whitewater site, the compliance point for the lower Gunnison River (fig. 1), were determined. Many sites have fewer than 10 samples; therefore, data interpretation should be viewed with caution, especially when examining selenium loads. The mean loads shown in table 1 for sites with a small number of samples may or may not accurately represent the mean daily load throughout the year. Also, for sites where most or all of the selenium concentrations were reported as "less than" values, using 0.7 times the MRL to calculate loads could overestimate loads, especially for samples collected at high flows during snowmelt runoff from high-altitude areas.

North Fork Basin

Selenium sampling in the North Fork Basin was done at sites 2 through 17 (fig. 2), and the selenium data are summarized in table 1. The main stem was sampled at the USGS streamflow-gaging station (09132500) near Somerset and at the mouth. Additional sampling of the North Fork at the mouth was done using resources from NIWQP to develop a better estimate of annual selenium loading. All major tributary streams downstream from the site near Somerset were sampled.

In the North Fork Basin, selenium concentrations were less than 5 µg/L in tributary streams at and upstream from Paonia (fig. 2). Based on historical data and data collected for this study at the Somerset gage (site 2) and from several tributaries upstream from Paonia, selenium concentrations in the upper North Fork Basin are equal to or less than 1 µg/L. Some outcrops of Mancos Shale are present along the North Fork in the vicinity of Terror Creek, but the shale outcrops are much more extensive downstream from Paonia, especially on the south side of the river. Selenium concentrations in all or nearly all samples from Jay Creek, Cottonwood Creek, Short Draw, Leroux Creek, and Big Gulch were equal to or greater than 5 µg/L. The largest selenium loads from tributaries were in Bell, Cottonwood, and Leroux Creeks and in Short Draw. Based on the selenium data for the main-stem sites (sites 2 and 17) and the measured tributaries, there is an unmeasured selenium load between the Somerset site and the mouth. The unmeasured selenium load probably is from diffuse ground-water inflow and from tributary streams and ditches that were not sampled.

Annual selenium loads for water years 1999 and 2000 were computed for the North Fork at mouth (site 17) to enable comparison to the selenium load in the Gunnison River at the Whitewater site (Site 50, USGS streamflow-gaging station 09152500, also referred to as "Gunnison River near Grand Junction"). For computing the annual load for the North Fork at the mouth, a linear regression equation relating selenium load to streamflow was computed using selenium data and streamflow measurements collected at site 17. Regression analysis was done using logarithm-transformed data from 40 samples collected at various flow regimes during the study period. Statistical diagnostics indicate that the regression was able to explain approximately 60 percent of the variation in the data



Base from U.S. Geological Survey
1:24,000 digital data, 1927 North American Datum,
Universal Transverse Mercator projection,
Zone 13

Figure 2. Location of sampling sites in the North Fork Basin.

set (r squared = 0.6). The regression equation was applied to estimated daily streamflow values for site 17 to estimate a daily selenium load. The sum of the daily loads for the water year results in the annual load. The North Fork at the mouth does not have a gage; therefore, daily streamflow for site 17 was estimated using the instantaneous streamflow measurements made at site 17 during sample collection and the daily streamflow records for USGS streamflow-gaging station 09135950, located on the North Fork about 0.7 mi downstream from Leroux Creek (fig. 2). The method to compute annual load is similar for the Gunnison River at Whitewater except that a second regression equation relating selenium load to streamflow and specific conductance was computed because daily specific-conductance data are available for most days at that site. When specific conductance is included in the regression, the coefficient of determination increases and the standard error of estimate decreases compared to a regression based solely on streamflow. These regression equations are then used to compute daily selenium loads by using the streamflow and daily specific-conductance records for the Whitewater site (USGS streamflow-gaging station 09152500).

For water year 1999, the estimated selenium load for the North Fork was 1,400 lb, which is about 7 percent of the selenium load in the Gunnison River at Whitewater (20,100 lb). For 2000, the estimated load was 1,300 lb, which was about 8 percent of the selenium load in 2000 in the Gunnison River (16,200 lb). Based on the information in 1999 and 2000, the North Fork Basin contributes a relatively small part of the selenium load in the Gunnison River.

Smith Fork to the Uncompahgre River, Excluding the North Fork

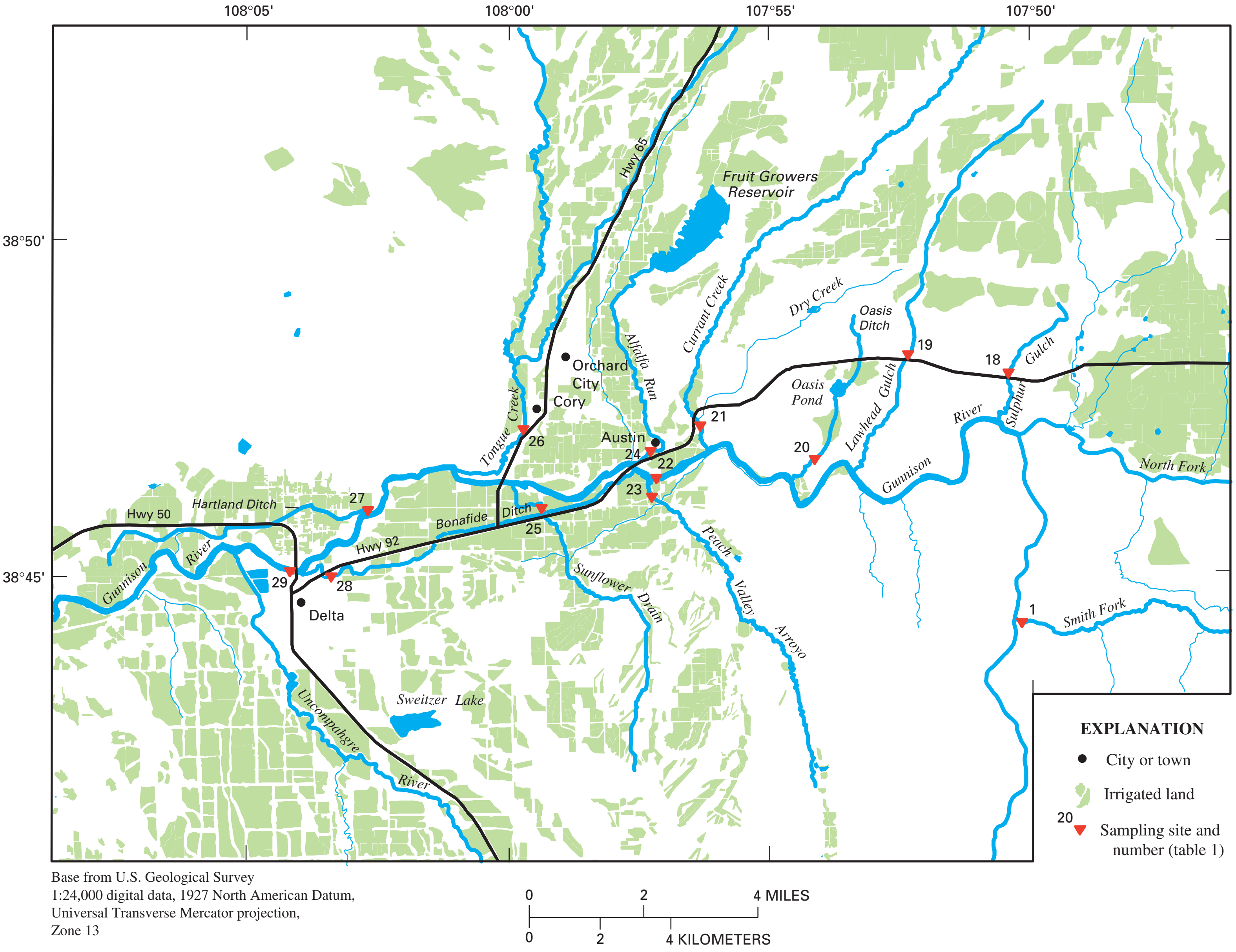
This reach includes the Smith Fork (site 1) and tributary and main-stem sites (sites 18–29) of the Gunnison River downstream from the North Fork to the USGS streamflow-gaging station (09144250) Gunnison River at Delta. The confluence of the Uncompahgre River with the Gunnison River is downstream from the Gunnison River at Delta gage. Sites are shown in figure 3, and selenium results are summarized in table 1.

All the sampled tributary streams in this reach except the Smith Fork and Tongue Creek had median selenium concentrations greater than 5 µg/L. The largest measured selenium loads in tributaries were from Sunflower Drain (site 25) and the Bonafide Ditch (site 28). Streamflow in Sunflower Drain consists entirely of irrigation drainage and tailwater from irrigated areas on Mancos Shale south of the Gunnison River. The Bonafide Ditch also receives irrigation tailwater from areas south of the Gunnison River, but part of the flow in the ditch is water from two canals that divert water from the Gunnison River upstream from Austin. Based on samples collected at the Austin site (table 1) and on other data collected from the canals upstream from Austin (Butler and Osmundson, 2000), the Gunnison River upstream from Austin probably has selenium concentrations of 2 µg/L or less during the irrigation season. Selenium loads from the north side of the river are discharged by Oasis Ditch, Currant Creek, Alfalfa Run, and Tongue Creek, but loads are considerably smaller than loads in Sunflower Drain and Bonafide Ditch (table 1). Considerable acreage from Currant Creek to Tongue Creek (fig. 3) is irrigated, and some of that area contains outcrops of Mancos Shale. Samples from small drainages such as Sulphur Gulch and Lawhead Gulch contain selenium; but the measured flows were small, and the selenium loads were insignificant.

The small number of samples for the site on the Gunnison River at Austin (site 22) adds uncertainty to analysis of selenium loading in the reach from Austin to Delta. The loading data listed in table 1 indicate a considerable amount of unmeasured selenium load in that reach. Only major tributary streams or ditches were sampled in this reach. Numerous surface inflows were not sampled, and selenium load from direct ground-water discharge into the Gunnison River and from the adjacent alluvium were not assessed. Based on the data for the site at Delta, selenium concentrations in the Gunnison River upstream from the Uncompahgre River usually do not exceed 5 µg/L.

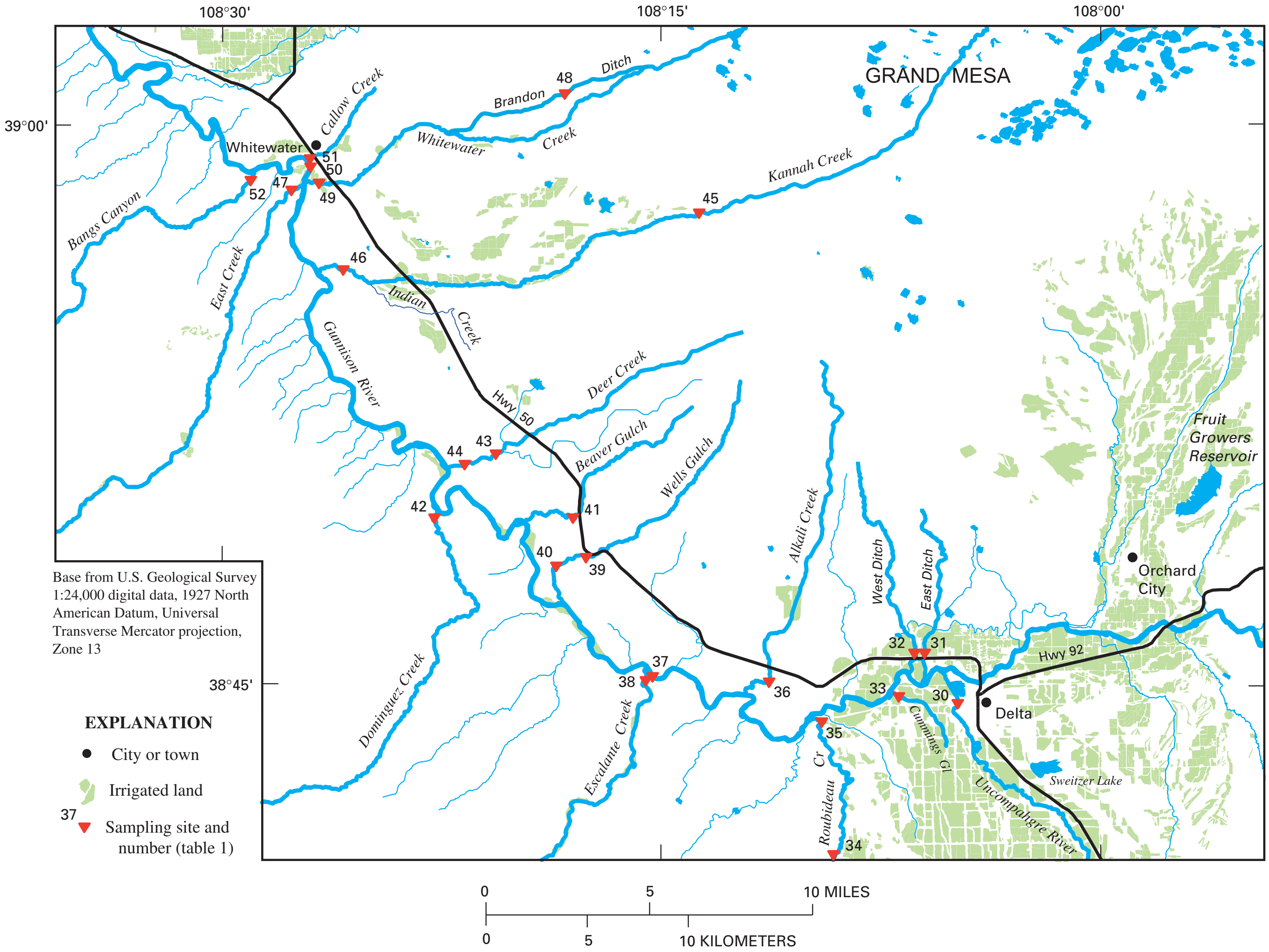
Uncompahgre River to Whitewater

This reach, which includes the lower Gunnison River and tributaries from the Uncompahgre River to Whitewater (sites 30–52; fig. 4), has mixed geology and land uses. Generally, tributaries on the north or east side of the Gunnison River between Delta and Grand Junction drain areas that contain outcrops of Mancos Shale. The west side of the Gunnison River



Base from U.S. Geological Survey
1:24,000 digital data, 1927 North American Datum,
Universal Transverse Mercator projection,
Zone 13

Figure 3. Location of sampling sites from the Smith Fork to the Uncompahgre River.



Base from U.S. Geological Survey 1:24,000 digital data, 1927 North American Datum, Universal Transverse Mercator projection, Zone 13

Figure 4. Location of sampling sites from the Uncompahgre River to Whitewater.

between Roubideau Creek and East Creek (fig. 4) does not have outcrops of Mancos Shale and is composed primarily of outcrops of sandstone, siltstone, and shale of Cretaceous age.

Nearly all selenium concentrations in the Uncompahgre River at Delta exceeded 5 μg/L during water years 1988–2000 (table 1). The lower Uncompahgre River is listed by the State as out of compliance for selenium. Annual selenium loads for the Uncompahgre River were computed using the same method described for the North Fork. Daily streamflow data are available for the Uncompahgre River at the USGS streamflow-gaging station 09149500 located in Delta (site 30 in fig. 4). Based on a mean annual selenium load for 1988–2000 of 7,600 lb/yr at the Delta site, the Uncompahgre River accounted for about 38 percent of the mean annual load in the Gunnison River at Whitewater for 1988–2000 (20,100 lb/yr) and is the largest loading source to the Gunnison River.

Selenium concentrations for tributary streams and washes on the north or east side of the Gunnison River downstream from Delta were variable. Four of the five sites affected by irrigation drainage from shale areas north or east of the river had median concentrations greater than 5 μg/L: the East Ditch in north Delta, Alkali Creek, Kannah Creek below Indian Creek, and Whitewater Creek near the mouth (fig. 4; table 1). Only the West Ditch in north Delta had a median concentration less than 5 μg/L. There is a marked contrast in selenium concentrations between upstream and downstream sites on Kannah Creek and on Whitewater Creek. Selenium concentrations at the upper site on Kannah Creek (site 45) and the Brandon Ditch (site 48), which represents water diverted from upper Whitewater Creek, were less than the MRL (0.7 μg/L) except for one sample from Brandon Ditch. Selenium concentrations at the downstream sites on the two creeks were much higher, with median concentrations of 10.5 μg/L for Kannah Creek below Indian Creek (site 46) and 27 μg/L for Whitewater Creek near mouth (site 49) (table 1). Water samples collected at the two upper sites are representative of streamflow off the Grand Mesa, which is upstream from irrigation and Mancos Shale outcrops.

The highest selenium concentrations sampled in the Uncompahgre River to Whitewater reach were from Alkali Creek (site 36; fig. 4), a basin that is affected by irrigation and a small reservoir located on Mancos Shale. Some additional samples were collected from Alkali Creek during snowmelt and rainfall runoff in January 2000. The runoff caused an increase in selenium concentrations and a small increase in streamflow. However, the maximum load was only 0.14 lb/d (at a concentration of 150 μg/L), and that sample was the only sample that had a selenium load greater than 0.10 lb/d from Alkali Creek.

The other three tributaries on the east side of the Gunnison River—Wells Gulch, Beaver Gulch, and Deer Creek—drain essentially nonirrigated areas. A small reservoir occasionally releases water into Deer Creek. The irrigated areas shown in figure 4 in the tributary basin of Deer Creek have had little irrigation in recent years. These streams probably are ephemeral and normally flow only after rain or snowmelt. No streamflow was observed in Beaver Gulch despite numerous visits during or after rain or snowmelt. The runoff measured in Wells Gulch and Deer Creek did mobilize selenium from the shale areas, but the selenium loads were small (maximum load was 0.03 lb/d in Wells Gulch) because measured streamflow was low. The highest streamflow measured for the 14 samples collected from Wells Gulch and Deer Creek was 0.74 ft^3/s in March 2000 at Wells Gulch, but 11 of the 14 samples collected from these two drainages had a measured streamflow of less than 0.10 ft^3/s. Much larger runoff has undoubtedly occurred in this area than what was measured during 1999–2000.

On the south and west side of the Gunnison River (Cummings Gulch to Bangs Canyon in fig. 4), selenium concentrations were less than 2 μg/L except for samples from Cummings Gulch and the downstream site on Roubideau Creek (table 1). These streams generally drain areas containing no Mancos Shale. Cummings Gulch and the downstream reach of Roubideau Creek (at mouth) receive considerable quantities of irrigation return flows from the west side of the Uncompahgre Valley. The streams downstream from Roubideau Creek have little or no irrigation and no outcrops of Mancos Shale. The upstream site on Roubideau Creek is upstream from irrigation return flows from the Uncompahgre Valley. Nearly all selenium concentrations from the upstream Roubideau Creek (at upper) site, Escalante Creek, Dominguez Creek, East Creek, and Bangs Canyon were less than or equal to 1.3 μg/L (table 1).

The largest selenium loads in tributary streams of the Gunnison River downstream from the Uncompahgre River were in basins affected by irrigation drainage and return flows: Kannah Creek and Whitewater Creek on the north and east side of the river, and Cummings Gulch and lower Roubideau Creek (at mouth) on the south and west side (table 1). Selenium loads from other areas in this reach seems to be minor. Large, widespread rainstorms or significant snowmelt in the Mancos Shale areas north and east of the river could increase selenium loads to the lower Gunnison River for a short period. Such events are infrequent and of short duration, but snowmelt and rain did occur in January 2000. In the latter one-half of the month, a combination of low-elevation snowmelt and rain apparently caused an increase in selenium loads from Mancos Shale areas in the Delta area and the east side of the Uncompahgre Valley to the south. Selenium concentrations increased about 1-2 μg/L in the Gunnison River at Whitewater (site 50) and loads increased about 5–10 lb/d for about 2 weeks in the latter one-half of January 2000.

For water years 1988–2000, the median selenium concentration was 5 μg/L at the compliance point for the Gunnison River at the USGS streamflow-gaging station at the Whitewater site (site 50; fig. 4), which equals the selenium standard for the lower Gunnison River. Based on the median concentration, the lower Gunnison River would not seem to be out of compliance for selenium; however, the determination of whether a water body exceeds a water-quality standard in Colorado is based on the 85th-percentile concentration, not the median. For the Whitewater site the 85th percentile was 8 μg/L, and that is why the State set the temporary modification at 8 μg/L for selenium in the lower Gunnison River.

CHARACTERIZATION OF SELENIUM IN CEDAR CREEK AND LOUTZENHIZER ARROYO

The tributaries of the Uncompahgre River with the largest selenium loads are Cedar Creek and Loutzenhizer Arroyo (fig. 1). To aid remediation planning for reducing selenium in the Uncompahgre River, more detailed information about selenium loading in the Cedar Creek and Loutzenhizer Basins was needed by the Task Force and the NIWQP. The USGS has collected a considerable amount of selenium data at outflow sites on these tributaries, but selenium data generally were sparse for upstream areas. To fill in data gaps and help focus remediation efforts, the USGS conducted detailed sampling of Cedar Creek and Loutzenhizer Arroyo in 1999–2000 to determine the distribution of selenium loading in these basins.

One method of evaluating constituent loading to a stream is to make streamflow measurements and collect water samples for analysis of the constituents of interest at numerous main-stem sites and at major inflows. Because load is calculated using streamflow and concentration, both parameters must be known for every site. Streamflow measurements are usually measured using the current-meter method (Rantz and others, 1982), which involves measuring the water depth and velocity at numerous locations across a stream cross section. Accurate streamflow measurements can be made with ideal cross sections that are smooth and uniform. Measurements become less accurate as streambeds become rocky and banks and streambeds become irregular. Undercut banks and irregular stream channels with heavy brush are a common feature of Cedar Creek and Loutzenhizer Arroyo, which can degrade the accuracy of current-meter streamflow measurements. Less accurate streamflow measurements mean the loads calculated from those measurements will be less accurate, and evaluating loading inputs becomes subject to more uncertainty. This is especially true when attempting to determine loading from diffuse ground-water sources because ground-water discharge into a relatively short stream reach can be quite small compared to the flow in the stream.

Streamflow can be measured in streams with good precision by using the tracer-dilution method (Bencala and others, 1990; Kimball, 1997). A conservative salt tracer such as bromide, chloride, or lithium is commonly used and is injected into the stream at a known concentration and rate. The tracer is injected in sufficient quantities to raise the concentration of the tracer in the stream much higher than the background concentration in the stream. As the tracer moves downstream, it is diluted by inflow from tributaries and from diffuse ground water, and the discharge at any one point is related to the amount of dilution that has occurred downstream from the injection point. After the tracer concentration in the stream has reached a steady concentration, water sampling is done at preselected stations in the stream reach. The samples are analyzed for the tracer concentration and for the constituent concentrations of interest. The tracer concentration is used to calculate streamflow at each sampling station, and with the constituent concentration, a load can be calculated for each site. When using the tracer-dilution method, manual streamflow measurements are not required; however, a few measurements are usually made for comparison to the flows determined from the tracer data.

For this study, bromide was used as the tracer. After a preliminary reconnaissance, tracer-injection sites and sampling sites were selected. For each sampling site, water temperature, pH, and specific conductance were measured, and water samples were collected for analysis of dissolved selenium and bromide. At a few selected locations, streamflow was measured with a current meter for comparison to streamflow determined using the tracer method.

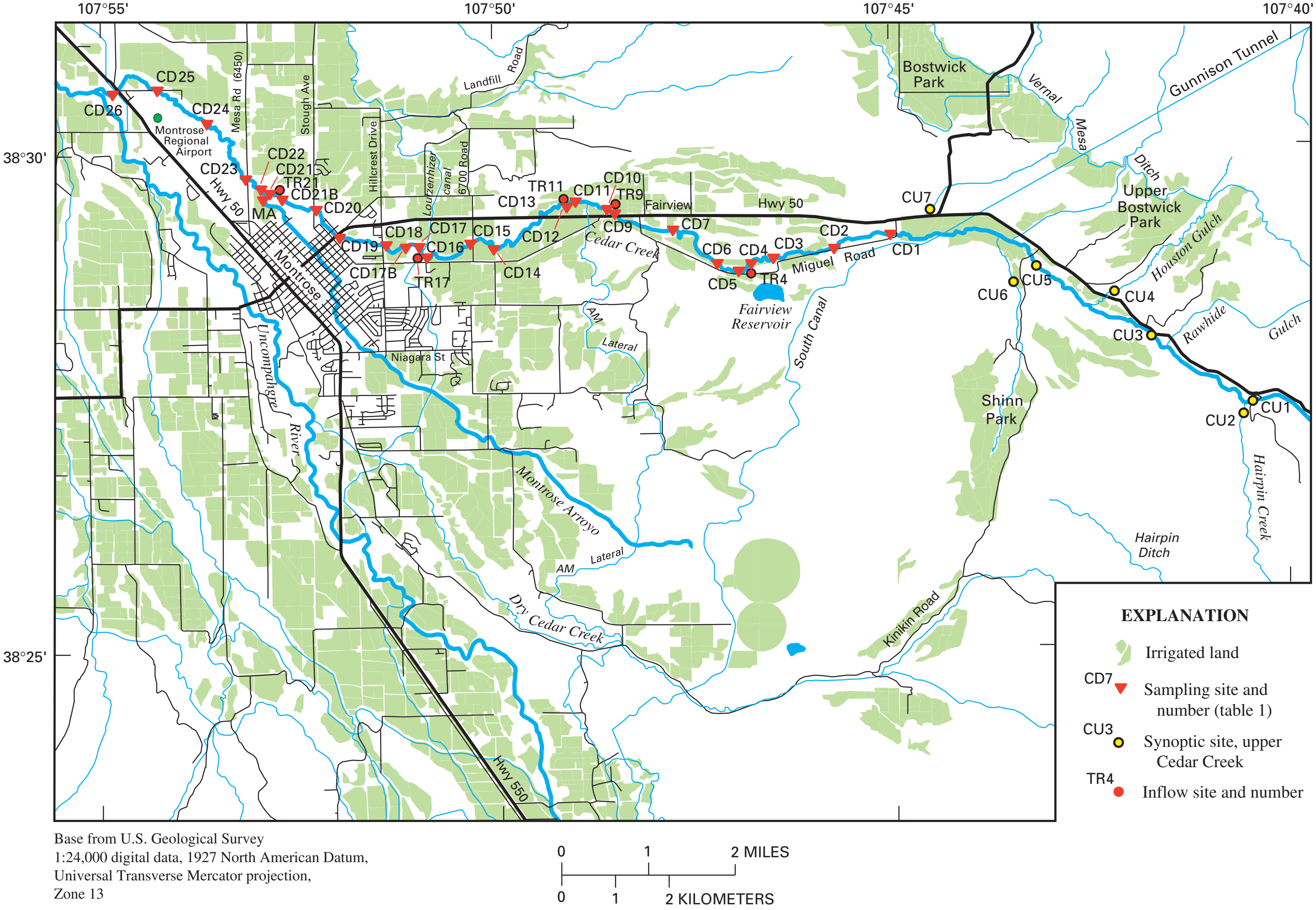
Cedar Creek

The characterization of Cedar Creek was done November 16–17, 1999. The stream reach where the tracer study was done was between Miguel Road (site CD1) and below Highway 50 (site CD26; fig. 5). The stream was separated into two reaches for tracer injections. The upper reach is from sites CD1 to CD13, the lower reach from site CD13 to site CD26 (fig. 5). In the upper reach, 12 main-stem sites and 3 inflows were sampled. In the lower reach, 16 main-stem and 3 inflow sites were sampled. Main-stem sites are designated “CD” and inflow sites “TR”.

Selenium concentrations and specific-conductance measurements at the main-stem sites are shown in figure 6, and selenium loads are shown in figure 7. In general, significant changes in selenium concentrations and loads occurred in reaches with major surface inflows, either from drainage ditches and washes or from discharge of ground-water seepage that is discharged from canals and laterals. Montrose Arroyo was the largest single source of selenium to Cedar Creek downstream from Miguel Road (fig. 7) and accounted for 32 percent of the load at the outflow site below Highway 50 (CD26) on November 16–17, 1999. Selenium load did not increase between sites CD1 and CD10, although the bromide concentrations indicate about a 3-ft^3/s gain in streamflow in this reach. The selenium concentrations in Cedar Creek decreased slightly between sites CD1 and CD10, indicating that the selenium concentrations in the gaining water were low. The only notable increase in selenium load in the upper reach (sites CD1–CD13 in fig. 5) was between sites CD10 and CD11(fig. 6) where seepage water from the AM lateral (fig. 5) would discharge into Cedar Creek. The AM lateral was not sampled, so the cause of the increase in load (about 0.4 lb/d) between sites CD10 and CD11 is not known.

About one-half of the increase in selenium load in the lower reach (sites CD13 to CD26 in fig. 5) was discharged from Montrose Arroyo (1.5 lb/d). The selenium load increases about 0.5 lb/d between 6700 Road (site CD15) and the cemetery downstream from the Loutzenhizer Canal (site CD17B). The increase in load between sites CD16 and CD17 was from the Loutzenhizer Canal, which has a small flow during the winter that apparently is the result of shallow ground-water seepage. The canal flow at the time of the tracer study was diverted into Cedar Creek. The remaining increase in load between sites CD15 and CD17B probably is diffuse ground-water discharge. The decrease in selenium load from site CD18 (Hillcrest Drive) to site CD19 (at Highway 50) was the result of a 3-μg/L decrease in the selenium concentration. The computed streamflows at sites CD18 and CD19 were equal (20.5 ft^3/s). The specific-conductance measurements at sites CD18 and CD19 were almost equal (fig. 6); therefore, it is possible that the selenium concentration for site CD19 might be too low because of sampling or analytical error. Inflow from a drainage ditch accounts for the increase in load between sites CD21B and CD21 (fig. 7). Downstream from Montrose Arroyo, the selenium load increased 0.56 lb/d between sites CD22 and CD23. The tracer data indicate a gain in streamflow of only 0.3 ft^3/s in this reach, which means the selenium concentration of the gaining flow would be 346 μg/L to account for a load of 0.56 lb/d. The specific conductance readings (fig. 6) were identical at sites CD22, CD23, and CD24, which indicates that the selenium concentration for the sample at site CD23 (28.2 μg/L) might be high, resulting in a selenium load for site CD23 that is too high. Therefore, the selenium gain between sites CD22 and CD23 could be overestimated. Inflow into Cedar Creek with a selenium concentration of 346 μg/L that has virtually no salinity (as measured by specific conductance) seems unlikely.

A review of the Cedar Creek tracer study for November 16–17, 1999, indicates that selenium concentrations at main-stem sites ranged from 12 to 28 μg/L. The increase in selenium load between Miguel Road and Highway 50 was about 3.5 lb/d. This increase indicates that 27 percent of the load was from the basin upstream from Miguel Road, 23 percent from the reach between Miguel Road and Montrose



Base from U.S. Geological Survey
1:24,000 digital data, 1927 North American Datum,
Universal Transverse Mercator projection,
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Figure 5. Cedar Creek and location of sampling sites.

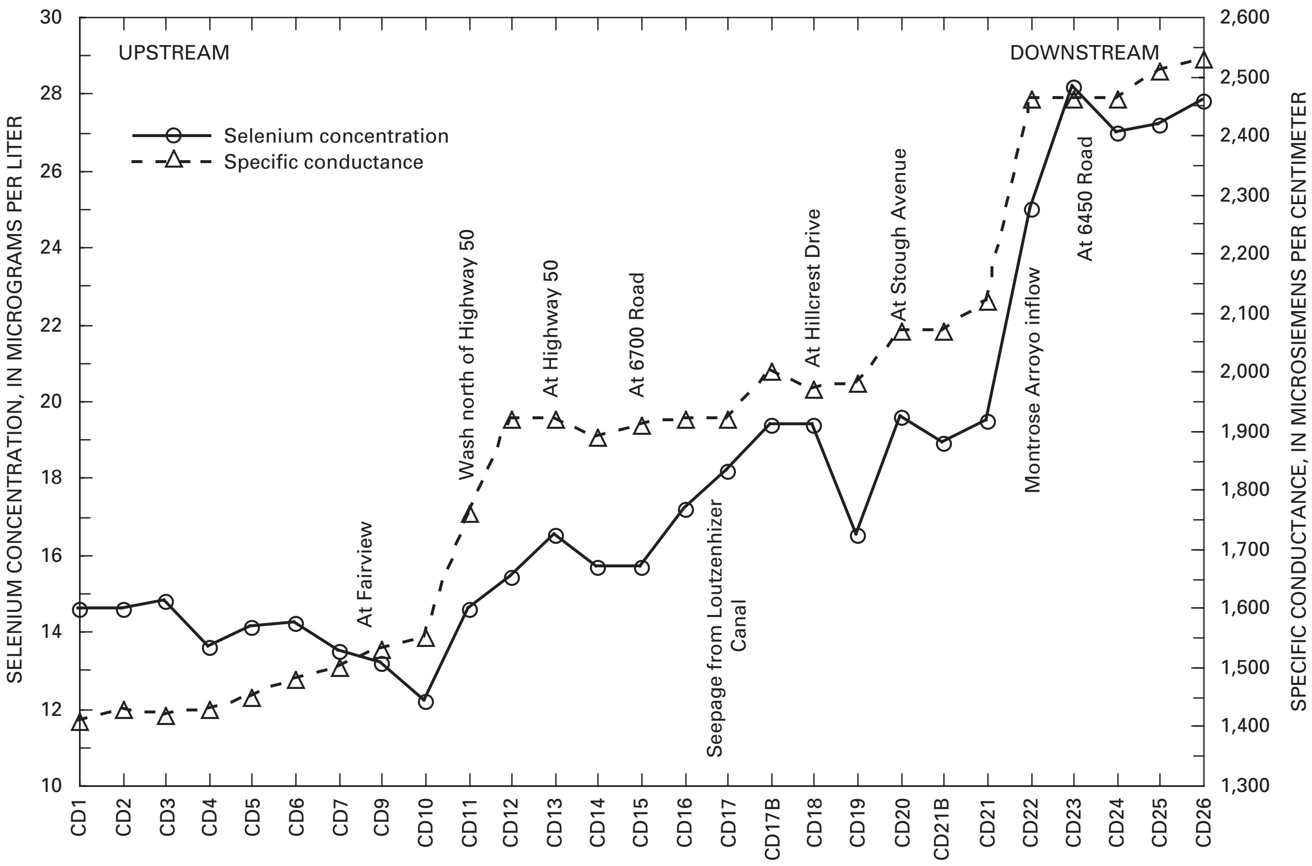


Figure 6. Selenium concentrations and specific conductance in Cedar Creek, November 16–17, 1999.

Arroyo, 32 percent from Montrose Arroyo, and 18 percent was downstream from Montrose Arroyo. That loading distribution for Cedar Creek is applicable to the conditions of November 1999 when the tracer study was done. The relative percentages of the selenium loading in Cedar Creek from the reaches described may be different at different times of the year.

Several sources of selenium to Cedar Creek in the tracer-study reach from Miguel Road (site CD1) to Highway 50 (site CD26) are possible, but irrigation-related sources would seem to be the largest single source of selenium. Seepage from canals, laterals, and ditches and deep percolation from irrigated fields provide recharge to shallow ground water in shale or unconsolidated deposits derived from shale, and water movement through those materials can mobilize selenium (Wright and Butler, 1993). The Cedar Creek Basin has about 6,650 acres of irrigated land (Bureau of Reclamation, written commun., 2001), most of which is downstream from site CD1 (fig. 5). A demonstration project in the Montrose Arroyo Basin in 1998–2000 indicated that piping of 7.5 mi of laterals in that basin caused about a 27-percent decrease in selenium load in Montrose Arroyo at Niagara Street (fig. 5) (Butler, 2001). Other sources of selenium loading, like deep percolation from residential lawn and garden and golf-course watering, septic systems, ponds, and natural runoff, also would be a source of selenium load.

The relatively high percentage of the selenium load in Cedar Creek from the upper basin (upstream from site CD1 at Miguel Road) is typical of the nonirrigation season (November–March) based on selenium data collected since 1991 at sites CD1 and CD26 (downstream from Highway 50) for the NIWQP. The percentage of the selenium load in Cedar Creek at site CD26 representing selenium load from the upper basin was considerably less during the irrigation season compared to the nonirrigation season and averaged about 12 percent of the load at site CD26 for seven sets of concurrent irrigation-season samples.

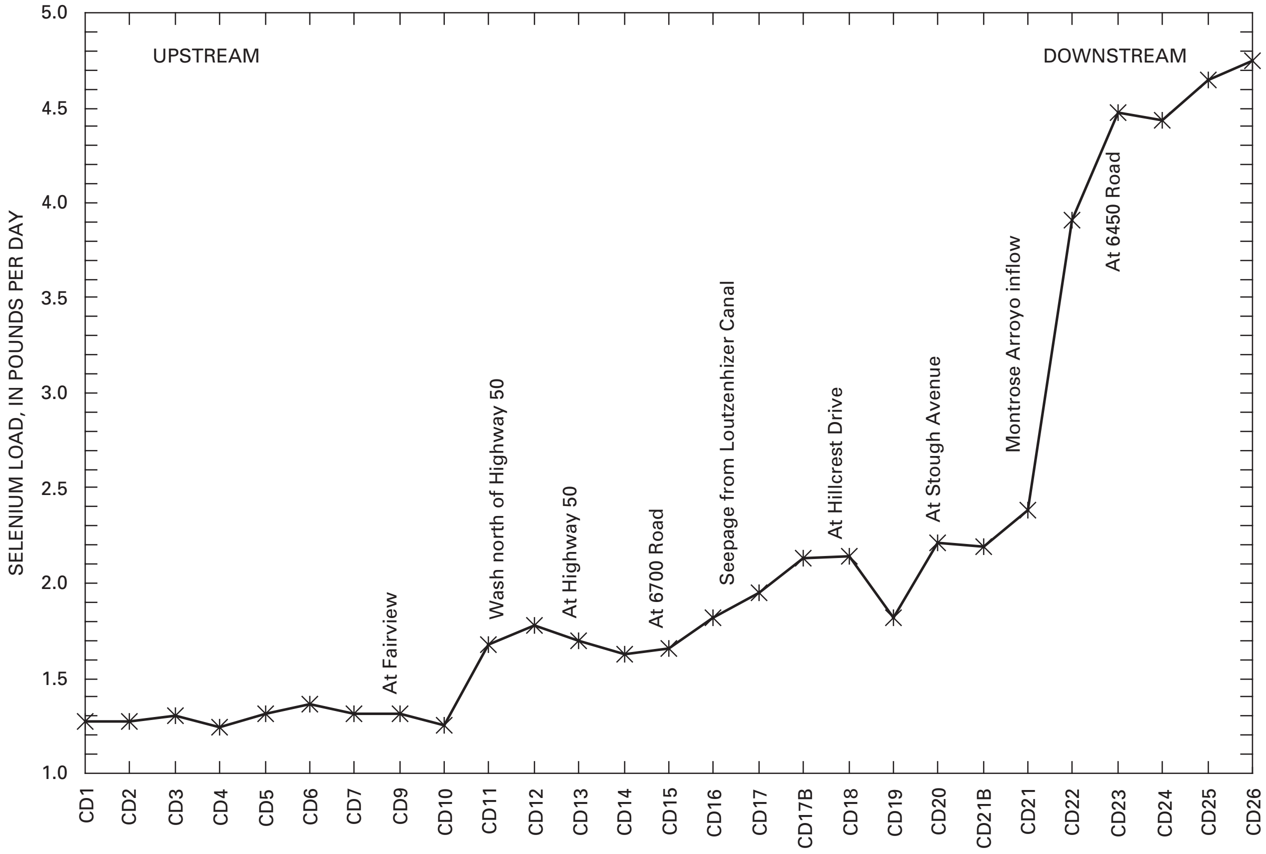


Figure 7. Selenium loads in Cedar Creek, November 16–17, 1999.

Selenium loads at site CD1 generally were lower in irrigation-season samples than in nonirrigation season samples; the opposite was true for loads at site CD26. Reasons for lower irrigation-season loads at site CD1 have not been studied but could be related to higher consumptive-use losses in the irrigation season compared to the nonirrigation season in the upper Cedar Creek Basin. During the summer, water and selenium could be lost from irrigation use and water uptake by the extensive natural vegetation present in much of the basin upstream from site CD1. Estimates of annual loads for sites CD1 and CD26 using selenium data for 1991–2000 indicate that the selenium load from the Cedar Creek Basin upstream from site CD1 accounted for about 20 percent of the annual selenium load in Cedar Creek below Highway 50 (site CD26).

Synoptic sampling was done at seven sites on November 18, 1999, in the upper basin, upstream from Miguel Road, to provide information on selenium concentrations and loads in the upper Cedar Creek Basin (table 2; sites CU1–CU7 in fig. 5). Streamflow was measured using a current meter for the upper-basin synoptic sampling. Selenium concentrations were high at the uppermost sites: 181 μg/L in Cedar Creek above Hairpin Creek (site CU1) and 361 μg/L in Hairpin Creek at the mouth (site CU2). The selenium load in Cedar Creek below Hairpin Creek was about 38 percent of the

Table 2. Synoptic data for upper Cedar Creek Basin, November 18, 1999

[Streamflow in cubic feet per second; specific conductance in microsiemens per centimeter at 25° Celsius; selenium concentration in micrograms per liter; selenium load in pounds per day; <, less than]

Site (fig. 5)	Streamflow	Specific conductance	Selenium concentration	Selenium load
CU1	0.24	7,890	181	0.23
CU2	.10	8,520	361	.19
CU3	.24	7,040	190	.25
CU4	1.33	595	<2.4	<.02
CU5	3.06	2,000	26	.43
CU6	3.78	964	6	.12
CU7	.79	1,020	20	.09

load measured at site CD1 the previous day (using streamflow from current-meter measurements for calculating load). The synoptic sampling was not a detailed study of the upper basin, and about 40 percent of the selenium load at site CD1 was unmeasured. Landslide areas in the upper Cedar Creek Basin are composed primarily of material derived from Mancos Shale. Irrigation ditches in the headwater areas of Cedar Creek and Hairpin Creek are dug through the landslide deposits. Also, several areas in the upper basin and along Cedar Creek downstream from Rawhide Gulch have irrigated lands (fig. 5). The selenium load in the upper Cedar Creek Basin is probably derived from a combination of natural recharge and runoff from the landslide areas, from deep percolation from irrigated fields, and from irrigation canal and ditch seepage.

Loutzenhizer Arroyo

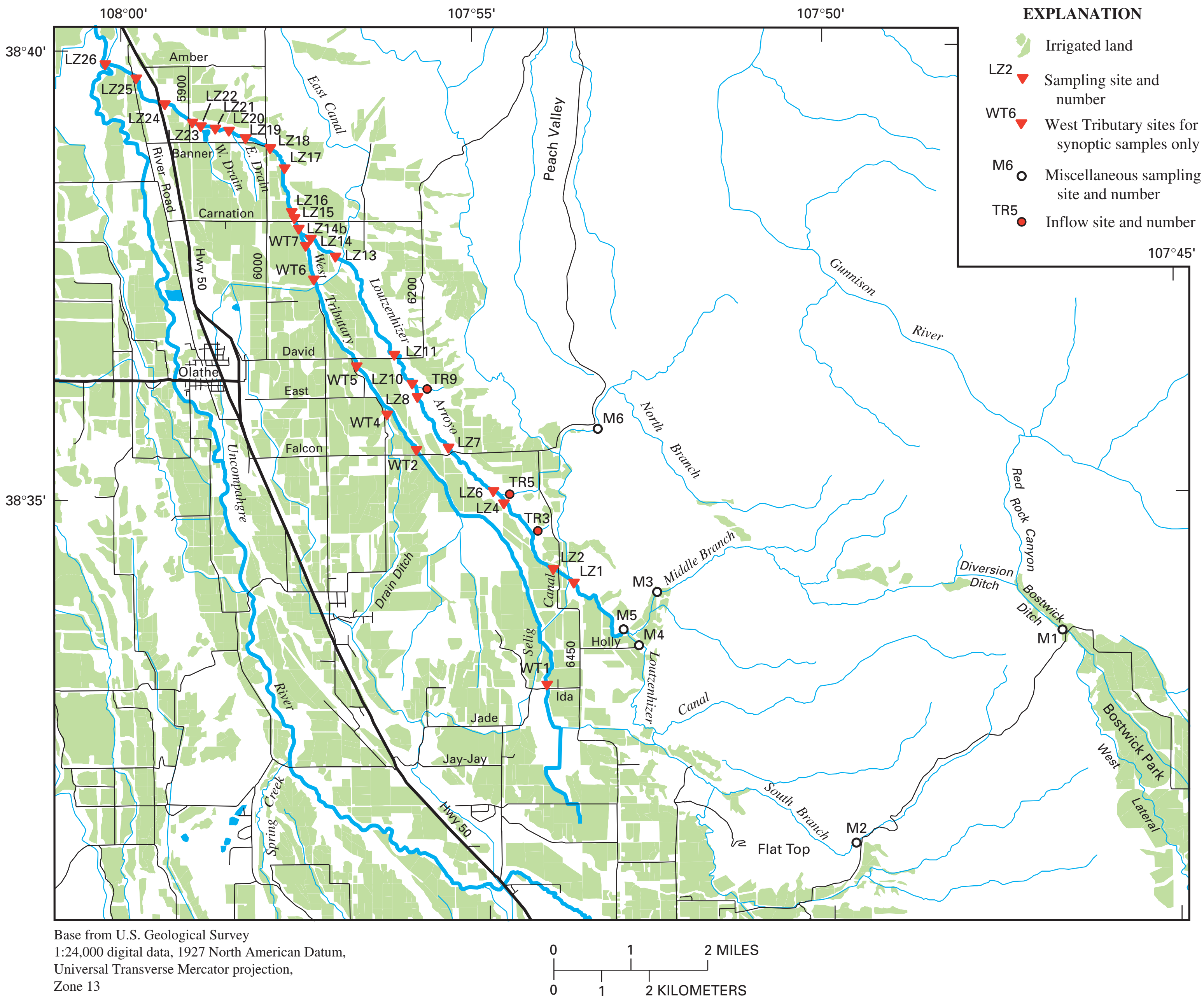
The Loutzenhizer Arroyo characterization study was done February 28–29, 2000. The tracer study was done in the stream reach between the Selig Canal (site LZ1) and the mouth (site LZ26 in fig. 8). The stream was separated into two reaches for tracer injections. The upper reach was from sites LZ1 to LZ15 and the lower reach was from site LZ15 to site LZ26. In the upper reach, 12 main-stem sites and 4 inflows were sampled. In the lower reach, 12 main-stem and 2 inflow sites were sampled (East and West Drains). Main-stem sites are designated “LZ” and inflow sites “TR”.

Unexpected problems adversely affected obtaining loading information for the Loutzenhizer Arroyo study. Initially, three stream reaches were selected for tracer studies, two on the main stem of Loutzenhizer Arroyo and one on the west tributary (fig. 8). A lack of access in certain areas made doing a tracer study on the west tributary impractical; therefore, the only data collected on the west tributary were synoptic samples at the six “WT” sites shown in figure 8. The streamflow and selenium data for the west tributary samples are listed in table 3. During the tracer runs on the main stem of the arroyo, various problems occurred during both runs that invalidated some of the bromide data. Therefore, streamflow could be calculated from the tracer data for only a limited number of sites, which means that determination of loads also was limited. However, selenium-concentration and specific-conductance data are available for all the sites that were sampled (fig. 9). Streamflow was measured with a current meter at all sites in the west tributary basin and at sites LZ1, LZ14, and LZ26 on the main stem of the arroyo.

The most apparent changes in selenium concentrations and in specific conductance in Loutzenhizer Arroyo were the increases between sites LZ2 and LZ4 and the decreases between sites LZ14 and LZ14b (fig. 9). The selenium concentration increased from 184 µg/L at site LZ2 to 331 µg/L at site LZ4. Because the bromide data for these sites were available, the selenium loads could be calculated; there was an increase of about 1.4 lb/d of selenium between sites LZ2 and LZ4. A small ditch (site TR3; fig. 8) between sites LZ2 and LZ4 had a selenium concentration of 655 µg/L, and the ditch accounted for at least part of the increase in selenium load in that reach. The reach between sites LZ2 and LZ4 and the area drained by the ditch are downgradient from the Selig Canal (fig. 8), which cuts through Mancos Shale in this area. Part of the increase in selenium load in the arroyo between sites LZ2 and LZ4 might be from canal seepage.

Selenium concentrations were relatively unchanged in the main stem of Loutzenhizer Arroyo between sites LZ4 and the confluence with the west tributary at site LZ14 (fig. 9). Concentrations were between 310 and 347 µg/L. Detailed selenium-load data could not be determined for the reach between sites LZ4 and LZ14. Inflow from the west tributary (site WT7) caused a decrease in selenium concentrations and specific conductance in Loutzenhizer Arroyo (fig. 9). The selenium and specific-conductance data shown for site LZ14b in figure 9 were back calculated using the measured streamflow and the selenium and specific-conductance data for sites LZ14 and WT7.

The synoptic data (streamflow measured with a current meter) for the west tributary (table 3) indicate downstream increases in streamflow and selenium load from Ida Road (WT1) to the mouth (WT7). Site WT4 is on a drainage ditch. The largest increase in selenium load (about 1.7 lb/d) occurred in the reach between WT1 and WT2 and accounted for 50 percent of the total load in the west tributary. However, the reach between sites WT1 and WT2 also is 52 percent of the total stream length between sites WT1 and the mouth, so the loading is directly proportional to the length of the reach. The selenium load downstream



Base from U.S. Geological Survey
1:24,000 digital data, 1927 North American Datum,
Universal Transverse Mercator projection,
Zone 13

Figure 8. Loutzenhizer Arroyo and location of sampling sites.

Table 3. Streamflow, specific conductance, and selenium concentrations for the west tributary of Loutzenhizer Arroyo, February 29, 2000

[Streamflow in cubic feet per second; specific conductance in microsiemens per centimeter at 25° Celsius; selenium concentration in micrograms per liter; selenium load in pounds per day]

Site (fig. 8)	Streamflow	Specific conductance	Selenium concentration	Selenium load
WT1	1.11	4,790	125	0.75
WT2	2.98	5,110	151	2.43
WT4	.34	7,560	45	.08
WT5	3.40	5,280	149	2.73
WT6	4.55	5,200	139	3.41
WT7	4.85	5,160	130	3.40

from the East Canal (WT6), despite a small gain in streamflow (table 3), did not change.

In the lower reach of Loutzenhizer Arroyo (sites LZ15 to LZ26; fig. 9), downstream from the west tributary, selenium concentrations were unchanged to Banner and 6000 Roads (site LZ18), and then concentrations to the mouth decrease gradually. Specific conductance throughout the lower reach was essentially unchanged, varying by no more than 3 percent. Therefore, surface and subsurface inflows in

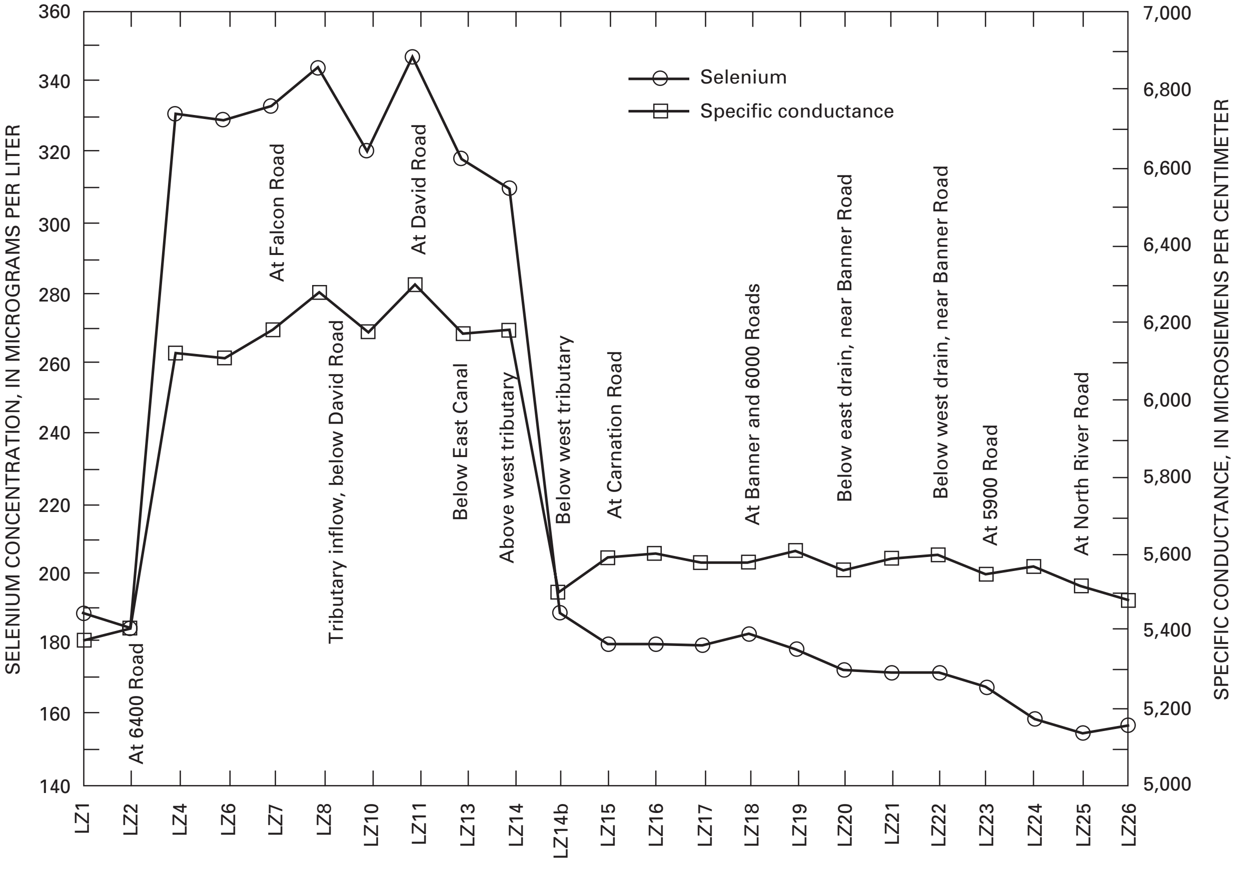


Figure 9. Selenium concentrations and specific conductance in Loutzenhizer Arroyo, February 28–29, 2000.

the lower reach had little effect on salinity (as approximated by specific conductance) in the arroyo and had a dilution effect on selenium concentrations. Some of the bromide data were usable in this reach, allowing limited analysis of selenium loads. The streamflow computed by tracer dilution was about 9.8 ft^3/s at sites LZ15 and LZ16, compared to the measured streamflow of 7.2 ft^3/s at site LZ14b (sum of measured flows at sites LZ14 and WT7). Between sites LZ16 and LZ18 there was a gain of about 0.7 ft^3/s and a small increase in selenium load using the streamflow computed by tracer dilution. Streamflow and load data could not be determined for sites LZ19 through LZ24. The selenium concentrations sampled in two tributaries (east and west drains) between sites LZ19 and LZ22 had relatively low selenium concentrations compared to the main-stem arroyo (fig. 8). Selenium concentrations were 49 μg/L in the east drain and only 8 μg/L in the west drain (fig. 8). The sampling site on the west drain is at the mouth of a drainage that flows through a densely vegetated swale above Banner Road and then through a small wetland and pond below Banner Road. Such a flow pathway could be conducive to removal of selenium from the water column by chemical and biological processes.

The calculated streamflow at sites LZ25 and LZ26 using the bromide data indicate a gain in streamflow of about 1.3 ft^3/s between sites LZ18 and LZ25 and a gain of 0.5 ft^3/s between sites LZ25 and LZ26. The total gain in streamflow for the lower reach was about 2.5 ft^3/s. The calculated streamflow at site LZ26 using the bromide data of 12.3 ft^3/s was about 40 percent greater than the measured streamflow at that site of about 8.8 ft^3/s. Because the selenium concentrations at sites LZ25 and LZ26 were lower than sites LZ16–LZ18, the load increase from site LZ16 to LZ26 was small despite a gain in streamflow. From site LZ16 to LZ26, the selenium load increase was about 0.9 lb/d.

Because it was not possible to obtain detailed loading information from the Loutzenhizer tracer study at all sites, analysis of selenium loading into Loutzenhizer Arroyo was limited to major stream reaches and the west tributary. Loads were computed using streamflow measured with a current meter at sites LZ1, LZ14, WT7, and LZ26 (table 4). Streamflow and selenium load for site LZ14b (below the confluence of the main stem of the arroyo with the west tributary) was computed as the sum of measured streamflow and loads for sites LZ14 and WT7. Selenium loads for the upper basin (the load at site LZ1), for the reach on the main stem between the Selig Canal and the west tributary (load difference between sites LZ14 and LZ1), the load from the west tributary (load at site WT7), and the selenium load into the lower main stem of the arroyo (load difference between sites LZ26 and LZ14b) were compared to the selenium load at the mouth (site LZ26). Using the measured streamflow data for February 28–29, 2000, about 10 percent of the selenium load in Loutzenhizer Arroyo was from the upper basin, 43 percent from the reach between the Selig Canal and the west tributary, 46 percent from the west tributary, and only 1 percent from the lower reach downstream from the west tributary confluence to the mouth.

An analysis of the selenium loading in the Loutzenhizer Arroyo Basin for the same reaches or subbasins also was done using the tracer data, but several assumptions are necessary to do this analysis. If site LZ2 is considered equivalent to site LZ1 and site LZ15 equivalent to site LZ14b, then there are usable tracer data for three of the five sites where streamflow was directly measured (table 4). Tracer data were not available for sites LZ14 and WT7. However, the selenium loads for sites LZ14 and WT7 were approximated for the tracer-data set. From the measured data (table 4), selenium load increased by 6.59 lb/d between sites LZ1 and LZ14b (7.34–0.75). Of that increase, 3.40 lb/d was from the west tributary

Table 4. Selected streamflow and selenium load data for Loutzenhizer Arroyo, February 28–29, 2001

[Streamflow in cubic feet per second; selenium concentration in micrograms per liter; selenium load in pounds per day]

Site (fig. 8)	Streamflow	Selenium concentration	Selenium load
Loads Computed From Measured Streamflow			
LZ1	0.74	188	0.75
LZ14	2.36	310	3.94
WT7	4.85	130	3.40
LZ14b[1]	7.21	189	7.34
LZ26	8.78	157	7.43
Loads Computed From Streamflow Computed Using Tracer Data			
LZ2	1.34	184	1.33
LZ15	9.80	180	9.51
LZ26	12.30	157	10.41

[1] Computed as the sum of measured streamflow and loads for sites LZ14 and WT7.

(site WT7), which is 52 percent of the load increase in that reach. The remaining increase of 3.19 lb/d (6.59–3.40 or 3.94–0.75) was in the reach between LZ1 and LZ14. If the loads computed from the tracer data are used, there was a gain of 8.18 lb/d between sites LZ2 and LZ15 (9.51–1.33; table 4), which for this analysis, was considered equivalent to the loading for the reach between sites LZ1 and LZ14b. If it is assumed that the west tributary accounted for 52 percent of the gain in selenium load between sites LZ1 and LZ14b that was determined using the measured streamflow data, then the selenium load from the west tributary at site WT7 was 4.25 lb/d (0.52 times 8.18 lb/d). The remaining load of 3.93 lb/d is the selenium load gain between sites LZ2 (or LZ1) and site LZ14, which is the reach on the main stem between the Selig Canal and the west tributary. Using the estimated selenium loads based on the tracer data indicates that on February 28–29, 2000, about 12 percent of the selenium load in Loutzenhizer Arroyo was from the upper basin, 38 percent from the upper main-stem reach between the Selig Canal and the west tributary, 41 percent from the west tributary, and 9 percent from the lower reach downstream from the west tributary. The percentage for the upper basin was rounded to 12 percent so that the total percentages add up to 100 percent. Differences in the relative loading percentages between the two data sets are not large, except for the lower reach of the arroyo between the west tributary confluence (site LZ14b) and the mouth (site LZ26). The increase in selenium load in the lower reach was only 0.09 lb/d (1 percent of the load at site LZ26) using the measured streamflow data compared to 0.90 lb/d (9 percent of the load at site LZ26) using the tracer data.

For the entire study reach of Loutzenhizer Arroyo in February 2000, selenium concentrations ranged from 157 μg/L at site LZ26 to 347μg/L at site LZ11 (fig. 9). Selenium load in the reach (where streamflow values were available for use in load calculations) ranged from 0.75 lb/d (LZ1) to 7.43 lb/d (LZ26) using measured streamflow and 1.33 lb/d (LZ2) to 10.41 lb/d (LZ26) using streamflow values calculated from the tracer data (table 4).

Because detailed selenium-load information could not be obtained for Loutzenhizer Arroyo using tracer data, selenium data collected prior to 2000 by the USGS for the NIWQP also were examined in an attempt to augment the results of the tracer study. However, most of the selenium data collected by the USGS in the Loutzenhizer Arroyo Basin prior to the tracer study were collected at River Road (site LZ25) for the purpose of estimating the outflow load from the basin. Limited data were collected elsewhere in the basin, so not much information is available to augment the results of the Loutzenhizer tracer study.

One data set that can be used to examine selenium loading for Loutzenhizer Arroyo was collected for synoptic sampling of the Loutzenhizer Basin on March 9–10, 1992. Those samples were collected for the NIWQP detailed study of the Uncompahgre Project. Results are discussed in Butler and others (1996), and the data were published in Butler and others (1994). The sampling in 1992 was limited in scope, and only five sites were sampled on the main stem of the arroyo (sites LZ2, LZ11, LZ14, LZ18, and LZ25) and three sites on the west tributary (sites WT2, WT5, and WT7). When the 1992 samples were collected, snowmelt runoff from shale areas in the upper basin was discharging into the main stem of the arroyo. The selenium load at 6400 Road (site LZ2) accounted for about 36 percent of the load at River Road (site LZ25 in fig. 8) in March 1992. By contrast, in February 2000, the selenium load at site LZ1 accounted for about 12 percent of the selenium load at site LZ25. Other results from March 1992 are not consistent with results for February 2000. The March 1992 data indicate a smaller increase in selenium load between 6400 Road (site LZ2) and the west tributary (site LZ14) and a much larger increase in load in the lower reach downstream from Carnation Road (site LZ15) than in February 2000. For the March 1992 samples, the selenium concentrations were 160 μg/L at site LZ18 and 190 μg/L at site LZ25, which is different from the results of the sampling in 2000 when concentrations gradually decreased throughout that reach from 183 μg/L at site LZ18 to 155 μg/L at site LZ25. Because many more samples were collected in 2000 than in 1992, the selenium concentrations shown in figure 9 are assumed to be more representative of present-day selenium concentrations during low-flow conditions in the lower reach of Loutzenhizer Arroyo than are the two samples from March 1992. For the west tributary, the selenium load at site WT2 was 64 percent higher in February 2000 than in March 1992, but the loads at sites WT5 and WT7 were only 7 percent higher in February 2000 than in March 1992.

Questions have been raised at Task Force meetings about selenium loading in the Loutzenhizer Arroyo Basin from the upper part of the drainage basin upstream from the Loutzenhizer and Selig Canals (fig. 8). Selenium data have been collected since 1992 at a few locations that provide a minimal amount of information to address such questions. During 1992–2000, 13 samples were collected on the middle branch of Loutzenhizer Arroyo at sites M3, M5, LZ1, and LZ2 (fig. 8; table 5). The mean selenium load for the 13 samples is 1.39 lb/d. Assuming that the mean load for the 13 samples represents daily selenium loads throughout the year, the annual load in the middle branch is about 507 lb/yr, or about 10 percent of the estimated annual selenium load of 4,900 lb/yr for Loutzenhizer Arroyo at River Road (site LZ25). The selenium load for the middle branch is considered uncertain because it is based on data collected at four

Table 5. Selenium data for the upper Loutzenhizer Arroyo Basin and lower Bostwick Park, 1992–2000

[Streamflow in cubic feet per second; specific conductance in microsiemens per centimeter at 25° Celsius; selenium concentration in micrograms per liter; selenium load in pounds per day; E, estimated; --, no data; <, less than]

Site (fig. 8)	Site location	Sampling date	Stream-flow	Specific conduc-tance	Selenium, dissolved	Selenium load
M1	Drain in lower Bostwick Park	04–10–00	E3.0	1,220	36	E0.58
M1		05–15–00	7.9	930	29	1.23
M1		07–26–00	18.3	856	20	1.97
M1		10–05–00	7.8	1,130	29	1.22
M2	South branch of Loutzenhizer Arroyo at Landfill Road bridge	11–21–95	E.05	11,060	1,500	E.40
M2		02–14–96	.01	10,600	1,700	.10
M2		07–19–00	.21	1,110	69	.08
M2		10–05–00	2.49	492	20	.27
M3	Loutzenhizer Arroyo upstream from Loutzenhizer Canal	05–14–93	.88	3,040	96	.46
M4	Loutzenhizer Canal at Holly Road	07–14–93	7.52	406	4	.16
M4		08–13–93	15.7	443	5	.42
M4		09–08–93	3.30	488	7	.12
M5	Loutzenhizer Arroyo downstream from Loutzenhizer Canal	07–14–93	8.27	591	12	.53
M5		08–13–93	16.8	552	8	.72
M5		09–08–93	5.48	1,190	19	.56
LZ1	Loutzenhizer Arroyo upstream from Selig Canal	02–29–00	.74	5,370	188	.75
LZ1		04–10–00	15.0	684	13	1.05
LZ1		07–26–00	2.42	813	14	.18
LZ1		10–05–00	14.9	1,260	36	2.89
LZ2	Loutzenhizer Arroyo at 6400 Road	03–10–92	4.74	3,830	220	5.62
LZ2		03–02–93	1.37	4,010	190	1.40
LZ2		03–23–93	27.8	1,150	21	3.15
LZ2		05–14–93	3.87	472	2	.04
LZ2		10–03–96	--	1,470	26	--
LZ2		02–29–00	.74	5,400	184	.73
M6	North branch of Loutzenhizer Arroyo upstream from Selig Canal	05–15–00	.34	3,930	23	.04
M6		07–26–00	.86	1,820	9	.04
M6		10–05–00	.01	6,940	52	<.01

sites over a period of almost 9 years, and selenium loads at the four sites are not equivalent.

Additional factors complicate obtaining an accurate estimate of selenium loading from the upper Loutzenhizer Arroyo Basin using the available data. During the irrigation season, tailwater from the Loutzenhizer Canal (site M4 in fig. 8 and table 5) discharges into the middle branch, so some of the load measured in the middle branch of the arroyo downstream from that site might include part of the load associated with the canal tailwater. However, not all of the tailwater necessarily remains in the middle branch because there is a diversion ditch on the arroyo between sites M5 and LZ1, and the ditch discharges into the Selig Canal immediately downstream from site LZ1 (fig. 8). Therefore, throughout the irrigation season (April through October), an unknown portion of the flow in Loutzenhizer Arroyo upstream from site LZ1 is diverted into the Selig Canal and flows out of the Loutzenhizer Arroyo drainage basin. Site M3 would be a better location to determine selenium load for the middle branch, but only one sample was collected at that site. Natural runoff from the Mancos Shale hills in the upper basin was accounted for in the sampling because two samples for site LZ2 were collected in March 1992 and March 1993 during snowmelt runoff. Data probably are not sufficient to determine annual selenium loads for the south branch (site M2) and north branch (site M6) of Loutzenhizer Arroyo, but the data in table 5 indicate that the loads in those branches are relatively small. At low streamflow, high selenium concentrations at site M2 (table 5) in the south branch along Landfill Road were likely caused by some saline seeps near the head of the drainage. Because the south branch discharges into the Loutzenhizer Canal near Flat Top (fig. 8), an unknown part of the selenium load in the canal came from the south branch of Loutzenhizer Arroyo.

To further complicate the determination of selenium loading and sources in the upper Loutzenhizer Arroyo Basin, part of the selenium load is composed of irrigation-drainage water and tailwater from Bostwick Park (fig. 8), which is not in the Loutzenhizer drainage basin. During the irrigation season, irrigation tailwater is occasionally discharged from the west side of Bostwick Park into the south branch of the arroyo. The samples collected at site M2 in July and October 2000 reflect tailwater discharge into the south branch (table 5). Part of the tailwater and drainage water collected in a drainage ditch in lower Bostwick Park (site M1; fig. 8) is used to irrigate some fields in the upper Loutzenhizer Basin. Before the Bostwick Ditch flows into Red Rock Canyon, a diversion from the Bostwick Ditch carries part of flow into the head of the middle branch (fig. 8). The diverted Bostwick Ditch water is used for irrigation of the fields (fig. 8) in the middle and north branch drainages. The Bostwick Ditch water has moderate levels of selenium and selenium load (site M1 in table 5). The selenium load diverted into Loutzenhizer Arroyo from Bostwick Park has not been quantified.

Because much of the Loutzenhizer Arroyo Basin contains Mancos Shale outcrops or soils derived from the shale, sources of selenium are widespread in the Loutzenhizer Basin. About 12,000 acres of irrigated land in the Loutzenhizer Arroyo Basin are served by the Uncompahgre Project (Bureau of Reclamation, 1982) with the associated canals, laterals, and ditches. The Uncompahgre Project lands are essentially all irrigated land shown in figure 8 west of the Loutzenhizer and Selig Canals. A hydrosalinity study of the Uncompahgre Project (Bureau of Reclamation, 1982) concluded that salt loading from the project was primarily from distribution-system leakage and deep percolation from fields. If selenium loading is occurring from the same sources as salt, then much of the selenium load in Loutzenhizer Arroyo probably is derived from irrigation drainage. Because there is less residential and urban development in the Loutzenhizer Arroyo Basin compared to the Cedar Creek Basin, sources of selenium from septic tanks, lawns and gardens, golf courses, and ponds would be less important in the Loutzenhizer Basin than in the Cedar Creek Basin at this time (2001). Except for surface inflows measured upstream from the Selig Canal, the hydrosalinity study assumed that natural sources of salt load on the east side of the Uncompahgre Valley were small and attributed less than 1 percent of the salt load to natural ground-water discharge (Bureau of Reclamation, 1982). The study by Bureau of Reclamation used mass-balance methods and investigations of shallow ground water in the Loutzenhizer Arroyo Basin to estimate salt loads. Studies of deep ground-water flow in the Mancos Shale in the lower Gunnison River Basin have not been done. Selenium sources in the Loutzenhizer Basin outside of the Uncompahgre Project include episodic periods of natural runoff from the upper basin, discharge of irrigation return flows and drainage water from Bostwick Park, and subsurface drainage and return flows from irrigated fields upgradient from the project.

SUMMARY

Studies by the National Irrigation Water Quality Program (NIWQP) since 1988 have reported high selenium concentrations in some water, bottom sediment, and biota samples collected in the lower Gunnison River Basin. A planning effort was started in 1994 by the NIWQP to examine possible remediation methods for selenium in the basin. In 1997, the State Water Quality Control Commission changed the selenium standard for the Gunnison River Basin from 17 µg/L to 5 µg/L, which resulted in the lower Gunnison River, the lower Uncompahgre River, and some other water bodies in the lower basin being out of compliance for selenium. The Gunnison River Basin Selenium Task Force (Task Force), composed of various government agencies, irrigators, and local residents in the lower Gunnison River Basin, was formed in 1998 to address the selenium concerns. As part of its investigations, the Task Force decided more information was needed about tributary selenium loading to the Gunnison River. Data collected previously for the NIWQP indicated that Cedar Creek and Loutzenhizer Arroyo contributed the largest selenium loads to the Uncompahgre River. In 1999, the USGS began studies to characterize tributary selenium concentrations and loads to the lower Gunnison River and to characterize selenium concentrations and loads within the Cedar Creek and Loutzenhizer Arroyo Basins.

Sampling of Gunnison River tributaries included the North Fork Basin plus tributary streams downstream from the Smith Fork to Whitewater. Seasonal sampling was done from April 1999 to March 2000. To provide detailed characterization of selenium loads in Cedar Creek and Loutzenhizer Arroyo, tracer studies using bromide were done. The Cedar Creek study was done in November 1999 and the Loutzenhizer Arroyo study in February 2000.

In water years 1999 and 2000, the North Fork of the Gunnison River accounted for about 7 percent of the selenium load in the Gunnison River at Whitewater. Selenium concentrations in the main stem of the North Fork and in tributaries at or upstream from Paonia were less than 5 µg/L, and many concentrations were less than 1 µg/L. Selenium concentrations were greater than 5 µg/L in most of the tributaries sampled downstream from Paonia. The largest selenium loads were from Bell, Cottonwood, and Leroux Creeks and Short Draw.

In the reach downstream from the North Fork to the Uncompahgre River (including the Smith Fork), the Smith Fork and Tongue Creek had median selenium concentrations less than 5 µg/L, and the eight other sampled tributaries had selenium concentrations greater than 5 µg/L. The largest measured selenium loads into the Gunnison River between the North Fork and Delta were from Sunflower Drain and the Bonafide Ditch, where selenium loads are derived primarily from irrigation drainage and return flows from the east side of the Uncompahgre Valley, south of the Gunnison River. The selenium loads in each of those two drains were equal to or slightly greater than the selenium load from the entire North Fork Basin. Selenium loads in tributaries north of the river were much less than from Sunflower Drain and Bonafide Ditch, but there were moderate selenium loads in Currant Creek and Tongue Creek. Small streams such as Sulphur Gulch and Lawhead Gulch had selenium concentrations greater than 5 µg/L, but selenium loads were not significant because of low measured streamflow in those gulches.

The Uncompahgre River accounted for about 38 percent of the load in the Gunnison River in water years 1988–2000 and discharges the largest selenium load to the Gunnison River. Between the Uncompahgre River and Whitewater, many samples collected from tributaries on the north or east side of the Gunnison River had selenium concentrations exceeding 5 µg/L. Areas north and east of the Gunnison River contain outcrops of Mancos Shale. By contrast, all samples collected from the tributaries on the west side of the Gunnison River downstream from Roubideau Creek had selenium concentrations less than 2 µg/L, and most concentrations were less than 1 µg/L. The largest selenium loads in this reach were from Cummings Gulch and lower Roubideau Creek, which receive considerable amounts of irrigation tailwater from the west side of the Uncompahgre Valley, and in Kannah and Whitewater Creeks, which drain some irrigated lands in the Whitewater area. The tributaries in the desert area north of Delta and south of Kannah Creek that are unaffected by irrigation probably are ephemeral streams and had low selenium loads. Alkali Creek, which drains a small area of irrigated land in Mancos Shale terrain, had much higher selenium concentrations, but the selenium loads were small because of low streamflow. Runoff from occasional rain and snowmelt events in the nonirrigated shale areas can temporarily increase selenium loads and concentrations in the lower Gunnison River.

A tracer study was done on Cedar Creek from Miguel Road to below Highway 50 in November 1999. Selenium concentrations at main-stem sites ranged from 12 to 28 µg/L. The gain in selenium load between Miguel Road and Highway 50 was about 3.5 lb/d. The largest selenium load into Cedar Creek was from Montrose Arroyo, which accounted for about 32 percent of the load in Cedar Creek that was measured downstream from Highway 50. The Cedar Creek Basin upstream from Miguel Road accounted for 27 percent of the selenium load in November 1999. Of the remaining selenium load, 23 percent was from the reach between Miguel Road and Montrose Arroyo and 18 percent from the lower reach downstream from Montrose Arroyo. Load increases were associated with surface inflows from drainage ditches and from canals and laterals that were carrying small quantities of ground-water seepage. Selenium loading from diffuse ground-water discharge into Cedar Creek probably was widespread, but generally the loads were small. This study did not distinguish selenium sources, but it is likely that the largest source of selenium to Cedar Creek downstream from Miguel Road is the result of seepage from canals, laterals, and ditches and deep percolation from irrigated fields. Other sources include deep percolation from residential lawn and garden watering, golf course watering, septic systems, and natural runoff and leakage from ponds.

Using periodic data collected from 1991 to 2000, the estimated annual selenium load from upper Cedar Creek Basin (upstream from Miguel Road) was about 20 percent of the annual load in Cedar Creek downstream from Highway 50. A limited synoptic study of the upper basin in November 1999 indicates highly variable selenium concentrations. The selenium load in the upper Cedar Creek Basin is probably derived from a combination of natural recharge and runoff from the landslide areas, deep percolation from irrigated fields, and irrigation canal and ditch seepage.

A tracer study on Loutzenhizer Arroyo was done between the Selig Canal and the mouth of the arroyo in February 2000. Synoptic sampling was done on the west tributary of Loutzenhizer Arroyo. Selenium concentrations ranged from 155 to 347 µg/L in the main arroyo and 125 to 151 µg/L in the west tributary. Detailed determination of selenium loading was limited because of various problems that invalidated some of the tracer data that were needed to calculate stream discharges.

Selenium concentrations increased from 184 to 331 µg/L in a 1.4-mi reach in upper Loutzenhizer Arroyo between site LZ2 and site LZ4 with an associated increase in load of 1.4 lb/d. Selenium concentrations were greater than 300 µg/L in Loutzenhizer Arroyo from LZ4 to the confluence with the west tributary. Inflow from the west tributary caused a decrease in selenium concentrations in the main stem of the arroyo from 310 to 189 µg/L. Downstream from the west tributary, selenium concentrations gradually decreased in Loutzenhizer Arroyo. There was a gain in streamflow in the lower reach; however, selenium concentrations in the arroyo generally decreased from this point. The reduction most likely resulted from drain ditch inflows and diffuse ground-water inputs downstream from the west tributary having lower selenium concentrations.

In February 2000, an estimated 12 percent of the selenium load in Loutzenhizer Arroyo was from the upper basin upstream from the Selig Canal, 38 percent from the reach between the Selig Canal and the west tributary, 41 percent from the west tributary, and 9 percent from the lower reach downstream from the west tributary. Results of the 2000 study differ from those of a synoptic study of Loutzenhizer Arroyo done in March 1992. The study in March 1992 had a much higher percentage (36 percent) of the selenium load from areas upstream from the Selig Canal, which might have been caused in part by snowmelt runoff, which did not occur during the February 2000 study. Because many more samples were collected in 2000 than in 1992, the selenium concentrations shown in figure 9 are assumed to be more representative of present-day selenium concentrations during low-flow conditions in the lower reach of Loutzenhizer Arroyo than are the two samples from March 1992.

The major land use in the Loutzenhizer Arroyo Basin is irrigated agriculture, and the largest source of selenium loading in the basin is expected to be from canal and lateral leakage and deep percolation from fields. A part of the selenium load in Loutzenhizer Arroyo probably is from natural runoff in the upper basin from episodic rain and snowmelt events. Selenium also is transported into the headwater drainages of Loutzenhizer Arroyo in irrigation tailwater diverted from Bostwick Park.

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