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Analysis of Dissolved Selenium Loading for Selected Sites in the Lower Gunnison River Basin, Colorado, 1978–2005

Scientific Investigations Report 2007–5287

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph. Agricultural area in foreground with Mancos Shale outcropping at the base of the Grand Mesa in the background, Whitewater Creek area (photograph by Cory A. Williams, U.S. Geological Survey).

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U.S. Geological Survey
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Conversion Factors, Abbreviations, and Datums

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
pound per day (lb/d)	0.4536	kilogram per day (kg/d)
pound per year (lb/y)	0.4536	kilogram per year (kg/y)

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

$$°F=(1.8\times°C)+32$$

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

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Chemical concentrations are given in micrograms per liter (μg/L).

Water year is the 12-month period from October 1 through September 30. The water year is designated by the year in which it ends; for example, the water year from October 1, 2004, through September 30, 2005, is called the 2005 water year.

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Abstract

Elevated selenium concentrations in streams are a water-quality concern in western Colorado. The U.S. Geologic Survey, in cooperation with the Colorado Department of Public Health and Environment, summarized selenium loading in the Lower Gunnison River Basin to support the development of total maximum daily selenium loads at sites that represent the cumulative contribution to U.S. Environmental Protection Agency 303(d) list segments. Analysis of selenium loading included quantifying loads and determining the amount of load that would need to be reduced to bring the site into compliance, referred to as "the load reduction," with the State chronic aquatic-life standard for dissolved selenium [85th percentile selenium concentration not to exceed 4.6 µg/L (micrograms per liter)], referred to as "the water-quality standard." Streamflow and selenium concentration data for 54 historical water-quality/water-quantity monitoring sites were compiled from U.S. Geological Survey and Colorado Department of Public Health and Environment data sources. Three methods were used for analysis of selenium concentration data to address the variable data density among sites. Mean annual selenium loads were determined for only 10 of the 54 sites due to data availability limitations. Twenty-two sites had 85th percentile selenium concentrations that exceeded the water-quality standard, 3 sites had 85th percentile selenium concentrations less than the State standard, and 29 sites could not be evaluated with respect to 85th percentile selenium concentration (sample count less than 5). To bring selenium concentrations into compliance with the water-quality standard, more than 80 percent of the mean annual selenium load would need to be reduced at Red Rock Canyon, Dry Cedar Creek, Cedar Creek, Loutzenhizer Arroyo, Sunflower Drain, and Whitewater Creek. More than 50 percent of the mean annual load would need to be reduced at Dry Creek to bring the site into compliance with the water-quality standard. The Uncompahgre River, Gunnison River at Delta, and Gunnison River near Grand Junction would require 69, 34 and 53 percent, respectively, of the mean annual load to be reduced for water years 2001 through 2005 to meet the water-quality standard. Mean annual load reductions can be further reduced by targeting the periods of time when selenium would be removed from streams by remediation. During a previous study of selenium loads in the Lower Gunnison River Basin, mean annual load reductions were estimated at the Gunnison River near Grand Junction for the 1997–2001 study period. Mean annual load reductions estimated for this study period were less than those estimated for the 2001–05 study period, emphasizing the importance of understanding that different study periods can result in different load reduction estimates.

Introduction

Selenium is a trace element that occurs naturally in the environment. Various human-related activities such as mining and agriculture can act to mobilize selenium in their waste products. Selenium readily dissolves in oxygenated water and moves through the aquatic environment where it can bioaccumulate in organisms and potentially reach toxic levels (Lemly, 2002). Because elevated selenium concentrations are a water-quality concern, some stream segments in the Lower Gunnison River Basin have been placed on the State 303(d) list as impaired for selenium (Colorado Department of Public Health and Environment, 1998). Section 303(d) of the 1972 Clean Water Act requires that States identify impaired streams. These impaired streams are segments of streams that exceed the State chronic aquatic-life standard. To address chronic aquatic-life standard exceedances for these impaired streams, a priority ranking (the 303(d) list) is established, and a total maximum daily load (TMDL) is determined. A TMDL represents the sum of all contributing loading sources of a pollutant (both point and non-point sources) that are allowed to contribute to an impaired stream so that the chronic aquatic-life standard is not exceeded (U.S. Environmental Protection Agency, 2006).

In Colorado, the Water Quality Control Division (Division) of the Colorado Department of Public Health and Environment is required to develop TMDLs for 303(d) list segments (Colorado Department of Public Health and Environment, 2007a). The Water Quality Control Commission (Commission) through the Water Quality Control Division intends to prepare more than 90 percent of the TMDLs for segments listed on the 1998 303(d) list by 2008 (Colorado Department of Public Health and Environment, 2007b). Owing to the complexities associated with characterizing selenium fate and transport, the U.S. Geological Survey (USGS), in cooperation with Colorado Department of Public Health and Environment conducted data analysis in support of the development of selenium TMDLs in the Lower Gunnison River Basin.

Purpose and Scope

This report summarizes selenium loading for selected sites in the Lower Gunnison River Basin for 1978–2005 to support the TMDL-development process. This report provides a brief description of the study area and a summary of selenium issues, methods of data analysis, and results. Selenium issues in the Lower Gunnison River Basin were summarized and include identification of primary land uses that cause selenium loading. Results include the assessment of selenium concentrations and loads, 85th percentile selenium concentrations, and quantification of the amount of selenium load (pounds annually) that would need to be reduced to bring the site into compliance with the State chronic aquatic-life standard for dissolved selenium. This assessment occurred at 54 sites that represent the cumulative contribution of selenium concentration to 303(d) list segments (table 1). The amount of selenium load that would need to be reduced (herein referred to as a “load reduction”) was determined for sites that exceeded the State chronic aquatic-life standard for dissolved selenium (85th percentile selenium concentration not to exceed 4.6 µg/L (micrograms per liter)), referred to as the “water-quality standard” (Colorado Department of Public Health and Environment, 2007c). Throughout the report, the use of the term “selenium” refers to dissolved selenium in micrograms per liter.

Acknowledgments

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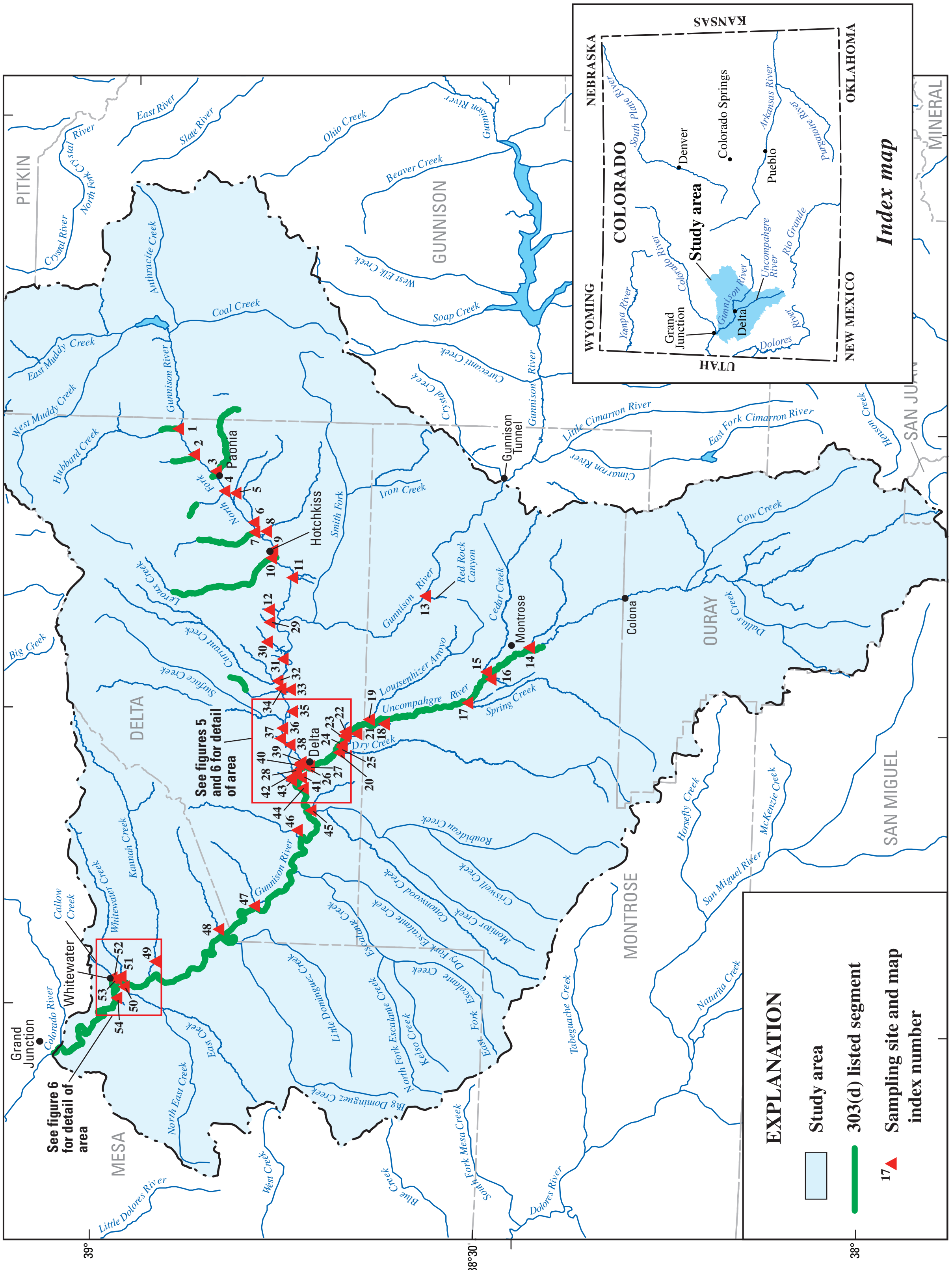
Description of Study Area

The study area is located in Delta, Mesa, and Montrose Counties in west-central Colorado. The study is focused on selected streams within the Lower Gunnison River Basin. The Lower Gunnison River Basin is locally defined as the Gunnison River from below the Gunnison Tunnel to Whitewater, Colorado, and includes the North Fork Gunnison River and the Uncompahgre River Basins (fig. 1). Whitewater is approximately 10 miles upstream from the confluence of the Gunnison and Colorado Rivers in Grand Junction, Colorado, and is approximately 40 miles downstream from Delta, Colorado. The Uncompahgre River joins the Gunnison River in Delta. From Delta, the study area extends approximately 26 miles upstream along the Uncompahgre River to Montrose, Colorado, and approximately 35 miles upstream along the Gunnison River and the North Fork Gunnison River to Paonia, Colorado. The land-surface elevation is 4,659 feet at Whitewater, 4,957 feet at Delta, 5,682 feet at Paonia, and 5,807 feet at Montrose (Geographic Names Information System, 2007).

The primary land use in the study area is irrigated agriculture (fig. 2); however, residential and urban land-use development is increasing as population growth occurs in the study area. 2005 population estimates for major population centers in the study area were 15,479 in Montrose, 8,135 in Delta, 1,584 in Paonia, and 1,402 in Whitewater (U.S. Census Bureau, 2007). Areas near Kannah Creek, Whitewater Creek, and Callow Creek are experiencing increased demand for residential housing. Changes in land use have resulted in a shift from open range and irrigated agricultural land uses to residential and urban land uses as well as the use of independent septic drainage systems. These shifts in land use have the potential to introduce new paths of selenium loading to the main stem Gunnison River (Gunnison Basin Selenium Task Force, 2007).

Climate in the study area is predominately semiarid, but some variation in climate occurs at higher elevations (in general, more precipitation and cooler temperatures occur at higher elevations). Average annual precipitation ranges from 8.9 inches at Grand Junction to 9.6 inches at Montrose. Average annual snowfall ranges from 12.3 inches at Grand Junction to 25.9 inches at Montrose. Average high temperatures are approximately 66.1 degrees Fahrenheit for Grand Junction and approximately 63.3 degrees Fahrenheit for Montrose; average lows are 40.5 and 34.6 degrees Fahrenheit, respectively (Western Regional Climate Center, 2007).

The geology of the study area is dominated by two major structural features, the Uncompahgre Uplift and the north-dipping southwestern flank of the Piceance structural basin (Brooks and Ackerman, 1985). The Uncompahgre Uplift forms the Uncompahgre Plateau and is an asymmetrical anticline that plunges northwest to southeast. Mancos Shale is the dominant bedrock material outcropping in the study area (fig. 3) east of the Uncompahgre Uplift (Green, 1992). The Mancos Shale is of Late Cretaceous age and is composed of massive, fossiliferous marine shale with interbedded sandstone, siltstone, and devitrified volcanic ash layers. The Mancos is the lateral equivalent to the Niobrara Formation, Cody Shale, and Pierre Shale in Colorado, Montana, Nebraska, South Dakota, and Wyoming (Wright and Butler, 1993). The other two dominant bedrock units in the



Base from U.S. Geological Survey digital data, 1:24,000
Universal Transverse Mercator projection, Zone 13
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83)

Figure 1. Location of study area, sites, and 303(d) list segments within the Lower Gunnison River Basin, western Colorado.

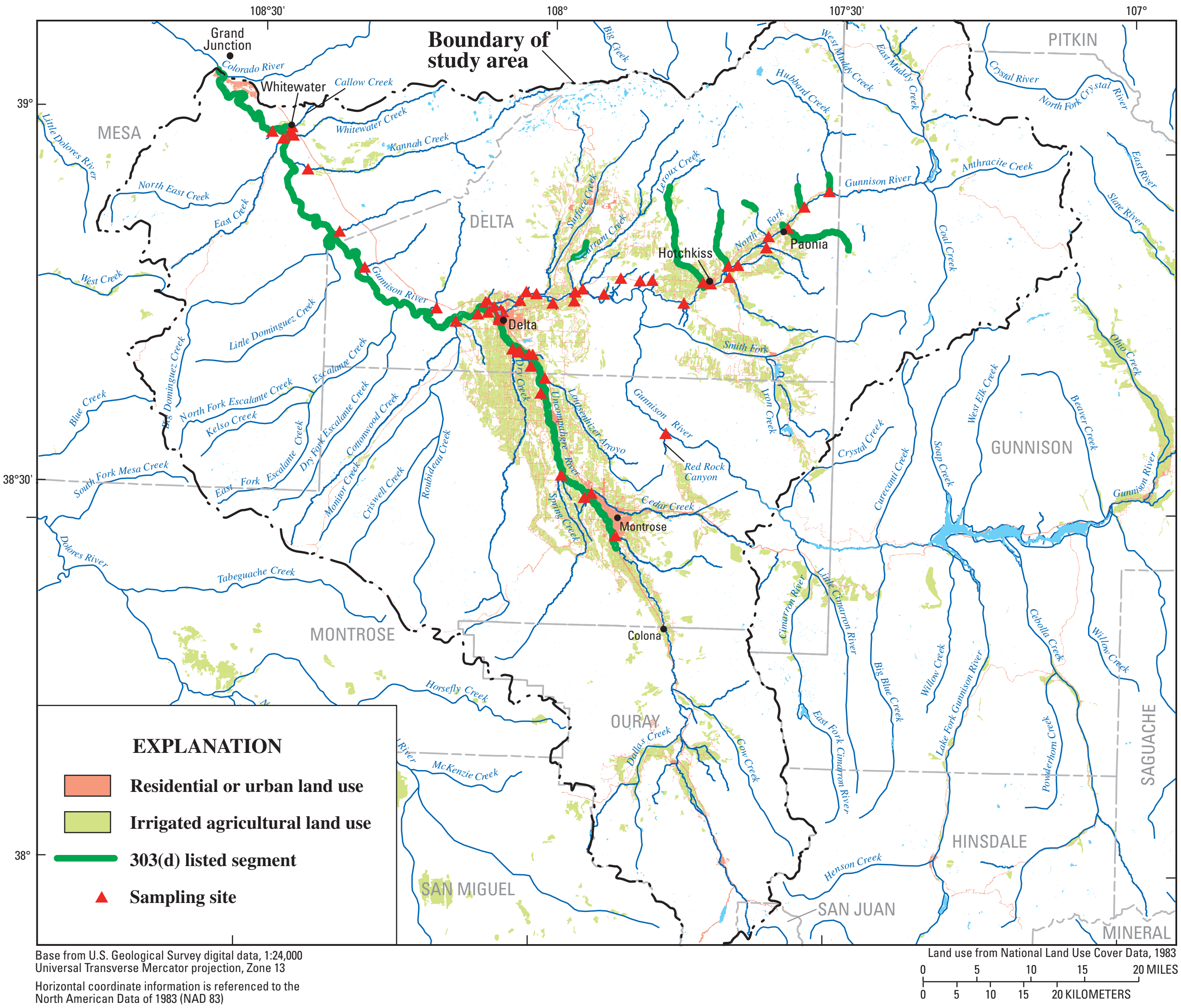


Figure 2. Select land-use types in the Lower Gunnison River Basin, western Colorado.

study area are the Dakota Sandstone of Early Cretaceous age and various alluvial units of Quaternary age.

Summary of Selenium Issues in Study Area

Selenium has been the subject of a series of local water-quality studies throughout the Western United States since 1983, when adverse biological effects were observed in aquatic bird populations at Kesterson Reservoir, a U.S. Department of the Interior (DOI) National Wildlife Refuge in the western San Joaquin Valley (California). Increased incidents of bird mortality, inherited birth defects, and reproductive failures were determined to be caused by selenium toxicity. The selenium source was found to be water conveyed to the area through constructed irrigation drainages (Ohlendorf and others, 1986, 1988). To determine if the biological effects observed at Kesterson Reservoir were an anomaly or an indication of what could be expected to occur in other water bodies that receive irrigation drain water, the National Irrigation Water Quality Program (NIWQP) was formed. NIWQP's objectives were to determine the extent and nature of irrigation–induced water-quality problems in the Western United States and to remediate those water-quality problems identified to be risks to human health or to DOI trust responsibilities (Seiler and others, 2003).

The NIWQP study was conducted as a five-phase approach that included site identification, reconnaissance investigations, detailed studies, remediation planning, and finally remediation. Of the 26 study areas investigated as part of the NIWQP program, the Gunnison River ranked as the fourth most contaminated with respect to selenium (Seiler and others, 2003). A study of selenium budgets for Lake Powell

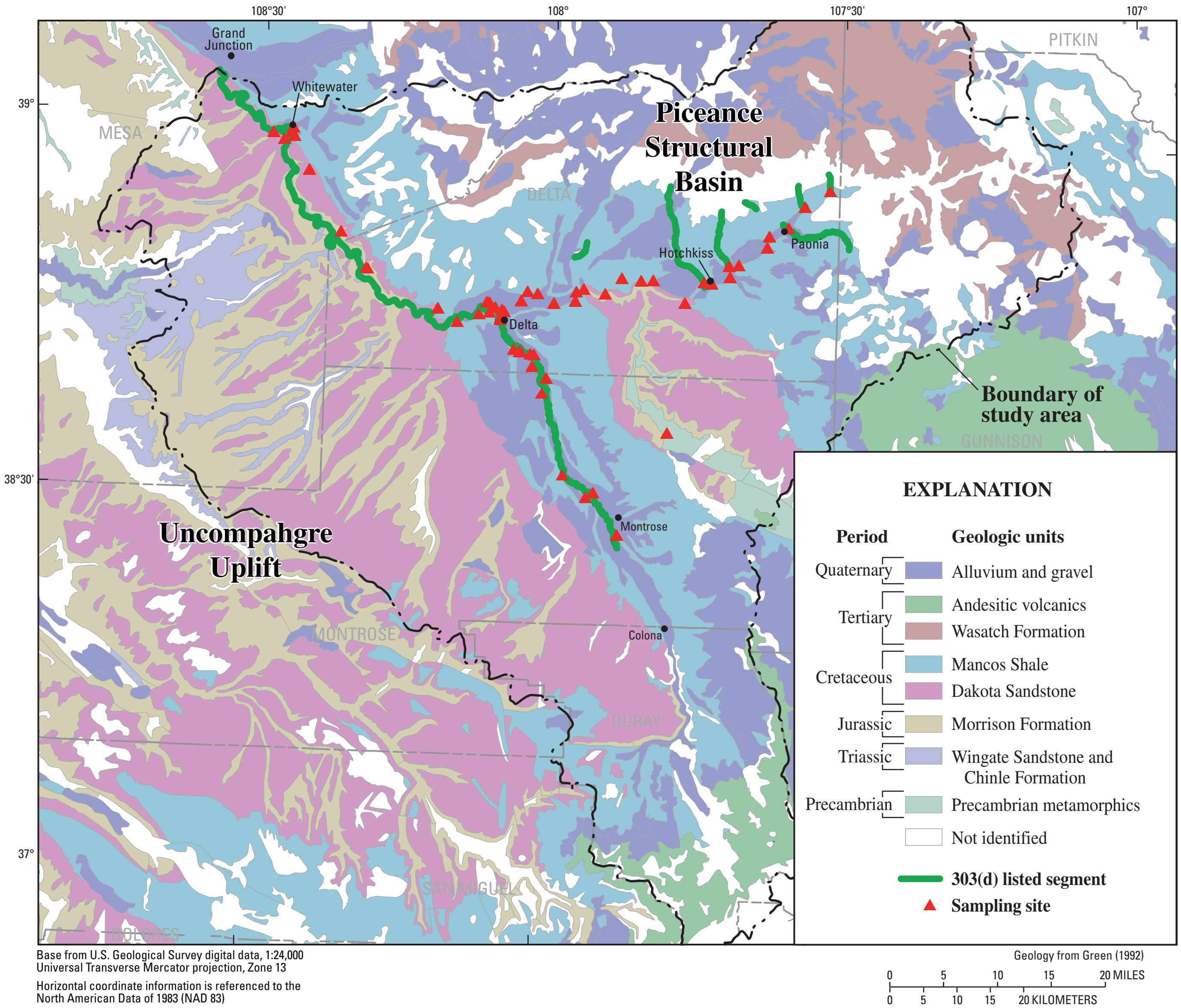


Figure 3. Selected geologic units outcropping in the Lower Gunnison River Basin, western Colorado.

(located on the Colorado River downstream from Moab, Utah) found that the Gunnison River Basin and the Grand Valley in Colorado produced 31 and 30 percent, respectively, of the total selenium load to Lake Powell (Engberg, 1999). Because the Gunnison River Basin has been identified as a significant contributor of selenium to streams, the Gunnison River Basin has been the focus of many detailed studies with emphasis on the relations of climate, geology, geography, and land use to selenium mobilization.

Selenium is a priority pollutant and the U.S. Environmental Protection Agency has been working closely with local entities to reduce selenium loading in the Gunnison River Basin (U.S. Environmental Protection Agency, 2006). The Gunnison Basin Selenium Task Force (Task Force) was established by the CDPHE's Water Quality Control Division in 1988 following the listing of several streams in the Gunnison River Basin on the 303(d) list. Task Force membership includes local governments, organizations, and citizens. The Task Force and NIWQP (now inactive) worked together to identify and resolve selenium contamination issues while supporting the economic and lifestyle needs of the citizens of the Gunnison River Basin (U.S. Environmental Protection Agency, 2007). Many focused studies have been conducted in the Gunnison River Basin to aid in the understanding of selenium-related water-quality issues. USGS conducted several of these studies, including reconnaissance investigations of water quality, sediment, and biota; effects of selenium mobilization on ground-water quality; quantification of the effectiveness of irrigation best management practices; and characterization of selenium loads from point and nonpoint sources (Butler and others, 1991, 1996; Wright and Butler, 1993; Butler, 2001; Butler and Leib, 2002).

From these studies in the Gunnison River Basin, it was determined that the variation in the magnitude of selenium concentration and load in streams is directly related to the application of irrigation water. A USGS reconnaissance study conducted in 1988 and 1989 determined that the highest selenium concentrations occurred at the Uncompahgre River at Delta (33 to 34 μg/L), whereas the lowest selenium concentrations (2 μg/L) were observed farther upstream in the Uncompahgre River at Colona (Butler and others, 1991). Butler and others (1991) concluded that the observed increases in selenium concentration in the Uncompahgre River between Colona and Delta were related to irrigation drainage. A 1998–2000 study of the Montrose Arroyo Basin determined that replacing open-ditch irrigation laterals with pipes significantly decreased the selenium and salt loads to the Montrose Arroyo. More than 90 percent of the decrease in selenium load was attributed to a decrease in ground-water selenium load (Butler, 2001). A detailed characterization study in 1999–2000 on Cedar Creek and Loutzenhizer Arroyo determined that Montrose Arroyo was the largest source of selenium to Cedar Creek and that 41 percent of the total selenium load from Loutzenhizer Arroyo originated from its west tributary (Butler and Leib, 2002).

Methods for Analysis of Selenium Loading

Site Selection

A list of current and historical USGS sampling sites in the Lower Gunnison River Basin was retrieved from USGS National Water Information System (NWIS). The minimum criteria for data retrieval were location within the Lower Gunnison River Basin and the presence of selenium concentration data. The site list was refined to contain only sites that represent the cumulative contribution of selenium concentration to 303(d) list segments in the Lower Gunnison River Basin (table 1, fig. 1). Sites that represent cumulative contribution of selenium concentration to a segment are typically sites that are at or close to the mouth of a particular segment. The 303(d) list segments included in this report for selenium loading analysis are:

- the main stem of the Uncompahgre River near Montrose, Colorado, to the confluence with the Gunnison River at Delta, Colorado (segments COGUNUN04b and COGUNUN04c; sites 26 and 28 in table 1),
- Uncompahgre River tributaries between the South Canal and the confluence with the Gunnison River (COGUNUN12; sites 14-25 and 27 in table 1),
- Leroux Creek, Jay Creek, Big Gulch, and Short Draw, tributaries to the North Fork Gunnison River (segments COGUNNF05, COGUNNF06a, and COGUNNF06b; sites 1–12 in table 1),
- Red Rock Canyon at the Mouth (COGUNLG04c; site 13 in table 1),
- the Gunnison River main stem from the confluence with the Uncompahgre River to the confluence with the Colorado River (segment COGUNLG02; sites 40 and 52 in table 1),
- Gunnison River tributaries between Crystal Reservoir and the confluence with the Colorado River (segments COGUNLG04a and COGUNLG07; sites 29–39, 41–48, 50–51, and 53–54 in table 1), and
- Kannah Creek (segment COGUNLG04b; site 49 in table 1).

A more detailed description of each segment can be found on the Water Quality Control Commission regulations Web site (Colorado Department of Public Health and Environment, 2007a).

Historical data for 54 stream water-quality/water-quantity monitoring sites were selected in consultation with Division staff who reviewed the site list and provided final approval. Division staff approval involved modifying the site list by either adding or removing sites based on Division needs. For example, Dominguez Creek, a tributary to the Gunnison River, was removed from the list and Red Rock Canyon at the Mouth was added to the list based on input from Division staff. Using the Division-approved site list, USGS data were retrieved from NWIS *(http://waterdata.usgs.gov/nwis)*, and CDPHE data were retrieved from the U.S. Environmental Protection Agency's (USEPA) STOrage and RETrieval (STORET) database *(http://www.epa.gov/storet/)*. CDPHE selenium concentration data did not have accompanying streamflow data and were not used to estimate mean daily loads. CDPHE selenium concentration data were used for sites with low sample counts to aid in determining 85th percentile selenium concentrations. For sites with low sample counts, CDPHE and USGS site aggregation occurred on the basis of site name and geographic location. For six locations in the study area, two USGS sites were near enough to one another to combine available data (table 1). Although TMDL-development guidelines recommend using the most recent 5 years of data (U.S. Environmental Protection Agency, 2006), it was necessary in many cases to use all available selenium concentration data; therefore, USGS and CDPHE data represent the period from 1978 through 2005. In this report, all annual values are expressed by water year where a water year is designated as the 12-month period from October 1 through September 30.

Table 1. List of sites that represent the cumulative contribution of selenium concentration to 303(d) list segments in the Lower Gunnison River Basin, western Colorado, 1978–2005.

[303(d) list segment, 303(d) list segment identifier (Colorado Department of Public Health and Environment, 2007a); USGS site ID, USGS site identification number; n, number of samples (selenium concentration and instantaneous discharge)]

Site number (fig. 1)	Site name	USGS site ID	n	303(d) list segment
	North Fork Gunnison River Basin and Red Rock Canyon at the mouth			
1	Hubbard Creek[1]	385532107310501 and 385532107310400	11	COGUNNF05
2	Terror Creek[1]	385414107334001 and 385414107334000	12	COGUNNF05
3	Minnesota Creek at Paonia	09134050	5	COGUNNF05
4	Roatcap Creek at Highway 133, near mouth	385144107371701	4	COGUNNF05
5	Reynolds Creek at Cty Road J75	385051107372701	4	COGUNNF06b
6	Bell Creek at county road and railroad tracks, near mouth	384922107402001	6	COGUNNF06b
7	Jay Creek at Highway 133, near mouth	384915107412101	4	COGUNNF05
8	Cottonwood Creek near Hotchkiss	09134200	7	COGUNNF06b
9	Short Draw West of county fairgrounds, at Hotchkiss	384747107430501	7	COGUNNF06a
10	Leroux Creek[1]	384732107434801 and 09135900	21	COGUNNF05
11	Alum Gulch at mouth	384610107455001	5	COGUNNF06b
12	Big Gulch at Highway 92	384756107490801	4	COGUNNF06b
13	Red Rock Canyon at mouth near Montrose	383537107471500	23	COGUNLG04c
	Uncompahgre River Basin			
14	Dry Cedar Creek[1]	382711107520101 and 382716107520701	34	COGUNUN12
15	Cedar Creek near mouth	383041107544201	45	COGUNUN12
16	Mexican Gulch near mouth	383013107552501	1	COGUNUN12
17	Spring Creek[1]	09149400 and 383201107575301	14	COGUNUN12
18	Drain at Blossom Road, near Chipeta	383834108001701	1	COGUNUN12
19	Loutzenhizer Arroyo at N. River Road	383946107595301	87	COGUNUN12
20	Dry Creek at mouth, near Delta	384202108032001	17	COGUNUN12
21	Drain at B Road, near 1800, Ash Mesa	384043108012201	1	COGUNUN12
22	Drainage ditch near Highway 50, Overholt Wetland	384137108011401	1	COGUNUN12
23	Drainage ditch 2 at Overholt Wetland Area	384140108013601	1	COGUNUN12
24	Drain at D10 and Ash Mesa Roads	384152108024401	1	COGUNUN12
25	Drain at Ash Mesa Road, upper ditch	384150108023101	2	COGUNUN12
26	Uncompahgre River at Delta	09149500	124	COGUNUN04b
27	Ditch at 5th Street bridge at mouth, in Delta	384423108044801	1	COGUNUN12
28	Uncompahgre River at mouth	384523108052101	3	COGUNUN04c
	Gunnison River from North Fork Gunnison River to Grand Junction, Colorado			
29	Sulphur Gulch at Highway 92	384752107502201	4	COGUNLG04a
30	Lawhead Gulch at Highway 92	384802107522201	4	COGUNLG04a
31	Unnamed drainage below Oasis Pond, at county road	384643107540301	6	COGUNLG04a
32	Currant Creek[1]	09137050 and 384651107561001	10	COGUNLG04a
33	Peach Valley Arroyo near mouth	384604107570701	10	COGUNLG04a
34	Alfalfa Run at Austin	384649107570501	7	COGUNLG04a
35	Sunflower Drain at Highway 92, near Read	384551107591901	106	COGUNLG04a
36	Tongue Creek at mouth	384635108010301	1	COGUNLG07
37	Unnamed drainage along 1825 Road, north of Delta	384643108020501	1	COGUNLG04a
38	Dry Gulch above confluence with Heartland ditch near Delta	384557108024300	2	COGUNLG04a
39	Drainage ditch at Confluence Park, at Delta	384502108042701	3	COGUNLG04a
40	Gunnison River at Delta	09144250	44	COGUNLG02
41	Drainage ditch near 1400 Road, at mouth	384457108055801	3	COGUNLG04a
42	East unnnamed drain at Highway 50, near Delta	384544108060001	4	COGUNLG04a
43	West unnamed drain at Highway 50, near Delta	384545108061601	4	COGUNLG04a
44	Cummings Gulch at mouth	384448108070301	13	COGUNLG04a
45	Seep Creek at G Road, near mouth	384408108091501	4	COGUNLG04a
46	Alkali Creek below Highway 50, near Delta	384510108111801	10	COGUNLG04a
47	Wells Gulch at Dominguez Road crossing	384813108184301	3	COGUNLG04a
48	Deer Creek below Windy Creek, near mouth	385104108213501	2	COGUNLG04a
49	Kannah Creek about .1 miles below Indian Creek	385600108250301	17	COGUNLG04b
50	East Creek at Highway 141 Bridge, near Whitewater	385824108274401	2	COGUNLG04a
51	Whitewater Creek .4 miles above mouth, at Whitewater	385839108264401	19	COGUNLG04a
52	Gunnison River near Grand Junction	09152500	202	COGUNLG02
53	Callow Creek at Whitewater	09152520	10	COGUNLG04a
54	Bangs Canyon at mouth, near Whitewater	385855108285501	1	COGUNLG04a

[1] Combined two nearby sites into a single site.

Estimating Selenium Loads, 85th Percentile Selenium Concentrations, and Load Reductions

Historical data for 54 stream water-quality/water-quantity monitoring sites with selenium sample results were compiled from USGS and CDPHE data sources for this study. Three of the sites were located at gaging stations (gaged) and therefore had continuous streamflow data. The remaining 51 sites were not located at streamflow-gaging stations (ungaged); however, instantaneous streamflow was measured at the time selenium concentration data were collected. The amount of available data and the period of data collection varied considerably from site to site. This resulted in a varying ability to estimate selenium loads and selenium load reductions.

Three methods were used for loading analysis of selenium concentration data to address the variable data density among sites. For sites with low sample counts (typically 20 samples or less), USGS and CDPHE data were combined to provide statistical summaries. For ungaged sites that had monthly samples for one or more water years (typically 20 or more total samples that contained both selenium concentration and instantaneous streamflow data), a time-weighting technique was used for estimation of annual selenium loads using USGS data. For gaged sites, a regression analysis was used to estimate daily mean selenium concentrations using USGS data from which annual selenium loads and 85th percentile selenium concentrations were determined. Selenium load reductions were determined for sites where 85th percentile selenium concentrations exceeded the water-quality standard and a mean annual selenium load had been determined.

USGS water-quality data retrieved from NWIS were collected and processed using standard USGS techniques and procedures (U.S. Geological Survey, variously dated). USGS streamflow data were collected using standard USGS stream-gaging methods (Rantz and others, 1982). CDPHE water-quality data retrieved from STORET were collected using standard methods (Colorado Department of Public Health and Environment, 1998). For the historical USGS data used in this report, two minimum reporting limits (MRL) were used, 1 and 2 μg/L. Concentrations found to be less than the MRL are referred to as “censored data.” For censored data, one-half the value of the MRL was used for data analysis; however, most selenium concentrations were substantially greater than the MRL. Additionally, it was not necessary to alter censored-data values for regression analysis as the method already has a means for dealing with censored data.

Statistical Summary of Available Data

Statistical summaries were calculated for sites that did not have sufficient data to estimate an annual selenium load. Sites that did not have sufficient data typically had less than 20 samples. Statistical summaries included sample counts for matched pairs of selenium concentration and streamflow data, median and range of selenium concentration data, 85th percentile selenium concentrations for sites with five or more samples, mean loads in pounds per day, and sample date range. Because CDPHE selenium concentration data did not have accompanying streamflow data, statistical summaries for USGS data are presented separately from CDPHE data. Where CDPHE selenium concentration data were available, a recalculated 85th percentile selenium concentration is determined that represents an 85th percentile selenium concentration based on the combination of USGS and CDPHE selenium concentration data.

Load Estimation Using Annual Time-Weighted Means

For ungaged sites with approximately 20 or more samples that contained both selenium concentration and instantaneous streamflow data, an annual time-weighted mean (ATWM) was determined that represents an annual selenium load in pounds. To evaluate a site with respect to ATWM, selenium concentration and instantaneous streamflow data were needed to proportionally represent water-quality conditions for 1 or more water years. Proportional representation of a water year implies that samples were collected during each season, and typically at least 1 sample was collected per month. A selenium load was calculated for each matched pair of selenium concentration and streamflow. Each calculated selenium load was assigned a weight on the basis of the number of days between samples. Weights were computed as the amount of time extending from one-half the time interval between a sample and the preceding sample and one-half the time interval extending from the sample to the subsequent sample divided by the total time in a year. Weights were computed using the following general equation:

$$Wc = \frac{[1/2\,(Dc - Dp) - 1/2\,(Dc - Ds)]}{365.25} \times 100, \qquad (1)$$

where

- Wc is the weight for the sample, as a percentage;
- Dc is the date of the sample, in days;
- Dp is the date of the preceding sample, in days;
- Ds is the date of the subsequent sample, in days;

and

- 365.25 is the number of days in a year including leap years.

The weight was multiplied by the corresponding load, and the weighted loads were summed to represent the mean annual load for a given water year (Crawford, 2004; Larson and others, 2004).

Ideally, ATWM sample weights were approximately equal to one another; however, each water year was evaluated to determine if the distribution of the selenium samples was proportionally weighted. Proportional data typically implied samples collected monthly or more frequently, resulting in monthly weights that were approximately equal to the other months of the year. In the event that a weight for one particular month was greater than that for the other months in the year, that weight was evaluated to determine if it adequately represented that portion of the water year. Factors such as the amount of irrigation water that the site receives were used to evaluate the adequacy of a sample weight. The irrigation season occurs typically from April through October. The remaining portion of the year (November through March) is the nonirrigation season (no irrigation water is delivered). Owing to the annual variability of the dates when irrigation water is turned on or off, transition periods were identified that represented intervals when selenium loads and concentrations could be expected to be highly variable due to the presence or absence of irrigation water. These transition periods were defined as occurring from March through April (irrigation water on) and mid-October through the end of November (irrigation water off). For sites where water quality and water quantity were dominated by the use of irrigation water, emphasis was placed on the need for samples collected during these transition periods. During periods when there was no use of irrigation water, a single sample could be allowed to represent more than 1 month as no appreciable changes were expected in selenium concentrations and loads during these periods.

Load Estimation Using Regression Analysis

A multiple linear regression model was developed for estimating mean daily selenium concentration using the FORTRAN program LOAD ESTimator (LOADEST) for gaged sites. LOADEST provides users the ability to develop a regression model for estimating constituent loads or concentrations over a user-specified time period (Runkel and others, 2004). Load estimates were derived in three steps—model development, calibration of the developed model, and estimates of loads using the model. LOADEST provides 11 predefined regression models and also allows for the creation of user-defined models. The 11 predefined models in LOADEST are a series of models starting with the simplest model and increasing in complexity by the addition of one or more explanatory variables. The regression model used in this analysis takes the following general form:

$$\ln(C) = a_0 + a_1 \ln Q + a_2 \ln Q^2 + a_3 \sin(2\pi dtime) + a_4 \cos(2\pi dtime) + a_5 dtime, \quad (2)$$

where

- C is constituent concentration, in micrograms per liter;
- Q is the stream discharge, in cubic feet per second;
- *dtime* is decimal years from the beginning of the calibration period;
- $\sin(2\pi dtime)+\cos(2\pi dtime)$ is used to describe seasonality;

and

- a_n are model coefficients where n = 0, 1, 2,…., n.

Not every regression model in this study used all of the explanatory variables listed above; each model was developed to best represent the site characteristics and the available data. Where continuous specific conductance data were available, specific conduction was used to estimate selenium concentrations in place of streamflow in the general equation. Regression models were developed from a set of calibration data that consisted of matched pairs of selenium concentration data and streamflow (or specific conduction) data. An estimation file containing continuous data (either mean daily streamflow or mean daily specific conductance) was used as input to the regression model to predict mean daily selenium concentrations.

Model coefficients were developed using ordinary least-squares (OLS) regression. OLS is a method for linear regression that estimates unknown quantities in a statistical model by minimizing the sum of the residuals (difference between the predicted and observed values) squared (Helsel and Hirsch, 1992). Evaluation of a model's significance included looking at the following diagnostics—the coefficient of determination (r^2), p-values, residual plots, and the standard error of estimate. Generally, a model exhibited poor correlation if the r^2 value was less than 0.6 and the p-value was greater than 0.05. Residual plots (not included in this report) were evaluated to confirm normality and constant variance throughout the range of prediction (homoscedasticity) (Helsel and Hirsch, 1992). Serial correlation also was evaluated using residual plots (where a residual is an estimated value minus its corresponding observed value) related to loading concentration estimates and time. The presence of a serial correlation indicates that sampling bias or a trend may exist in the data set. All diagnostics were considered collectively to determine the most appropriate regression model (Leib and others, 2003). Loads were estimated using the calibrated regression equation and a time series of daily streamflow and/or specific conductance values. The primary load estimation method used within LOADEST was Adjusted Maximum Likelihood Estimation (AMLE) (Runkel and others, 2004).

85th Percentile Selenium Concentrations

For all sites with five or more samples, 85th percentile selenium concentrations were calculated. All 85th percentile selenium concentrations were calculated in Microsoft Excel using the PERCENTILE function (Microsoft Corporation, 2003). For sites lacking sufficient data to calculate annual selenium loads, all available data were used for calculation of 85th percentile selenium concentrations. For sites where ATWM was used to estimate mean annual selenium loads, the 85th percentile selenium concentration was computed from the selenium concentrations used to determine ATWM (proportionally weighted samples). For sites where LOADEST was used to estimate daily selenium concentrations, the 85th percentile selenium concentration was computed from the estimated daily selenium concentrations.

Load Reductions

Load reductions represent the amount of selenium load (pounds annually) that would need to be reduced to meet the water-quality standard. Load reductions were determined for sites with mean annual selenium loads (ATWM or LOADEST methods). To determine if a load reduction would be needed at a site, the site was evaluated with respect to its 85th percentile selenium concentration. If the 85th percentile selenium concentration exceeded the water-quality standard, the load reduction was calculated using a simple mass-balance approach. This approach assumed that the selenium load reduction would take place with no change in streamflow volume and that only selenium would be removed from the system. On the basis of this assumption, a new selenium load was determined that equaled the load that would result if the 85th percentile selenium concentration were to equal the water-quality standard of 4.6 µg/L.

This method of calculating load reductions uses the ratio of the water-quality standard to the 85th percentile selenium concentration, which inherently preserves the distribution of the concentrations through the year. The hypothetical load at compliance with the water-quality standard was subtracted from the mean annual load, and the resulting value represents the amount of selenium load that would need to be reduced to bring the site into compliance with the water-quality standard. Load reduction is defined by the following equation:

$$L_R = L_A - (\text{STD [Se]} / \text{85th [Se]})\, L_A, \qquad (3)$$

where

L_R is mean annual load reduction, in pounds;

L_A is mean annual load at a site, in pounds;

STD [Se] is 4.6 µg/L, the State chronic aquatic-life standard for dissolved selenium;

and

85th [Se] is the 85th percentile selenium concentration at a site, in micrograms per liter.

Dissolved Selenium Loading for Selected Sites in the Lower Gunnison River Basin

This section of the report contains a summary of dissolved selenium loading for the 54 selected sites in the Lower Gunnison River Basin, organized as follows: North Fork Gunnison River Basin and Red Rock Canyon at the mouth, Uncompahgre River Basin, and Gunnison River from North Fork Gunnison River to Grand Junction. Each section contains a map of the sites and reference to one or more of the three tables that contain results of selenium loading analysis for the three methods used. This loading analysis summary contains summary statistics, 85th percentile selenium concentrations, mean daily and mean annual selenium loads, and annual load reductions for sites whose 85th percentile selenium concentration exceeded the water-quality standard.

North Fork Gunnison River Basin and Red Rock Canyon at the Mouth

Twelve sites within the North Fork Gunnison River Basin (sites 1–12, table 1) and Red Rock Canyon at the mouth (site 13, table 1) (fig. 4) were selected for analysis. For the Nork Fork Gunnison River Basin, sites 1 through 12 represent the cumulative contribution of selenium concentration to 303(d) list segments COGUNNF05, and COGUNNF06a and b (table 1). All 12 sites lacked sufficient data to calculate mean annual selenium loads (table 2). Seven of the 12 sites had CDPHE data in addition to USGS data (table 2). Sample dates ranged from 1982 through 2000 for USGS selenium concentration data and from 1998 through 2005 for CDPHE selenium concentration data. Based on USGS data, 4 of the 12 sites had 85th percentile selenium concentrations that exceeded the water-quality standard (4.6 µg/L). These sites were Bell Creek (site 6), Cottonwood Creek (site 8), Short Draw (site 9), and Leroux Creek (site 10).

The cumulative mean selenium load from the 12 sites in the North Fork Gunnison River Basin was 2.3 pounds per day (table 2). Assuming that this load is a reasonable representation of the cumulative mean daily load from these sites, the resulting mean annual selenium load would be approximately 840 pounds. In a previous report on selenium loading by Butler and Leib (2002), the mean annual selenium load for the North Fork Gunnison River at the mouth was approximately 1,300 and 1,400 pounds per year for 1999 and 2000, respectively. The cumulative mean annual selenium load calculated for the selected sites (table 2) represents more than one-half of the mean annual selenium load to the North Fork Gunnison River. The source of the remaining mean annual selenium load is not known, but sources may include unquantified naturally occurring selenium load from ground water and surface water, deep percolation of irrigation water, or septic systems. Further quantification of the combination of selenium sources such as agricultural land use, residential and urban development, and the occurrence of selenium parent material in this basin may aid in more completely understanding the source of the selenium observed in North Fork Gunnison River.

Red Rock Canyon at the mouth near Montrose (site 13) represents the cumulative contribution of selenium concentration to 303(d) list segment COGUNLG04c (fig. 4, table 3). Red Rock Canyon data spans the 2001 to 2005 water-year period. Water years 2004 and 2005 had sufficient data to compute an ATWM. For the 2004 water year, the 85th percentile selenium concentration was 72.1 µg/L and mean daily load was 0.571 pound (209 pounds annually). Based on 2004 results, to bring this site into compliance with the water-quality standard, 93 percent (195 pounds) of the mean annual load would need to be reduced. For the 2005 water year, the 85th percentile selenium concentration was 53.1 µg/L and the

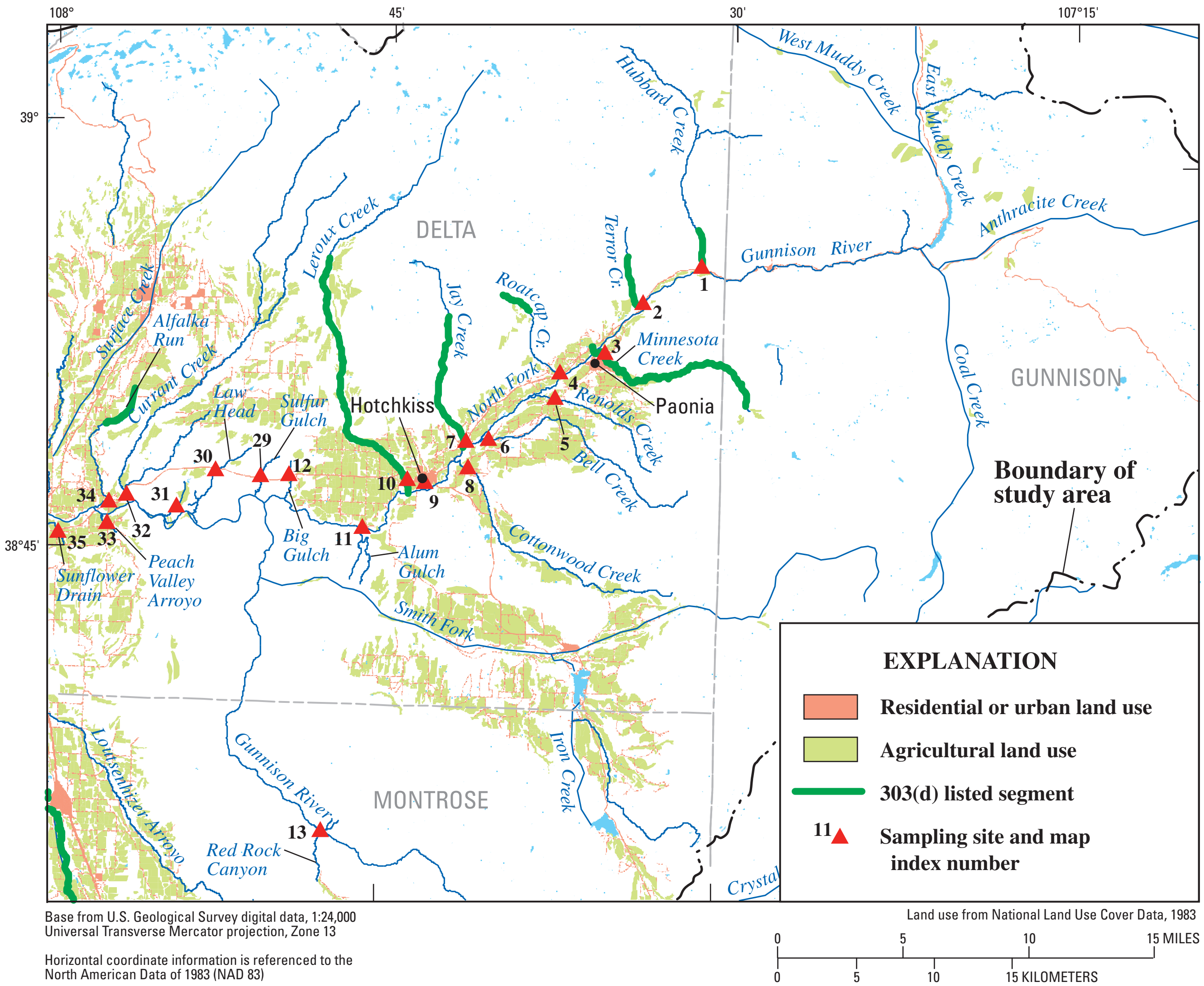


Figure 4. Location of sites and land use in the North Fork Gunnison River Basin and Red Rock Canyon at the mouth (site 13), western Colorado.

mean daily load was 0.710 pound (259 pounds annually). The mean annual load would need to be reduced by 92 percent to bring this site into compliance with the water-quality standard. The average amount of load that would need to be reduced at this site for water years 2004 and 2005 was 217 pounds or 93 percent of the mean annual load. This high percentage of load reduction represents almost the entire mean annual load at this site.

Uncompahgre River Basin

Fifteen sites within the Uncompahgre River Basin were selected that represent the cumulative contribution of selenium concentration to 303(d) list segments COGUNUN12 (table 1, sites 14-25 and 27), COGUNUN04b (table 1, site 26), and COGUNUN04c (table 1, site 28), which are segments on the main stem of the Uncompahgre River near Montrose, Colorado, to the confluence with the Gunnison River at Delta (fig. 5).

Data for 5 of the 15 sites were sufficient to determine mean annual selenium loads (tables 3 and 4). For the remaining 10 sites that lacked sufficient data to calculate mean annual selenium loads (table 2), only the Spring Creek site (site 17) had more than five samples, and its 85th percentile selenium concentration was 2.0 µg/L (table 2). Dry Cedar Creek (site 14), Cedar Creek (site 15), Loutzenhizer Arroyo (site 19), and Dry Creek (site 20) were ungaged and mean annual selenium loads were estimated using the ATWM method (table 3). The Uncompahgre River at Delta (site 26) is gaged; therefore, LOADEST was used to estimate mean annual selenium loads for the most recent 5 years of data (2001 through 2005) (table 5).

Dry Cedar Creek (site 14) data spans the 1991 through 2001 water-year period. Water years 1995 and 1996 had suffi-

Table 2. Statistical summary of selenium concentration data for sites with limited data sets in the Lower Gunnison River Basin, western Colorado, 1978–2005.

[303(d) list segment, 303(d) list segment identifier (Colorado Department of Public Health and Environment, 2007a); USGS, U.S. Geological Survey; CDPHE, Colorado Department of Public Health and Environment; n, number of samples; NA, no value computed; --, no data available; mean load; mean selenium load in pounds per day]

Site number (fig. 1)	Site name	303(d) list segment	USGS: Number of values/number of censored values	USGS: Selenium concentration (µg/L): Median	Range	85th percentile	Mean load	Date range
	North Fork Gunnison River Basin							
1	Hubbard Creek[1]	COGUNNF05	11/10	NA	<0.7–<1	NA	0.34	06/09/1982–03/13/2000
2	Terror Creek[1]	COGUNNF05	12/11	NA	<0.7–<1	NA	0.17	04/14/1982–03/13/2000
3	Minnesota Creek at Paonia	COGUNNF05	5/2	1.3	<1–1.5	1.4	0.038	05/11/1999–03/13/2000
4	Roatcap Creek at Highway 133, near mouth	COGUNNF05	4/2	2.5	<1–4.9	NA	0.056	05/11/1999–03/13/2000
5	Reynolds Creek at Cty Road J75	COGUNNF06b	4/2	4.6	<1–8.0	NA	0.020	05/11/1999–03/13/2000
6	Bell Creek at county road and railroad tracks, near mouth	COGUNNF06b	6/0	4.5	3.0–7.0	7.0	0.21	05/11/1999–03/13/2000
7	Jay Creek at Highway 133, near mouth	COGUNNF05	4/0	12.9	6.4–18.8	NA	0.061	05/11/1999–03/13/2000
8	Cottonwood Creek near Hotchkiss	COGUNNF06b	7/0	7.3	4.2–12.8	9.6	0.32	05/11/1999–07/25/2000
9	Short Draw West of county fairgrounds, at Hotchkiss	COGUNNF06a	7/0	11.3	8.0–29.4	19.1	0.37	10/15/1998–03/14/2000
10	Leroux Creek[1]	COGUNNF05	21/0	9.5	1.0–21	15	0.47	12/18/1990–12/05/2000
11	Alum Gulch at mouth	COGUNNF06b	5/0	2.4	1.6–3.2	3.1	0.12	10/15/1998–03/14/2000
12	Big Gulch at Highway 92	COGUNNF06b	4/0	7.5	7.0–9.0	NA	0.13	05/12/1999–03/14/2000
	Uncompahgre River Basin							
16	Mexican Gulch near mouth	COGUNUN12	1/0	NA	2.0	NA	0.010	02/20/1992
17	Spring Creek	COGUNUN12	14/5	0.5	<1–3.0	2.0	0.16	01/11/1978–08/25/2003
18	Drain at Blossom Road, near Chipeta	COGUNUN12	1/0	NA	34	NA	0.020	02/20/1992
21	Drain at B Road, near 1800, Ash Mesa	COGUNUN12	1/0	NA	55	NA	0.0030	02/10/1992
22	Drainage ditch near Highway 50, Overholt Wetland	COGUNUN12	1/0	NA	71	NA	0.19	02/29/1996
23	Drainage ditch 2 at Overholt Wetland Area	COGUNUN12	1/0	NA	26	NA	0.014	02/29/1996
24	Drain at D10 and Ash Mesa Roads	COGUNUN12	1/0	NA	8.0	NA	0.021	02/20/1992
25	Drain at Ash Mesa Road, upper ditch	COGUNUN12	2/0	10	8.8–11	NA	0.12	02/20/1992–11/22/1999
27	Ditch at 5th Street bridge at mouth, in Delta	COGUNUN12	1/0	NA	38.5	NA	0.35	06/29/1999
28	Uncompahgre River at mouth	COGUNUN04c	3/0	16.5	11.5–17.1	NA	14.9	12/20/2000–07/11/2001
	Gunnison River from North Fork Gunnison River to Grand Junction, Colorado							
29	Sulphur Gulch at Highway 92	COGUNLG04a	4/0	10	5.0–21	NA	0.0080	05/17/1999–03/14/2000
30	Lawhead Gulch at Highway 92	COGUNLG04a	4/0	7.0	5.0–8.0	NA	0.011	05/17/1999–03/14/2000
31	Unnamed drainage below Oasis Pond, at county road	COGUNLG04a	6/0	9.5	5.0–15	14	0.30	05/17/1999–03/14/2000
32	Currant Creek[1]	COGUNLG04a	10/0	20.2	10–43.6	34.2	0.65	07/16/1991–03/28/2001
33	Peach Valley Arroyo near mouth	COGUNLG04a	10/0	6.5	5.0–95	27.9	0.39	07/22/1991–03/15/2000
34	Alfalfa Run at Austin	COGUNLG04a	7/1	16.4	<1–18.1	17.5	0.28	07/22/1991–03/15/2000
36	Tongue Creek at mouth	COGUNLG07	1/0	NA	11.9	NA	0.78	06/05/2000
37	Unnamed drainage along 1825 Road, north of Delta	COGUNLG04a	1/0	NA	32.8	NA	0.0053	01/18/2000
38	Dry Gulch above confluence with Heartland ditch near Delta	COGUNLG04a	2/0	2450	321–4580	NA	1.4	03/02/2002–07/23/2002
39	Drainage ditch at Confluence Park, at Delta	COGUNLG04a	3/0	29	28–37	NA	0.76	07/15/1993–09/10/1993
41	Drainage ditch near 1400 Road, at mouth	COGUNLG04a	3/0	10	9–11	NA	0.42	07/20/1993–09/10/1993
42	East unnnamed drain at Highway 50, near Delta	COGUNLG04a	4/0	6.5	4.6–65.1	NA	0.082	04/27/1999–03/20/2000
43	West unnamed drain at Highway 50, near Delta	COGUNLG04a	4/0	3.5	2.0–5.0	NA	0.12	04/27/1999–11/16/1999
44	Cummings Gulch at mouth	COGUNLG04a	13/0	8.4	3.4–16	14	0.92	07/15/1991–03/20/2000
45	Seep Creek at G Road, near mouth	COGUNLG04a	4/0	6.0	6.0–10	NA	0.55	01/29/1992–09/10/1993
46	Alkali Creek below Highway 50, near Delta	COGUNLG04a	10/0	88.5	18.0–150	117	0.042	11/24/1995–04/04/2000
47	Wells Gulch at Dominguez Road crossing	COGUNLG04a	3/1	8.0	<1–10	NA	0.021	06/17/1999–03/21/2000
48	Deer Creek below Windy Creek, near mouth	COGUNLG04a	2/0	3.5	2.0–5.0	NA	0.0048	02/07/2000–03/21/2000
49	Kannah Creek about .1 miles below Indian Creek	COGUNLG04b	17/0	13.7	3.5–65.0	42.0	0.40	04/29/1999–03/12/2002
50	East Creek at Highway 141 Bridge, near Whitewater	COGUNLG04a	2/0	1.4	1.3–1.5	NA	0.010	04/29/1999–09/08/1999
53	Callow Creek at Whitewater	COGUNLG04a	10/0	11.6	5.2–48.5	15.2	0.0034	04/29/1999–05/23/2002
54	Bangs Canyon at mouth, near Whitewater	COGUNLG04a	1/1	NA	<1	NA	0.0038	04/30/1999

Table 2. Statistical summary of selenium concentration data for sites with limited data sets in the Lower Gunnison River Basin, western Colorado, 1978–2005.—Continued

[303(d) list segment, 303(d) list segment identifier (Colorado Department of Public Health and Environment, 2007a); USGS, U.S. Geological Survey; CDPHE, Colorado Department of Public Health and Environment; n, number of samples; NA, no value computed; --, no data available; mean load; mean selenium load in pounds per day]

			USGS with CDPHE	CDPHE				
			Selenium concentration (µg/L)		Selenium concentration (µg/L)			
Site number (fig. 1)	Site name	303(d) list segment	85th percentile (n)	Number of values/number of censored values	Median	Range	85th percentile	Date range for CDPHE data
			North Fork Gunnison River Basin					
1	Hubbard Creek[1]	COGUNNF05	NA (17)	6/6	NA	NA	NA	07/24/2000–03/16/2005
2	Terror Creek[1]	COGUNNF05	NA (18)	6/6	NA	NA	NA	07/24/2000–03/16/2005
3	Minnesota Creek at Paonia	COGUNNF05	2.0 (10)	5/0	2	1.1–2	2	03/31/1998–01/12/2005
4	Roatcap Creek at Highway 133, near mouth	COGUNNF05	3.8 (9)	5/0	2.1	1.0–3.0	3	03/31/1998–01/12/2005
5	Reynolds Creek at Cty Road J75	COGUNNF06b	--	--	--	--	--	--
6	Bell Creek at county road and railroad tracks, near mouth	COGUNNF06b	--	--	--	--	--	--
7	Jay Creek at Highway 133, near mouth	COGUNNF05	--	--	--	--	--	--
8	Cottonwood Creek near Hotchkiss	COGUNNF06b	12 (10)	3/0	11	9.8–13	NA	03/31/1998–01/11/2005
9	Short Draw West of county fairgrounds, at Hotchkiss	COGUNNF06a	--	--	--	--	--	--
10	Leroux Creek[1]	COGUNNF05	12 (43)	22/0	6.9	2.2–9.0	8	04/01/1998–03/15/2005
11	Alum Gulch at mouth	COGUNNF06b	3.1 (6)	1/0	NA	1.0	NA	04/01/1998
12	Big Gulch at Highway 92	COGUNNF06b	--	--	--	--	--	--
			Uncompahgre River Basin					
16	Mexican Gulch near mouth	COGUNUN12	--	--	--	--	--	--
17	Spring Creek	COGUNUN12	--	--	--	--	--	--
18	Drain at Blossom Road, near Chipeta	COGUNUN12	--	--	--	--	--	--
21	Drain at B Road, near 1800, Ash Mesa	COGUNUN12	--	--	--	--	--	--
22	Drainage ditch near Highway 50, Overholt Wetland	COGUNUN12	--	--	--	--	--	--
23	Drainage ditch 2 at Overholt Wetland Area	COGUNUN12	--	--	--	--	--	--
24	Drain at D10 and Ash Mesa Roads	COGUNUN12	--	--	--	--	--	--
25	Drain at Ash Mesa Road, upper ditch	COGUNUN12	--	--	--	--	--	--
27	Ditch at 5th Street bridge at mouth, in Delta	COGUNUN12	--	--	--	--	--	--
28	Uncompahgre River at mouth	COGUNUN04c	--	--	--	--	--	--
			Gunnison River from North Fork Gunnison River to Grand Junction, Colorado					
29	Sulphur Gulch at Highway 92	COGUNLG04a	--	--	--	--	--	--
30	Lawhead Gulch at Highway 92	COGUNLG04a	--	--	--	--	--	--
31	Unnamed drainage below Oasis Pond, at county road	COGUNLG04a	--	--	--	--	--	--
32	Currant Creek[1]	COGUNLG04a	33.6 (15)	5/0	7.0	1–26	21	04/01/1998–5/11/2005
33	Peach Valley Arroyo near mouth	COGUNLG04a	--	--	--	--	--	--
34	Alfalfa Run at Austin	COGUNLG04a	--	--	--	--	--	--
36	Tongue Creek at mouth	COGUNLG07	--	--	--	--	--	--
37	Unnamed drainage along 1825 Road, north of Delta	COGUNLG04a	--	--	--	--	--	--
38	Dry Gulch above confluence with Heartland ditch near Delta	COGUNLG04a	--	--	--	--	--	--
39	Drainage ditch at Confluence Park, at Delta	COGUNLG04a	--	--	--	--	--	--
41	Drainage ditch near 1400 Road, at mouth	COGUNLG04a	--	--	--	--	--	--
42	East unnnamed drain at Highway 50, near Delta	COGUNLG04a	--	--	--	--	--	--
43	West unnamed drain at Highway 50, near Delta	COGUNLG04a	--	--	--	--	--	--
44	Cummings Gulch at mouth	COGUNLG04a	14 (14)	1/0	NA	14	NA	03/09/1999
45	Seep Creek at G Road, near mouth	COGUNLG04a	11 (5)	1/0	NA	12	NA	03/10/1999
46	Alkali Creek below Highway 50, near Delta	COGUNLG04a	116 (11)	1/0	NA	34	NA	03/10/1999
47	Wells Gulch at Dominguez Road crossing	COGUNLG04a	--	--	--	--	--	--
48	Deer Creek below Windy Creek, near mouth	COGUNLG04a	--	1/0	NA	6	NA	03/09/1999
49	Kannah Creek about .1 miles below Indian Creek	COGUNLG04b	41 (19)	2/0	31	24–37	NA	03/09/1999–07/13/2005
50	East Creek at Highway 141 Bridge, near Whitewater	COGUNLG04a	--	1/0	NA	1	NA	03/10/1999
53	Callow Creek at Whitewater	COGUNLG04a	--	--	--	--	--	--
54	Bangs Canyon at mouth, near Whitewater	COGUNLG04a	--	--	--	--	--	--

[1] Combined two nearby sites into a single site.

Table 3. Selenium loading analyses for sites using average time-weighted mean (ATWM) method, Lower Gunnison River Basin, western Colorado, 1992–2005.

[303(d) list segment, 303(d) list segment identifier (Colorado Department of Public Health and Environment, 2007a); n, number of samples (selenium concentration and instantaneous discharge); 85th percentile, 85th percentile selenium concentration in µg/L; mean daily load, pounds per day; mean annual load, pounds per year; load reduction, pounds per year; Percent load reduction, percent of total load that needs to be reduced to bring site into compliance with water-quality standards]

Site number (fig. 1)	Site name	303(d) list segment	n	Water year	85th percentile	Mean daily load	Mean annual load	Load reduction	Percent load reduction
13	Red Rock Canyon at mouth near Montrose	COGUNLG04c	6	2004	72.1	0.571	209	195	93
			6	2005	53.1	0.710	259	238	92
				Average[1]	62.6	0.641	234	217	93
				Uncompahgre River basin					
14	Dry Cedar Creek[2]	COGUNUN12	10	1995	56.5	0.636	232	213	92
			12	1996	67.4	0.843	309	287	93
				Average[1]	61.9	0.740	270	250	93
15	Cedar Creek near mouth	COGUNUN12	9	1992	40.8	6.69	2,440	2,170	89
			5	1993	33.0	5.92	2,160	1,860	86
			9	1996	40.0	5.12	1,870	1,650	88
			8	1997	40.0	5.22	1,910	1,690	88
			6	2000	29.5	4.20	1,540	1,300	84
				Average[1]	36.7	5.43	1,980	1,730	87
19	Loutzenhizer Arroyo at N. River Road	COGUNUN12	12	1996	180	14.4	5,240	5,110	98
			12	1997	154	12.3	4,490	4,360	97
			12	2002	215	16.1	5,870	5,740	98
				Average[1]	183	14.2	5,200	5,070	98
20	Dry Creek at mouth, near Delta	COGUNUN12	9	1992	9.80	3.37	1,230	653	53
		Gunnison River from North Fork Gunnison River to Grand Junction, Colorado							
35	Sunflower Drain at Highway 92, near Read	COGUNLG04a	12	1996	157	4.02	1,470	1,420	97
			17	2000	36.5	2.64	964	844	88
			27	2001	104	3.18	1,160	1,110	96
				Average[1]	99.2	3.28	1,200	1,130	94
51	Whitewater Creek .4 miles above mouth, at Whitewater	COGUNLG04a	6	2001	62.6	0.332	121	112	93

[1]Average is the average of available water years.

[2]Combined two nearby sites into a single site.

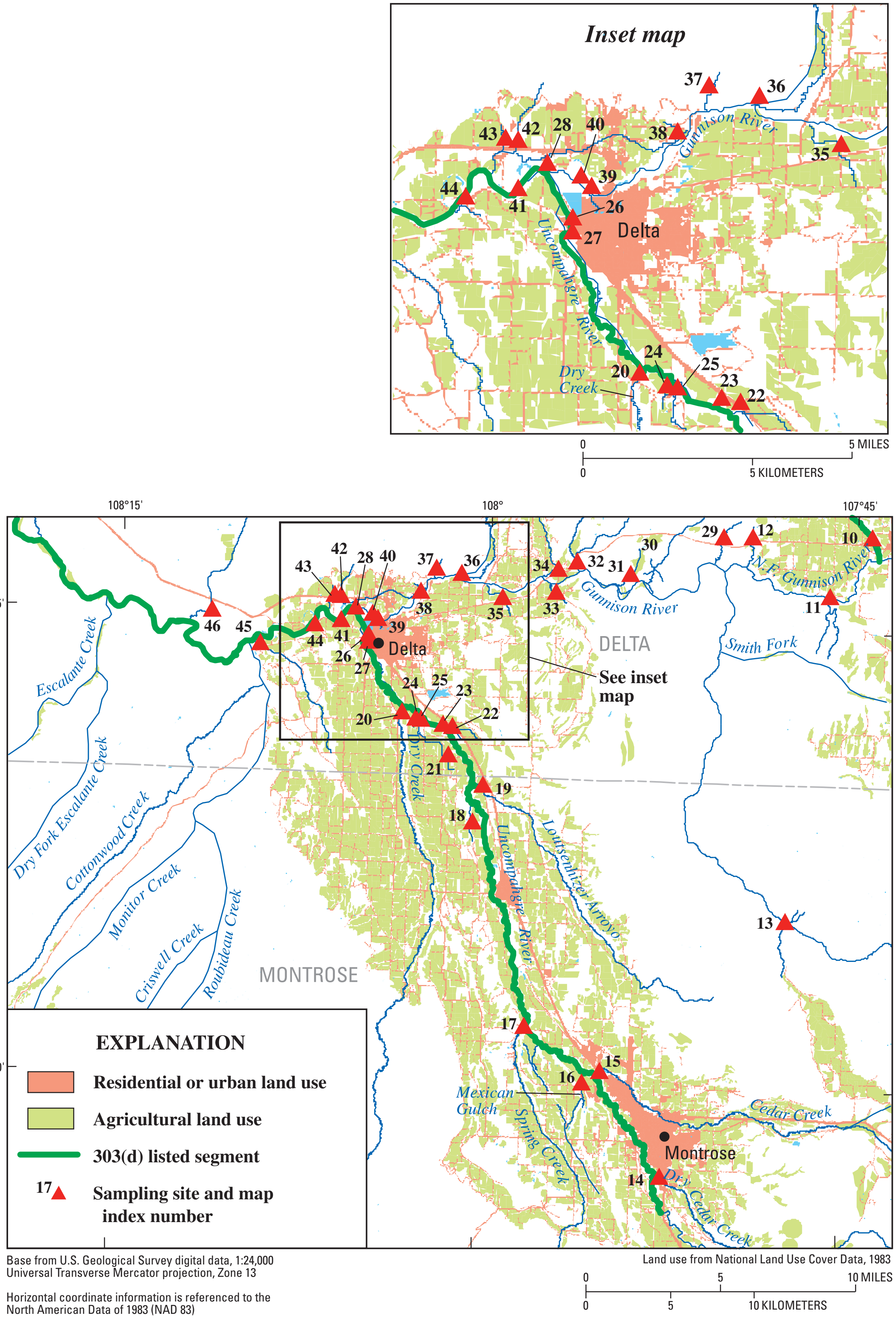


Figure 5. Location of sites and land use in the Uncompahgre River Basin, western Colorado.

cient data to compute an ATWM. For the 1995 water year, the 85th percentile selenium concentration was 56.5 µg/L (table 3), and the mean daily load was 0.636 pound (232 pounds annually). For water year 1995, 92 percent (213 pounds) of the mean annual load would need to be reduced to bring this site into compliance with the water-quality standard. Similarly for the 1996 water year, the 85th percentile selenium concentration was 67.4 µg/L, and the mean daily load was 0.843 pound (309 pounds annually). The mean annual load would need to be reduced by 93 percent (287 pounds) to bring this site into compliance with the water-quality standard. The average amount of load that would need to be reduced at this site for water years 1995 and 1996 was 250 pounds or 93 percent of the mean annual load.

Streamflow quantity and quality affect the results of loading analysis at Dry Cedar Creek and similar sites like Cedar Creek and Loutzenhizer Arroyo. The percentage of the mean annual selenium load that needs to be reduced at a site to bring it into compliance with the water-quality standard is affected by the amount of streamflow as well as the selenium concentration in the streamflow. Due to geology, land use, and climate in the Lower Gunnison River Basin, the concentration of selenium in streamflow at some sites tends to be high. In the study area, streamflow with low selenium concentrations tends to originate from snowmelt or storm-related streamflow (Butler and others, 1991). Dry Cedar Creek does not receive appreciable amounts of snowmelt or storm-related streamflow which, in combination with geology and land use, would explain the high selenium concentrations observed at this site.

Cedar Creek (site 15) data spans the 1991 through 2001 water-year period. Water years 1992, 1993, 1996, 1997, and 2000 had sufficient data to compute an ATWM (table 3). Of the 5 water years analyzed, the greatest amount of load that needed to be reduced to meet the water-quality standard occurred in the 1992 water year and the least amount of load that needed to be reduced occurred in 2000. For water year 1992, the 85th percentile selenium concentration was 40.8 µg/L, and the mean daily load of selenium was 6.69 pounds (2,440 pounds annually) (table 3). For 1992, the mean annual load would need to be reduced by 89 percent to bring this site into compliance with the water-quality standard. For water year 2000, the 85th percentile selenium concentration was 29.5 µg/L, the mean daily load was 4.20 pounds (1,540 pounds annually). For 2000, the mean annual load would need to be reduced by 84 percent to bring this site into compliance with the water-quality standard. The average amount of load that would need to be reduced for this site for water years 1992, 1993, 1996, 1997, and 2000 was 1,730 pounds or 87 percent of the mean annual load.

Loutzenhizer Arroyo (site 19) data spans the 1991 through 2003 water-year period. Water years 1996, 1997, and 2002 had sufficient data to compute an ATWM. For the 1996 water year, the 85th percentile selenium concentration was 180 µg/L, which is nearly 40 times the water-quality standard of 4.6 µg/L. The mean daily load was 14.4 pounds (5,240 pounds annually) (table 3). Ninety-eight percent of the mean annual load would need to be reduced to bring this site into compliance with the water-quality standard. For the 1997 water year, the 85th percentile selenium concentration was 154 µg/L, and the mean daily load was 12.3 pounds (4,490 pounds annually). Consistent with the 1996 water year, 97 percent of the mean annual load would need to be reduced to bring this site into compliance with the water-quality standard. For the 2002 water year, the 85th percentile selenium concentration was 215 µg/L, and the mean daily load was 16.1 pounds (5,870 pounds annually). Ninety-eight percent of the mean annual load would need to be reduced to bring this site into compliance with the water-quality standard. The average amount of load that would need to be reduced for this site for water years 1996, 1997, and 2002 was 5,070 pounds, or 98 percent of the mean annual load. Streamflow at Loutzenhizer Arroyo is almost entirely comprised of irrigation water, which is likely the reason for the high percentage of mean annual load that needs to be reduced to bring the site into compliance with the water-quality standard (Butler and Leib, 2002).

Dry Creek (site 20) data spans the 1991 through 2001 water-year period. Water year 1992 had sufficient data to compute an ATWM. For the 1992 water year, the 85th percentile selenium concentration was 9.80 µg/L, and the mean daily load was 3.37 pounds (1,230 pounds annually). Fifty-three percent of the mean annual load would need to be reduced to bring this site into compliance with the water-quality standard.

The Uncompahgre River at Delta (site 26) is a gaged site; therefore, mean annual selenium loads were calculated using regression analysis developed with the FORTRAN program LOADEST (Runkel and others, 2004) for water years 2001 through 2005. Daily selenium concentration was estimated using the following regression model:

$$a_0 + a_1 \text{ per} + a_2 \ln Q + a_3 \ln Q\text{per}, \qquad (4)$$

Explanatory variables used for this regression model include variables that describe selenium concentration dependence on streamflow and using a dummy variable (per) to define irrigation water use. The dummy variable was assigned a value of either 1 or 0 to indicate the irrigation season. November through April is the non-irrigation season and was assigned a value of 1, whereas March through October are considered the irrigation season and were assigned a value of 0. Approximately 60 percent of the variability in the data was explained ($r^2 = 0.589$), the regression model was significant at the 5-percent level ($p<0.05$) (table 4), and generally showed constant variance throughout the range of prediction in residual plots. The low r^2 value could be due in part to the effect of diversions by water users on streamflow conditions during the estimation period.

For water years 2001 through 2005, the average 85th percentile selenium concentration was 14.8 µg/L (table 5), and the mean daily selenium load was 14.9 pounds (5,420 pounds annually). The average amount of load that would need to be reduced for water years 2001 through 2005 was 3,730 pounds

Table 4. Summary of regression model diagnostics at sites, Lower Gunnison River Basin, western Colorado, 2001–05.

[r^2, the coefficient of determination]

Site number (fig. 1)	Site name	303(d) list segment	Equation number from text	Number of values/ number of censored values	r^2	p-value	Standard error of estimate (µg/L)	Mean selenium concentration (µg/L)	95 percent confidence interval	
									Lower	Upper
26	Uncompahgre River at Delta	COGUNUN04b	4	50/0	0.589	0.0134	0.49	11.9	11.0	12.9
40	Gunnison River at Delta	COGUNLG02	5	22/0	0.734	0.0496	0.55	4.87	3.88	6.04
52	Gunnison River near Grand Junction	COGUNLG02	6	48/0	0.869	0.0181	0.19	6.26	5.88	6.65
			7	48/0	0.778	0.0184	0.53	8.43	7.45	9.51

Table 5. Selenium loading analyses for sites using regression analysis (LOADEST) method, Lower Gunnison River Basin, western Colorado, 2001–05 water years.

[303(d) list segment, 303(d) list segment identifier (Colorado Department of Public Health and Environment, 2007a); n, number of samples (selenium concentration and instantaneous discharge); 85th percentile, 85th percentile selenium concentration in µg/L; mean daily load, pounds per day; mean annual load, pounds per year; load reduction, pounds per year; Percent load reduction, percent of total load that needs to be reduced to bring site into compliance with water-quality standards]

Site number (fig. 1)	Site name	303(d) list segment	Water year	85th percentile	Mean daily load	Mean annual load	Load reduction	Percent load reduction
Uncompahgre River Basin								
26	Uncompahgre River at Delta	COGUNUN04b	2001	14.8	16.3	5,940	4,090	69
			2002	14.7	11.9	4,350	2,990	69
			2003	15.5	12.5	4,570	3,210	70
			2004	14.6	15.5	5,670	3,890	69
			2005	14.1	18.1	6,600	4,450	67
			Average[1]	14.8	14.9	5,420	3,730	69
Gunnison River from North Fork Gunnison River to Grand Junction, Colorado								
40	Gunnison River at Delta	COGUNLG02	2001	6.91	26.8	9,790	3,270	33
			2002	6.59	21.2	7,750	2,340	30
			2003	9.42	18.4	6,720	3,440	51
			2004	7.21	16.3	5,940	2,150	36
			2005	5.14	17.9	6,550	689	11
			Average[1]	6.99	20.1	7,350	2,510	34
52	Gunnison River near Grand Junction	COGUNLG02	2001	7.27	45.9	16,800	6,170	37
			2002	8.18	40.9	14,900	6,530	44
			2003	11.8	40.1	14,700	8,960	61
			2004	11.0	44.7	16,300	9,510	58
			2005	8.94	53.3	19,500	9,460	49
			Average[1]	9.70	45.0	16,400	8,640	53

[1] Average is computed with all the daily values available for 2001–05 water years.

or 69 percent of the mean annual load. The 85th percentile selenium concentration for the 5 water years ranged from 14.1 to 15.5 µg/L (water years 2005 and 2003, respectively). The mean daily loads calculated for each year ranged from 11.9 to 18.1 pounds or 4,350 to 6,600 pounds annually (water years 2002 and 2005, respectively).

Gunnison River from North Fork Gunnison River to Grand Junction, Colorado

Twenty-six sites were selected along the Gunnison River from North Fork Gunnison River to Grand Junction, Colorado, that represent the cumulative contribution to 303(d) list segments COGUNLG02 (sites 40 and 52), COGUNLG04a and b (sites 29-35, 37-39, 41-51 and 53-54) , and COGUNLG07 (site 36) (table 1 and fig. 6). Of the 26 sites, 4 had sufficient data to determine mean annual selenium loads (tables 3 and 5). For the 22 sites that lacked sufficient data to calculate mean annual selenium loads, dates ranged from 1991 to 2002 for USGS data and from 1991 to 2005 for CDPHE data (table 2). Eight of the 22 sites had five or more samples and 85th percentile selenium concentrations that exceeded the water-quality standard (sites 31-34, 44, 46, 49, and 53, table 2).

Mean annual selenium loads were estimated for Sunflower Drain (site 35) and Whitewater Creek (site 51) using ATWM method (table 3). Mean annual selenium loads were estimated for Gunnison River at Delta (site 40) and Gunnison River near Grand Junction (site 52) using LOADEST for the most recent 5 years of data (2001 through 2005) (table 5).

Sunflower Drain (site 35) data spans the 1991 to 2001 water-year period. Water years 1996, 2000, and 2001 had sufficient data to compute an ATWM (table 3). For the 1996 water year, the 85th percentile selenium concentration was 157 µg/L, and the mean daily load was 4.02 pounds (1,470 pounds annually). For the 1996 water year, the mean annual load would need to be reduced by 97 percent (1,420 pounds) to bring this site into compliance with the water-quality standard. For the 2000 water year, the 85th percentile selenium concentration was 36.5 µg/L, and the mean daily load was 2.64 pounds (964 pounds annually). For the 2000 water year, the mean annual load would need to be reduced by 88 percent (844 pounds) to bring this site into compliance with the water-quality standard. For the 2001 water year, the 85th percentile selenium concentration was 104 µg/L, and the mean daily load was 3.18 pounds (1,160 pounds annually). For 2001, the mean annual load would need to be reduced by 96 percent (1,110 pounds) to bring this site into compliance with the water-quality standard. The average amount of load that would need to be reduced for this site for water years 1996, 2000, and 2001 was 1,130 pounds or 94 percent of the mean annual load. The 85th percentile selenium concentration in 2000 was appreciably less than that observed in 2001, whereas mean annual selenium loads were approximately the same, which would indicate the presence of more dilution water in 2000; however, annual streamflow information was not available to confirm this.

Whitewater Creek (site 51) data spans the 1999 through 2002 water-year period. Only water year 2001 had sufficient data to compute an ATWM. The 85th percentile selenium concentration was 62.6 µg/L, and the mean daily load of selenium was 0.332 pound (121 pounds annually) (table 3). The average amount of load that would need to be reduced for water year 2001 was 112 pounds or 93 percent of the mean annual load.

The Gunnison River at Delta (site 40) is a gaged site; therefore, mean annual selenium loads were calculated using LOADEST for water years 2001 through 2005. Daily selenium concentration was estimated by the following regression model:

$$a_0 + a_1 \ln Q + a_2 \ln Q^2 + a_3 \sin(2\pi dtime) + a_4 \cos(2\pi dtime) + a_5 dtime, \quad (5)$$

Explanatory variables used for the regression model included variables that describe selenium concentration's dependence on streamflow, seasonality, and time trends as described for equation 2. Approximately 70 percent of the variability in the data was explained ($r^2 = 0.734$), the regression model was significant at the 5-percent level ($p<0.05$) (table 4), and generally showed constant variance throughout the range of prediction in residual plots.

For water years 2001 through 2005 at the Gunnison River at Delta, the average 85th percentile selenium concentration was 6.99 µg/L (table 5), and the mean daily load was 20.1 pounds (7,350 pounds annually) (table 5). The average amount of load that would need to be reduced for this site for water years 2001 through 2005 was 2,510 pounds or 34 percent of the mean annual load. The 85th percentile selenium concentration for the 5 water years ranged from 5.14 to 9.42 µg/L (water years 2005 and 2003, respectively). Mean daily loads ranged from 16.3 to 26.8 pounds, or 5,940 to 9,790 pounds annually (water years 2004 and 2001, respectively). Load reductions ranged from 689 pounds (or 11 percent of the mean annual load) to 3,440 pounds (or 51 percent of the mean annual load) (water years 2005 and 2003, respectively).

The Gunnison River near Grand Junction (site 52) is a gaged site with continuous specific conductance data; therefore, mean annual selenium loads were calculated using LOADEST for water years 2001 through 2005. Due to gaps in the specific conductance data record, it was necessary to model selenium concentrations in two steps. Where specific conductance data were available, daily selenium concentration was estimated by the following regression model:

$$a_0 + a_1 \ln(SC) + a_3 \sin(2\pi dtime) + a_4 \cos(2\pi dtime), \quad (6)$$

Explanatory variables used for the regression model include those that describe selenium concentration dependence on specific conductance and seasonality as described for equation 2. Approximately 90 percent of the variability in the data was

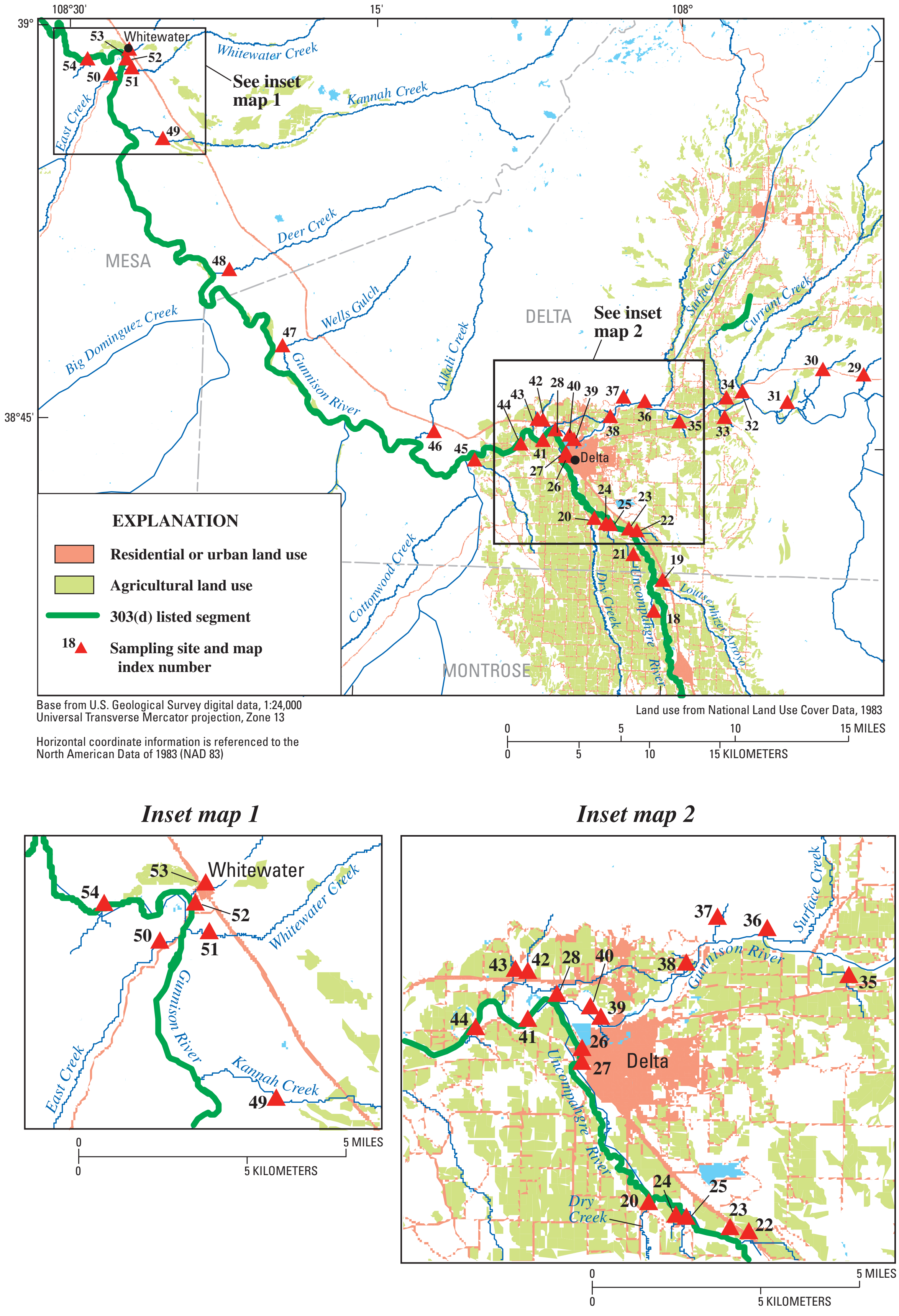


Figure 6. Location of sites and land use associated with the Gunnison River from North Fork Gunnison River to Grand Junction, western Colorado.

explained ($r^2 = 0.869$), the regression model was significant at the 5-percent level ($p<0.05$) (table 4), and generally showed constant variance throughout the range of prediction in residual plots.

Because specific conductance data were not available for the entire 2001-05 water-year period (94 percent of the period had specific conductance data), streamflow was used to estimate selenium concentration where specific conductance data were not available. Where specific conductance data were not available, daily selenium concentration was estimated by the following regression model:

$$a_0 + a_1 \ln Q + a_2 \sin(2\pi dtime) + a_3 \cos(2\pi dtime) + a_4 dtime, \quad (7)$$

Explanatory variables used for this regression model include those that describe selenium concentration dependence on streamflow, seasonality, and time trends as described for equation 2. Approximately 78 percent of the variability in the data was explained ($r^2 = 0.778$), the regression model was significant at the 5-percent level ($p<0.05$) (table 4), and generally showed constant variance throughout the range of prediction in residual plots. Specific conductance is an indication of the amount of dissolved material (like selenium) that is in natural waters (Hem, 1985). Specific conductance cannot completely describe the variability in selenium concentrations; however, specific conductance is a better estimator of selenium concentration than streamflow, as observed from the higher r^2 value for equation 6 compared to equation 7. The selenium concentration data estimated using equation 6 were combined with the estimated selenium concentration data from equation 7 to create a complete daily record for selenium concentration over the time period.

For water years 2001 through 2005 at the Gunnison River near Grand Junction site, the average 85th percentile selenium concentration was 9.70 µg/L, and the mean daily load was 45.0 pounds (16,400 pounds annually) (table 5). The average amount of load that would need to be reduced for this site for water years 2001 through 2005 was 8,640 pounds or 53 percent of the mean annual load. The 85th percentile selenium concentration for the 5 water years ranged from 7.27 to 11.8 µg/L (water years 2001 and 2003, respectively). Mean daily load ranged from 40.1 to 53.3 pounds or 14,700 to 19,500 pounds annually (water years 2003 and 2005, respectively). Load reductions ranged from 6,170 pounds (or 37 percent of the mean annual load) to 9,510 pounds (or 58 percent of the mean annual load) (water years 2001 and 2004, respectively).

Applicability of Selenium Loading Analysis

The average load reductions from table 5 can be reduced further by targeting the periods of time when selenium could be removed from streams by remediation. The methods used to calculate the load reductions provided in tables 3 and 5 use the ratio of the water-quality standard and the 85th percentile selenium concentration (see the “Methods for Analysis of Selenium Loading” section), which inherently preserves the distribution of the concentrations throughout the year. The amount of mean annual load in tables 3 and 5 that need to be removed to bring a site into compliance (load reduction) with the water-quality standard is calculated from a daily load which is then multiplied by 365.25 days. This would be a set amount of selenium load that would need to be reduced every day over the entire year to achieve an 85th percentile selenium concentration that does not exceed the water-quality standard.

The water-quality standard is the 85th percentile selenium concentration that does not exceed 4.6 µg/L. The 85th percentile selenium concentration is the concentration of selenium below which 85 percent of the selenium concentrations occur. Therefore, load reduction does not need to occur during periods when selenium concentrations are less than the water-quality standard. Additionally, load reductions do not need to occur during every instance when selenium concentrations exceed the water-quality standard. Only 85 percent of the selenium concentrations need to be less than the water-quality standard, which means 15 percent can exceed the standard. However, by reducing loads for a portion of the 15 percent that exceeds the water-quality standard, the 85th percentile selenium concentration can be more effectively reduced. The number of days can be determined empirically by manipulating the loading equation and solving for selenium concentration. By targeting load reductions, the resulting number of days when load reductions would need to occur would be less than if load reductions occurred every day by some constant value as table 5 would indicate.

The sensitivity of when loads could be reduced was tested for the Gunnison River near Grand Junction (site 52). Multiple targeted load reduction scenarios were tested that included changing both the daily amount of selenium load reduced along with the number of days when load reductions were occurring within a water year. To determine the effect of these targeted load reduction scenarios, the load equation was manipulated to solve for selenium concentration (where load = streamflow x selenium concentration x conversion factor). Selenium concentrations were back calculated from the “new” mean daily loads (post-load-reduction scenario) to calculate the 85th percentile selenium concentration. As an additional test of the sensitivity of load reductions, targeted load reduction scenarios were tested for water years 2003 and 2005 for the Gunnison River near Grand Junction. Streamflow during the 2003 water year was less than the 2005 water year. Multiple load reduction scenarios were tested on these 2 years to demonstrate the relative effect that variable streamflow has on the amount and duration of load reductions.

During 2003, the average annual load reduction needed to bring the Gunnison River near Grand Junction into compliance with the water-quality standard listed in table 5 was approximately 9,000 pounds (25 pounds daily for 365.25 days). By targeting load reductions during specific periods of the water year when selenium concentrations exceeded the water-quality standard, the annual amount of load that would need to be

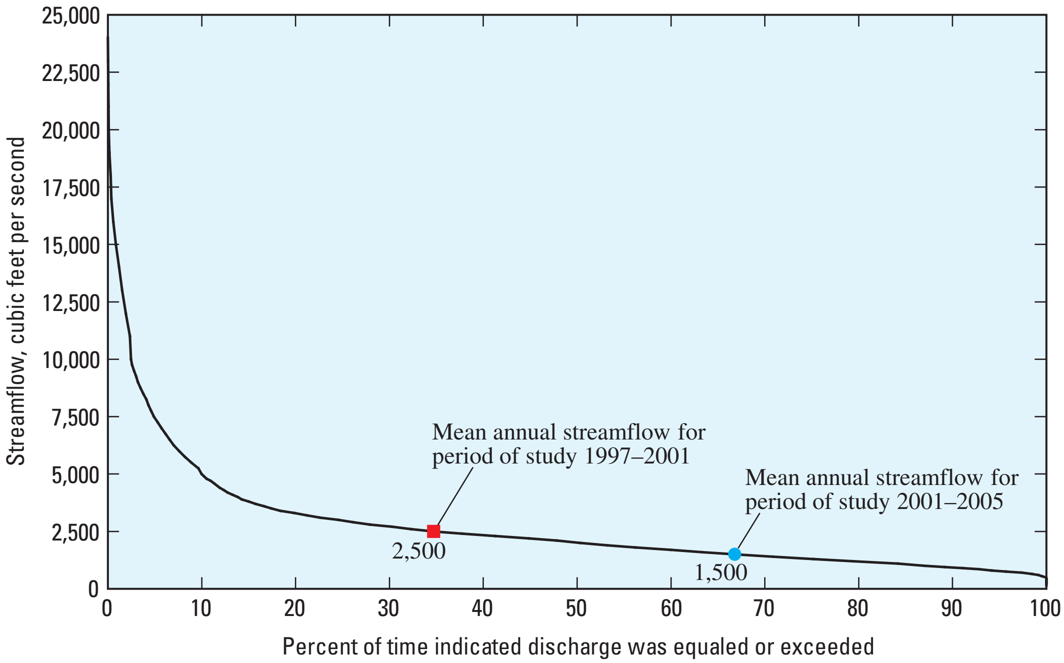


Figure 7. Relation between flow-duration curve (water years 1976–2005) and mean annual streamflow for two periods, 1997–2001 and 2001–05, at Gunnison River near Grand Junction, Colorado, western Colorado.

reduced would be approximately 8,000 pounds (32 pounds daily for 249 days). During 2005, the average annual load reduction needed to bring the Gunnison River near Grand Junction into compliance with the water-quality standard listed in table 5 was approximately 9,500 pounds (26 pounds daily for 365.25 days). By targeting load reductions during specific periods of the water year when selenium concentrations exceeded the water-quality standard, the annual amount of load that would need to be reduced would be approximately 6,000 pounds (29 pounds daily for 205 days). Therefore, using the Gunnison River near Grand Junction as an example, if load reductions could be targeted, there is a potential to greatly reduce the total amount of selenium load reduction required to bring a specific site into compliance with the water-quality standard.

To further illustrate the variability in load reductions, the results of this study were compared to a previous study of load reductions at the Gunnison River near Grand Junction. The previous study was conducted from 1997–2001 and used similar methods for determining load reductions (Bureau of Reclamation, 2006). The 1997–2001 study estimated the average load reduction at 5,000 lbs/year as compared to over 8,000 lbs/year reported in this study. The difference between these two values can be explained in large part by variations in streamflow. Mean annual streamflows for the two study periods were plotted on a flow-duration curve for Gunnison River near Grand Junction, water years 1976–2005 (fig. 7). A flow-duration curve is a cumulative frequency curve compiled by ranking all daily mean streamflows for a given time period (in this case, 1976–2005) in order of their magnitude, then computing the percentage of time a given streamflow is equaled or exceeded (Searcy, 1959). Mean annual streamflows for the two study periods were plotted along the flow-duration curve to determine the percentage of time that each mean annual streamflow was equaled or exceeded. Streamflow during the 1997–2001 study period was equaled or exceeded 35 percent of the time, whereas streamflow observed during the 2001–05 study period was equaled or exceeded 68 percent of the time, indicating that streamflow during the 1997–2001 study period was appreciably higher (33 percent) than that observed during the 2001–05 study period. Assuming that the source of selenium in the study area has not increased from the 1997–2001 study period, it can be assumed that the additional streamflow acted to dilute selenium concentrations during the 1997–2001 study period. This overall reduction in selenium concentrations would result in a reduced 85th percentile selenium concentration as compared to that observed for the 2001–05 study period. This example illustrates that a different study period can result in a different load reduction at the same site.

Summary

Elevated selenium concentrations in streams are a water-quality concern in western Colorado. Segments of and tributaries to the North Fork Gunnison River, Red Rock Canyon at the mouth, Uncompahgre River, and the Gunnison River from North Fork Gunnison River to Grand Junction, Colorado, have been placed on the State 303(d) list as impaired with respect to dissolved selenium. In Colorado, the Water Quality Control Division (Division) of the Colorado Department of Public

Health and Environment is required to develop total maximum daily loads of selenium for the 303(d) list segments.

The U.S. Geological Survey, in cooperation with Colorado Department of Public Health and Environment, summarized selenium loading in the Lower Gunnison River Basin to support the total maximum daily loads development process. This report provides a brief description of the study area including a summary of selenium issues, methods of data analysis, and results. Selenium issues in the study area were summarized and include identification of primary land uses that cause selenium loading. Results include the assessment of available selenium concentrations and loads, 85th percentiles of selenium concentration, and quantification of the amount of the selenium load (pounds annually) that would need to be reduced to bring the site into compliance with the State chronic aquatic-life standard for dissolved selenium, herein referred to as “a load reduction.” Selenium load reductions were determined for sites where selenium concentrations exceeded the State chronic aquatic-life standard for dissolved selenium (85th percentile selenium concentration not to exceed 4.6 μg/L), referred to as the “water-quality standard.”

Data for 54 historical monitoring sites with selenium sample results were compiled from U.S. Geological Survey and Colorado Department of Public Health and Enivronment data sources for this study. Three of the sites were located at continuous streamflow-gaging stations (gaged) and the remaining 51 sites were not located at streamflow-gaging stations (ungaged) but did have streamflow data associated with the selenium concentration data. This resulted in a varying ability to estimate mean annual selenium loads. Three methods were used for analysis of selenium concentration data to address variable data density among sites. For sites with low sample counts (typically 20 samples or less), statistical summaries were determined. For ungaged sites with approximately 20 or more samples, a time-weighting technique was used for estimation of mean annual selenium loads. For gaged sites, a regression analysis was used to estimate daily mean selenium concentration and mean annual selenium loads. The 85th percentile selenium concentrations were determined for all sites with five or more samples. In the event of a water-quality standard exceedance, the amount of the selenium load (pounds annually) that would need to be reduced to bring the site into compliance with the water-quality standard was determined. The load reduction calculation used a simple mass-balance approach that assumed no change in streamflow volume and that only selenium would be removed from the system.

None of the sites in the North Fork Gunnison River Basin had sufficient data to determine a mean annual selenium load. Red Rock Canyon at the mouth, on average, would need 92 percent of the mean annual load reduced to bring this site into compliance with the water-quality standard.

Five of the 15 sites in the Uncompahgre River Basin (Dry Cedar Creek, Cedar Creek, Dry Creek, Loutzenhizer Arroyo, and the Uncompahgre River at Delta) had sufficient data to determine mean annual selenium loads. All five sites except Dry Creek (53 percent) would require more than 70 percent of their mean annual load to be reduced in order to bring these sites into compliance with the water-quality standard on the basis of available data. Cedar Creek and Loutzenhizer Arroyo, like Dry Cedar Creek, do not receive appreciable snowmelt-related streamflow and are more influenced by the application of irrigation water.

Four of the 26 sites along the Gunnison River from North Fork Gunnison River to Grand Junction, Colorado, had sufficient data to determine mean annual selenium loads. For Sunflower Drain and Whitewater Creek, on average more than 90 percent of their mean annual loads would need to be reduced to bring these sites into compliance with the water-quality standard based on available data. For the Gunnison River at Delta, 34 percent of the mean annual load on average needed to be reduced to bring the site into compliance with the water-quality standard from 2001 through 2005. For Gunnison River near Grand Junction, 53 percent of the mean annual load on average needed to be reduced to bring the site into compliance with the water-quality standard from 2001 through 2005.

The method used to calculate the load reductions provided in this report used the ratio of the water-quality standard and the 85th percentile selenium concentration, which inherently preserves the distribution of the concentrations throughout the year. The average load reductions needed to bring these sites into compliance with the water-quality standard could be reduced further by targeting the periods of time when selenium is removed from streams through remediation. The sensitivity of when loads could be reduced was tested on the Gunnison River near Grand Junction.

Multiple targeted load reduction scenarios were tested that included changing both the daily amount of selenium load reduced along with the number of days when load reductions were occurring within a water year. As an additional test of the sensitivity of load reductions, targeted load reduction scenarios were tested on water years 2003 and 2005 for the Gunnison River near Grand Junction. Streamflow during the 2003 water year was lower than the 2005 water year. Multiple load reduction scenarios were tested for the 2003 and 2005 water years to demonstrate the relative effect that variable streamflow has on the amount and duration of load reductions.

During 2003, the average annual load reduction for the Gunnison River near Grand Junction was approximately 9,000 pounds (25 pounds for 365.25 days). By targeting load reductions during specific periods of the water year when selenium concentrations exceeded the water-quality standard, the annual amount of load that would need to be reduced would be approximately 8,000 pounds (32 pounds for 249 days). During 2005, the average annual load reduction for the Gunnison River near Grand Junction was approximately 9,500 pounds (26 pounds for 365.25 days). By targeting load reductions during specific periods of the water year when selenium concentrations exceeded the water-quality standard, the annual amount of load that would need to be reduced would be approximately 6,000 pounds (29 pounds for 205 days).

Load reductions were previously studied from 1997-2001 at the Gunnison River near Grand Junction. Estimated load reduction was 5,000 pounds per year as compared to more than 8,000 pounds per year estimated in this report for the 2001–05 study period. Streamflow during the 1997–2001 study period was appreciably higher (33 percent) than that observed during the 2001–05 study period. Higher streamflow during the 1997–2001 study period was likely the reason for the smaller load reduction (more dilution water). This example illustrates that a different study period can result in a different load reduction at the same site.

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