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Selenium and Mercury Concentrations in Fish, Wolford Mountain Reservoir, Colorado, 2005

Scientific Investigations Report 2007–5019

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

COVER PHOTOGRAPH: Wolford Mountain Reservoir, June 2005.
Photograph courtesy of Nancy J. Bauch, U.S. Geological Survey.

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Conversion Factors and Abbreviations

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
centimeter (cm)	0.3937	inch
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
gram (g)	0.03527	ounce, avoirdupois
inch (in.)	2.54	centimeter
microgram per gram (µg/g)	1	milligram per kilogram
microgram per gram (µg/g)	1	part per million (ppm)
microgram per liter (µg/L)	1	part per billion (ppb)
mile (mi)	1.609	kilometer
millimeter (mm)	0.03937	inch

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

$$°F=(1.8\times°C)+32$$

Additional Abbreviations

CDOW: Colorado Division of Wildlife
CRV: Certified reference value
CRWCD: Colorado River Water Conservation District
CWRUL: Cooperative Wildlife Research Unit Laboratory
DOLT-2: Dogfish (*Squalus acanthias*) liver
DORM-2: Dogfish (*Squalus acanthias*) muscle
MDL: Method detection level
QA/QC: Quality assurance and quality control
RPD: Relative percent difference
SRM: Standard reference material
TERL: Trace Element Research Laboratory (at Texas A&M University, College Station, Texas)
$\mu g/m^2$: microgram per square meter
µg/s: microgram per second
USEPA: U.S. Environmental Protection Agency
USFWS: U.S. Fish and Wildlife Service
USGS: U.S. Geological Survey

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By Nancy J. Bauch

Abstract

A reconnaissance investigation of selenium and total mercury in fish in Wolford Mountain Reservoir, Colorado, was conducted by the U.S. Geological Survey in June 2005, in cooperation with the Colorado River Water Conservation District. A total of 32 game and nongame fish were collected from three sites in the reservoir for analysis of selenium and total mercury. Five species of fish were sampled: white sucker (*Catostomus commersonii*, n=17), brown trout (*Salmo trutta*, n=5), rainbow trout (*Oncorhynchus mykiss*, n=5), cutthroat trout (*Oncorhynchus clarkii,* n=3), and splake (*Salvelinus fontinalis x Salvelinus namaycush*, n=2). Selenium concentrations ranged from 1.05 to 11.7 micrograms per gram (equivalent to parts per million or ppm) dry weight, whole body. Almost 22 percent (7 of 32) of fish samples had selenium concentrations greater than 7.91 micrograms per gram dry weight, the U.S. Environmental Protection Agency 2004 draft freshwater chronic criterion for selenium in whole-body fish tissue. Total mercury concentrations in muscle plug samples ranged from 0.012 to 0.320 microgram per gram wet weight. Concentrations of mercury in muscle plug samples are comparable to concentrations in fillet samples, and only one fish sample, a nongame white sucker, had a total mercury concentration greater than the U.S. Environmental Protection Agency water-quality criterion for the protection of human health of 0.3 microgram per gram wet weight in fillets. Converting muscle plug or fillet concentrations of mercury to whole-body concentrations, four fish samples (12.5 percent) had estimated whole-body total mercury concentrations greater than 0.1 microgram per gram wet weight concentration in whole-body fish tissue, the U.S. Fish and Wildlife Service criterion for protection of fish-eating birds and wildlife.

Water-quality data for dissolved selenium and total mercury in two tributaries and three reservoir sites were compiled and compared. Dissolved concentrations of selenium in one tributary and one reservoir site (prior to 1998) were greater than 4.6 micrograms per liter, the State of Colorado chronic water-quality standard for dissolved selenium for protection of aquatic life. Total mercury concentrations in most water samples from two tributaries and three reservoir sites were less than or equal to 0.01 microgram per liter, the State of Colorado chronic water-quality standard for total mercury for protection of aquatic life. Selenium and mercury in fish in Wolford Mountain Reservoir most likely are not directly related to selenium and mercury concentrations in reservoir water, as most selenium and mercury in fish tissue results from the presence of selenium and mercury in the diet rather than through gill uptake from water.

Results of this reconnaissance investigation of selenium and total mercury in fish in Wolford Mountain Reservoir indicate that concentrations of selenium were elevated in some fish. Most total mercury concentrations in fish were less than criteria levels.

Introduction

Selenium and mercury are trace elements that bioaccumulate in fish and wildlife and are toxic at high concentrations. Selenium is an essential trace nutrient, but there is a very narrow margin between being nutritionally optimal and toxic to fish and wildlife. Selenium occurs as a natural element in aquatic ecosystems in the Western United States through the natural weathering of Upper Cretaceous marine sedimentary rocks and Tertiary marine and continental sedimentary deposits (Seiler and others, 2003). Irrigation applied to seleniferous soils derived from these sedimentary rocks and deposits can mobilize and introduce selenium to aquatic ecosystems through the drainage of irrigation return flows to nearby water bodies. Selenium also can be introduced through the disposal of fly ash from coal combustion. Excessive concentrations of selenium are most acutely felt in the larval stage of fish and in the embryo stage of birds (Lemly, 1998; Heinz, 1996). Deformities in fish may include abnormal curvature of the spine and deformed or missing eyes or fins. In birds, deformed chicks cannot hatch (Seiler and others, 2003).

Mercury occurs naturally in the environment as the rock cinnabar (mercury sulfide) and in volcanic gases. The dominant source of mercury to most aquatic ecosystems is atmospheric deposition of mercury, primarily from human activity through coal-combustion electrical power generation (National Research Council, 2000). It is estimated that wet deposition of mercury accounts for 50 to 90 percent of the mercury

load to many inland United States water bodies and estuaries (National Atmospheric Deposition Program and Illinois State Water Survey, 2005). Total mercury wet deposition in 2005 at two sites in Colorado was 5.4 and 8.6 micrograms per square meter (μg/m^2); deposition for 77 other sites across the Nation ranged from 2.5 to 21.5 μg/m^2 (National Atmospheric Deposition Program, 2005). Anthropogenic mercury emissions have resulted in widespread elevation of mercury concentrations in some aquatic ecosystems throughout the world, relative to pre-industrial times (Swain and others, 1992). Aquatic ecosystems also may contain high levels of mercury due to the presence of cinnabar, current or historical mercury or gold mining operations, and industrial releases of mercury.

In the environment, mercury can be converted by microorganisms in soil and sediment to methylmercury, a potent neurotoxin that affects the central nervous system (National Research Council, 2000). Methylmercury readily crosses biological membranes and can accumulate to harmful concentrations in exposed organisms and biomagnify in aquatic food webs, posing a threat to humans and fish-eating wildlife (Krabbenhoft and others, 1999). Depending on environmental conditions, newly created reservoirs can have high rates of mercury methylation (Bodaly and others, 1997; St. Louis and others, 2004). Selenium can protect against mercury exposure by suppressing mercury bioavailability (Belzile and others, 2006; Chen and others, 2001; Raymond and Ralston, 2004).

Wolford Mountain Reservoir, in north-central Colorado near Kremmling (fig. 1), was constructed between 1992 and 1994 and began to fill during 1995. Lower elevation areas of the reservoir's watershed and most of the length of the main tributary Muddy Creek are underlain by the Pierre Shale, an Upper Cretaceous marine formation containing selenium (Tweto, 1979; Ruddy, 1987). Selenium concentrations in Alkali Slough, another tributary to the reservoir, have exceeded chronic (4.6 micrograms per liter, μg/L) or acute (18.4 μg/L) State of Colorado aquatic life water-quality standards (Stevens and Sprague, 2003; appendix). The nearest potential anthropogenic source of mercury emissions to the reservoir is a coal-fired electrical-generating power plant, about 65 mi northwest of the reservoir. With these considerations, U.S. Geological Survey (USGS) scientists, in cooperation with the Colorado River Water Conservation District (CRWCD), conducted a reconnaissance investigation of selenium and total mercury in game and nongame fish in Wolford Mountain Reservoir in June 2005. This study represents the first assessment of trace elements in fish from Wolford Mountain Reservoir and will provide useful baseline data for assessing potential changes in selenium and total mercury in fish over time.

Purpose and Scope

This report describes the results of the reconnaissance investigation of selenium and total mercury concentrations in fish tissue at three sites in Wolford Mountain Reservoir during June 2005. Concentrations of selenium and total mercury in fish samples are compared to U.S. Environmental Protection Agency (USEPA) aquatic-life and water-quality criteria, fish-consumption advisories, U.S. Fish and Wildlife Service (USFWS) criterion for the protection of wildlife, and threshold effect levels. Concentrations also are compared to fish data collected from other field and laboratory studies, and dissolved selenium and total mercury concentrations in the reservoir and in two tributaries.

Description of Study Area

Wolford Mountain Reservoir, created by the impoundment of Muddy Creek, is 5 mi north of Kremmling, Colorado (fig. 1). The reservoir, owned and operated by the CRWCD, covers 1,550 acres and has storage of 66,000 acre-feet at capacity (Colorado River Water Conservation District, 2006). The long and narrow reservoir has a length of about 4.5 mi and is one-quarter to one-half mile wide at full capacity. Several embayments and coves are located on the western shore where tributaries enter the reservoir. Intermittent tributaries to the reservoir include Pinto Creek, Pass Creek, Red Dirt Creek, and Alkali Slough (Stevens and Sprague, 2003). Lower elevation areas of the Muddy Creek watershed are arid to semiarid, with average annual precipitation from 10 to 15 inches (Oregon State University, 2000). Agricultural activities on these sparsely vegetated, lower elevation lands include irrigated hay and grass production and rangeland (Stevens and Sprague, 2003).

The reservoir is a popular destination for fishing, camping, and recreation. Fishing opportunities are available year round, and the reservoir commonly is featured in the media for its fishing. The reservoir has routinely been stocked by the CRWCD and the Colorado Division of Wildlife (CDOW) with trout and kokanee salmon. White suckers, present in Muddy Creek before impoundment (J.A. Collins, U.S. Geological Survey, oral commun., 2005), are common in the reservoir.

Acknowledgments

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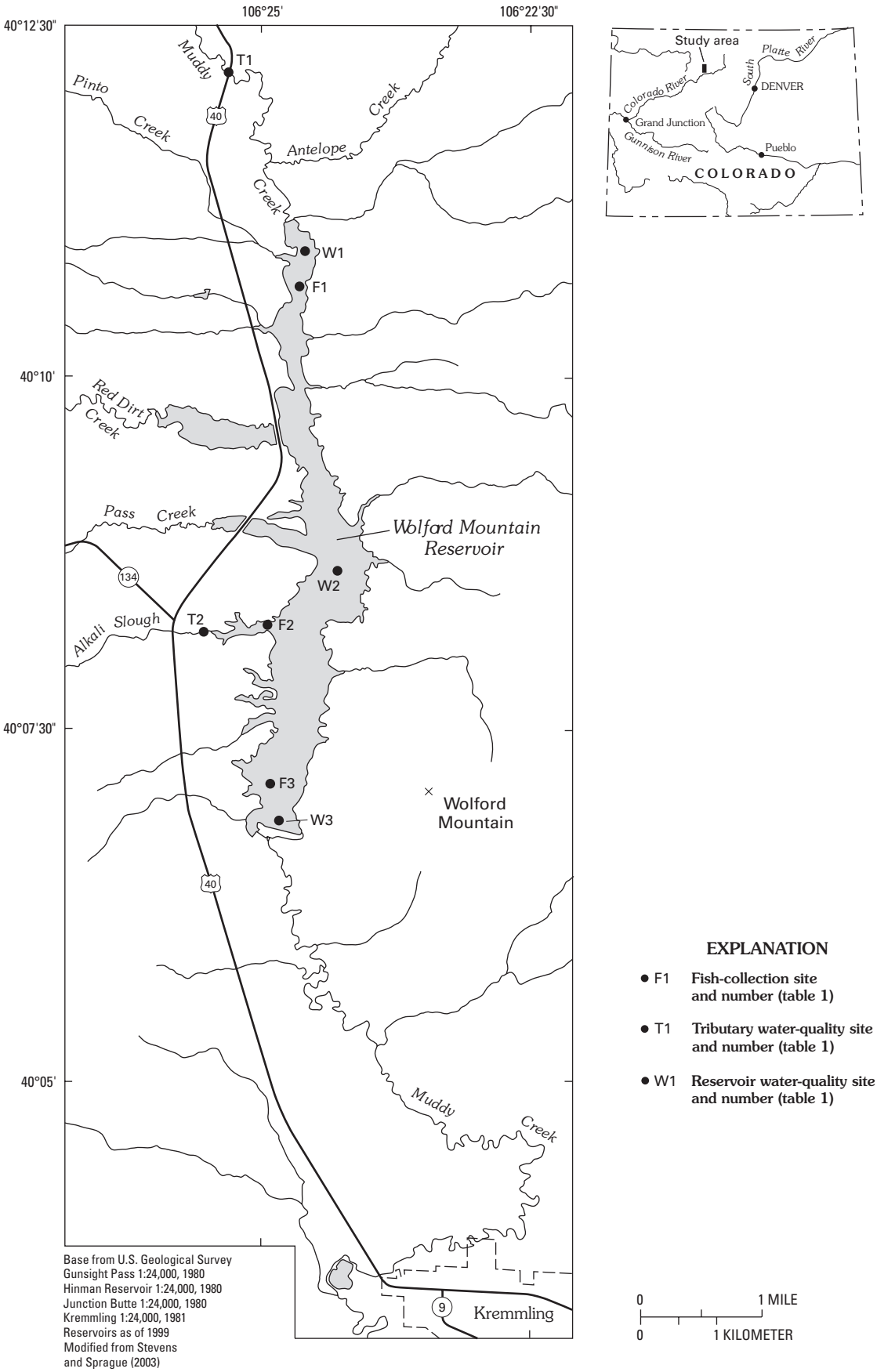
Figure 1 (facing page). Location of fish-collection sites in Wolford Mountain Reservoir, Colorado, June 2005, and historic water-quality sampling sites in Muddy Creek, Alkali Slough, and Wolford Mountain Reservoir.


106°25'
106°22'30"
40°12'30"
40°10'
40°07'30"
40°05'
Muddy
T1
Pinto
Creek
40
Antelope
Creek
Creek
W1
F1
Red Dirt
Creek
Pass
Creek
Wolford Mountain
Reservoir
W2
134
T2
F2
Alkali
Slough
F3
W3
Wolford
Mountain
40
Muddy
Creek
9
Kremmling
Study area
Platte River
South
Colorado River
DENVER
Grand Junction
Gunnison River
Pueblo
COLORADO
EXPLANATION
F1 Fish-collection site and number (table 1)
T1 Tributary water-quality site and number (table 1)
W1 Reservoir water-quality site and number (table 1)
0 1 MILE
0 1 KILOMETER
Base from U.S. Geological Survey
Gunsight Pass 1:24,000, 1980
Hinman Reservoir 1:24,000, 1980
Junction Butte 1:24,000, 1980
Kremmling 1:24,000, 1981
Reservoirs as of 1999
Modified from Stevens
and Sprague (2003)

Data Collection

Sample collection, laboratory methods for selenium and total mercury analysis, and quality assurance and quality control are discussed in this section. Fish samples were analyzed for total mercury (henceforth referred to as "mercury" for fish) rather than methylmercury because virtually all of the mercury in fish is present as methylmercury (Bloom, 1992; Wiener and others, 2002).

Sample Collection

Experimental gill nets measuring 6 by 125 ft were set at three sites in the reservoir (fig. 1, table 1) on June 15, 2005, by CDOW personnel and retrieved on June 16, 2005. Each net was placed at different depths through a system of weights and floats (table 1) and remained in the water overnight for approximately 11 to 16 hours. With each net retrieval, all fish were removed from the net, and game and nongame fish were stored on ice for onshore measuring and processing for selenium and mercury analysis.

A maximum of 12 fish per site were measured for total length and weighed to the nearest gram. Three plugs of axial muscle from between the lateral line and dorsal fin area of each fish were removed for analysis of mercury content using a 6-millimeter AcuDerm punch; a new punch was used for each fish. Skin was removed from each plug with a stainless steel scalpel, and the three plugs for each fish were stored in a polypropylene vial on dry ice. Muscle plugs provide an accurate measure of mercury in fish fillet tissue (Baker and others, 2004; Pearson, 2000) and can be accurately converted to whole-body concentrations (Peterson and others, 2005).

Otoliths, inner ear bones of fish, were used to determine fish age. One or two otoliths from 23 fish were removed from the fish heads onsite, dried, and stored in vials prior to shipment to the laboratory. For nine fish, otoliths could not be removed onsite; the whole head was removed, frozen, and stored on dry ice for otolith removal in the laboratory. After removal of muscle plugs and the otoliths or head, the whole or headless fish were stored in plastic bags on dry ice for selenium analysis.

Laboratory Methods for Selenium and Mercury Analysis

Fish-tissue samples were shipped on dry ice to the Trace Element Research Laboratory (TERL) at Texas A&M University in College Station, Texas, for determination of moisture, selenium, and mercury content. Moisture content was determined by weight loss upon freeze-drying and is reported as the weight percentage of the original wet sample. Freeze-dried samples were homogenized to a fine powder and then digested with nitric acid at 130 degrees Celsius prior to chemical analysis. The concentration of selenium in the digested fish samples was determined by hydride generation atomic fluorescence spectroscopy, and the concentration of mercury was determined by cold-vapor atomic absorption spectroscopy. Detailed descriptions of the laboratory methods for selenium and mercury analysis are reported in U.S. Fish and Wildlife Service (2006). Selenium and mercury concentrations are reported from the laboratory on a dry-weight basis and can be converted to a wet-weight (or live) basis using the measured moisture content of each sample.

Otoliths and frozen fish heads were shipped to the USGS Cooperative Wildlife Research Unit Laboratory (CWRUL) at Clemson University in Clemson, South Carolina. Fish age was determined using methods adapted from Nielsen and Johnson (1983). Otoliths first were divided into thin sections in the CWRUL. The age of the fish then was determined by counting annuli or rings of growth on the otolith, similar to the counting of tree rings for determination of tree age.

Quality Assurance and Quality Control

Quality assurance (QA) and quality control (QC) samples were analyzed at the TERL for selenium and mercury. These included procedural blanks, laboratory control samples, laboratory replicate samples, laboratory spiked samples, and standard reference material. Except for laboratory control samples, two samples of each type of QA/QC sample were analyzed for selenium; and three samples of each type of QA/QC sample, including two different standard reference materials, were analyzed for mercury. Two laboratory control samples only were analyzed for selenium. Replicate and spike sample analysis only included subsamples from individual homogenized fish in the laboratory. Samples were not collected from multiple fish and analyzed as replicate pairs or spiked samples because of the inherent variability of contaminant and other compound concentrations in fish.

Procedural blanks measure the amount of selenium or mercury that may be introduced in a sample during sample processing in the laboratory. One blank sample for selenium had a selenium concentration that was less than the method detection level (MDL), and the other blank sample had a selenium concentration of 0.022 microgram per gram (μg/g) (dry weight), which was slightly higher than the MDL of 0.0179 μg/g (dry weight). Of the three blank samples for mercury, one had a concentration that was less than the MDL, and the other two samples had concentrations equal to the MDL of 0.00004 μg/g (dry weight). The detection of selenium and mercury in blank samples with concentrations at or near the MDLs does not affect the analysis of selenium and mercury in the 32 fish samples collected in Wolford Mountain Reservoir because reported concentrations in the 32 fish samples were orders of magnitude higher than concentrations in the blanks samples.

Laboratory control samples were used to assess method performance for initial method validation and routine accuracy assessment. Percent recoveries of selenium for the two laboratory control samples were 105 and 109 percent. Laboratory control samples for mercury were not evaluated during the analysis of the Wolford Mountain Reservoir fish samples.

Table 1. Fish-collection sites in Wolford Mountain Reservoir, Colorado, June 2005, and historic water-quality sampling sites in Muddy Creek, Alkali Slough, and Wolford Mountain Reservoir.

[USGS, U.S. Geological Survey; ft, feet; n/a, not applicable]

Site number (figure 1)	Site name	Site abbreviation	USGS site identifier	Sample date	Net placement (ft below water surface)	Latitude	Longitude
			Fish-collection site				
F1	Wolford Mountain Reservoir near Muddy Creek near Kremmling	near Muddy Creek	401014106243901	6/16/05	2–9	40º10'14"	106º24'39"
F2	Wolford Mountain Reservoir at Alkali Slough near Kremmling	near Alkali Slough	400813106251501	6/16/05	3–19	40º08'13"	106º25'15"
F3	Wolford Mountain Reservoir near dam near Kremmling	near dam	400708106250701	6/16/05	0–35	40º07'08"	106º25'07"
			Water-quality site				
T1	Muddy Creek above Antelope Creek near Kremmling	Muddy Creek	09041090	1990–2005	n/a	40º12'09"	106º25'19"
T2	Alkali Slough #2 at Wolford Mountain Reservoir near Kremmling	Alkali Slough	400812106254800	1995–2004	n/a	40º08'12"	106º25'48"
W1	Wolford Mountain Reservoir at inflow near Kremmling	inflow	401110106244800	1996–2004	n/a	40º11'10"	106º24'48"
W2	Wolford Mountain Reservoir at midlake near Kremmling	midlake	400841106240600	1995–2004	n/a	40º08'41"	106º24'06"
W3	Wolford Mountain Reservoir near Kremmling	near dam	09041395	1995–2005	n/a	40º06'46"	106º24'52"

Laboratory replicate samples are used to test for data variability. All replicate samples were created by taking subsamples from the original homogenized fish sample. By comparing the analytical results of the replicate pair (original sample and QA/QC sample), information is obtained on the precision of the methods used for analysis. Replicate samples were analyzed by calculating the relative percent difference (RPD) of the replicate pair—the absolute value of the difference between the replicate analyses divided by the average of the two analyses times 100. The RPD values for the five replicate pairs ranged from 0.26 to 1.51 percent.

Laboratory spiked samples are used to measure the accuracy of analytical methods by determining the amount of spike recovery in a sample. Once the fish sample was homogenized, two subsamples were taken. One subsample was analyzed as a normal fish sample, and the other subsample was spiked with either 0.205 µg/g of selenium or 1.0 µg/g of mercury prior to analysis. Percent recoveries for the two spiked samples for selenium were 92 and 106 percent, and recoveries for the three spiked samples for mercury ranged from 99 to 102 percent.

A standard reference material (SRM) also is used to assess the accuracy of analytical methods. The SRM used by TERL for selenium fish tissue was the National Institute of Standards and Technology mussel tissue 2976, with a certified reference value (CRV) of 1.8 µg/g. The percent recoveries for the two analyses of SRM 2976 were 93 and 95 percent.

Two SRMs were used by TERL for mercury fish tissue: dogfish (*Squalus acanthias*) liver (DOLT-2) and dogfish (*Squalus acanthias*) muscle (DORM-2). Both are certified by the National Research Council of Canada, with DOLT-2 having a CRV of 2.14 µg/g mercury (dry weight), and DORM-2 having a CRV of 4.64 µg/g mercury (dry weight). The percent recoveries for three analyses of DOLT-2 ranged from 98 to 100 percent, and recoveries for three analyses of DORM-2 ranged from 96 to 101 percent.

In general, the quality of selenium and mercury determinations was excellent. Replicate sample analyses indicated excellent precision. Accuracy, as measured by percent recovery of spiked samples and SRMs also was excellent.

Selenium and Mercury Concentrations in Fish

A total of 32 game and nongame fish from 5 species were collected at 3 sites in Wolford Mountain Reservoir. At each site, all game fish and a maximum of six nongame fish were collected (table 2). A maximum of 12 fish were collected from each site. Most fish caught in the nets were white sucker (*Catostomus commersonii*), a nongame fish. Other fish caught in the nets and retrieved for processing and analysis were the game fish brown (*Salmo trutta*), rainbow (*Oncorhynchus mykiss*), and cutthroat (*Oncorhynchus clarkii*) trout and splake (*Salvelinus fontinalis x Salvelinus namaycush*). Game fish typically are caught for human consumption, whereas nongame fish usually are not caught for human consumption. The abdominal cavities for two trout were removed for CDOW purposes and were not included for sample processing and analysis for this report.

Selenium concentrations in fish samples are discussed on a dry-weight basis; the draft USEPA aquatic life criterion for selenium is based on dry weight (U.S. Environmental Protection Agency, 2006). Mercury concentrations are discussed on a wet-weight basis. The USEPA water-quality criterion for mercury concentration in fish for protection of human health is based on a wet-weight concentration (U.S. Environmental Protection Agency, 2001).

Selenium concentrations in whole-body fish samples from Wolford Mountain Reservoir ranged from 1.05 to 11.7 µg/g dry weight (table 2). Almost 22 percent (7 of 32) of fish had concentrations greater than 7.91 µg/g dry weight, the USEPA 2004 draft freshwater chronic criterion for selenium in whole-body fish tissue (U.S. Environmental Protection Agency, 2006). The draft criterion states that if fish-tissue samples exceed 5.85 µg/g dry weight during summer or fall, fish should be monitored during the winter to determine if selenium exceeds 7.91 µg/g dry weight because of the uncertainty of juvenile fish concentrating selenium over the winter. Most (75 percent, 24 of 32) fish samples collected from Wolford Mountain Reservoir in June 2005 had selenium concentrations greater than 5.85 µg/g dry weight. The draft criterion value of 7.91 µg/g is undergoing further investigation by the USEPA, because there is some concern that the value may not adequately protect the health of fish and wildlife.

The maximum selenium concentration of 11.7 µg/g dry weight was detected in one brown trout sample (table 2). Among the 32 fish samples, this 1 brown trout, 1 cutthroat trout, both splake, and 3 white sucker samples had selenium concentrations greater than 7.91 µg/g dry weight. Two rainbow trout samples had selenium concentrations that were slightly less than 7.91 µg/g. Two other rainbow trout samples were the only samples with selenium concentrations less than 2.0 µg/g dry weight.

Across the United States, background concentrations of selenium in fish tissue other than liver range from 1 to 4 µg/g dry weight (U.S. Department of the Interior, 1998). Lemly (2002) recommends that a whole-body selenium concentration of 4 µg/g dry weight be used as a toxic-effect threshold for overall health and reproductive vigor of freshwater fish. The threshold is described as the level at which toxic effects begin to occur in sensitive species of fish and wildlife. The threshold range for reproductive impairment in sensitive species such as perch, bluegill, and salmon is estimated to be 4 to 6 µg/g dry weight for whole-body fish (U.S. Department of the Interior, 1998). Mortality of adult fish, even sensitive species, only begins to occur at concentrations much higher than threshold levels. For Wolford Mountain Reservoir, all but two fish samples had selenium concentrations greater than 4 µg/g dry weight.

Table 2. Concentrations of selenium and total mercury in fish collected at three sites in Wolford Mountain Reservoir, Colorado, June 2005.

[cm, centimeters; g, grams; yr, year; µg/g, micrograms per gram; --, no available data]

Site number (see figure 1, table 1)	Common name	Species	Total length (cm)	Weight (g)	Age (yr)	Whole-body fish			Muscle plugs, skin-off		
						Selenium, dry weight (µg/g)	Moisture percent	Selenium, wet weight (µg/g)	Mercury, dry weight (µg/g)	Moisture percent	Mercury, wet weight (µg/g)
F1	Rainbow trout	*Oncorhynchus mykiss*	37.0	736	7	1.05	67.4	0.34	0.0472	74.6	0.012
F1	Rainbow trout	*Oncorhynchus mykiss*	38.0	507	6	6.98	81.7	1.28	0.534	81.5	0.099
F1	Rainbow trout	*Oncorhynchus mykiss*	35.0	485	5	1.49	72.5	0.41	0.0682	78.2	0.015
F1	Cutthroat trout	*Oncorhynchus clarkii*	40.0	587	6	[1]**8.57**	79.0	1.80	0.375	80.5	0.073
F1	Cutthroat trout	*Oncorhynchus clarkii*	39.5	559	7	6.40	79.0	1.34	0.402	80.5	0.078
F1	White sucker	*Catostomus commersonii*	38.5	614	--[2]	[3]6.29	78.6	[3]1.35	1.61	80.1	[4]**0.320**
F1	White sucker	*Catostomus commersonii*	38.5	574	--[2]	[3]5.34	79.7	[3]1.08	1.03	83.8	0.167
F1	White sucker	*Catostomus commersonii*	33.5	417	--[2]	[1,3]**8.09**	77.3	[3]1.84	0.505	82.6	0.088
F1	White sucker	*Catostomus commersonii*	37.0	535	--[2]	[3]6.53	75.4	[3]1.61	0.579	81.4	0.108
F1	White sucker	*Catostomus commersonii*	34.0	406	--[2]	[3]6.75	76.9	[3]1.56	0.286	82.2	0.051
F1	White sucker	*Catostomus commersonii*	34.3	484	--[2]	[3]6.51	77.7	[3]1.45	0.529	81.6	0.097
F2	White sucker	*Catostomus commersonii*	35.0	470	8	5.84	74.0	1.52	0.579	80.2	0.115
F2	White sucker	*Catostomus commersonii*	33.4	423	9	5.32	71.6	1.51	0.552	81.1	0.104
F2	White sucker	*Catostomus commersonii*	36.7	550	12	4.68	73.0	1.26	0.578	80.0	0.116
F2	White sucker	*Catostomus commersonii*	32.5	405	9	[1]**9.78**	76.9	2.26	0.284	81.7	0.052
F2	White sucker	*Catostomus commersonii*	34.5	432	8	5.82	75.4	1.43	0.550	81.6	0.101
F2	White sucker	*Catostomus commersonii*	35.0	435	9	6.53	79.8	1.32	0.527	83.2	0.089
F2	Cutthroat trout	*Oncorhynchus clarkii*	40.0	751	4	7.39	77.1	1.69	0.280	80.3	0.055
F2	Brown trout	*Salmo trutta*	26.5	200	2	[1]**11.7**	76.0	2.81	0.198	77.2	0.045
F2	Brown trout	*Salmo trutta*	27.0	193	--[2]	[3]6.04	76.0	[3]1.45	0.116	76.6	0.027
F3	Splake	*Salvelinus fontinalis x Salvelinus namaycush*	47.8	972	[5]14	[1]**9.38**	72.5	2.58	0.264	76.6	0.062
F3	Splake	*Salvelinus fontinalis x Salvelinus namaycush*	44.3	728	[5]11	[1]**8.09**	73.5	2.14	0.294	76.5	0.069
F3	Rainbow trout	*Oncorhynchus mykiss*	38.2	540	7	7.89	71.1	2.28	0.0737	76.4	0.017
F3	Brown trout	*Salmo trutta*	27.5	209	3	6.28	74.8	1.58	0.127	81.9	0.023
F3	Brown trout	*Salmo trutta*	23.5	140	3	7.47	76.5	1.75	0.0911	83.2	0.015
F3	Brown trout	*Salmo trutta*	26.5	186	4	7.41	76.4	1.75	0.103	79.6	0.021
F3	Rainbow trout	*Oncorhynchus mykiss*	35.3	335	6	7.88	80.8	1.51	0.287	81.2	0.054
F3	White sucker	*Catostomus commersonii*	36.5	582	8	6.85	76.6	1.60	1.02	81.2	0.192
F3	White sucker	*Catostomus commersonii*	33.8	432	8	5.06	72.0	1.42	0.576	81.1	0.109
F3	White sucker	*Catostomus commersonii*	36.0	554	8	7.04	76.3	1.67	0.913	81.1	0.173
F3	White sucker	*Catostomus commersonii*	31.0	343	--[2]	[3]7.19	76.8	[3]1.67	0.590	82.7	0.102
F3	White sucker	*Catostomus commersonii*	33.7	437	--[2]	[1,3]**8.01**	78.5	[3]1.72	0.609	83.0	0.104

[1]Concentration is greater than U.S. Environmental Protection Agency 2004 draft freshwater chronic criterion for selenium in whole-body fish tissue of 7.91 µg/g dry weight (U.S. Environmental Protection Agency, 2006).

[2]Laboratory results for otolith analysis were not available at the time of this report.

[3]Whole-body fish, headless.

[4]Concentration is greater than U.S. Environmental Protection Agency water-quality criterion for mercury for protection of human health of 0.3 µg/g wet weight in fillets (U.S. Environmental Protection Agency, 2001).

[5]Fish age for species not found in Muddy Creek before impoundment is greater than age of the reservoir. Fish may have been stocked in the reservoir as an older fish.

A detailed study of irrigation drainage in the Uncompahgre Project Area and Grand Valley in western Colorado was conducted between 1991 and 1992 and included analysis of white sucker and brown and rainbow trout whole-body samples for selenium and mercury (Butler and others, 1994). Fish were collected from main-stem rivers and tributaries and from one reservoir and one lake. Parts of the Uncompahgre Project Area and Grand Valley are underlain by Mancos Shale, a Cretaceous marine formation containing selenium that is similar to the Pierre Shale that underlies Wolford Mountain Reservoir. The median whole-body dry-weight selenium concentration in white sucker (7.1 µg/g) collected from the Uncompahgre Project Area and Grand Valley was similar to that in white sucker (6.53 µg/g) collected from Wolford Mountain Reservoir. Median selenium concentrations in brown trout (5.9 µg/g) and rainbow trout (4.1 µg/g) in these two areas were lower than those in brown trout (7.41 µg/g) and rainbow trout (6.98 µg/g) collected from Wolford Mountain Reservoir.

Mercury concentrations in skin-off axial muscle-plug (biopsy) samples in fish from Wolford Mountain Reservoir ranged from 0.012 to 0.320 µg/g wet weight (table 2). All concentrations but one were less than 0.200 µg/g wet weight. One white sucker sample from the near Muddy Creek site had a mercury concentration of 0.320 µg/g wet weight and was the only sample with a concentration greater than the USEPA water-quality criterion for the protection of human health of 0.3 µg/g wet weight in fillets (U.S. Environmental Protection Agency, 2001). The value of 0.3 µg/g is the concentration of mercury in fish tissue that should not be exceeded based on a total fish and shellfish consumption-weighted rate of 17.5 gram (g) fish/day (U.S. Environmental Protection Agency, 2001). For the State of Colorado, the policy for fish consumption advisories states that when mercury is detected at a concentration of 0.5 µg/g wet weight or greater in fish tissue, the body of water from which the fish were sampled is listed as impaired, and additional studies are warranted. All fish collected from Wolford Mountain Reservoir had mercury concentrations that were less than 0.5 µg/g.

Mercury concentrations in fish are not only a concern for human health but also can affect fish and wildlife. Beckvar and others (2005) determined a threshold effect level of 0.2 µg/g wet-weight mercury concentration in whole-body fish tissue to be protective of growth, reproduction, development, and behavior. Using the model developed by Peterson and others (2005) to convert muscle plug or biopsy mercury concentration to whole-body mercury concentration, the maximum whole-body concentration of mercury in fish collected in Wolford Mountain Reservoir is estimated to be 0.192 µg/g wet weight. The USFWS criterion concentration of 0.1 µg/g wet-weight concentration of mercury in whole-body fish tissue for protection of fish-eating birds and wildlife (Eisler, 1987) was exceeded in 12.5 percent (4 of 32) samples. In total, most mercury concentrations in fish samples from the reservoir were less than criteria for the protection of human, fish, and wildlife health and a threshold effect level.

Median wet-weight mercury concentrations in brown trout (0.073 µg/g) and rainbow trout (0.040 µg/g) fillet samples collected as part of the detailed study of irrigation drainage in the Uncompahgre Project Area and Grand Valley in western Colorado between 1991 and 1992 (Butler and others, 1994) were two to three times greater than the median concentration in brown trout (0.023 µg/g) and rainbow trout (0.017 µg/g) collected in Wolford Mountain Reservoir. Even though median mercury concentrations were higher in fish in the Uncompahgre Project Area and Grand Valley, all mercury concentrations in brown and rainbow trout from these two areas were less than the USEPA water-quality criterion for the protection of human health of 0.3 µg/g wet weight (U.S. Environmental Protection Agency, 2001). Fillet samples from white suckers were not collected as part of the irrigation drainage study by Butler and others (1994).

Trace-element concentrations are highly variable in fish and other biological organisms. Bioaccumulation of selenium and mercury in fish is complex and depends on many factors, including fish size and age, fish diet and food-web length, selenium speciation, mercury speciation (especially the amount of methylmercury in an ecosystem), and the quality of sediment and water. Numerous studies have reported interactions between selenium and mercury (Cuvin-Aralar and Furness, 1991; Eisler, 2000; Jacobs, 1989; U.S. Department of the Interior, 1998). Selenium has been shown to affect tissue concentrations of mercury and vice versa. In many studies, selenium has protected plant and animal species from the toxic effects of mercury by suppressing mercury methylation and bioaccumulation. For Wolford Mountain Reservoir, the sample size for each fish species was too small to determine any relation between selenium and mercury.

Dissolved selenium and total mercury concentrations in water samples from two tributaries (Muddy Creek and Alkali Slough) to Wolford Mountain Reservoir and in Wolford Mountain Reservoir (fig. 1, table 1) were retrieved from the USGS National Water Information System database for comparison to selenium and mercury concentrations in fish samples. Water-quality data between 1990 and 2005 were available for Muddy Creek; data for Alkali Slough and the reservoir were available between 1995 and 2004 or 2005 (appendix). For the midlake and near dam sites, two water-column samples were collected during each sampling trip, one sample near the water surface and one near the reservoir bottom.

All dissolved selenium concentrations in Muddy Creek were less than the State of Colorado chronic water-quality standard for dissolved selenium for protection of aquatic life of 4.6 µg/L (fig. 2, appendix; Colorado Department of Public Health and Environment, 2006). Most concentrations were less than laboratory detection levels (appendix). In Alkali Slough, most (17 of 19) concentrations of dissolved selenium were greater than the State of Colorado chronic standard of 4.6 µg/L (fig. 2, appendix; Colorado Department of Public Health and Environment, 2006). All but one sample were collected in July or October. For a given year, selenium

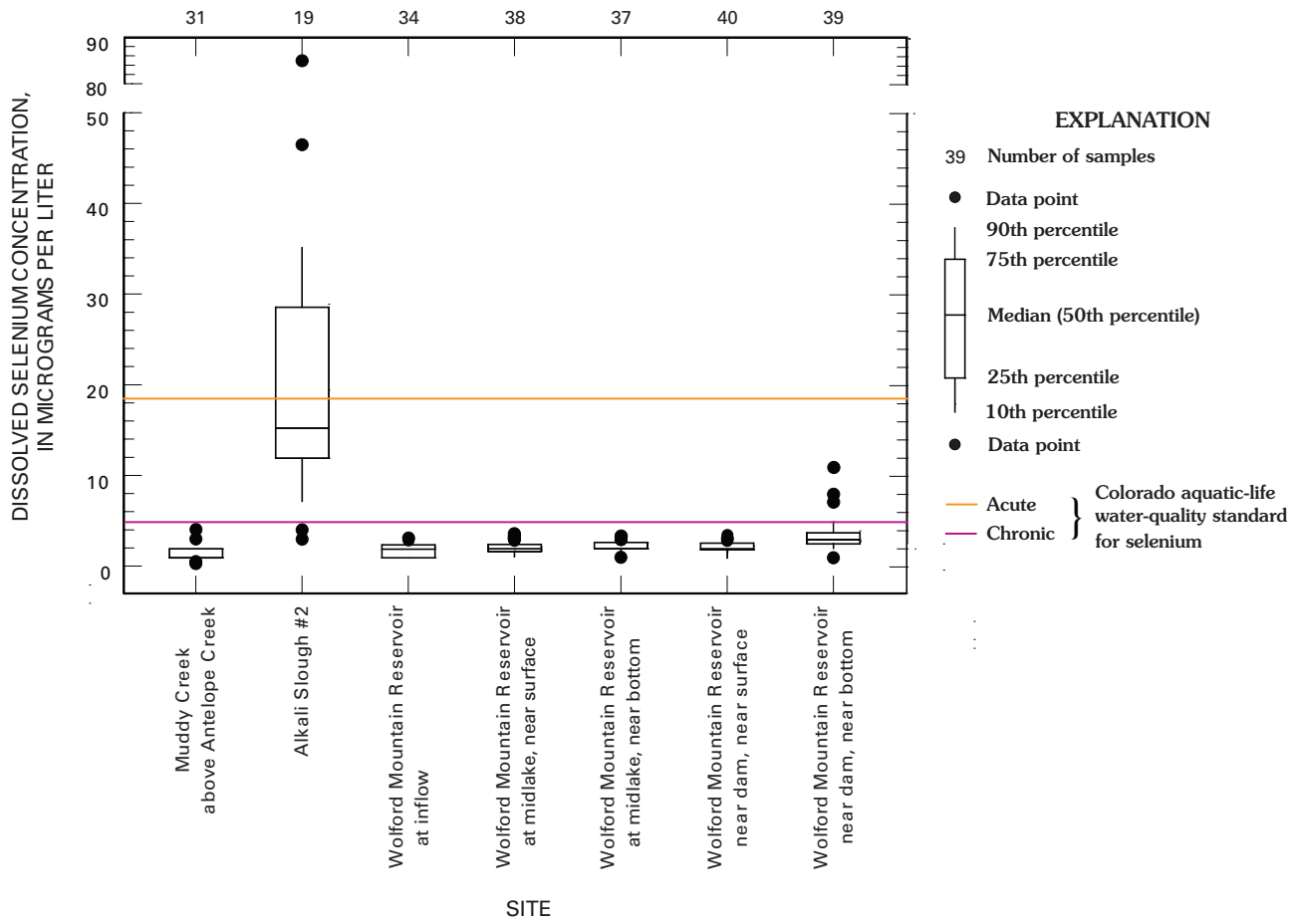


Figure 2. Historic concentrations of dissolved selenium in Muddy Creek, (between 1990 and 2005), Alkali Slough (between 1995 and 2004), and Wolford Mountain Reservoir (between 1995 and 2005), Colorado.

concentrations in Alkali Slough typically were higher for the July sample than the October sample. Instantaneous loads, calculated as the product of streamflow and concentration at the time of sampling, also were higher for July than October. The median instantaneous load for July samples was 354 micrograms per second (µg/s) and for October samples was 106 µg/s. Although most concentrations of dissolved selenium in Alkali Slough were elevated, the load of dissolved selenium that flowed into the reservoir was small. Measured discharge was less than or equal to 1 cubic foot per second (ft^3/s) for all samples (appendix). Concentrations of total (dissolved and particulate) selenium in Alkali Slough were similar to dissolved concentrations; therefore, loads also would be expected to be similar.

Dissolved selenium concentrations in Wolford Mountain Reservoir primarily were low and less than the State of Colorado chronic water-quality standard for dissolved selenium for protection of aquatic life of 4.6 µg/L (fig. 2, appendix; Colorado Department of Public Health and Environment, 2006). Only six samples, all collected in the reservoir at the near dam site before 1998, had dissolved selenium concentrations greater than 4.6 µg/L. Since 1998, all dissolved selenium concentrations in the reservoir have been less than or equal to 4 µg/L (appendix). Elevated selenium concentrations in fish samples from the reservoir do not reflect the low selenium concentrations in the reservoir water.

Total mercury concentrations in most (224 of 240) water samples from Wolford Mountain Reservoir and the two tributaries were less than laboratory detection levels (appendix). Only six samples had detected total mercury concentrations that were greater than 0.01 µg/L (appendix), the State of Colorado chronic water-quality standard for total mercury for protection of aquatic life (Colorado Department of Public Health and Environment, 2006). Ten samples had detected concentrations that were equal to 0.01 µg/L (appendix). Laboratory detection levels varied from 0.01 to 0.3 µg/L (appendix). Most fish samples also had mercury concentrations that were low and less than the USEPA water-quality criterion for the protection of human health of 0.3 µg/g wet weight in fillets (U.S. Environmental Protection Agency, 2001). Many studies have reported that most selenium and mercury in fish tissue results from selenium and mercury in the diet rather than through gill uptake from water (Lemly, 2002; Luoma and others, 1992; U.S. Department of the Interior, 1998); therefore selenium and mercury in fish in Wolford Mountain Reservoir most likely are not directly related to concentrations in reservoir water.

Summary and Conclusions

The U.S. Geological Survey, in cooperation with the Colorado River Water Conservation District, conducted a reconnaissance investigation of selenium and mercury in fish in Wolford Mountain Reservoir, Colorado, in June 2005. Selenium and mercury are trace elements that bioaccumulate in fish and wildlife and can be toxic at high concentrations. In the Western United States, selenium is common in aquatic systems and primarily results from the weathering of marine and continental sedimentary rocks and deposits. The dominant source of mercury to aquatic systems is atmospheric deposition, primarily from coal-powered powerplants. Wolford Mountain Reservoir, in north-central Colorado, is located in an area with seleniferous marine shales and soils. A coal-fired electrical-generating plant is about 65 miles northwest of the reservoir.

A total of 32 game and nongame fish were collected at 3 sites in the reservoir for analysis of selenium and total mercury. Five fish species were collected: white sucker (n=17), brown trout (n=5), rainbow trout (n=5), cutthroat trout (n=3), and splake (n=2). Concentrations of selenium in whole-body fish ranged from 1.05 to 11.7 micrograms per gram (µg/g) dry weight. The U.S. Environmental Protection Agency 2004 draft freshwater chronic criterion for selenium of 7.91 µg/g dry weight concentration in whole-body fish tissue was exceeded in 7 of 32 fish samples. All but two fish samples had selenium concentrations greater than 4 µg/g, a toxic effect threshold level for overall health and reproductive vigor in sensitive species of freshwater fish. Concentrations of mercury in skin-off fillet (axial muscle) tissue, determined on tissue biopsy (muscle plug) subsamples, ranged from 0.012 to 0.320 µg/g wet weight. Only one fish sample had a total mercury concentration greater than U.S. Environmental Protection Agency human-health criterion of 0.3 µg/g wet-weight concentration in fillets. All other fish samples had concentrations less than 0.2 µg/g. The State of Colorado fish-consumption advisory of 0.5 µg/g wet weight was not exceeded. Converting concentrations of mercury in muscle plug samples to concentrations in whole-body samples, estimated whole body total mercury concentrations for four fish samples (12.5 percent) were greater than 0.1 µg/g wet-weight concentration in whole-body fish tissue, the U.S. Fish and Wildlife Service criterion for protection of fish-eating birds and wildlife.

Historic dissolved selenium and total mercury concentrations in water samples from two tributaries to the reservoir and in the reservoir were compiled and compared. Dissolved selenium concentrations in Muddy Creek were less than the State of Colorado chronic water-quality standard for dissolved selenium for protection of aquatic life of 4.6 micrograms per liter (µg/L). Most concentrations of dissolved selenium in Alkali Slough were greater than 4.6 µg/L. Selenium loads flowing into the reservoir from Alkali Slough were small, however, with discharge of 1 cubic foot per second or less. Dissolved selenium concentrations in Wolford Mountain Reservoir primarily were less than 4.6 µg/L. Concentrations greater than this level occurred before 1998. All dissolved selenium concentrations in the reservoir since 1998 have been less than or equal to 4 µg/L. Total mercury concentrations in most water samples from Muddy Creek, Alkali Slough, and Wolford Mountain Reservoir were less than laboratory detection levels. Only 16 samples had total mercury concentrations that were greater than or equal to 0.01 µg/L, the State of Colorado chronic water-quality standard for total mercury for protection of aquatic life. Many studies report that most selenium and mercury in fish tissue results from the presence of selenium and mercury in the diet rather than through gill uptake from water. Selenium and mercury in fish in Wolford Mountain Reservoir most likely are not directly related to selenium and mercury concentrations in reservoir water.

Results of the reconnaissance investigation of selenium and mercury concentrations in fish in Wolford Mountain Reservoir indicate that selenium concentrations were elevated and greater than criterion or threshold effect levels in some or most fish samples, respectively. Most mercury concentrations in fish samples were less than criteria levels.

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Appendix. Historic concentrations of dissolved selenium and total mercury in Muddy Creek, Alkali Slough, and Wolford Mountain Reservoir near Kremmling, Colorado.

[ft, feet; ft^3/s, cubic feet per second; µg/L, micrograms per liter --, no data; <, less than; E, estimated. Number in parentheses after site number and name refers to U.S. Geological Survey National Water Information System site identification number. See figure 1 for site locations]

Date	Time	Sampling depth (ft)	Instantaneous discharge (ft^3/s)	Dissolved selenium (µg/L)	Total mercury (µg/L)
T1: Muddy Creek above Antelope Creek near Kremmling (09041090)					
05/10/1990	14:15	--	152	<1	[1]**1.2**
09/27/1990	12:00	--	2.6	<1	<0.1
05/30/1991	10:30	--	433	<1	<0.1
09/25/1991	12:30	--	6.4	<1	<0.1
05/07/1992	12:00	--	255	<1	<0.1
09/03/1992	11:30	--	8.2	<1	<0.1
05/17/1993	15:45	--	585	<1	<0.1
09/13/1993	16:30	--	11	1	<0.1
05/04/1994	12:30	--	146	<2	<0.1
09/13/1994	13:45	--	1.9	<1	<0.1
05/23/1995	15:00	--	484	<1	<0.1
09/18/1995	14:40	--	3.2	<1	<0.1
05/22/1996	12:00	--	567	<1	<0.1
08/28/1996	11:30	--	5.8	<1	<0.1
05/14/1997	15:00	--	742	<1	<0.1
09/03/1997	11:45	--	14	<1	<0.1
07/22/1998	12:45	--	10	<1	<0.1
08/11/1998	13:35	--	16	<1	<0.1
05/10/1999	14:40	--	262	<1	<0.1
08/10/1999	14:00	--	16	<1	<0.1
05/09/2000	14:25	--	409	<2	<0.3
08/22/2000	14:00	--	21	<2	<0.3
06/06/2001	11:30	--	67	<2	--
08/29/2001	9:15	--	5.6	<2	<0.01
06/13/2002	12:15	--	3	<4	[1]**E 0.01**
07/29/2002	12:00	--	3	<2	<0.01
05/28/2003	12:30	--	608	<3	[1]**E 0.02**
08/19/2003	11:30	--	9.5	<3	[1]**E 0.01**
05/19/2004	12:30	--	183	E 0.3	[1]**E 0.01**
08/11/2004	15:00	--	2.7	0.6	<0.02
05/23/2005	12:20	--	509	0.5	[1]**0.02**
T2: Alkali Slough #2 at Wolford Mountain Reservoir near Kremmling (400812106254800)					
04/12/1995	15:30	--	0.04	3	<0.2
07/16/1996	15:00	--	1	[2]**28**	<0.1
10/17/1996	14:00	--	0.3	[2]**12**	<0.1
07/10/1997	9:30	--	1	[2]**30**	<0.1
10/16/1997	11:15	--	1	[2]**12**	<0.1
07/21/1998	14:45	--	0.5	[2]**25**	<0.1
10/14/1998	12:20	--	0.25	[2]**15**	<0.1
07/08/1999	10:00	--	1	[2]**29**	<0.2
10/13/1999	13:00	--	0.5	[2]**8**	<0.3
07/12/2000	10:45	--	0.5	[2]**24**	<0.3
10/11/2000	15:20	--	0.1	[2]**9**	<0.1
07/03/2001	10:30	--	0.5	[2]**26**	<0.01
10/04/2001	11:00	--	E 0.10	[2]**12**	<0.01
07/30/2002	8:30	--	E 0.10	[2]**14**	<0.01
10/07/2002	15:00	--	0.1	4	<0.02
07/23/2003	10:20	--	0.1	[2]**33**	<0.02
10/28/2003	11:45	--	0.1	[2]**46.4**	<0.02
07/07/2004	13:30	--	0.06	[2]**84.7**	<0.02
10/19/2004	11:00	--	0.5	[2]**15.7**	<0.01

Appendix. Historic concentrations of dissolved selenium and total mercury in Muddy Creek, Alkali Slough, and Wolford Mountain Reservoir near Kremmling, Colorado.—Continued

[ft, feet; ft^3/s, cubic feet per second; µg/L, micrograms per liter --, no data; <, less than; E, estimated. Number in parentheses after site number and name refers to U.S. Geological Survey National Water Information System site identification number. See figure 1 for site locations]

Date	Time	Sampling depth (ft)	Instantaneous discharge (ft^3/s)	Dissolved selenium (µg/L)	Total mercury (µg/L)
W1: Wolford Mountain Reservoir at inflow near Kremmling (401110106244800)					
06/06/1996	13:20	5	--	<1	<0.1
07/17/1996	13:00	5	--	1	<0.1
08/27/1996	14:00	5	--	1	<0.1
10/16/1996	11:40	5	--	2	<0.1
06/04/1997	11:45	5	--	<1	<0.1
07/09/1997	12:00	5	--	1	<0.1
09/04/1997	12:00	5	--	2	<0.1
10/15/1997	11:30	5	--	1	<0.1
06/10/1998	12:00	5	--	<1	<0.1
07/21/1998	11:20	5	--	1	<0.1
08/17/1998	11:45	5	--	1	<0.1
10/05/1998	11:30	10	--	1	<0.1
06/01/1999	11:20	5	--	<1	<0.1
07/22/1999	11:15	10	--	1	<0.1
08/18/1999	11:35	5	--	2	<0.1
10/22/1999	11:45	7	--	3	<0.3
06/08/2000	11:15	10	--	E 2	<0.3
07/06/2000	11:40	5	--	E 2	<0.3
08/24/2000	11:30	5	--	1.9	<0.3
10/13/2000	11:00	5	--	2.6	<0.1
06/21/2001	11:30	7	--	1.5	**[1]0.01**
07/10/2001	11:15	5	--	2	<0.01
08/29/2001	12:00	3	--	--	<0.01
10/11/2001	11:15	3	--	2.2	<0.01
06/14/2002	10:20	5	--	2.8	**[1]0.01**
07/02/2002	11:00	5	--	3.1	<0.01
08/22/2002	11:15	5	--	3.1	<0.01
06/26/2003	11:30	5	--	2	<0.02
07/17/2003	11:15	4	--	2.1	<0.02
08/26/2003	12:00	5	--	2.2	<0.02
09/30/2003	11:30	5	--	2.6	<0.02
10/09/2003	11:20	5	--	2.4	<0.02
06/16/2004	11:45	5	--	1.5	<0.02
07/21/2004	12:00	5	--	1.7	<0.02
08/03/2004	11:30	5	--	1.7	<0.02
W2: Wolford Mountain Reservoir at midlake near Kremmling (400841106240600)					
07/20/1995	12:00	0.1	--	1	<0.1
07/20/1995	12:15	40	--	<1	<0.1
08/31/1995	12:45	0.1	--	<2	<0.1
08/31/1995	13:00	40	--	<1	<0.1
10/19/1995	10:15	0.1	--	2	<0.1
10/19/1995	10:30	35	--	2	<0.1
06/06/1996	9:45	0.1	--	1	<0.1
06/06/1996	10:00	60	--	2	<0.1
07/17/1996	12:00	0.1	--	1	<0.1
07/17/1996	12:15	60	--	3	<0.1
08/27/1996	13:15	0.1	--	1	<0.1
08/27/1996	13:30	60	--	2	<0.1
10/16/1996	11:15	0.1	--	2	<0.1
10/16/1996	11:30	50	--	3	<0.1

Appendix. Historic concentrations of dissolved selenium and total mercury in Muddy Creek, Alkali Slough, and Wolford Mountain Reservoir near Kremmling, Colorado.—Continued

[ft, feet; ft^3/s, cubic feet per second; µg/L, micrograms per liter --, no data; <, less than; E, estimated. Number in parentheses after site number and name refers to U.S. Geological Survey National Water Information System site identification number. See figure 1 for site locations]

Date	Time	Sampling depth (ft)	Instantaneous discharge (ft^3/s)	Dissolved selenium (µg/L)	Total mercury (µg/L)
W2: Wolford Mountain Reservoir at midlake near Kremmling (400841106240600)—Continued					
06/04/1997	11:00	0.1	--	2	<0.1
06/04/1997	11:15	60	--	2	<0.1
07/09/1997	11:15	0.1	--	1	<0.1
07/09/1997	11:30	60	--	2	<0.1
09/04/1997	11:30	0.1	--	2	<0.1
09/04/1997	11:45	60	--	2	<0.1
10/15/1997	11:00	0.1	--	2	<0.1
10/15/1997	11:15	60	--	2	<0.1
06/10/1998	11:00	0.1	--	1	<0.1
06/10/1998	11:15	50	--	2	<0.1
07/21/1998	10:50	0.1	--	2	<0.1
07/21/1998	11:05	65	--	2	<0.1
08/17/1998	11:00	0.1	--	2	<0.1
08/17/1998	11:15	60	--	1	<0.1
10/05/1998	10:45	0.1	--	2	<0.1
10/05/1998	11:00	50	--	2	<0.1
06/01/1999	10:40	0.1	--	2	<0.1
06/01/1999	10:55	70	--	2	<0.1
07/22/1999	10:30	0.1	--	1	<0.1
07/22/1999	10:45	60	--	1	<0.1
08/18/1999	10:55	0.1	--	1	<0.1
08/18/1999	11:00	65	--	2	<0.1
10/22/1999	11:00	0.1	--	3	<0.3
10/22/1999	11:15	55	--	E 2	<0.3
06/08/2000	10:45	0.1	--	E 2	<0.3
06/08/2000	11:00	67	--	3	<0.3
07/06/2000	10:30	0.1	--	E 2	<0.3
07/06/2000	10:45	67	--	3	<0.3
08/24/2000	10:45	0.1	--	2.1	<0.3
08/24/2000	11:00	58	--	2	<0.3
10/13/2000	10:30	0.1	--	2.6	<0.1
10/13/2000	10:45	45	--	2.7	<0.1
06/21/2001	10:50	--	--	1.9	<0.01
06/21/2001	10:55	--	--	2.7	**[1]0.01**
07/10/2001	10:45	0.5	--	1.9	<0.01
07/10/2001	11:00	60	--	2	<0.01
08/29/2001	11:15	0.5	--	2	<0.01
08/29/2001	11:30	58	--	--	<0.01
10/11/2001	10:45	1.0	--	2.2	<0.01
10/11/2001	10:55	50	--	2.1	<0.01
06/14/2002	9:55	1.0	--	2.9	**[1]0.02**
06/14/2002	10:05	45	--	3.3	**[1]0.01**
07/02/2002	10:30	1.0	--	3.2	<0.01
07/02/2002	10:40	45	--	3.4	<0.01
08/22/2002	10:50	1.0	--	3.5	<0.01
08/22/2002	11:00	--	--	2.5	<0.01
06/26/2003	11:00	0.1	--	2.4	<0.02
06/26/2003	11:15	45	--	3.1	<0.02
07/17/2003	10:45	0.1	--	2.4	<0.02
07/17/2003	11:00	45	--	2.6	<0.02

Appendix. Historic concentrations of dissolved selenium and total mercury in Muddy Creek, Alkali Slough, and Wolford Mountain Reservoir near Kremmling, Colorado.—Continued

[ft, feet; ft^3/s, cubic feet per second; µg/L, micrograms per liter --, no data; <, less than; E, estimated. Number in parentheses after site number and name refers to U.S. Geological Survey National Water Information System site identification number. See figure 1 for site locations]

Date	Time	Sampling depth (ft)	Instantaneous discharge (ft^3/s)	Dissolved selenium (µg/L)	Total mercury (µg/L)
W2: Wolford Mountain Reservoir at midlake near Kremmling (400841106240600)—Continued					
08/26/2003	11:30	0.1	--	2.5	<0.02
08/26/2003	11:45	45	--	2.5	<0.02
09/30/2003	11:00	0.1	--	2.2	<0.02
09/30/2003	11:10	55	--	3	<0.02
10/09/2003	10:50	1.0	--	2.7	<0.02
10/09/2003	11:00	45	--	2.8	<0.02
06/16/2004	11:10	0.5	--	1.8	<0.02
06/16/2004	11:20	55	--	2.1	<0.02
07/21/2004	11:35	0.5	--	1.8	<0.02
07/21/2004	11:45	55	--	1.9	<0.02
08/03/2004	11:10	0.5	--	2.1	<0.02
08/03/2004	11:20	50	--	2.1	<0.02
W3: Wolford Mountain Reservoir near Kremmling (09041395)					
07/20/1995	11:00	0.1	--	2	[1]**0.3**
07/20/1995	11:15	80	--	--	<0.1
08/31/1995	11:00	0.1	--	1	<0.1
08/31/1995	11:15	70	--	4	<0.1
10/19/1995	9:00	0.1	--	2	<0.1
10/19/1995	9:15	70	--	[2]**7**	<0.1
06/06/1996	11:45	0.1	--	1	<0.1
06/06/1996	12:00	90	--	3	<0.1
07/17/1996	11:00	0.1	--	1	<0.1
07/17/1996	11:15	90	--	[2]**5**	<0.1
08/27/1996	11:15	0.1	--	1	<0.1
08/27/1996	11:30	100	--	[2]**8**	<0.1
10/16/1996	10:15	0.1	--	2	<0.1
10/16/1996	10:30	90	--	[2]**11**	<0.1
06/04/1997	10:00	0.1	--	2	<0.1
06/04/1997	10:15	110	--	4	<0.1
07/09/1997	10:25	0.1	--	1	<0.1
07/09/1997	10:40	100	--	4	<0.1
09/04/1997	10:30	0.1	--	2	<0.1
09/04/1997	10:45	100	--	[2]**5**	<0.1
10/15/1997	10:00	0.1	--	2	<0.1
10/15/1997	10:15	90	--	[2]**5**	<0.1
06/10/1998	10:00	0.1	--	1	<0.1
06/10/1998	10:15	110	--	<1	<0.1
07/21/1998	10:00	0.1	--	2	<0.1
07/21/1998	10:15	100	--	2	<0.1
08/17/1998	9:50	0.1	--	2	<0.1
08/17/1998	10:05	100	--	2	<0.1
10/05/1998	10:00	0.1	--	2	<0.1
10/05/1998	10:15	90	--	2	<0.1
06/01/1999	9:50	0.1	--	2	<0.1
06/01/1999	10:05	100	--	3	<0.1
07/22/1999	9:50	0.1	--	1	<0.1
07/22/1999	10:10	110	--	2	<0.1
08/18/1999	10:00	0.1	--	2	<0.1
08/18/1999	10:15	100	--	2	<0.1
10/22/1999	10:05	0.1	--	E 2	<0.3

Appendix. Historic concentrations of dissolved selenium and total mercury in Muddy Creek, Alkali Slough, and Wolford Mountain Reservoir near Kremmling, Colorado.—Continued

[ft, feet; ft^3/s, cubic feet per second; µg/L, micrograms per liter --, no data; <, less than; E, estimated. Number in parentheses after site number and name refers to U.S. Geological Survey National Water Information System site identification number. See figure 1 for site locations]

Date	Time	Sampling depth (ft)	Instantaneous discharge (ft^3/s)	Dissolved selenium (µg/L)	Total mercury (µg/L)
W3: Wolford Mountain Reservoir near Kremmling (09041395)—Continued					
10/22/1999	10:20	90	--	4	<0.3
06/08/2000	10:00	0.1	--	E 2	<0.3
06/08/2000	10:15	100	--	3	<0.3
07/06/2000	9:35	0.1	--	E 2	<0.3
07/06/2000	9:50	100	--	3	<0.3
08/24/2000	10:00	0.1	--	2.2	<0.3
08/24/2000	10:15	88	--	3	<0.3
10/13/2000	9:45	0.1	--	2.7	<0.1
10/13/2000	10:00	90	--	3.2	<0.1
06/21/2001	10:00	--	--	1.7	[1]**0.01**
06/21/2001	10:10	--	--	3.3	[1]**0.01**
07/10/2001	10:05	0.5	--	1.9	<0.01
07/10/2001	10:20	100	--	3.2	<0.01
08/29/2001	10:15	0.5	--	2.6	<0.01
08/29/2001	10:30	99	--	3.8	<0.01
10/11/2001	10:10	1	--	2.4	[1]**0.01**
10/11/2001	10:15	85	--	3	<0.01
06/14/2002	9:25	1	--	2.8	<0.01
06/14/2002	9:35	80	--	3.1	<0.01
07/02/2002	9:45	--	--	3	<0.01
07/02/2002	9:55	80	--	3.3	<0.01
08/22/2002	10:15	1	--	3.5	<0.01
08/22/2002	10:30	--	--	3	<0.01
06/26/2003	10:25	0.1	--	2.3	<0.02
06/26/2003	10:35	85	--	3.4	<0.02
07/17/2003	10:15	0.1	--	2.3	<0.02
07/17/2003	10:30	80	--	3	<0.02
08/26/2003	10:50	0.1	--	2.5	<0.02
08/26/2003	11:00	90	--	2.9	[1]**0.05**
09/30/2003	10:30	0.1	--	3.1	<0.02
09/30/2003	10:40	88	--	2.8	<0.02
10/09/2003	10:15	1	--	2.7	<0.02
10/09/2003	10:30	75	--	2.9	<0.02
06/16/2004	10:15	0.5	--	1.9	<0.02
06/16/2004	10:30	100	--	2.3	<0.02
07/21/2004	11:00	0.1	--	1.8	<0.02
07/21/2004	11:15	90	--	2.2	<0.02
08/03/2004	10:40	0.1	--	2	<0.02
08/03/2004	10:50	90	--	2.4	<0.02
10/13/2004	12:45	1	--	2.5	<0.01
10/13/2004	12:50	61	--	2.5	<0.01
06/16/2005	11:05	1	--	2.3	< 0.01
06/16/2005	11:15	103	--	2.9	< 0.01

[1]Concentration is greater than or equal to the State of Colorado chronic water-quality standard for total mercury for protection of aquatic life of 0.01 µg/L (Colorado Department of Public Health and Environment, 2006).

[2]Concentration is greater than or equal to the State of Colorado chronic water-quality standard for dissolved selenium for protection of aquatic life of 4.6 µg/L (Colorado Department of Public Health and Environment, 2006).

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