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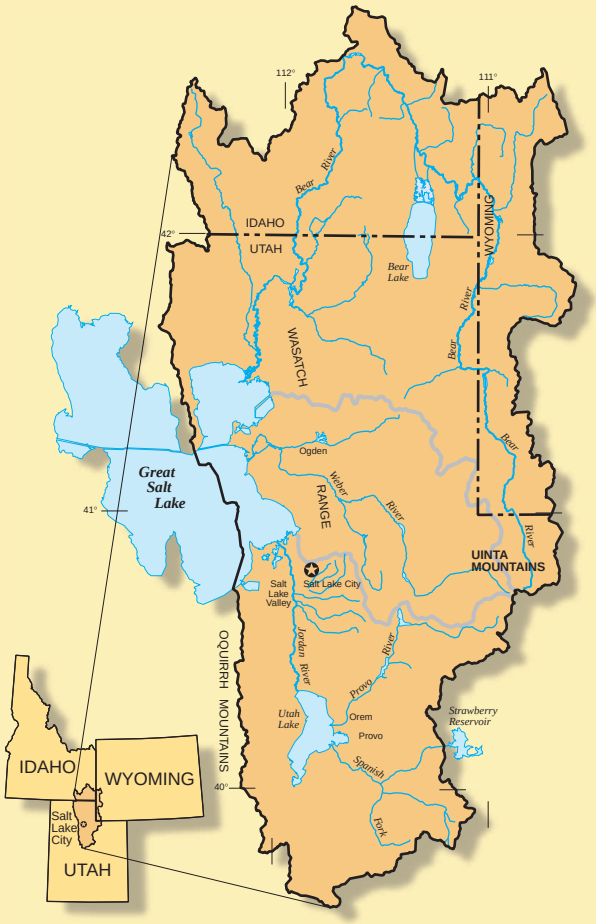
Trace Elements and Organic Compounds in Sediment and Fish Tissue from the Great Salt Lake Basins, Utah, Idaho, and Wyoming, 1998–99

Water-Resources Investigations Report 03–4283



U.S. Department of the Interior
U.S. Geological Survey
National Water-Quality Assessment Program

Trace Elements and Organic Compounds in Sediment and Fish Tissue from the Great Salt Lake Basins, Utah, Idaho, and Wyoming, 1998-99

By Kidd M. Waddell and Elise M. Giddings

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 03-4283

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Salt Lake City, Utah
2004

U.S. DEPARTMENT OF THE INTERIOR

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FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources (http://www.usgs.gov/). Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity and quality, even more critical to the long-term sustainability of our communities and ecosystems.

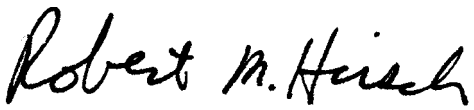
The USGS implemented the National Water-Quality Assessment (NAWQA) program to support national, regional, and local information needs and decisions related to water-quality management and policy (http://water.usgs.gov/nawqa). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units (http://water.usgs.gov/nawqa/nawqamap.html). Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings (http://water.usgs.gov/nawqa/natsyn.html).

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.



Robert M. Hirsch
Associate Director for Water

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Multiply	By	To obtain
foot (ft)	0.3048	meter
ton (t)	907.18	kilogram
mile (mi)	1.609	kilometer
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
inch (in.)	25,400	micrometer
square mile (mi^2)	2.591	square kilometer
kilogram (kg)	2.205	pound
gram (g)	0.03527	ounce
milligram (mg)	0.00003527	ounce
microgram (µg)	0.0000003527	ounce

Water temperature is reported in degrees Celsius (^oC), which may be converted to degrees Fahrenheit (^oF) by the following equation:

$$^oF = 1.8(^oC) + 32.$$

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 concentration is reported only in metric units. Chemical concentration in sediment and biological tissue is reported in micrograms per gram (µg/g), which is equal to parts per million (ppm), or micrograms per kilogram (µg/kg), which is equal to parts per billion (ppb), or grams per kilogram (g/kg). Specific conductance is reported in microsiemens per centimeter at 25 degrees Celsius (µS/cm).

Trace Elements and Organic Compounds in Sediment and Fish Tissue from the Great Salt Lake Basins, Utah, Idaho, and Wyoming, 1998-99

By Kidd M. Waddell and Elise M. Giddings

ABSTRACT

A study to determine the occurrence and distribution of trace elements, organochlorine pesticides, polychlorinated biphenyls (PCBs), and semivolatile organic compounds in sediment and in fish tissue was conducted in the Great Salt Lake Basins study unit of the National Water-Quality Assessment (NAWQA) program during 1998-99. Streambed-sediment and fish-tissue samples were collected concurrently at 11 sites and analyzed for trace-element concentration. An additional four sites were sampled for streambed sediment only and one site for fish tissue only. Organic compounds were analyzed from streambed-sediment and fish-tissue samples at 15 sites concurrently.

Bed-sediment cores from lakes, reservoirs, and Farmington Bay collected by the NAWQA program in 1998 and by other researchers in 1982 were used to examine historical trends in trace-element concentration and to determine anthropogenic sources of contaminants. Cores collected in 1982 from Mirror Lake, a high-mountain reference location, showed an enrichment of arsenic, cadmium, copper, lead, tin, and zinc in the surface sediments relative to the deeper sediments, indicating that enrichment likely began after about 1900. This enrichment was attributed to atmospheric deposition during the period of metal-ore mining and smelting. A core from Echo Reservoir, in the Weber River Basin, however, showed a different pattern of trace-element concentration that was attributed to a local source. This site is located downstream from the Park City mining district, which is the most likely historical source of trace elements. Cores collected in 1998 from Farmington Bay show that the concentration of lead began to increase after 1842 and peaked during the mid-1980s and has been in decline since. Recent sediments deposited during 1996-98 indicate a 41- to 62-percent reduction since the peak in the mid-1980s.

The concentration of trace elements in streambed sediment was greatest at sites that have been affected by historic mining, including sites on Little Cottonwood Creek in the Jordan River basin, Silver Creek in the Weber River basin, and the Weber River below the confluence with Silver Creek. There was significant correlation of lead concentrations in streambed sediment and fish tissue, but other trace elements did not correlate well. Streambed sediment and fish tissue collected from sites in the Bear River basin, which is predominantly rangeland and agriculture, generally had low concentrations of most elements.

Sediment-quality guidelines were used to assess the relative toxicity of streambed-sediment sites to aquatic communities. Sites affected by mining exceeded the Probable Effect Concentration (PEC), the concentration at which it is likely there will be a negative effect on the aquatic community, for arsenic, cadmium, copper, lead, silver, mercury, and zinc. Sites that were not affected by mining did not exceed these criteria. Concentrations of trace elements in samples collected from the Great Salt Lake Basins study unit (GRSL) are high compared to those of

samples collected nationally with the NAWQA program. Nine of 15 streambed-sediment samples and 11 of 14 fish-tissue samples had concentrations of at least one trace element greater than the concentration of 90 percent of the samples collected nationally during 1993-2000.

Organic compounds that were examined in streambed sediment and fish-tissue samples also were examined in bed-sediment cores. A bed-sediment core from Farmington Bay of Great Salt Lake showed an increase in total polycyclic aromatic hydrocarbon (PAH) concentrations coincident with the increase in population in Salt Lake Valley, which drains into this bay. Analysis of streambed-sediment samples showed that the highest concentrations of PAHs were detected at urban sites, including two sites in the lower Jordan River (the Jordan River flows into Farmington Bay), the Weber River at Ogden Bay, and the Provo River near Provo. Other organic compounds detected in streambed sediment in the lower Jordan River were PCBs, DDT compounds, and chlordane compounds.

Organic compounds were detected more frequently in fish tissue than in streambed sediment. Chlordane compounds and PCBs were detected more frequently at urban sites. DDT compounds were detected at 13 of 15 sites including urban and agricultural sites. Concentrations of total DDT in fish tissue exceeded the guideline for protection of fish-eating wildlife at two urban sites. The concentration of organic compounds in the GRSL study unit is low compared with that of samples collected nationally.

INTRODUCTION

The U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) program is a perennial program designed to produce a comprehensive assessment of the quality of the Nation's stream and aquifer resources (Hirsch and others, 1988; Leahy and Wilbur, 1991). Fifty-one NAWQA study units were divided across the United States into three groups on a rotational schedule, with the first group beginning in 1991. The Great Salt Lake Basins (GRSL) study unit was among the third group. Investigations in the study units use an integrated approach to assess the status and trends of water quality in the major river basins of the Nation (Gurtz, 1994). This assessment consists of the collection of chemical, physical, and biological data at sites representing a wide range of water-quality conditions. During 1998-99, as part of this assessment of water quality, a study was done to examine the occurrence and distribution of trace elements and organochlorine pesticides and polychlorinated biphenyl organic constituents (PCBs) in biological tissue and streambed sediment, and semivolatile organic compounds (SVOCs) in streambed sediments on a basin-wide scale.

Characterizing the geographic distribution of trace elements and organic compounds with regard to background conditions and sources was one goal of the assessment. Data were collected at 15 sites representing a range of land uses and stream sizes.

Concentrations of trace elements have been reported to be higher in streambed sediment and biota than in water (Lynch and others, 1988); thus, sampling streambed sediment and biota increases the probability of detecting trace amounts of these constituents in the environment. Sediment samples provide a composite over time compared to the relatively transient snapshots provided by water. Streambed sediment provides habitats for many aquatic organisms and can act as the primary exposure pathway for contaminants in aquatic ecosystems. Trace elements in aquatic systems may be attributed to natural geologic sources or to past and present land uses. Although trace elements originate from natural sources, human activities such as mining, agriculture, and urbanization can affect their concentration and distribution. In contrast, synthetic organic compounds such as insecticides, PCBs, and PAHs (polycyclic aromatic hydrocarbons) are primarily associated with human activities.

Analysis of streambed sediment and fish tissue was done to assess the current status of hydrophobic contaminants in the Great Salt Lake Basins study unit; however, the data record to assess changes over time was inadequate. Bed-sediment cores obtained from an urban pond, a reservoir, and Farmington Bay of Great Salt Lake were analyzed to provide a historical record for assessment of trends.

Purpose and Scope

The purpose of this report is to (1) identify the occurrence and distribution of trace elements and organic compounds in streambed sediment and fish tissue from selected streams in the GRSL, (2) compare the results with national guidelines, (3) speculate on possible sources and processes controlling the observed distributions in sediments and tissues in the study area, and (4) compare the results with those of other study units across the nation. Fish-tissue and sediment analyses and related data from samples collected for the GRSL NAWQA during the summer and fall of 1998-99 are presented in this report.

Description of Study Area

Most of the 14,500 mi^2 of the GRSL study unit is in Utah, but part of the study unit is in Idaho and Wyoming. The study unit encompasses three major river systems that discharge into Great Salt Lake: the Bear, the Weber, and the Utah Lake—Jordan River drainages. The Provo and Spanish Fork Rivers are large tributary drainages to Utah Lake, which is considered to be the headwaters of the Jordan River. The Jordan River flows northward through the Salt Lake City metropolitan area before discharging into Great Salt Lake.

The GRSL study unit includes the Salt Lake City metropolitan area and about 1.7 million people, or 76 percent of the population of the State of Utah live along the western flanks of the Wasatch Range. The study unit includes diverse topography, geomorphology, natural vegetation, geology, and climate. The headwaters of all three major river systems are in the western end of the Uinta Mountains. These rivers flow through the valleys of the Wasatch Range, emerge through the Range to the west, and discharge into Great Salt Lake.

The western side of the GRSL study unit is in the Basin and Range Physiographic Province and the eastern side is in the Middle Rocky Mountains Physiographic Province (Fenneman, 1931). The stratigraphy is varied and includes formations from many geologic eras and periods and most types of rocks. Annual precipitation ranges from less than 12 in. in Salt Lake Valley to greater than 50 in. in the Wasatch Range, 10 to 15 mi to the east.

Predominant land use in the GRSL study unit is forest and rangeland (fig. 1). Within the forest and rangeland setting, other major land uses include mining, urban, recreation, and agriculture. Salt Lake Valley, which is currently a highly urbanized setting, once had several smelters in operation. Mining was active in several of the canyons of the Wasatch Range within a 30-mi radius of Salt Lake Valley and at the higher altitudes of the Weber and Provo River drainages. Historic mining activities in the vicinity of Park City, Utah, have greatly impacted Silver Creek (Giddings and others, 2001), a tributary to the Weber River in northern Utah. Park City was founded as a mining town in the mid-1800s when large deposits of lead and silver were discovered in the nearby mountains. Large piles of tailings from the mining activities still exist in the upper part of the Silver Creek drainage.

Acknowledgments

The authors thank Bruce Waddell, Elise Boeke, Nathan Darnall, Rex Sohn, and Melanie Markin of the U.S. Fish and Wildlife Service for assisting with sampling and use of equipment. Doyle Stephens (deceased USGS employee) provided enthusiasm, insight, and guidance in selection of sites and in the collection of the data.

METHODS OF SAMPLE COLLECTION, PREPARATION, AND ANALYSIS

Collection and field processing of sediment and fish-tissue samples followed established NAWQA protocols (Crawford and Luoma, 1993; Shelton and Capel, 1994). Streambed-sediment samples were collected at 15 sites for analysis of trace elements and 15 sites for organic compounds during 1998-99 in the GRSL study unit (table 1 and fig. 1). Streambed-sediment and fish-tissue samples were collected concurrently at 11 sites and analyzed for trace-element concentration. An additional four sites were sampled for streambed sediment only and one site for fish tissue only. Streambed-sediment and fish-tissue samples collected concurrently at 15 sites were analyzed for organic compounds. Sampling was confined to the upper 2 cm of bed sediment to ensure that the most recent deposition was being sampled. Each depositional zone was subsampled at several locations, and the subsamples were composited. Samples were processed in the field by wet-sieving sediments through a 63-μm nylon sieve for the trace

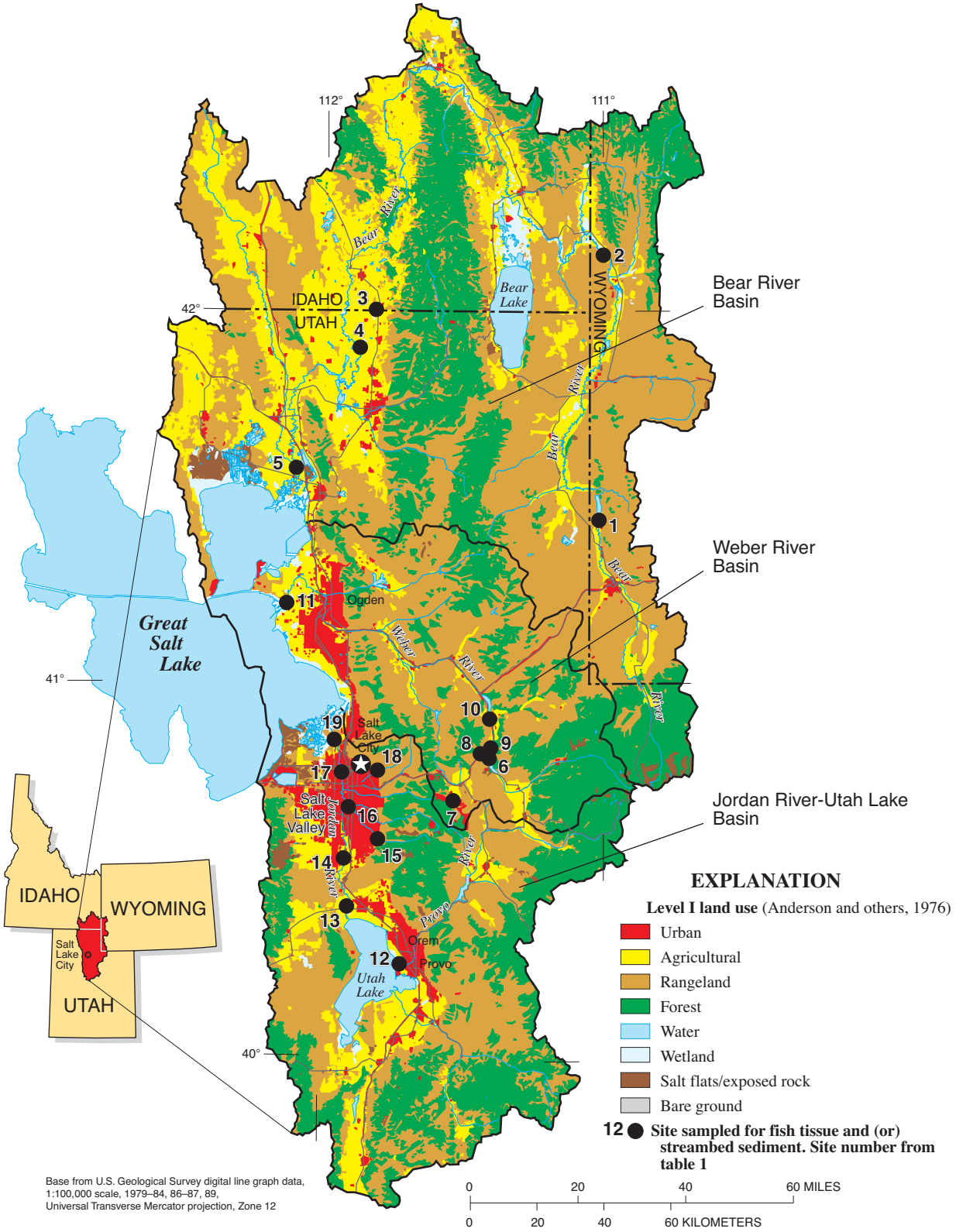


Figure 1. Land use and location of sites where fish-tissue and (or) streambed-sediment samples were collected in the Great Salt Lake Basins study unit.

Table 1. Stream sites where samples were collected for analysis of trace elements and organic compounds in streambed sediment and fish tissue, Great Salt Lake Basins study unit

[X, sample collected; Q, regular and replicate samples collected for quality assurance]

Site number (see fig. 1)	Stream	Date	Time	Bed sediment		Fish tissue	
				Trace elements	Organic compounds	Trace elements	Organic compounds
1	Bear River above Woodruff Reservoir, near Woodruff, Utah	09-08-1998	1700	X	X	X	X
2	Bear River below Smiths Fork, near Cokeville, Wyoming	08-12-1998	1000	X	X	X	X
3	Cub River near Franklin, Idaho	07-20-1999	1230		X		X
4	Cub River near Richmond, Utah	08-11-1998	1100	X	X	Q	X
4	Cub River near Richmond, Utah	07-19-1999	1300			X	
5	Bear River near Corinne, Utah	08-07-1998	1400	X	X	Q	X
5	Bear River near Corinne, Utah	08-07-1998	1410			X	
6	Weber River near Wanship, Utah	07-22-1999	1030	X			
7	Silver Creek above Richardson Flat	07-22-1999	1430	X			
8	Silver Creek at Wanship, Utah	07-22-1999	1315	X			
9	Weber River Northeast of Wanship, Utah	07-22-1999	1130	X			
10	Weber River near Coalville, Utah	09-08-1998	1220	X	X	X	X
11	Weber River Middle Fork near Ogden Bay Dike	08-06-1998	1200	Q	Q	Q	Q
12	Provo River at Provo, Utah	07-26-1999	1200		X		X
13	Jordan River below Utah Lake at Pumping Station, near Lehi, Utah	08-20-1998	1400		X	X	X
14	Jordan River at 9000 South near Midvale, Utah	07-29-1999	1300		X		X
15	Little Cottonwood Creek at Crestwood Park, Salt Lake City, Utah	08-25-1998	1130	X	X	X	X
16	Little Cottonwood Creek at Jordan River, near Salt Lake City, Utah	08-04-1998	1300	Q	Q	Q	Q
17	Jordan River at 1700 South, Salt Lake City, Utah	08-03-1998	1300	X	X	X	X
18	Red Butte Creek at Fort Douglas, near Salt Lake City, Utah	08-10-1998	1500	X	X	Q	X
19	Jordan River at Cudahy Lane near Salt Lake City, Utah	08-05-1998	1010	Q	Q	Q	Q

elements and 2-mm stainless steel sieve for organic compounds (Shelton and Capel, 1994).

The National Water Quality Laboratory in Denver, Colorado, analyzed samples for 110 organochlorine pesticides, semivolatile organic compounds, and PCBs, and for organic and inorganic carbon (table 2). Minimum reporting levels (MRLs) for sediment (dry weight) were 1 or 2 µg/kg for most organochlorine compounds; 5 µg/kg for chlorneb, DCPA, methoxychlor, and permethrin; 100 µg/kg for total PCBs, and 200 µg/kg for toxaphene. The MRL for all SVOCs in sediment was 50 µg/kg (dry weight). The USGS Branch of Geochemistry Analytical Services Group Laboratory, Denver, Colorado, analyzed samples for 43 trace elements (table 3).

Fish were collected by electrofishing (fig. 2) a stream reach that was 500 to 1,000 ft long at wadeable sites and 1,640 to 3,280 ft long at nonwadeable sites. The fish taxa collected for analysis were selected from a National Target Taxa List, which was established to provide consistency within the NAWQA program and prioritizes species to be collected (Crawford and Luoma, 1993). Carp and suckers are the highest priority species and were collected where available, at most sites. At sites where they were not available, one of the following species was collected: mottled sculpin, redside shiner, rainbow trout, or cutthroat trout. For trace elements, fish livers were analyzed for carp, suckers and trout, and whole-body fish were analyzed for sculpins and shiners, which were too small to practically extract livers from. Whole-body carp were analyzed at one site (site 5) in addition to carp livers for comparison with historical data. Five to 10 adult fish or fish livers were composited at each site. The National Water Quality Laboratory in Denver, Colorado, analyzed samples (Hoffman, 1996; Timme, 1995; Leiker and others, 1995) for 22 trace elements, 28 organic compounds, and for lipids. Minimum reporting levels for organochlorine pesticides and PCBs in fish were 5

Table 2. Organic compounds analyzed for in the Great Salt Lake Basins study unit

Organochlorine pesticides and PCBs in fish and sediment		
cis-Chlordane	*p,p'*-DDT	Mirex
trans-Chlordane	Aldrin	Pentachloroanisole
Heptachlor	Dacthal (DCPA)	Toxaphene
Heptachlor epoxide	Dieldrin	Total PCB
cis-Nonachlor	Endrin	Chloroneb [1]
trans-Nonachlor	Hexachlorobenzene	Endosulfan I[1]
Oxychlordane	*alpha*-BHC	Isodrin[1]
o,p'-DDD	*beta*-BHC	*cis*-Permethrin[1]
p,p'-DDD	*delta*-BHC	*trans*-Permethrin[1]
o,p'-DDE	Lindane (*gamma*-BHC)	Lipids (percent)
p,p'-DDE	*o,p'*-Methoxychlor	
o,p'-DDT	*p,p'*-Methoxychlor	
Other semivolatile organic compounds in sediment		
1,2,4-Trichlorobenzene	4-Nitrophenol	Dimethyl phthalate
1,2-Dichlorobenzene	4*H*-cyclopenta[*d,e,f*]phenanthrene	Fluoranthene
1,2-Dimethylnaphthalene	Acenaphthene	Fluorene
1,3-Dichlorobenzene	Acenaphthylene	4-Bromophenylphenylether
1,4-Dichlorobenzene	Acridine	4-Chloro-3-methylphenol
1,6-Dimethylnaphthalene	Anthracene	Isophorone
1-Methyl-*9H*-fluorene	Anthraquinone	Isoquinoline
1-Methylphenanthrene	Azobenzene	*N*-Nitroso-di-*n*-propylamine
1-Methylpyrene	Benz[*a*]anthracene	*N*-Nitrosodiphenylamine
2,2'-Biquinoline	Benzo[*a*]pyrene	Naphthalene
2,3,5,6-Tetramethylphenol	Benzo[*b*]fluoranthene	Nitrobenzene
2,3,6-Trimethylnaphthalene	Benzo[*c*]cinnoline	Pentachloronitrobenzene
2,4,6-Trichlorophenol	Benzo[*g,h,i*]perylene	Pentachlorophenol
2,4,6-Trimethylphenol	Benzo[*k*]fluoranthene	Phenanthrene
2,4-Dichlorophenol	Phenanthrene	Hexachlorobutadiene
2,4-Dinitrophenol	Phenol	Hexachlorocyclopentadiene
2,4-Dinitrotoluene	Pyrene	Hexachloroethane
2,6-Dimethylnaphthalene	Bis(2-ethylhexyl)phthalate	Indeno[1,2,3-*cd*]pyrene
2,6-Dinitrotoluene	Butybenzyl phthalate	Quinoline
2-Chloronaphthalene	C8-Alkylphenol	Bis(2-Chloroethoxy)methane
2-Chlorophenol	Carbazole	Bis(2-Chloroethyl)ether
2-Ethylnaphthalene	Chrysene	Bis(2-Chloroisopropyl)ether
2-Methylanthracene	Di-n-butyl-phthlate	*p*-Cresol
2-Nitrophenol	Di-n-octyl phthlate	Inorganic carbon (g/kg)
3,5-Dimethylphenol	Dibenz[*a,h*]anthracene	Organic carbon (g/kg)
4,6-Dinitro-2-methylphenol	Dibenzothiophene	
4-Chlorophenyl phenyl ether	Diethyl phthalate	

[1]Sediment only

Table 3. Method reporting limits for trace-element concentration in streambed sediment and fish liver, Great Salt Lake Basins study unit

[Concentration reported in micrograms per gram, dry weight, unless expressed as a percent (%); MRL, method reporting limit[1]]

Analyte	MRL	Analyte	MRL	Analyte	MRL	Analyte	MRL	Analyte	MRL
Streambed sediment									
Aluminum	0.005%	Chromium	1	Lithium	2	Potassium	0.05%	Tin	10
Antimony	.1	Cobalt	1	Magnesium	.005%	Scandium	2	Titanium	.005%
Arsenic	.1	Copper	1	Manganese	4	Selenium	.1	Uranium	.05
Barium	1	Gallium	4	Mercury	.02	Silver	.1	Vanadium	2
Beryllium	1	Gold	8	Molybdenum	2	Sodium	.005%	Ytterbium	1
Bismuth	10	Holmium	4	Neodymium	4	Strontium	2	Yttrium	2
Cadmium	.1	Iron	.005%	Nickel	2	Sulfur	.05%	Zinc	4
Calcium	.05%	Lanthanum	2	Niobium	4	Tantalum	40		
Cerium	4	Lead	4	Phosphorus	.005%	Thorium	4		
Carbon									
Carbonate	.01%	Total carbon	.01%	Total organic carbon	.01%				
Fish liver									
Aluminum	1	Cadmium	.1	Manganese	.1	Silver	.1		
Antimony	.1	Chromium	.5	Mercury	.1	Strontium	.1		
Arsenic	.1	Cobalt	.1	Molybdenum	.1	Uranium	.1		
Barium	.1	Copper	.5	Nickel	.1	Vanadium	.1		
Beryllium	.1	Iron	1	Selenium	.1	Zinc	.5		
Boron	.2	Lead	.1						

[1]The method reporting limit is the smallest measured concentration of a constituent that may be reliably reported using a given analytical method (Timme, 1995).

µg/kg wet weight for all compounds except total PCBs (50 µg/kg) and toxaphene (200 µg/kg).

Concentrations of trace metals, organochlorine compounds, and SVOCs were compared with "consensus-based" sediment-quality guidelines (SQG) devised by MacDonald and others (2000). Two SQGs—probable effect concentration (PEC) and threshold effect concentration (TEC)—were developed for 10 organochlorines, 10 SVOCs and total PAH, and 8 trace elements. Most PEC and TEC values provide an accurate basis for predicting sediment toxicity or absence of toxicity, respectively, to sediment dwelling organisms (MacDonald and others, 2000). PEC is the concentration above which adverse effects are expected to occur more often than not; TEC is the concentration below which adverse effects are not expected. Because bed-sediment samples in this study are from sediments finer than 0.063 mm where concentrations tend to be greatest, comparisons with the "consensus-based" sediment-quality guidelines may overestimate the effects on aquatic organisms, especially if the amount of fine material is less than 60 percent of the bulk sample. Trace-element concentrations also may be overestimated because of the strong acid digestion used for the analysis of samples.

Concentrations of total DDT in fish tissue were compared with criteria that were established by Environment Canada to protect wildlife that consume of aquatic biota (Canadian Council of Ministers of the Environment, 2001). Total DDT is the sum of *o,p′* - and *p,p′* - DDD, *o,p′* - and *p,p′* DDE, and *o,p′* - and *p,p′* DDT.

Quality Assurance and Control

Quality-assurance and quality-control techniques (QA/QC) have been established for NAWQA data collection and analysis. As part of the procedures, replicate samples were collected for streambed sediment and triplicate samples were collected for fish tissue. Site 11, near the mouth of the Weber River, and site 19, near the mouth of the Jordan River, were selected for collection of the replicate and triplicate samples. Statistical analysis of the replicates and triplicates was done to provide an estimate of the variability associated with

Figure 2. USGS personnel electrofishing on the Weber River at Coalville, Utah.

sample processing, handling, and analysis. Relative percent differences (RPD) were calculated for detected constituents as follows:

$$RPD = \frac{[Rmax - Rmin]x100}{Ravg} \quad (1)$$

where

Rmax-Rmin = range in concentration of environmental sample and replicate or triplicate samples, and

Ravg = average concentration of environmental sample and replicate or triplicate samples.

For sites 11 and 19, the RPD ranged from 0 to 24 percent for all trace elements except silver, which was 77 percent at site 11 and 34 percent at site 19 (table 4). For organic compounds in sediment, the RPD ranged from 3 to 69 percent. For trace elements in fish tissue, the RPD ranged from 0 to 97 percent (table 5). In fish tissue, the variability between environmental and triplicate samples was high for some organic compounds, especially at site 11. For site 11, the RPD for PCB and *p,p'*-DDD in fish tissue were 168 and 134 percent, respectively, and the RPD for the other organic compounds ranged from 19 to 65 percent. At site 19, the maximum RPD for organic compounds in fish tissue was 55 percent for all the organic compounds except hexachlorobenzene, for which the RPD was 86 percent. The reasons for the high variability of PCB and *p,p'*-DDD derivatives in samples collected at site 11, and hexachlorobenzene at site 19, are not known.

On the basis of the QA/QC results, it was concluded that presence (or) absence of most constituents, concentration distributions, and comparisons to water-quality criteria could be determined. The QA/QC results, however, indicate that the concentrations of PCB and DDT derivatives in fish tissue are of such high variability that comparisons to water-quality criteria are probably less credible than for other organic compounds in fish tissue.

Table 4. Statistical comparison of analytical data for split samples of streambed sediment for samples collected from the Weber River at Ogden Bay, Utah (site 11), and Jordan River at Cudahy Lane, Utah (site 19), 1998

[See figure 1 for location of sites. Only compounds that were detected in concentrations greater than the method reporting limit are included in the table. Concentration of trace elements is reported in micrograms per gram (dry weight), organic compounds in micrograms per kilogram (dry weight); relative percent difference, computed as the range in concentration in the split and environmental samples expressed as a percentage of the average of the samples; <, less than value indicated; NC, not calculated when concentration less than reporting limit]

Analyte	Site 11			Site 19		
	Sample 1	Sample 2	Relative percent difference	Sample 1	Sample 2	Relative percent difference
Organic compounds in sediment						
trans-Nonachlor	<1	<1	NC	3.3	3	10
cis-Chlordane	<1	<1	NC	2.8	3	7
trans-Chlordane	<1	<1	NC	3.3	3.4	3
p,p'-DDE	2.5	1.3	63	8.2	5.9	33
Pyrene	<50	<50	NC	268	380	35
Benzo(*a*)pyrene	<50	<50	NC	95	160	51
Indeno[1,2,3-*cd*]pyrene	<50	<50	NC	56	74	28
Benzo(*k*)fluoranthene	<50	<50	NC	73	150	69
2,6-Dimethylnaphthalene	<50	<50	NC	87	96	10
Benzo(*g,h,i*)perylene	<50	<50	NC	61	84	32
Phenanthrene	<50	<50	NC	141	220	44
Anthracene	<50	<50	NC	63	97	42
Benz(*a*)anthracene	<50	<50	NC	105	130	21
Chrysene	<50	<50	NC	139	230	49
Benzo(*b*)fluoranthene	<50	<50	NC	108	130	18
PCB, total	<50	<50	NC	72	66	9
Fluoranthene	<50	<50	NC	207	330	46
Trace elements in sediment						
Arsenic	8.6	8	7	20	19	5
Cadmium	1.2	1.2	0	2.9	2.8	4
Chromium	53	49	8	55	60	9
Copper	42	37	13	122	120	2
Lead	113	100	12	205	200	2
Mercury	.21	.18	15	.14	.11	24
Nickel	19	18	5	23	22	4
Selenium	.55	.5	10	1.1	1.1	0
Silver	1.8	.8	77	1.6	.9	34
Zinc	208	200	4	367	360	2

Table 5. Statistical comparison of analytical data for split samples of fish tissue for samples collected from the Weber River at Ogden Bay, Utah (site 11), and Jordan River at Cudahy Lane, Utah (site 19), 1998

[See figure 1 for location of sites. Only compounds that were detected in concentrations greater than the method reporting limit are included in the table. Concentration of trace elements is reported in micrograms per gram, organic compounds in micrograms per kilogram; relative percent difference, computed as the range in concentration in the split and environmental samples expressed as a percentage of the average of the samples; <, concentration less than value indicated; NC, not calculated when concentration less than reporting limit]

Analyte	Site 11				Site 19			
	Sample 1	Sample 2	Sample 3	Relative percent difference	Sample 1	Sample 2	Sample 3	Relative percent difference
Organic compounds in fish tissue								
alpha-BHC	98	99	81	19	93	84	99	16
PCB, total	25	437	650	168	270	450	340	51
trans-Nonachlor	13	8.8	16	57	26	23	17	41
Hexachlorobenzene	<5	<5	<5	NC	2.5	5.4	6.7	86
Dieldrin	<5	<5	<5	NC	7.2	6.7	8.2	20
p,p'-DDE	43	86.6	73	65	89	72	50	55
o,p'-DDD	<5	17.8	<8.2	NC	<5	<5	<5	NC
p,p'-DDD	17	63.8	24	134	22	19	13	50
cis-Chlordane	12	8.4	15	56	29	23	21	33
trans-Chlordane	<5	6	6.5	NC	9.7	7.7	7.7	24
Trace elements in fish tissue								
Arsenic	.24	.4	.4	46	.28	.3	.3	7
Cadmium	.45	.3	.8	97	1.55	.6	1.4	80
Chromium	.79	1	.7	36	.75	.9	.6	40
Copper	99	86	100	15	62	81	100	47
Lead	.79	1.2	1.1	40	1.7	1.8	1.6	12
Mercury	.14	.1	.2	68	.11	.1	.1	10
Nickel	.33	.6	.4	61	.2	.2	.2	0
Selenium	5.8	5	5.4	15	7.1	5.5	5.8	26
Silver	2.7	1.5	2	58	.97	.8	1.2	40
Zinc	1,240	1,300	730	52	1,241	880	900	36

TRACE ELEMENTS

Weathering of rocks and soils provides a pathway for the natural release of trace elements into the aquatic environment (Long and others, 2000). Human activities can accelerate this accumulation through point and nonpoint sources. Major point sources of trace elements are industrial and domestic waste-water discharges. Chemical industries and petroleum refining companies often use and expel trace elements associated with their processes. Effluents containing trace elements can be discharged in the receiving waters or can be diverted to waste-water treatment plants and eventually end up in the streams.

Nonpoint sources also contribute to the accumulation of trace elements in the aquatic environment. Emissions from automobile exhaust (Ondov and others, 1982) and combustion of fossil fuels from smelting, refining, and metal processing emit trace elements to the atmosphere, including cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), antimony (Sb), and zinc (Zn). These elements fall to earth through dry or wet deposition and may eventually be mobilized through storm runoff and enter streams (Brigham and others, 1997; Harte and others, 1991; O'Brien, 1997; Winter, 1998). Leaching from abandoned mine tailings or other workings is a common source of trace elements to the environment. Mining activities since the mid-1800s have accelerated metal cycling in aquatic systems (Giddings and others, 2001).

Although naturally occurring enriched ore bodies can contribute relatively minor loadings to these systems, extraction and processing of metals can enrich the metals in the water bodies (Moore and Luoma, 1990). When introduced to the aquatic environment, trace elements tend to adsorb to fine-grained sediments (Carter, 1997). These trace-element-sorbed particles settle in depositional areas of streambeds where they continue to accumulate, often making sediments the most concentrated pool of trace elements in the aquatic environment (Miller and others, 1992).

Trace elements in the water or sediments may enter the aquatic food chain and, in high enough concentrations, pose a threat to the health of fish, wildlife, and eventually humans. Some elements, notably Hg, bioaccumulate in the food chain, making human consumption of contaminated fish unsafe (Eisler, 1987). However, because fish livers or whole fish rather than the edible portion (fillets) were analyzed in this study, the values reported are not appropriate for human-health risk assessment.

Concentrations of contaminants in fish tissue also are important in the evaluation of contaminants in the aquatic environment because they can be used to estimate the proportion of contaminants in sediments that are biologically available (Long and others, 2000). To better detect trace element and organochlorine compounds in fish tissues, fish livers and whole fish (respectively) were analyzed. Concentrations of trace elements in fish livers and concentrations of organochlorine compounds in whole fish are generally higher than in fish-fillet samples because muscle tissue contains lower concentrations of these substances (Crawford and Luoma, 1993; Schmitt and others, 1981). The discussion of trace elements in bed sediment and fish tissue is focused on selected elements as determined from comparison with historical concentrations and criteria, and potential adverse effects to either aquatic life or human health.

Efforts were made to determine the major anthropogenic sources of metals to bed sediments. Prior investigators have tried several methods to determine either "background" concentration or "baseline" concentration so that the naturally occurring concentrations could be separated from the anthropogenic sources of trace elements. Rice (1999) defined "background" concentration of a trace element in bed sediment as the concentration that is the result of natural processes, including weathering and subsequent erosion of local soil and bedrock, and atmospheric deposition unaffected by anthropogenic activity. Because almost every place on Earth has been affected by human activities, a more appropriate term is "baseline", which is defined as the concentration measured at a particular time, such as the onset of a study. Some investigators subtracted baseline concentrations from total concentrations with the expectation that adjusted data would correlate with land use in the sampled basin. Through examination of efforts by earlier investigators, Rice concluded that the correlations with land use were rarely improved. Rice also concluded that the sieving procedure (less than 63 micrometers (μm)) appeared to provide normalization for the data collected according to NAWQA guidelines. Consequently, no efforts were made in this study to determine baseline concentrations or to make any adjustments to the trace-element concentrations. Instead, association of trace elements in sediment with anthropogenic sources was done indirectly by association among differing land uses in the drainage basin above the sampling site.

Relation of Trace-Element Concentration in Sediments to Anthropogenic Sources

Analysis of bed-sediment cores from reservoirs, lakes, and Farmington Bay provided information on water-quality trends through age dating and chemical analysis of the sediments. A study was done by Kada, and others (1994) to determine the chronology of anthropogenic trace-element input to Echo Reservoir, Deer Creek Reservoir, Mirror Lake, and Panguitch Lake. The first two sites are within the GRSL study unit (fig. 3). The data for Echo Reservoir were used in conjunction with streambed-sediment data in the drainage basin upstream from the reservoir to evaluate the source of the trace-element enrichment in the reservoir. Although mining has occurred upstream from Deer Creek Reservoir, no streambed-sediment data were collected in the drainage basin upstream from the reservoir. There has been no mining upstream from Mirror Lake and because of its remote location, the data were used to evaluate possible atmospheric deposition. As part of the NAWQA program to evaluate historical trends in contaminant accumulation, sediment cores from Farmington Bay, Decker Lake, and Red Butte Reservoir were collected during 1998. These sites are within Salt Lake Valley, which is the most highly urbanized area within the GRSL study unit (fig. 3).

Figure 3. Location of sites where bed-sediment cores were collected for (1) trend analysis during 1998 as part of the National Water-Quality Assessment program, Great Salt Lake Basins study unit, and (2) by Kada and others (1994) to determine chronology of anthropogenic input of trace elements to lakes and reservoirs.

Mirror Lake

Mirror Lake is remotely located in the Uinta Mountains, about 50 mi east of Salt Lake City, Utah. Sediment cores from this lake were collected in 1982 and analyzed by Kada and others (1994). The surface sediments of cores collected were enriched in arsenic (As), Cd, Cu, Pb, tin (Sn), and Zn relative to the deeper sediments (fig. 4). A sediment-deposition chronology was developed from age dating results obtained from cesium-137 and lead-210 isotopes. Age dating indicates that the trace-element concentrations first began to increase in 1870, with substantial increases occurring after 1900. Because of the remote location of Mirror Lake, Kada and others (1994) attributed the increase in trace-element concentrations over time to atmospheric deposition from anthropogenic sources. Large-scale mining and smelting of nonferrous metal ores began in the region after 1868, which would have contributed trace elements to the atmosphere. Industrial and energy related sources in the Salt Lake City area also would have contributed trace elements to the atmosphere because of the growth of these industries after 1900. These dates coincide with increases in trace-element concentrations in the sediment cores.

Echo Reservoir is located on the Weber River downstream from the Park City mining complex, a large historic mining area (Boutwell, 1912). Kada and others (1994) collected sediment cores from the reservoir and observed that sediment profiles of Sb, As, Cd, Cu, Pb, titanium (Ti), and Zn for Echo Reservoir were quite similar to one another with peak inputs occurring during 1950-51 (fig. 5). Sediment transport is typically greatest during periods of high runoff, and flows in many Utah streams were near historic highs during 1950. Although relatively greater sediment transport may have been a contributing factor to the peak trace-metal concentrations measured in the sediments of Echo Reservoir during 1950-51, greater sediment accumulation is not reflected in the cores. Record high flows occurred again during 1983-84, but because the latest date the core represented was 1982, no effects from the high flows were present.

Kada and others (1994) suggested that because both the timing and the intensity of trace-element deposition in Echo Reservoir cores differ substantially from Mirror Lake cores, the profiles do not reflect regional atmospheric inputs of anthropogenic trace elements, but instead record trace-element inputs to the reservoir originating from a local source. They further surmised that the synchronicity in deposition of the different elements in Echo Reservoir indicates that the enriched sediments originated from a single source whose relative elemental abundance ratio remained uniform over time. The sediments near the core tops, which had lower concentrations of trace elements relative to deeper sediments, were still considerably enriched in some elements relative to their abundances in typical crustal rock types (Salomons and Forstner, 1984). Analysis of a sediment sample from the 24- to 25-in. depth interval indicated that Pb, Zn, Cu, and Sn were highly enriched on discrete sulfur-rich sediment grains scattered throughout the sediment matrix. They surmised that those observations are consistent with the presence of sulphide-type ore minerals, and thus the trace-element deposition chronologies for this core probably reflect the history of wash-in ore minerals into Echo Reservoir from one of the now inactive mining or mineral processing sites of the Park City mining complex.

Farmington Bay, Red Butte Reservoir, and Decker Lake

Sediment cores were collected by the U.S. Geological Survey from Farmington Bay (of Great Salt Lake), Red Butte Reservoir, and Decker Lake as part of the NAWQA study during April 1998. Each of the three selected coring sites is within Salt Lake Valley and represents a different set of physical and chemical characteristics in its respective watershed. Farmington Bay is at the mouth of the Jordan River. The Jordan River originates at Utah Lake and flows about 35 mi north, draining the urban Salt Lake Valley before discharging into Farmington Bay, and its drainage basin covers about 3,490 mi^2. Historical sources of contamination to the Jordan River include irrigation return flows, waste discharge from industrial and mining facilities, and urban runoff (Stephens, 1984). Decker Lake is located in the Salt Lake City metropolitan area. It is a small urban pond (0.05-mi^2 maximum surface area) that receives runoff from about 10 mi^2 of urban lands and discharge from four irrigation canals. Outflow from Decker Lake is discharged to the Jordan River. The drainage basin of Red Butte Creek is in the northeastern corner of Salt Lake Valley and is adjacent to the metropolitan area of Salt Lake City. The upper drainage basin of Red Butte Creek is a nonurban, forested area that has been protected from development. The effects of trace elements in sediments in this drainage would be primarily from atmospheric deposition.

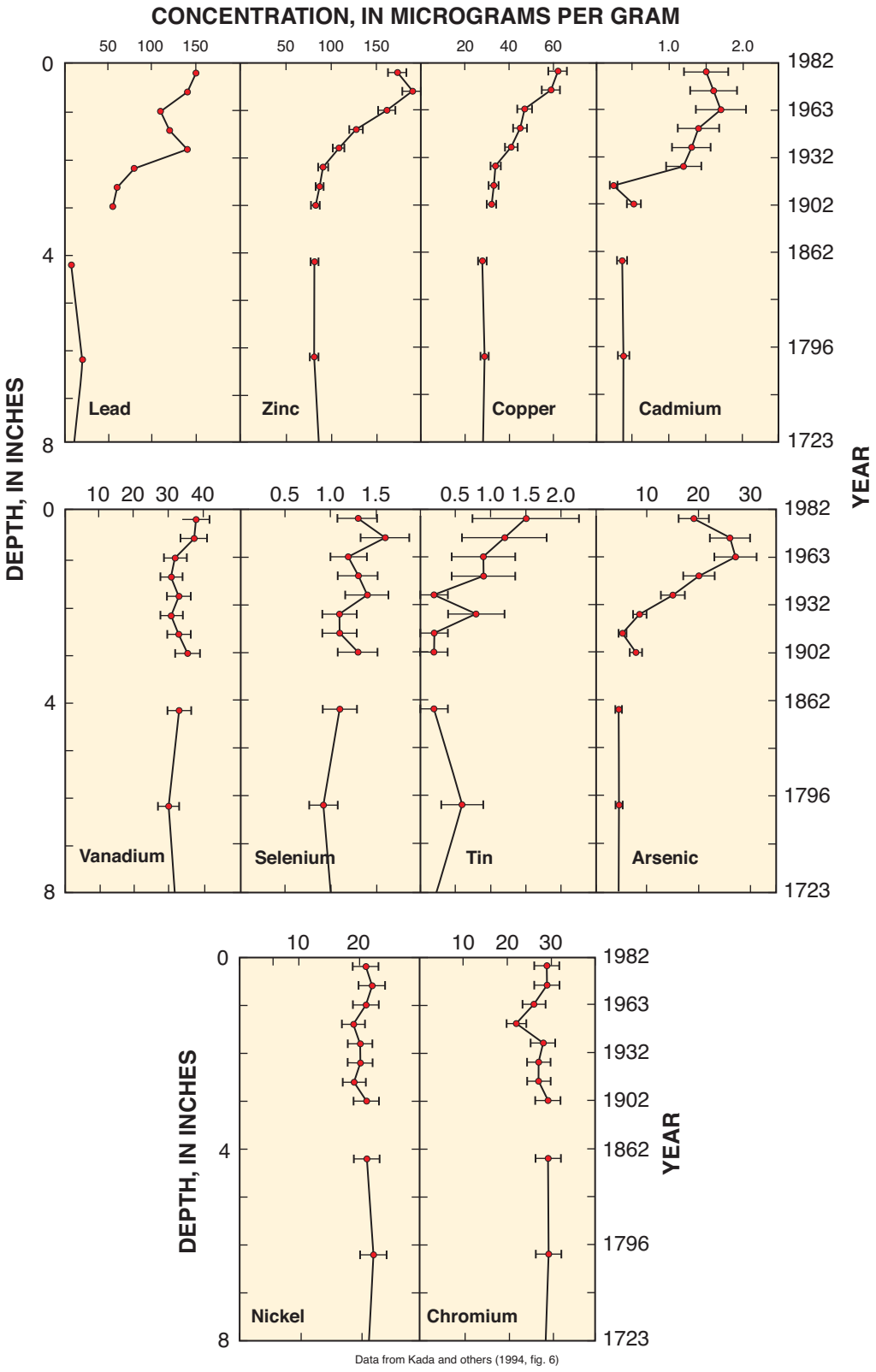


Figure 4. Selected trace-element concentration with depth and date of deposition for sediment cores from Mirror Lake, Utah.

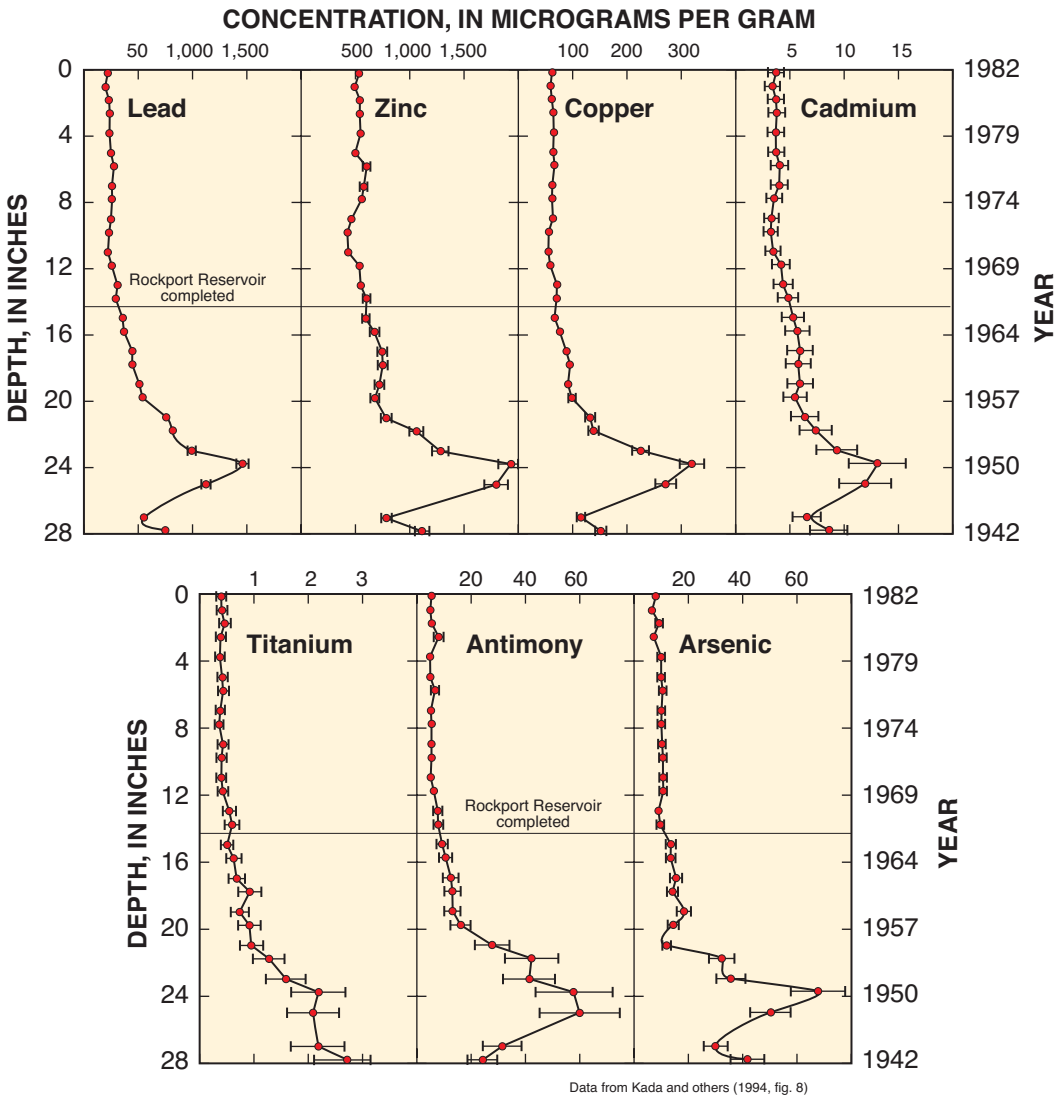


Figure 5. Selected trace-element concentration with depth and date of deposition for sediment cores from Echo Reservoir, Utah.

Sediment cores collected from Farmington Bay, Red Butte Reservoir, and Decker Lake were evaluated by Naftz and others (2000) to establish the environmental health of the respective drainages.

Naftz and others (2000) determined that sediments deposited in Red Butte Reservoir are strongly influenced by natural bedrock weathering and that weathering is less important in Decker Lake and Farmington Bay. The watershed above Red Butte Creek is protected from development. In contrast, the Farmington Bay and Decker Lake coring sites show a lesser influence from natural bedrock weathering in the shallower sediments of the cores, probably because of the urban and industrial influence as well as residual tailings from prior mining and smelter activities.

Naftz and others (2000) noted that for each watershed, the more recently deposited sediment samples near the surface of each core have the largest amount of contamination compared with the deeper sections. This is consistent with the increase in urban development and industrial activities in the Jordan River watershed.

Age dating of a core collected from Farmington Bay in 1998 (using cesium-137 and lead-210 isotopes) indicated that it represented the period from about 1730 to 1998. From 1730 (the bottom of the core) until the early 1900s, uncontaminated sediments were deposited in Farmington Bay. The most highly contaminated sediments were deposited during 1979-98.

Unlike other contaminants, Pb shows a recent decline in concentration in the Farmington Bay core. Lead concentration began to increase after about 1842, increased the most from about 1916 to 1950, and peaked in the 1980s (fig. 6). This profile is similar to the profile of Pb for Mirror Lake, which ends in 1982 (fig. 4). Mining and smelter activities had declined considerably in Salt Lake Valley by the time the concentration started to decrease during the mid-1980s, which could indicate a time lag, small errors in dating of the core, and (or) another source for Pb. Recent declines in Pb concentration in sediments have been noted elsewhere and are generally attributed to reduced Pb emissions following passage of the Clean Air Act of 1970 (Callender and Van Metre, 1997). Recent sediments deposited during 1996-98 indicate a 41- to 62-percent reduction in Pb concentration since the peak in the mid-1980s; however, concentrations still remain more than twice the baseline concentration that occurred prior to about 1850.

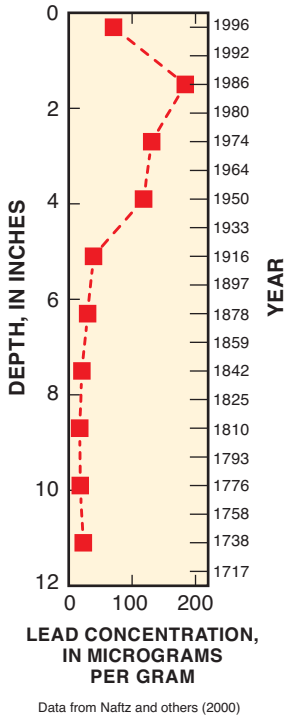


Figure 6. Lead concentration and estimated date of deposition for a sediment core collected from Farmington Bay, Utah, 1998.

Streambed Sediment

During 1998-99, 18 samples of streambed sediment were collected and analyzed by the USGS at 15 sites for trace elements (table 1). Forty-three trace elements were analyzed for and the method-reporting limit (table 3) for the 10 elements of concern was exceeded in every sample at all sites (table 6). For each site, the concentration of the 10 elements of concern is shown in figure 7.

Bear River Basin

In the Bear River Basin, bed sediment was sampled at sites 1, 2, and 5 on the Bear River and site 4, which is near the mouth of the Cub River, just above its confluence with the Bear River (fig. 1). The concentration of most of the elements of concern was among the lowest of all sites sampled in the Great Salt Lake Basins (table 6 and fig. 7). Some mining has occurred in the headwaters of the Bear River Basin but on a relatively small scale compared to the Weber and Utah Lake—Jordan River Basins. No bed-sediment samples

Table 6. Concentration of selected trace elements in streambed sediment from sites in the Great Salt Lake Basins study unit

[Concentration reported in micrograms per gram, dry weight]

Site number (see fig. 1)	Date	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Silver	Zinc
1	09-08-1998	6.3	0.44	58	19	17	0.03	21	0.4	0.78	73
2	08-12-1998	5.1	.56	54	17	13	.02	17	.45	.93	63
4	08-11-1998	6.1	.43	58	21	19	.02	22	.31	.71	83
5	08-07-1998	5.6	.42	52	18	15	.02	20	.32	.92	67
6	07-22-1999	4.8	.4	52	17	17	.03	16	.45	.28	57
7	07-22-1999	440	120	72	750	12,000	19	28	20	96	17,000
8	07-22-1999	110	35	59	190	2,900	6.8	17	2	26	4,700
9	07-22-1999	67	16	47	130	1,700	2.3	13	2	11	2,800
10	09-08-1998	58	15	50	116	1,730	2.8	17	1.2	9.0	2,880
11	08-06-1998	8.6	1.2	53	42	113	.21	19	.55	1.8	208
11	08-06-1998	8	1.2	49	37	100	.18	18	.50	.8	200
15	08-25-1998	51	7.2	58	246	588	.45	23	.91	2.4	963
16	08-04-1998	74	6.8	60	191	448	.33	23	1.2	2	801
17	08-03-1998	224	19	60	774	630	.34	22	2.5	2.1	822
18	08-10-1998	7.2	1.1	68	26	28	.02	27	1.5	.92	116
19	08-05-1998	20	2.9	55	122	205	.14	23	1.1	1.6	367
19	08-05-1998	19	2.8	60	120	200	.11	22	1.1	.9	360

were collected near the headwater areas of this basin, where the occurrence of metals may have been more likely, either from mining or natural occurrence. In the lower part of the drainage basin, Bear Lake and several power regulation reservoirs affect the sediment in the streams. Erosion has occurred from channel modification, stream-bank damage from fluctuating flows, and overgrazing of rangeland. Sediments eroded from the rangeland areas would tend to dilute any effects from metals that may have originated from the headwaters of the mountain block.

Utah Lake—Jordan River Basin

All sampling for trace metals in streambed sediment was done in the Jordan River part of the Utah Lake—Jordan River Basin. Land use in the Jordan River Basin, in Salt Lake Valley (fig. 1), is currently urban; but historically, mining and mine smelters, and agricultural land use, were extensive. Mining has occurred in both the Wasatch Range, on the east side of Salt Lake Valley, and in the Oquirrh Mountains, on the west side of the valley. Tailings and airborne ash from several mine smelters that were located in Salt Lake Valley have contaminated surrounding soils and remediation has been done at several sites. Historical mining activities have had such a large effect on trace-element concentration that effects from other land uses, such as urban and industrial development, have probably been masked.

Streambed sediment was sampled from five sites in the Jordan River Basin: sites 15 and 16 on Little Cottonwood Creek, sites 17 and 19 on the Jordan River, and site 18 on Red Butte Creek (fig. 1). Little Cottonwood Creek and Red Butte Creek are tributaries of the Jordan River. Red Butte Creek is in a protected watershed with no development and serves as a reference site for the urban area.

Sites 15 and 16 are located in Salt Lake Valley and bracket an urban reach of Little Cottonwood Creek (fig. 1). Sediments from sites 15 and 16 on Little Cottonwood Creek had considerably higher concentrations of As, Cd, Cu, Pb, Hg, Ag, and Zn than did the reference site 18 on Red Butte Creek (table 6 and fig. 7). Little Cottonwood Creek has been affected by historic mining in the headwaters and from smelters near site 16. Kimball and others (2001) reported that metal loading to surface water in the upper part of Little Cottonwood Creek is still occurring from past mining sites, especially for Zn. Except for As, the concentration of trace elements at site 16 is similar or even less than that at site 15, indicating that the contribution from the urban areas is negligible compared to the mining contribution in this stream. The concentration of As was higher at site 16 than at site 15 and probably a result of the presence of historic smelter activities near site 16.

Figure 7. Concentration of selected trace elements in streambed sediment from sites in the Great Salt Lake Basins study unit.

At site 17 on the Jordan River, the concentrations of As and Cu are elevated relative to all but site 7 on Silver Creek in the Great Salt Lake Basins study unit. At site 17 on the Jordan River, the concentrations of Pb, Hg, and Zn were near those of site 16 on Little Cottonwood Creek. This site is downstream from Little Cottonwood Creek and also receives urban runoff and waste-water treatment plant effluent. The concentrations of most trace elements measured at site 19 on the Jordan River are lower than those measured at site 17, probably because of the deposition of sediments containing a lower concentration of trace elements from tributaries in the intervening reach.

Weber River Basin

The Park City mining district was for years one of the most productive sources of Au-, Ag-, Pb-, Zn-, Cu-, and Cd-bearing ores in the State of Utah. Silver Creek drainage (fig. 8) is part of the Park City mining district and the creek has long been known as a significant source of trace elements to the Weber River. Silver Creek enters the Weber River about 2.5 mi downstream from Rockport Reservoir and 6 mi above Echo Reservoir. The effect of trace elements in sediments from Silver Creek on the Weber River was evaluated by analysis of streambed sediments collected from sites on the Weber River above and below the inflow of Silver Creek and from core data collected by Kada and others (1994) in Echo Reservoir. In addition, the primary source area of trace elements along Silver Creek was evaluated from data collected during a NAWQA synoptic study in 2000 (Giddings and others, 2001).

After Rockport Reservoir was completed in April 1966, most of the sediments from the upstream parts of the Weber River Basin would most likely have been deposited in the reservoir. The trend of trace-element concentrations in Echo Reservoir sediments (fig. 5) does not appear to have been affected by the completion of Rockport Reservoir in 1966. Because a large amount of sediment is deposited in a reservoir, the data indicate that drainage to the Weber River above Rockport Reservoir had very little effect on the enrichment of trace elements present downstream in Echo Reservoir (fig. 9). Thus, enrichment in Echo Reservoir as well as at sites on the Weber River below Silver Creek is primarily attributed to the inflow from Silver Creek.

Site 6 (fig. 8) is the farthest-upstream site that was sampled on the Weber River. The site is about 0.3 mi below Rockport Reservoir and above the inflow of Silver Creek and serves as a good reference to evaluate the effects of Silver Creek on the Weber River. Echo Reservoir, in which water was stored beginning in 1931, is about 6 mi below the inflow of Silver Creek. Sites 9 and 10 on the Weber River lie between the confluence with Silver Creek and Echo Reservoir. Chalk Creek, a tributary of the Weber River prior to construction of Echo Reservoir, directly enters Echo Reservoir. There has been very little mining activity in the drainage of Chalk Creek. Chalk Creek is believed to contribute a large amount of sediment to the reservoir, but the amount and chemical composition relative to that of the Weber River above Chalk Creek and the reservoir is unknown.

At sites 7 and 8 on Silver Creek and at sites 9 and 10 on the Weber River below the confluence with Silver Creek (fig. 9), the concentrations of As, Cd, Cu, Pb, Hg, Ag, and Zn in streambed sediment are enriched by the tailings and deposits from past mining activities in the upper part of the Silver Creek drainage (fig. 8). Concentrations of Cr, Ni, and Se in streambed sediments did not appear to be enriched downstream from areas affected by mining.

The highest trace-element concentrations in sediment occur at site 7 (fig. 9), which is the uppermost sampling site on Silver Creek. Trace-element concentrations decrease downstream along Silver Creek (site 8) and along the Weber River below the confluence with Silver Creek (sites 9 and 10) (fig. 9). Concentrations decrease downstream as a result of dilution by sediment from other sources that have lower concentrations of trace elements. During 2000, Giddings and others (2001) conducted a synoptic study to examine the occurrence and spatial distribution of trace metals in streambed sediment and surface water of streams near Park City, including sites on Silver Creek, and reported that several untreated and exposed tailings piles exist in the reach between sites 7 and 7b. The sites they sampled on Silver Creek included sites 7 and 8, which were sampled in 1999, as well as site 7a above and site 7b below site 7 (fig. 8). Even though Giddings and others (2001) used a weaker acid digestion than was used in the 1998 study, the relative concentrations provide some insight into the source of the sediments. They observed that at the farthest upstream site 7a, which is about 2 mi upstream from site 7, the concentration of most trace elements in the sediment was lower than at the downstream sites 7 and 7b. Thus, the major source of trace elements appears to be in the reach above site 7.

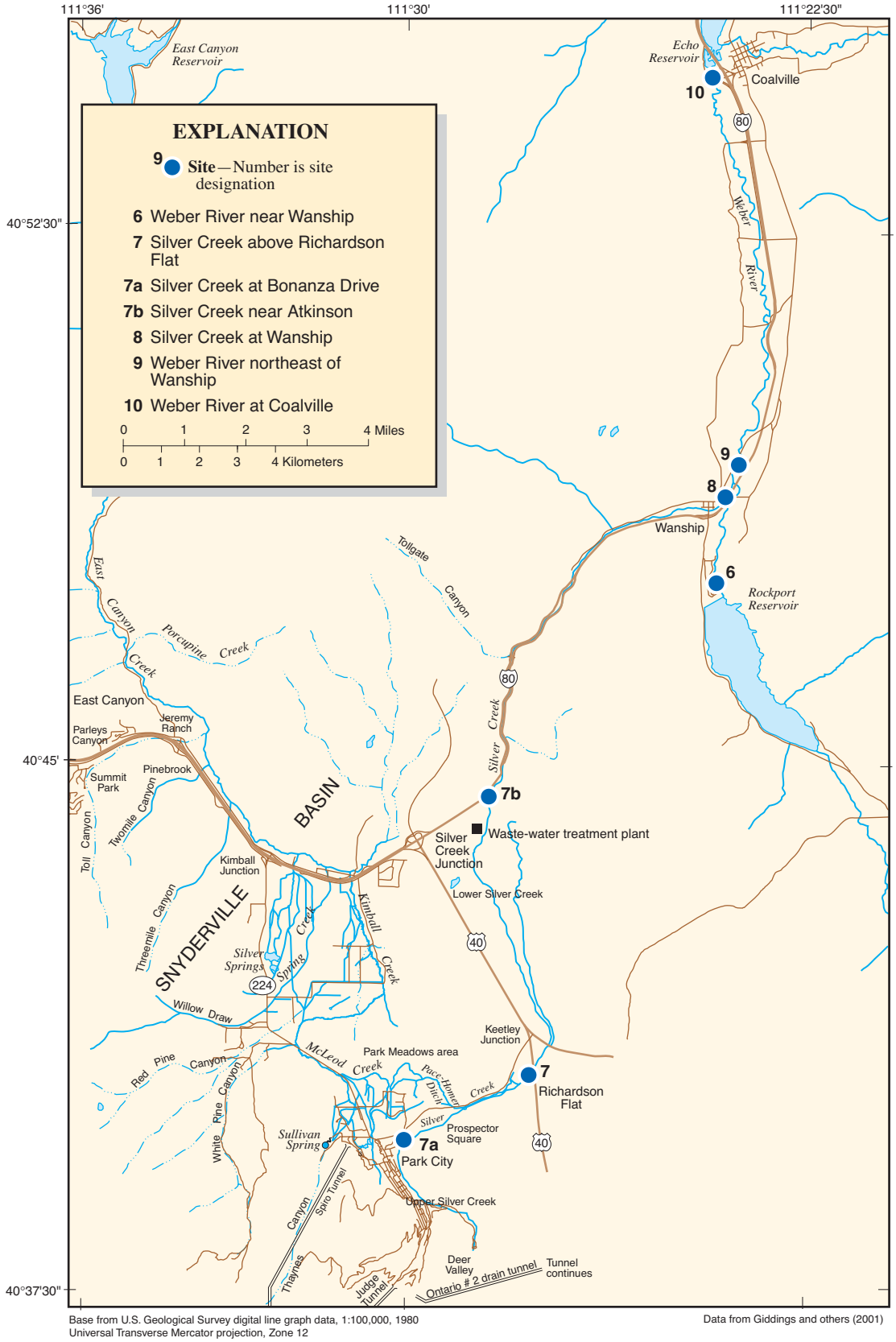


Figure 8. Location of sites where streambed sediment was collected in the upper Weber River Basin, Utah, 1998-2000.

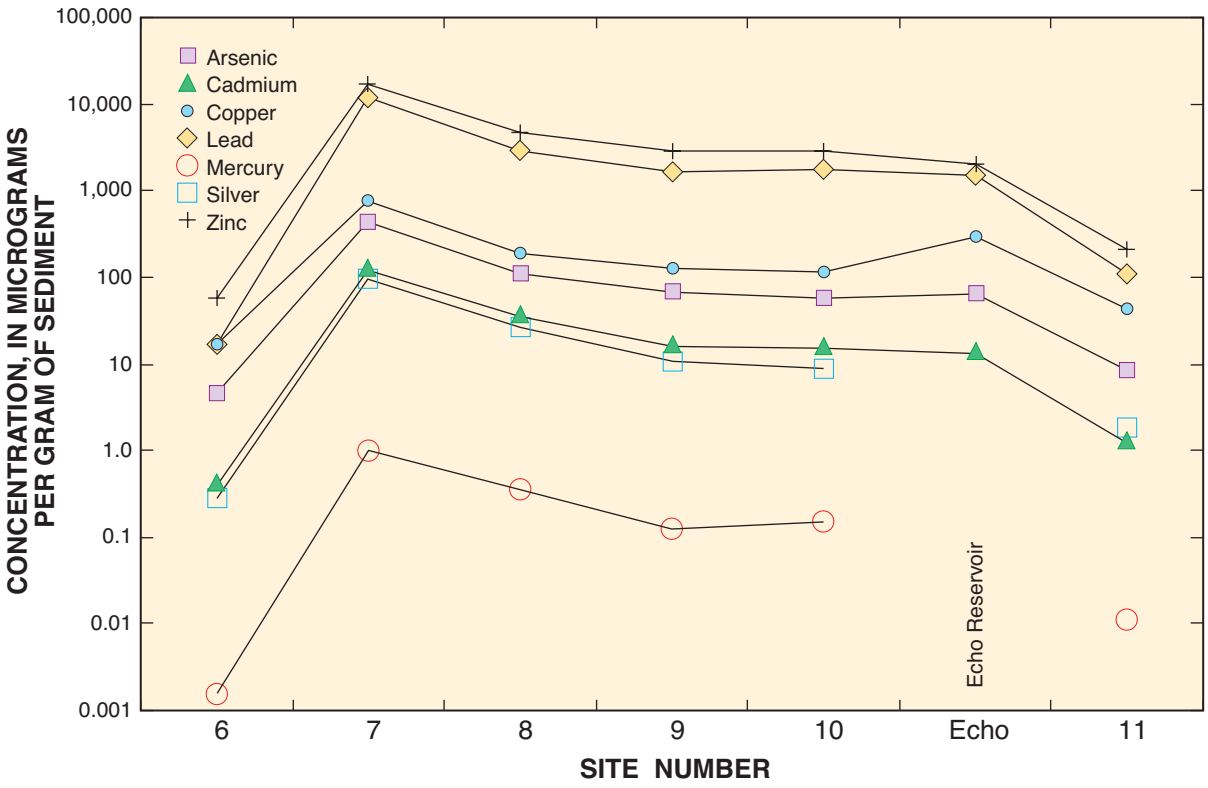


Figure 9. Concentration of selected trace elements in streambed sediment for sites on the Weber River and Silver Creek, 1998-2000, and in bed sediment from Echo Reservoir, Utah, 1952

By using the streambed-sediment data collected from Silver Creek during 1998-99 and the data from sediment cores collected from Echo Reservoir during the 1980s, ratios were computed for the trace-element concentrations at sites downstream of site 7 to site 7. Ratios were computed to show the similarity in dilution for each metal at each site (fig. 10). A ratio value of 1 indicates no dilution, whereas a ratio value of less than 1 indicates dilution. Concentrations for a section of the core from Echo Reservoir at a depth of about 2.5 in. (age dating indicates the sediments at that depth interval were deposited about 1952 (Kada and others, 1994) were used in figure 10 because the peak concentration of all the trace elements occurs in this section of the core. Similar ratios for trace elements at sites downstream of site 7 to that of site 7 are further indication that the source of sediments containing high concentrations of trace elements is the mining-affected Silver Creek drainage. The only exception was the ratio of Cu from the Echo Reservoir core, which may be a result of the addition of copper sulfate to the reservoir to control algae growth and (or) to another unknown Cu source.

Except for Cu, trace-element concentrations at site 11 near the mouth of the Weber River show very little enrichment related to mining activities. The concentrations of most of the metals at this site are similar to those at site 6 (fig. 9), which is on the Weber River above the inflow of Silver Creek. Also, the ratio of the metals at site 11 to that of site 7 on Silver Creek is near that of the ratio of site 6 to site 7 (fig. 10). This indicates that the metal-enriched sediments from Silver Creek are probably deposited in Echo Reservoir and that additional inflows of sediments from other tributaries downstream from Echo Reservoir are responsible for the trace-element concentrations at site 11. The ratio of Cu at the most downstream sampling site on the Weber River (site 11) is somewhat higher than the ratios for the other trace metals at site 11, which may indicate that some of the Cu observed in Echo Reservoir sediments is being transported downstream.

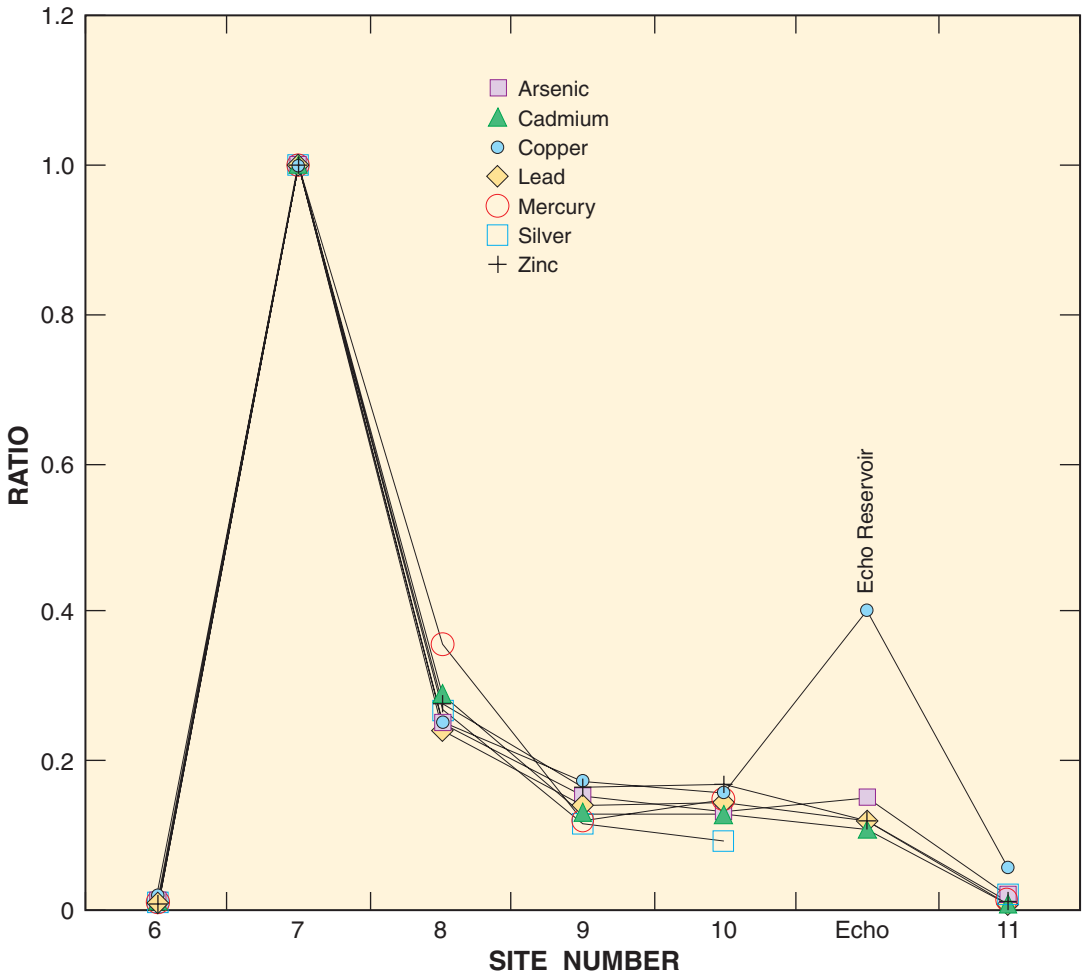


Figure 10. Ratio of trace-element concentrations in streambed sediment from sites on the Weber River, Silver Creek, and bed sediment from Echo Reservoir to the most upstream site on Silver Creek (site 7), Utah.

Comparison to Sediment-Quality Guidelines

MacDonald and others (2000) used the average concentration determined by independent investigators to establish the threshold effect concentration (TEC) and probable effect concentration (PEC) for 10 elements of concern (table 7). The TEC is the concentration in bulk sediment below which no adverse biological effect has been shown to occur, and the PEC is the concentration in bulk sediment above which adverse biological effects have been shown to occur. In table 7, the TEC and PEC for the 10 elements are shown along with concentrations occurring at sites in the GRSL study unit. The relation of the PECs to concentrations at sites in the GRSL study unit is shown in figure 11 by drainage basin.

In areas with very little mining, the PECs were not exceeded. Concentrations measured at sites 1, 2, 4, and 5 in the Bear River Basin, site 6 in the Weber River Basin above Silver Creek, and site 18 on Red Butte Creek did not exceed the PECs for any of the 10 elements. None of the concentrations measured at the 15 sites exceeded the PECs for Cr and Ni, and only the concentration measured at site 7 on Silver Creek exceeded the PEC for Se.

Table 7. Sediment-quality guidelines for adverse biological effects and comparison of guidelines for adverse biological effects with trace-element concentrations in streambed sediment for sites in the Great Salt Lake Basins study unit, 1998-99

[Concentrations in micrograms per gram dry weight; NLE, No threshold limit established]

Trace element	TEC[1]	PEC[2]	Site (fig. 1) with concentration	
			Greater than TEC but less than PEC	Greater than PEC[3]
Arsenic	9.79	33.0	19	7-10, 15-17
Cadmium	.99	4.98	11, 18, 19	7-10, 15-17
Chromium	43.4	111	All sites	No sites
Copper	31.6	149	9, 10, 11, 19	7, 8, 15-17
Lead	35.8	128	11	7-10, 15-17, 19
Mercury	.18	1.06	11, 15-17	7-10
Nickel	22.7	48.6	7, 15, 16, 18	No sites
Selenium	[4] 1	[4] 4	8-10, 16, 17, 18, 19	7
Silver	NLE	[5] 1.0		7-11, 15-17, 19
Zinc	121	459	11, 19	7-10, 15-17

[1] Threshold Effect Concentration represents the concentration in bulk sediment below which adverse biological effects have not been shown to occur, (MacDonald and others, 2000).

[2] Probable Effect Concentration represents the concentration in bulk sediment above which adverse biological effects are predicted to occur, (MacDonald and others, 2000).

[3] Sites are for the less than 63-micrometer fraction.

[4] From protocol for aquatic hazard assessment of selenium (Lemly, 1995).

[5] From Long and others, 1995.

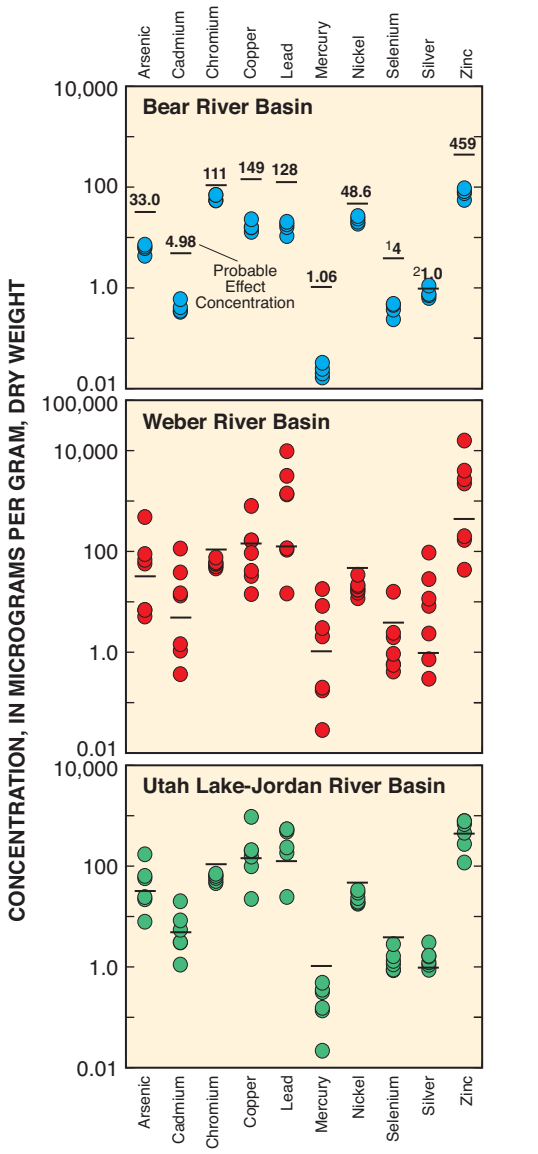
In areas with mining-related activities, concentrations of trace elements often exceeded the PECs. Concentrations measured at sites 7 and 8 on Silver Creek and sites 9 and 10 on the Weber River below the confluence with Silver Creek exceeded the PECs for As, Cd, Pb, Hg, Ag, and Zn. Concentrations measured at sites 15 and 16 on Little Cottonwood Creek and at site 17 on the Jordan River below the confluence with Little Cottonwood Creek exceeded the PECs for As, Cd, Cu, Pb, Ag, and Zn.

Fish Tissue

Fourteen samples of fish tissue collected from 12 sites were analyzed for trace elements. At the Cub River near Richmond (site 4), both trout and carp livers were collected. At the Bear River near Corinne (site 5), both whole-body carp and carp livers were collected. Twenty-two trace elements were analyzed for, and concentrations of 10 selected elements are shown in table 8 and figure 12. Analysis of tissue data is complicated by the fact that multiple species were collected and either the fish liver or the whole body was analyzed. Because different species may accumulate trace elements in differing ways depending on their physiology and feeding habits, direct comparison between species may not be appropriate (Crawford and Luoma, 1993). Relative concentrations measured at sites, however, can be compared. Also, livers may accumulate some trace elements at higher concentrations than muscle tissue (Crawford and Luoma, 1993), and thus, direct comparison of fish livers and whole-body-fish samples may not be appropriate.

Of the 10 selected elements, As, Cu, Zn, and Se were detected in every sample collected (table 8). Nickel also was detected at every site, but not in every sample. Lead and Ag had the most nondetects (6 each) of the 10 elements. Five samples were collected in which all of the 10 elements were detected. These samples were collected from four sites in an urban setting: site 11 on the Weber River at Ogden Bay, site 13 on the Jordan River at Utah Lake, site 16 on Little Cottonwood Creek at Jordan River, and site 19 on the Jordan River at Cudahy Lane, and one agricultural site: site 4 on the Cub River near Richmond. Carp livers were collected from four urban and two agricultural sites.

Trout livers also were collected from site 4 and can be compared with trout livers collected from reference site 18. Concentrations of Cu and Zn in the trout livers were elevated at site 4 compared with the reference condition, although the concentration of Se was similar to that measured in the sample collected at site 18, which indicates that site 4 has an additional source of metals that is causing higher concentrations of Cu and Zn there than at site 18.



[1] From protocol for aquatic hazard assessment of selenium (Lemly, 1995).
[2] From Long and others, 1995.

Figure 11. Concentration of selected trace elements in streambed sediment for sites in the Bear, Weber, and Utah Lake-Jordan River Basins, and relation to probable effect concentration.

Sites 15 and 16 on Little Cottonwood Creek were affected by both urban and historical mining land uses. Sucker livers collected from these sites contained higher concentrations of Pb and As than those collected at sites affected by urban land uses alone. Collection of whole-body sculpin from another site affected by mining (site 10) also had higher concentrations of Pb and As than did sculpin collected from rangeland site 2 and redside shiner collected from rangeland site 1. This evidence indicates that sites in basins affected by mining may have tissue concentrations higher in Pb and As than sites with other land uses.

Comparison of whole body and liver concentrations in carp at site 5 was made. Concentrations of Cr and Hg were higher in carp liver, and concentrations of Cu and Zn were higher in whole-body samples of carp tissue. Other elements had similar concentrations.

Comparison of Trace-Element Concentration in Streambed Sediment and in Fish Tissue

Arsenic, Cr, Pb, and Ni concentrations were higher in streambed sediment than in fish tissue at all sample sites (figs. 7 and 12). Correlation of most trace-element concentrations in streambed sediment and those in fish-liver tissue was not significant ($r<0.5$, $p>0.05$); however, correlation between Pb concentration in bed sediment and fish tissue was significant ($r=0.95$, $p<0.05$).

Comparison with Other National Water-Quality Assessment Program Study Units

Concentrations of trace elements in sediment and fish tissue for the Great Salt Lake Basins were compared with a national dataset compiled from samples collected for 48 other NAWQA study units during 1993-2000. Median and 90th-percentile concentrations were calculated from the national dataset for each element in the sediment (n=1,524 to 1,560) and in five groups of organisms representing comparable species: carp livers (n=151), sucker livers (n=168), trout and whitefish livers (n=46), whole-body carp (n=16), and whole-body sculpin (n=57). Calculated concentrations include only those samples with measured concentration above the detection limit (table 9).

Nine of 15 streambed-sediment samples and 11 of 14 fish-tissue samples in the GRSL study unit exceeded the 90th percentile of detected concentrations in the national dataset for at least 1 element (fig. 13). In addition, for 9 of 15 sediment samples and for 10 of 14 fish-tissue samples, 50 percent or more of the 10 selected elements exceeded the national median detected concentration for those elements (table 9). From this information, it appears that sites sampled in the GRSL study unit generally have higher trace-element concentrations than sites sampled in other study units. In the GRSL, most of the sites sampled were affected by mining, which would be expected to elevate

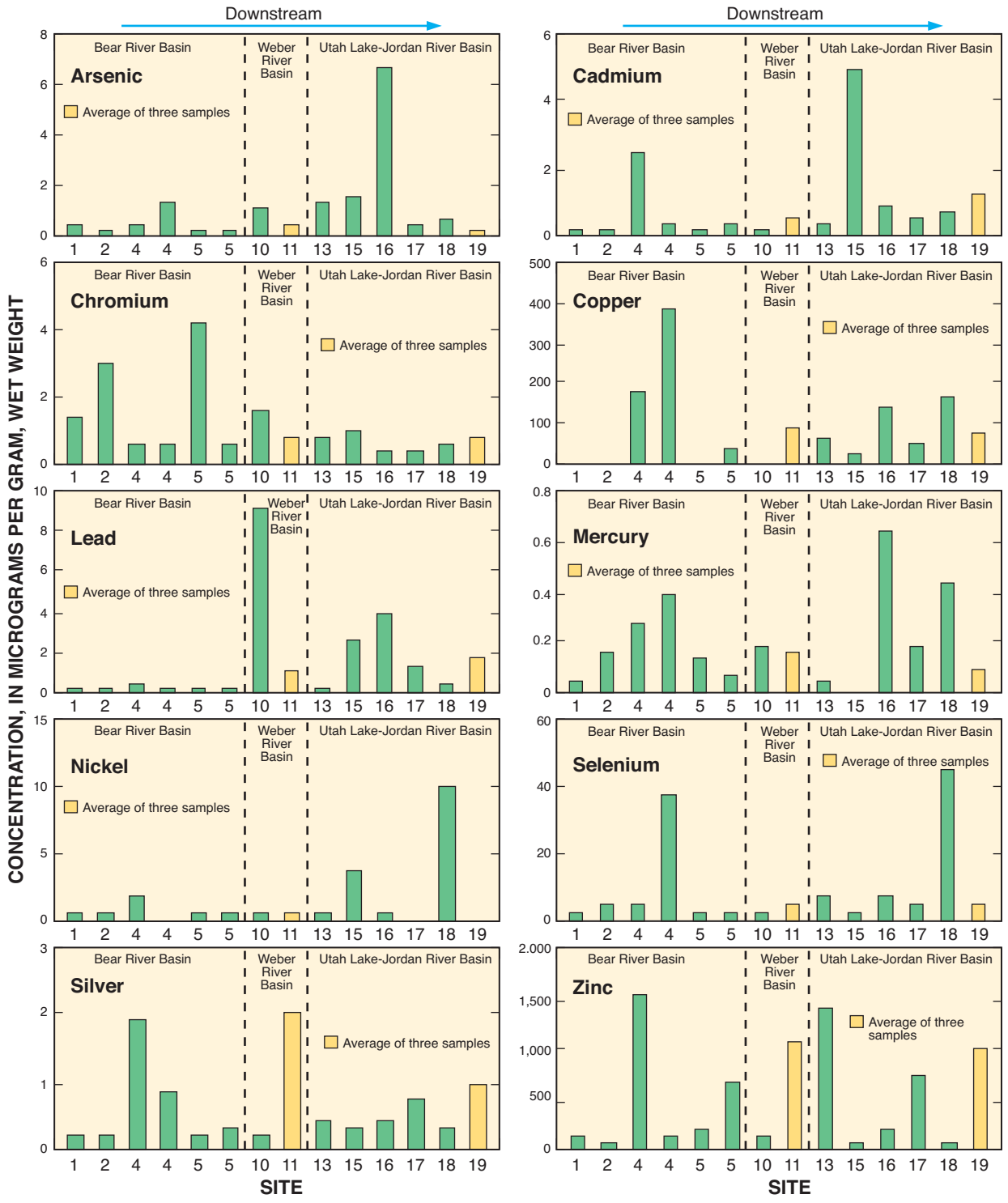


Figure 12. Concentration of selected trace elements in fish-tissue samples (livers and whole body) collected from streams in the Great Salt Lake Basins study unit.

Table 8. Concentration of trace elements in fish-tissue samples collected from streams in the Great Salt Lake Basins study unit

[Concentration reported in micrograms per gram, dry weight; nd, less than the method reporting limit (table 3)]

Site number	Species	Stream	Sample type	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Silver	Zinc
1	Redside shiner	Bear River	Whole body	0.36	nd	1.3	2.4	nd	0.04	0.41	2	nd	120
2	Sculpin	Bear River	Whole body	.31	nd	2.9	1.4	nd	.15	.56	5.1	nd	77
4	Carp	Cub River	Liver	.37	2.4	.61	180	.36	.27	1.6	6.1	2	1,530
4	Trout	Cub River	Liver	1.3	.29	.68	390	nd	.39	nd	38	.84	121
5	Carp	Bear River	Liver	.33	nd	4.1	2.1	nd	.14	.36	4.5	nd	179
5	Carp	Bear River	Whole body	.23	.42	.70	39	nd	.06	.37	2.1	.28	696
10	Sculpin	Weber River	Whole body	1.2	nd	1.5	2.9	9.1	.19	.40	2.8	nd	112
[1]11	Carp	Weber River	Liver	.35	.52	.83	95	1.0	.15	.44	5.4	2.0	1,090
13	Carp	Jordan River	Liver	1.4	.39	.78	69	.27	.05	.54	8.6	.46	1,380
15	Sucker	Little Cottonwood Creek	Liver	1.5	5.0	1.0	22	2.6	nd	4.0	2.5	nd	84
16	Sucker	Little Cottonwood Creek	Liver	6.8	.89	.50	140	3.9	.65	.41	8.1	.42	226
17	Carp	Jordan River	Liver	.43	.52	nd	49	1.3	.19	.28	4.7	.71	754
18	Trout	Red Butte Creek	Liver	.70	.78	.57	170	nd	.44	9.8	44	nd	82
[1]19	Carp	Jordan River	Liver	.29	1.2	.75	81	1.7	.10	.20	6.4	.99	1,000

[1] Average concentration for three samples.

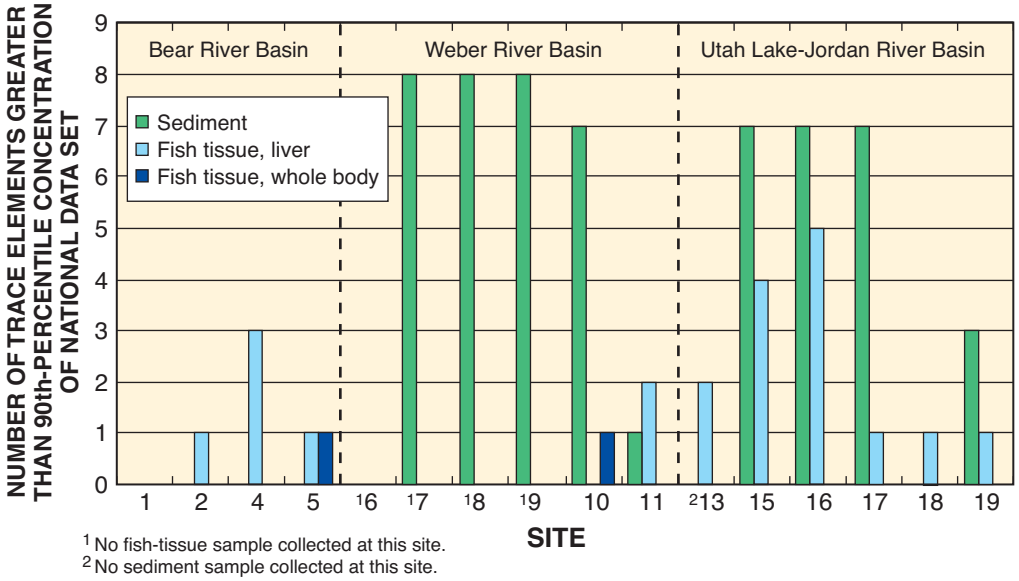


Figure 13. Trace-element concentration detected in streambed sediment and fish tissue in the Great Salt Lake Basins study unit dataset that exceeded the 90th-percentile concentration of the National Water-Quality Assessment program national dataset.

trace-element concentrations. The national dataset includes sites from all land uses, including reference sites, where concentrations were detected.

The GRSL dataset consists of 10 trace elements detected at selected sites in the GRSL study unit. The national dataset consists of selected samples from 48 NAWQA program study units, collected during 1993-2000.

Red Butte Creek in the Jordan River Basin (site 18, fig. 1), a reference site for GRSL streams, had sediment concentrations greater than the national median for four elements (Cd, Cr, Se, and Ag). Trout livers collected from Red Butte Creek exceeded the national 90th-percentile concentration for Ni and exceeded the national median concentrations for As, Cd, Hg, Ni, and Se. These results could indicate that background concentration in the GRSL study unit is higher than it is in other areas of the country. Follow-up sampling done by the U.S. Fish and Wildlife Service in cooperation with the USGS at Red Butte Creek examined trace-element concentrations in water, sediments, macroinvertebrates, aquatic plants, and additional fish-tissue samples, and compared the results with guidelines for aquatic health. This sampling effort indicated that trace elements do not pose a threat to aquatic life in the creek or downstream reservoir, where two threatened and endangered fish species exist (Nathan Darnall, U.S. Fish and Wildlife Service, written commun., 2001).

The sites with the highest concentrations of trace elements were located on Little Cottonwood Creek (Utah Lake—Jordan River Basin, sites 15 and 16), Silver Creek (Weber River Basin, sites 7 and 8), and the Weber River below the Silver Creek confluence (sites 9 and 10). All of these streams are affected by historical mining operations. In Little Cottonwood Creek, the concentration of 7 of 10 trace elements in sediment was greater than the detected national 90th-percentile concentration (As, Cd, Cu, Pb, Hg, Ag, and Zn). In fish tissue, the concentration of 7 of the 10 elements exceeded the national 90th-percentile concentration (As and Pb at sites 15 and 16; Cd and Ni at site 15; Cu, Hg, and Zn at site 16). Arsenic concentration, in particular, is substantially elevated above the national 90th-percentile concentration and is also a concern in Little Cottonwood Creek (Gerner and Waddell, 2003). In Silver Creek and the Weber River, the concentration of the same seven elements (As, Cd, Cu, Pb, Hg, Ag, and Zn) in sediment exceeded the national 90th-percentile concentration at sites 7 to 10 as in Little Cottonwood Creek. In addition, Se concentration exceeded the national 90th-percentile concentration at sites 7 to 9. Fish-tissue samples were collected only at one of these sites (site 10), and the concentration of Pb was elevated above the national 90th-percentile concentration.

The Bear River Basin is mostly agricultural and rangeland and has little mining influence. Trace-element concentrations in this basin were low compared to those of the national dataset. Only the concentration of Ag at sites 1, 2, 4, and 5 and Cd at site 2 were greater than the national median detected concentration in sediment. No samples of sediment exceeded the national 90th-percentile concentration for any element. In fish tissue, the concentration of several elements exceeded the national median concentrations, but only Cr and Zn consistently measured higher, exceeding the national 90th percentile in two of the five samples from this basin.

ORGANIC COMPOUNDS

The occurrence and distribution of two groups of hydrophobic compounds are assessed in the NAWQA program; organochlorine compounds and semivolatile-organic compounds (SVOCs). These compounds are known to accumulate in lipid tissues (Hebert and Keenleyside, 1995). Organochlorine compounds, which include pesticides and polychlorinated biphenyls (PCBs), have been widely used in the United States since World War II for industrial and agricultural purposes and to control disease-carrying insects (Harte and others, 1991). The organochlorine insecticides and metabolites, and total PCBs analyzed in the bed-sediment and fish-tissue samples are manmade organic compounds. Many pesticides, especially organochlorines, have been banned from use in the United States since the late 1970s when they were discovered to have adverse effects on humans, wildlife, and habitat (Nowell and others, 1999). Organochlorines share common characteristics, such as environmental persistence, stability, and toxicity (Nadakavukaren, 1995). With its discovery in 1939, DDT was used as an agricultural insecticide and pesticide. It was banned from general use in the United States, however, in 1972, when it was observed to accumulate in wildlife, causing substantial decline in numbers and detrimental effects in many species (Ware, 1994). In an aquatic environment, it adsorbs strongly to the sediment, bioaccumulates and biomagnifies in fish, and does not readily biodegrade in water (Long and others, 2000).

Table 9. Median and 90th-percentile concentration of trace elements in streambed-sediment and fish-tissue samples collected in the Great Salt Lake Basins and 48 National Water-Quality Assessment study units, 1993-2000

[Streambed-sediment and fish-tissue concentration reported in micrograms per gram, dry weight; GRSL, Great Salt Lake Basins study unit; nd, less than the method reporting limit (table 3)]

Data group	Number of national samples / number of GRSL samples	Arsenic	Cadmium	Chromium	Copper	Lead
Streambed Sediment	1,524-1,560 / 15					
National median		7.50	0.50	65	29	28
National 90th percentile		20	2	120	90	120
Percent national sites with detections		99	96	100	100	100
Number of GRSL sites greater than national median		9	11	2	9	9
Number of GRSL sites greater than national 90th percentile		7	8	0	8	8
Carp liver	151 / 6					
National median		.41	3.8	.60	90	.38
National 90th percentile		1.0	17	1.0	160	.94
Percent national sites with detections		88	98	36	100	55
Number of GRSL sites greater than national median		2	0	5	2	3
Number of GRSL sites greater than national 90th percentile		1	0	1	1	3
Sucker liver	168 / 2					
National median		.50	.80	.67	46	.30
National 90th percentile		1.3	3.8	1.1	100	2.5
Percent national sites with detections		58	71	65	95	20
Number of GRSL sites greater than national median		2	2	1	1	2
Number of GRSL sites greater than national 90th percentile		2	1	0	1	2
Trout liver	46 / 2					
National median		.60	.70	.69	230	2.1
National 90th percentile		1.4	16	.91	450	12
Percent national sites with detections		63	59	87	98	13
Number of GRSL sites greater than national median		2	1	0	1	0
Number of GRSL sites greater than national 90th percentile		0	0	0	0	0
Whole-body carp	16 / 1					
National median		.22	.48	.73	2.1	.20
National 90th percentile		.48	2.0	2.6	82	.32
Percent national sites with detections		88	75	81	100	38
Number of GRSL sites greater than national median		1	0	0	1	0
Number of GRSL sites greater than national 90th percentile		0	0	0	0	0
Whole-body sculpin	57 / 2					
National median		.53	.30	1.7	2.6	.70
National 90th percentile		1.2	.42	2.8	4.4	1.3
Percent national sites with detections		86	12	98	100	33
Number of GRSL sites greater than national median		1	0	1	1	1
Number of GRSL sites greater than national 90th percentile		0	0	1	0	1

Table 9. Median and 90th-percentile concentration of trace elements in streambed-sediment and fish-tissue samples collected in the Great Salt Lake Basins and 48 National Water-Quality Assessment study units, 1993-2000—Continued

Data Group	Mercury	Nickel	Selenium	Silver	Zinc
Streambed Sediment					
National median	0.070	29	0.70	0.20	120
National 90th percentile	.32	62	1.7	1.3	380
Percent national sites with detections	92	100	100	92	100
Number of GRSL sites greater than national median	9	0	9	15	9
Number of GRSL sites greater than national 90th percentile	7	0	4	8	7
Carp liver					
National median	.24	.38	5.9	.60	675
National 90th percentile	.67	1.9	10	1.6	1,210
Percent national sites with detections	91	39	100	93	100
Number of GRSL sites greater than national median	1	3	3	4	5
Number of GRSL sites greater than national 90th percentile	0	0	0	2	2
Sucker liver					
National median	.20	.50	4.4	.44	109
National 90th percentile	.54	2.3	8.5	1.2	177
Percent national sites with detections	67	46	94	57	95
Number of GRSL sites greater than national median	1	1	1	0	1
Number of GRSL sites greater than national 90th percentile	1	1	0	0	1
Trout liver					
National median	.21	.40	20	1.4	98
National 90th percentile	.60	3.0	51	3.6	130
Percent national sites with detections	74	20	91	74	98
Number of GRSL sites greater than national median	2	0	2	0	0
Number of GRSL sites greater than national 90th percentile	0	0	0	0	0
Whole-body carp					
National median	.67	.45	1.7	1.1	233
National 90th percentile	1.2	.60	4.1	2.0	382
Percent national sites with detections	94	69	94	38	100
Number of GRSL sites greater than national median	0	0	1	0	1
Number of GRSL sites greater than national 90th percentile	0	0	0	0	1
Whole-body sculpin					
National median	.16	1.2	2.8	nd	76
National 90th percentile	.42	3.2	5.5	nd	133
Percent national sites with detections	82	100	81	0	100
Number of GRSL sites greater than national median	1	0	2	0	2
Number of GRSL sites greater than national 90th percentile	0	0	0	0	0

PCBs are produced synthetically and tend to be chemically stable and inert. They have been shown to bioaccumulate in aquatic organisms and other animals (Ware, 1994; New York State Department of Environmental Conservation, 1985) and to cause many serious health effects (Nadakavukaren, 1995).

SVOCs consist of a variety of classes of compounds. The three classes most commonly detected in the Great Salt Lake Basins study unit were polycyclic aromatic compounds (PAHs), phthalates, and phenols. PAHs are a class of organic compounds that are combustion products from sources such as automobiles, airplanes, and fires. Some PAHs can be toxic at elevated

concentrations. PAHs represent the largest class of suspected carcinogens (Bjorseth and Ramdahl, 1985) and can present a threat to aquatic life (Long and Morgan, 1991). As a part of the USGS NAWQA reconstructed-trends program, trends in PAHs were tracked over the last several decades until the mid- to late 1990s in sediment cores from 10 lakes and reservoirs in 6 U.S. metropolitan areas (Van Metre and others, 2000). The study indicated that PAH concentrations during the last three decades are increasing and that the increase may be linked to the increasing amount of urban sprawl and associated vehicular traffic. Phthalates are aromatic esters widely used as solvents, plasticizers, and insect repellents (Budavari and others, 1989). Some of the phthalates are environmentally persistent and have become widespread contaminants (Manahan, 1992). Phenols are aromatic alcohols from vehicle exhaust and refined petroleum products and can be absorbed through the skin (Manahan, 1992).

Farmington Bay Core

Naftz and others (2000) reported that total PAHs in bed-sediment cores from Farmington Bay consistently increased from near 0 µg/kg in sediment deposited before 1940 to more than 2,000 µg/kg in several sediment layers deposited after the early to mid-1980s (fig. 14). They also noted a positive correlation between population growth in Salt Lake County and PAH concentration measured in lake sediment from Farmington Bay. This correlation indicates that the likely sources of PAHs in lake sediment deposited after 1940 are probably derived from human-induced combustion products. The highest concentrations of total DDTs, PCBs, and chlordane also were measured in the near-surface sediment of the Farmington Bay core. Nationally, total DDT concentrations generally followed the historical use of DDT in the United States, which peaked from the 1950s to the mid-1970s and then declined substantially, whereas in Farmington Bay the concentration was still increasing in the mid-1990s. Similarly, total PCB concentration increased in Farmington Bay as well as nationally between 1950 and 1965, coinciding with the peak production. In Farmington Bay, however, the concentration has not declined as it has nationally. Chlordane concentration began increasing substantially after 1950 and was still increasing in 1995 even though it was banned from general use in the 1970s. The reason for the continued trend of increasing concentration of total DDTs, PCBs, and chlordane in the Farmington Bay core is unknown.

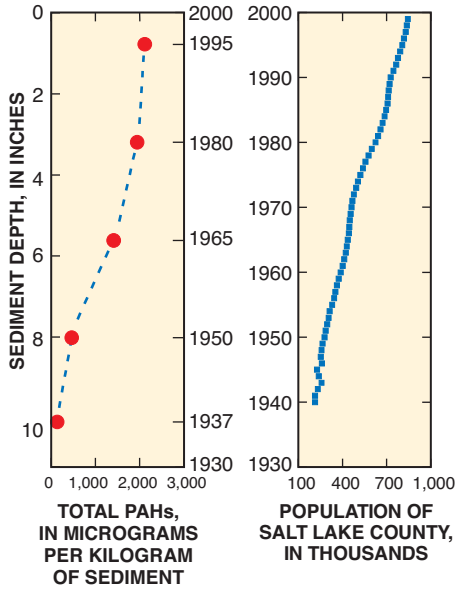


Figure 14. Vertical distribution of total polycyclic aromatic hydrocarbons (PAHs) in a gravity core from Farmington Bay, and relation to population growth in Salt Lake County, Utah.

Streambed Sediment

Samples for analysis of organic compounds in streambed sediments were collected at 15 sites. One hundred and fifteen organic compounds were analyzed for (table 2) and 24 were detected. Sites with one or more detections greater than the minimum reporting limit are shown in table A-1 in the appendix, and a summary of detections for more frequently detected organic compounds that can be toxic to the aquatic environment are shown in table 10.

PCB concentrations in sediment were greater than the minimum reporting limit only at site 11 on the Weber River and site 19 on the Jordan River, and in the near-surface sediments of the Farmington Bay core. Chlordane compounds were detected only at site 19 on the Jordan River, and in the near-surface sediments of the Farmington Bay core. DDT breakdown products were detected near the mouth of the Weber (site 11), Provo (site 12), and Jordan Rivers (sites 17 and 19)

Table 10. Concentration of selected organic compounds in streambed sediment for sites in the Great Salt Lake Basins study unit

[Concentration in micrograms per kilogram, dry weight; —, less than method reporting limit shown in table 2; E, estimated]

Site number (fig. 1)	Total PCBs (polychlorinated biphenyls)	Total PAHs (polycyclic aromatic hydrocarbons)	Total chlordane[1]	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	Total DDT[2]
1	—	—	—	—	—	—	—
2	—	58	—	—	—	—	—
3	—	E 49	—	—	—	—	—
4	—	73	—	—	—	—	—
5	—	—	—	—	—	—	—
10	—	61	—	—	—	—	—
11	74	278	—	E 1.5	E 2.5	—	E 4
12	—	647	—	—	E 1.5	—	E 1.5
13	—	E 32	—	—	—	—	—
14	—	E 14	—	—	—	—	—
15	—	151	—	—	—	—	—
16	—	136	—	—	—	—	—
17	—	1,093	—	E 4.5	E 3.3	—	7.8
18	—	E 18	—	—	—	—	—
19	72	1,630	6.1	E 4.9	8.2	—	13
Farmington Bay[3]	180	2,000	60	6	6	6	18

[1]Total chlordane is the sum of detected concentrations of cis-chlordane, trans-chlordane, cis-nonachlor, trans-nonachlor, and oxychlordane.
[2]Total DDTs is the sum of detected concentrations of p,p'-DDD, o,p'-DDD, p,p'-DDE, p,p'-DDT, and o,p'-DDT.
[3]Near-surface sediment sample.

and in the near-surface sediments of the Farmington Bay core.

The highest total PAH concentrations were detected in sediment of streams flowing through major urban areas of the Weber and Utah Lake—Jordan River Basins (fig. 15). At site 11, which is near the mouth of the Weber River, the total PAH concentration was 278 µg/kg of sediment. At site 12, which is at the mouth of the Provo River at Utah Lake, the concentration was 647 µg/kg of sediment. The Provo River crosses through the city of Provo and other suburban communities before entering Utah Lake. Industrial development lies along the lower reach of the Provo River above the lake. The Geneva smelter on the east side of Utah Lake has long been a substantial source of emissions to Utah Valley.

Sites 17 and 19 on the Jordan River had the highest total PAH concentrations of all streambed-sediment sites in the GRSL study unit. The total PAH concentration at site 17 was 1,093 µg/kg of sediment. Site 17 is about 35 mi below Utah Lake and 14 mi above the core site in Farmington Bay. The total PAH concentration at site 19 was 1,630 µg/kg of sediment. Site 19 is about 7 mi above the core site in Farmington Bay. Total PAH concentration in the near-surface sediment of the Farmington Bay core was about 2,000 µg/kg of sediment. The downstream increase of total PAH concentrations in the Utah Lake—Jordan River Basin is probably related to accumulation from increased exposure to industrial and urban emissions as the river traverses Salt Lake County.

Comparison of Organic-Compound Concentration to Sediment-Quality Guidelines

Samples from only four sites had concentrations of one or more organic compounds that exceeded the sediment-quality guidelines (table 11). At site 11, which is near the mouth of the Weber River, the TEC level for total PCBs was exceeded. All other exceedances of the TEC level occurred at sites 17 and 19 in the Jordan River and in the near-surface sediments of the Farmington Bay core. The organic compounds that frequently exceeded the TEC levels at these sites include total PCBs, total PAHs, total chlordane, dieldrin, and breakdown products of DDT. The PEC level

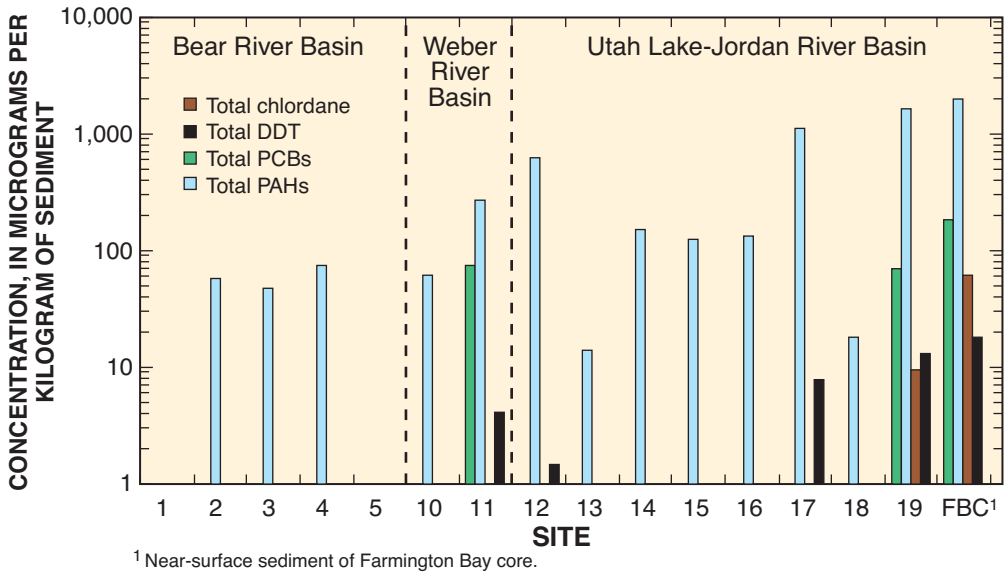


Figure 15. Total concentration of selected organic compounds in streambed sediment and near-surface sediment of Farmington Bay core, Great Salt Lake Basins study unit.

was exceeded only for chlordane and occurred in the near-surface sediments of the Farmington Bay core.

Fish Tissue

Fifteen samples at 15 sites were collected for analysis of 28 hydrophobic organic compounds in fish tissue and detections occurred at 13 sites. Whole fish were analyzed at each site, although several different species were collected (table 12). From zero to as many as eight compounds were detected at each site (table 12). A breakdown product of DDT, *p, p'*-DDE, was the most commonly detected compound, occurring at 13 sites. PCBs were detected in samples collected from eight sites, and chlordane-related compounds were detected in samples collected from four sites.

Samples collected from sites on the Jordan River and the Weber River at Ogden Bay contained the highest concentrations of detected organic compounds (table 12 and fig. 16). Samples collected from sites on the Bear River had very few detected organic compounds. Chlordane compounds were detected at the four most urban sites sampled: site 11 on the Weber River at Ogden Bay, site 16 on Little Cottonwood Creek at Jordan River, site 17 on the Jordan River at 1700 South, and site 19 on the Jordan River at Cudahy Lane. PCBs also were detected primarily at sites below drainages with significant urban land use in the basin. The only detection of PCBs in the Bear River basin was at site 4 on the Cub River, just upstream from the confluence with the Bear River. DDT compounds were detected at both urban and agricultural land-use sites, although concentrations were highest at urban sites.

Guidelines for the concentration of total DDT (DDD+DDE+DDT) in fish tissue were established by Newell and others (1987) to protect wildlife consumers of aquatic biota. DDT compounds were detected in fish tissue at 13 of 15 sampled sites. Tissue samples from two of these sites had total DDT concentrations that exceeded the guideline concentration of 200 µg/kg (table 12). PCBs were detected in samples from eight sites and exceeded the guideline of 110 µg/kg in four samples. Total chlordane was detected in tissue collected from four sites but did not exceed the guideline concentration of 500 µg/kg at any of the sites. These results indicate that wildlife that consumes aquatic biota from the Jordan River and other sites could be at risk for DDT and PCB contamination.

Table 11. Organic-compound concentration in streambed sediment and near-surface sediment of Farmington Bay core and sediment-quality guidelines for adverse biological effects, Great Salt Lake Basins study unit

[Concentration reported in micrograms per kilogram, dry weight; TEC, Threshold Effect Concentration; PEC, Probable Effect Concentration; FBC, Farmington Bay core]

Organic compound	TEC[1]	PEC[2]	Sites (fig. 1) with concentration	
			Greater than TEC	Greater than PEC
Polycyclic aromatic hydrocarbons (PAHs)				
Anthracene	57.2	845	19	
Fluorene	77.4	536		
Naphthalene	176	561		
Phenanthrene	204	1,170		
Benz[*a*]anthracene	108	1,050		
Benzo[*a*]pyrene	150	1,450		
Chrysene	166	1,290		
Dibenz[*a,h*]anthracene	33.0	2,230		
Fluoranthene	423	1,520		
Pyrene	195	1,520		
Total PAHs	1,610	22,800	19, FBC	
Polychlorinated biphenyls (PCBs)				
Total PCBs	59.8	676	11,19, FBC	
Organochlorine pesticides				
Total chlordane	3.24	17.6	19, FBC	FBC
Dieldrin	1.90	61.8	19, FBC	
Sum DDD	4.88	28.0	19, FBC	
Sum DDE	3.16	31.3	17,19, FBC	
Sum DDT	4.16	62.9	FBC	
Total DDT	5.28	572	17,19, FBC	
Endrin	2.22	207		
Heptachlor epoxide	2.47	16.0		
Lindane (*gamma*-BHC)	2.37	4.99		

[1] Threshold Effect Concentration represents the concentration in bulk sediment below which adverse biological effects have not been shown to occur (MacDonald and others, 2000).

[2] Probable Effect Concentration represents the concentration in bulk sediment above which adverse biological effects are predicted to occur, (MacDonald and others, 2000).

Comparison of Organic-Compound Concentration in Bed Sediment and Fish Tissue

Whole fish collected from 15 sites in the GRSL study unit were analyzed for 28 organochlorine compounds. Streambed sediment was analyzed for 27 of these 28 compounds at the same 15 sites. Twelve of the compounds were detected in fish tissue, and only 6 of the compounds were detected in sediment. All the compounds detected in sediment also were detected in fish tissue at each site, and those compounds detected in both media were present at a higher concentration in the fish tissue than in the sediment. These data illustrate the tendency for these compounds to accumulate in fatty tissue. Although use of DDT and production of PCBs were discontinued in the United States during the 1970s, these compounds or their breakdown products were detected in 1998 in whole-fish samples collected at 13 of 15 sites and 8 of 15 sites, respectively. PCBs were detected in streambed-sediment samples at only 2 of 15 sites and DDT compounds were detected at 4 of 15 sites.

Table 12. Concentration of selected organic compounds in whole-body fish tissue for sites in the Great Salt Lake Basins study unit

[Concentration reported in micrograms per kilogram, wet weight; PCB, polychlorinated biphenyls; HCB, hexachlorobenzene; —, less than method reporting limit; E, estimated value[1]]

Site number	Stream	Species	Percent lipids	PCB	HCB	Dieldrin	*cis*-Nonachlor	*trans*-Nonachlor	*trans*-Chlordane
1	Bear River	Redside shiner	7.4	—	—	—	—	—	—
2	Bear River	Sucker, Utah	6.6	—	—	—	—	—	—
3	Cub River	Carp	6.3	—	—	—	—	—	—
4	Cub River	Carp	4.2	300	—	—	—	—	—
5	Bear River	Carp	6.2	—	—	—	—	—	—
10	Weber River	Mountain whitefish	7.4	—	—	—	—	—	—
[2]11	Weber River	Carp	8.9	371	—	—	—	13	5.0
12	Provo River	Trout, rainbow	8.8	53	—	—	—	—	—
13	Jordan River	Carp	9.9	84	—	—	—	—	—
14	Jordan River	Carp	8.9	82	—	—	—	—	—
15	Little Cottonwood Creek	Sucker, white	5.7	—	—	—	—	—	—
16	Little Cottonwood Creek	Sucker, white	5.6	80	6.4	—	E 5.8	9.8	—
17	Jordan River	Carp	8.6	300	—	—	10	35	20
18	Red Butte Creek	Trout, cutthroat	5.2	—	—	—	—	—	—
[2]19	Jordan River	Carp	12.0	353	4.9	7.4	—	22	8.4
Method reporting limit				50	5	5	5	5	5

Site number	Stream	*cis*-Chlordane	Oxychlordane	Total chlordane[3]	*p,p'*-DDE	*p,p'*-DDD	*o,p'*-DDD	*p,p'*-DDT	Total DDT[4]	Number of detections
1	Bear River	—	—	—	6.9	—	—	—	6.9	1
2	Bear River	—	—	—	—	—	—	—	—	0
3	Cub River	—	—	—	15	—	—	—	15	1
4	Cub River	—	—	—	37	—	—	—	37	2
5	Bear River	—	—	—	24	—	—	—	24	1
10	Weber River	—	—	—	12	—	—	—	12	1
[2]11	Weber River	12	—	30	67	35	8.1	—	110	7
12	Provo River	—	—	—	49	—	—	—	49	2
13	Jordan River	—	—	—	85	7.1	—	—	92	3
14	Jordan River	—	—	—	300	12	—	—	310	3
15	Little Cottonwood Creek	—	—	—	6	—	—	—	6.0	1
16	Little Cottonwood Creek	5.8	—	21	91	—	—	E 13	104	7
17	Jordan River	20	13	98	290	E 22	—	—	312	7
18	Red Butte Creek	—	—	—	—	—	—	—	—	0
[2]19	Jordan River	24	—	55	70	18	—	—	88	8
Method reporting limit		5	5		5	5	5	5		

[1]Estimated values shown only if greater than minimum reporting limit.
[2]Average of three samples.
[3]Total chlordane is the sum of detected concentrations of *cis*-Chlordane, *trans*-Chlordane, *cis*-Nonachlor, *trans*-Nonachlor, and Oxychlordane.
[4]Total DDT is the sum of detected concentrations of *p,p'*-DDD, *o,p'*-DDD, *p,p'*-DDE, *o,p'*-DDE, *p,p'*-DDT, and *o,p'*-DDT.

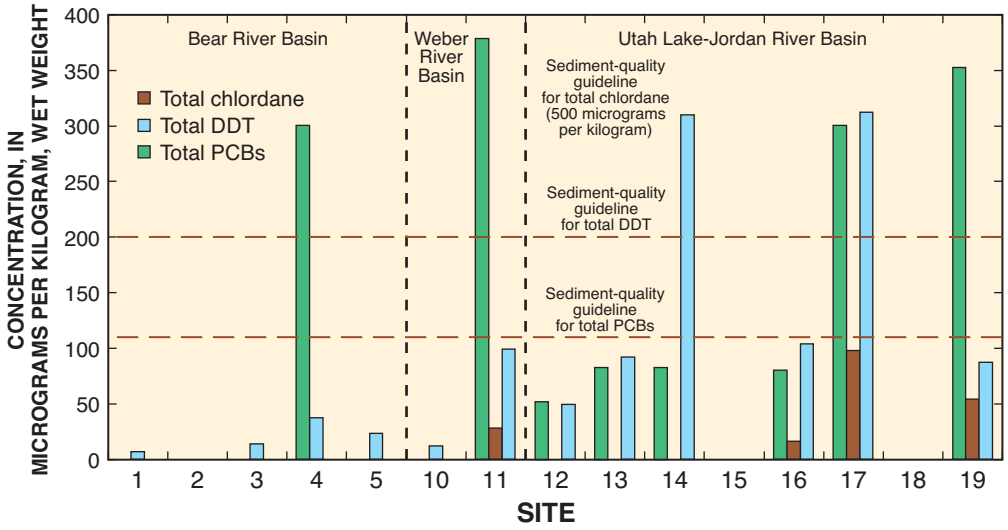


Figure 16. Total concentration of selected organic compounds in fish tissue, Great Salt Lake Basins study unit.

Comparison with Other National Water-Quality Assessment Program Study Units

Concentrations of organic compounds in sediment and fish tissue were compared with concentrations of samples collected from 48 NAWQA study units across the United States (table 13). During 1993-2000, 201 samples of common carp, 238 samples of sucker species, 32 samples of trout/whitefish species, and 1,329 sediment samples were collected. In general, concentrations of organic compounds in fish tissue and sediment from the GRSL are low compared with concentrations measured at sites across the United States.

No concentration measured in the GRSL study unit exceeded the 90th percentile for organic compounds in sediment or fish tissue. Concentrations of PCBs exceeded the national median in sediment at site 17 (Jordan River at 1700 South), and site 19 (Jordan River at Cudahy Lane). In fish tissue, the national median was exceeded at three urban sites: site 11 (Weber River at Ogden Bay), site 17 (Jordan River at 1700 South), and site 19 (Jordan River at Cudahy Lane). The concentration of PCBs in sediment did not exceed the national median at any site. Concentrations of total DDT exceeded the national median in fish tissue at three urban sites: site 12 (Provo River at Provo), site 14 (Jordan River at 9000 South), and site 17 (Jordan River at 1700 South). Concentrations of total chlordane in the GRSL study unit were lower than the national median for all sites except site 19 for sediment and site 17 for fish tissue, both also urban sites.

SUMMARY

Mining and smelter activities have contributed to elevated concentrations of trace elements in streambed sediment through erosion of mine tailings and atmospheric deposition. Age dating and chemical analysis of sediment cores from lakes, reservoirs, and Farmington Bay of Great Salt Lake provided information about the sources of these trace elements. Previous research determined that the surface sediments of cores collected from Mirror Lake were enriched in arsenic, cadmium, copper, lead, tin, and zinc relative to the deeper sediments. Age dating indicated that trace-element concentrations first began to increase in 1870, with substantial increases occurring after 1900. Because of the remote location of Mirror Lake and absence of mining in the associated drainage, the increases in trace-element concentrations over time are probably a result of atmospheric deposition from anthropogenic sources. Age dating of a core collected from Farmington Bay in 1998 also indicates a lead profile similar to that determined for Mirror Lake. In this core, the profile indicates that lead contamination began to increase

Table 13. Median concentration of selected organic compounds in fish-tissue and streambed-sediment samples collected from the Great Salt Lake Basins and 48 National Water-Quality Assessment program study units

[Concentration reported in micrograms per kilogram, dry weight]

Number of national samples	Species	Total PCBs	Hexachloro-benzene	Dieldrin	Total chlordane	Total DDT
201	Common carp					
	Percent National sites with detections	71	6	61	56	94
	National median	180	7	18	64	186
	Number of GRSL sites greater than national median	3	0	0	1	2
238	Sucker					
	Percent National sites with detections	55	7	30	43	85
	National median	180	9.3	14	56	121
	Number of GRSL sites greater than national median	0	0	0	0	0
32	Trout/whitefish					
	Percent National sites with detections	16	6	3	3	59
	National median	150	10	12	7.9	40
	Number of GRSL sites greater than national median	0	0	0	0	1
1,329	Streambed Sediment					
	Percent National sites with detections	12	3	15	20	46
	National median	96	2	2	6.6	5
	Number of GRSL sites greater than national median	0	0	0	1	2

after about 1842 and made the most marked increase between about 1916 and 1950. Large-scale mining and smelting of nonferrous metal ores began in the region after 1868, which would have contributed trace metals to the atmosphere. Industrial and energy-related sources in the Salt Lake City area also contributed trace metals to the atmosphere as a result of growth of these industries after 1900.

Unlike other contaminants, the concentration of lead peaked in the 1980s; however, a recent decline in concentration is shown in the Farmington Bay core. Analysis of sediments deposited during 1996-98 indicates a 41- to 62-percent reduction in lead concentration. Recent declines in lead concentration in sediments have been noted elsewhere and are generally attributed to reduced lead emissions following passage of the Clean Air Act of 1970.

The effect of trace elements in sediments from Silver Creek on the Weber River was evaluated by analysis of streambed sediments collected from sites on the Weber River above and below the inflow of Silver Creek and from core data collected in Echo Reservoir. Silver Creek enters the Weber River about 2.5 mi downstream from Rockport Reservoir and 6 mi above Echo Reservoir. Because both the timing and the intensity of trace-element deposition in the Echo Reservoir core differ substantially from the Mirror Lake core, the profiles did not reflect regional atmospheric inputs of anthropogenic trace elements, but instead record trace-element inputs to the reservoir originating from a local source. The trend of trace-element concentration in Echo Reservoir sediments does not appear to have been affected by the completion of Rockport Reservoir in 1966. Because a large portion of sediments are trapped in a reservoir, the data suggest that drainage to the Weber River above Rockport Reservoir had very little influence on the enrichment of trace elements downstream in Echo Reservoir. Thus, enrichment in Echo Reservoir, as well as at sites on the Weber River below Silver Creek, is largely a result of inflow from the creek.

In areas with very little mining, no Probable Effect Concentration (PEC) guidelines were exceeded for sediment. Concentrations of samples collected from all sites in the Bear River Basin, a site in the Weber River Basin above Silver Creek, and a reference site on Red Butte Creek did not exceed the PEC for any of the 10 elements of concern for aquatic health. In areas with mining-related activities, concentrations of trace elements often exceeded the PECs. Sites 7 and 8 on Silver Creek and sites 9 and 10 on the Weber River below the confluence with Silver Creek exceeded the PEC guide-

lines for arsenic, cadmium, lead, mercury, silver, and zinc. Concentrations measured at sites 15 and 16 on Little Cottonwood Creek, as well as site 17 on the Jordan River below the confluence with Little Cottonwood Creek, exceeded the PECs for arsenic, cadmium, copper, lead, silver, and zinc.

Arsenic, copper, zinc, and selenium were detected in every fish-tissue sample collected. Nickel was also detected at every site, but not in every sample. Lead and silver had the most nondetects (six) of the elements analyzed. Five samples were collected in which each of the 10 elements was detected.

Arsenic, chromium, lead, and nickel concentrations were higher in streambed sediment than in fish tissue at all sample sites. Correlations between most trace-element concentrations in streambed sediment and liver tissue were not significant ($r<0.5$, $p>0.05$); however, the correlation between lead concentration in bed sediment and in fish tissue was significant ($r=0.95$, $p<0.05$).

At the 15 stream sites sampled for streambed sediment, 115 organic compounds were analyzed for and 24 were detected. PCBs in sediment were detected above the minimum reporting limit only near the mouth of the Weber (site 11) and Jordan Rivers (site 19) and in the near-surface sediments of the Farmington Bay core. Chlordane compounds were detected only near the mouth of the Jordan River (site 19) and in the near-surface sediments of the Farmington Bay core. DDT breakdown products were detected only in samples collected near the mouth of the Weber (site 11), Provo (site 12), and Jordan Rivers (sites 17 and 19) and in the near-surface sediments of the Farmington Bay core. The highest total PAH concentrations were measured in sediments of streams draining through major urban areas of the Weber and Utah Lake—Jordan River drainage basins. The concentration of total PAHs in sediment cores from Farmington Bay consistently increased from near 0 micrograms per kilogram (µg/kg) in sediment deposited before 1940 to more than 2,000 µg/kg in selected sediment layers deposited after the early to mid-1980s. There was a positive correlation between the population growth in Salt Lake County and the PAH concentrations measured in the lake sediments from Farmington Bay. This correlation indicates the likely sources of PAHs in lake sediments deposited since 1940 are derived from human-induced combustion products.

Samples from only four sites had concentrations of one or more organic compounds that exceeded the sediment-quality guidelines. At site 11, which is near the mouth of the Weber River, the Threshold Effect Concentration (TEC) level for total PCBs was exceeded. All other exceedances of the TEC level occurred at sites 17 and 19 on the Jordan River and in the near-surface sediments of the Farmington Bay core. The organic compounds that frequently exceeded the TEC levels at these sites include total PCBs, total PAHs, total chlordane, dieldrin, and breakdown products of DDT. The PEC level was exceeded only for chlordane and occurred in the near-surface sediments of the Farmington Bay core.

Fifteen sites were sampled for 28 hydrophobic organic contaminants in fish tissue, and detections occurred at 13 sites. Sites on the Jordan River and the Weber River at Ogden Bay had the highest concentrations of detected organic compounds and sites on the Bear River had very few detected organic contaminants. A breakdown product of DDT, *p, p'*-DDE, was the most commonly detected compound, occurring at 13 sites. PCBs were detected at eight sites, and chlordane-related compounds were detected in samples from four sites. DDT was detected at sites in both urban and agricultural areas, although concentrations were highest at urban sites. PCBs were detected primarily at sites below drainages with substantial urban land in the basin. PCB was detected at agricultural site 4 on the Cub River, just upstream from the confluence with the Bear River. Concentrations of organic compounds in sediment and fish tissue were compared with the 48 NAWQA study units across the United States. During 1993-2000, 201 samples of common carp, 238 samples of sucker species, 32 samples of trout/whitefish species, and 1,329 sediment samples were collected. In general, concentrations of organic compounds in fish tissue and sediment from the Great Salt Lake Basins are low compared with concentrations measured at sites across the United States.

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APPENDIX

Table A-1. Concentration of organic compounds detected in streambed sediment for sites in the Great Salt Lake Basins study unit

[g/kg, grams per kilogram of sediment, dry weight; µg/kg, micrograms per kilogram of sediment, dry weight; <, less than; E, estimated]

Site number (fig. 1)	Date	Inorganic carbon (g/kg)	Organic carbon (g/kg)	Di-n-butyl-phthalate (µg/kg)	Di-n-octyl-phthalate (µg/kg)	Bis(2-ethylhexyl) phthalate (µg/kg)	Butybenzyl-phthalate (µg/kg)	Phenol (µg/kg)	*p*-Cresol (µg/kg)	Total PCBs (µg/kg)
1	08-12-1998	6.2	6.8	<50	<50	<50	<50	E 18	<50	<50
2	08-12-1998	13	10	E 30	<50	E 14	E 13	<50	E 15	<50
3	07-20-1999	22	9	<50	<50	165	E 15	E 15	116	<50
4	08-11-1998	26	18	<50	<50	160	<50	66	554	<50
5	08-07-1998	22	6	E 29	<50	E 23	<50	<50	<50	<50
10	08-13-1998	4.9	18	<50	<50	<50	<50	<50	287	<50
11	08-06-1998	8.1	9.9	E 45	<50	524	<50	<50	<50	74
12	07-26-1999	19	9	E 42	<50	292	E 33	<50	E 9	<50
13	07-27-1999	34	8	E 50	<50	74	61	<50	<50	<50
14	07-29-1999	8.2	5.8	<50	<50	209	E 8	<50	<50	<50
15	08-14-1998	9.4	29	E 41	<50	352	55	73	310	<50
16	08-04-1998	4.8	7.2	E 28	E 45	242	E 26	<50	<50	<50
17	08-03-1998	12	17	E 34	57	366	E 32	<50	E 32	<50
18	08-10-1998	19	23	E 35	<50	E 23	<50	E 8	<50	<50
19	08-05-1998	18	27	E 49	E 136	2,460	E 54	<50	E 36	72
Minimum reporting level				50	50	50	50	50	50	50

Site number (fig. 1)	Date	Anthracene (µg/kg)	Benzo(*a*)-pyrene (µg/kg)	Benzo(*b*) fluoran-thene (µg/kg)	Benzo(*k*) fluoran-thene (µg/kg)	Benzo[*g,h,i*]-perylene (µg/kg)	Chrysene (µg/kg)	Fluoran-thene (µg/kg)	1,6-Dimethyl-napthalene (µg/kg)	2,6-Dimethyl-naph-thalene (µg/kg)
1	08-12-1998	<50	<50	<50	<50	<50	<50	<50	<50	<50
2	08-12-1998	E 9.1	<50	<50	<50	<50	<50	E 20	<50	<50
3	07-20-1999	<50	<50	<50	<50	<50	E 2.5	<50	E 26	E 21
4	08-11-1998	<50	<50	<50	<50	<50	<50	<50	<50	73
5	08-07-1998	<50	<50	<50	<50	<50	<50	<50	<50	<50
10	08-13-1998	<50	<50	<50	<50	<50	<50	<50	<50	61
11	08-06-1998	<50	<50	E 33	E 29	<50	E 20	54	E 7	E 24
12	07-26-1999	<50	E 19	62	59	<50	86	127	E 31	E 24
13	07-27-1999	<50	<50	<50	<50	<50	<50	<50	E 32	<50
14	07-29-1999	<50	<50	<50	<50	<50	<50	<50	<50	E 14
15	08-14-1998	<50	<50	E 26	E 31	<50	E 30	E 29	<50	<50
16	08-04-1998	<50	E 15	E 15	E 15	E 16	E 7	E 19	<50	E 9
17	08-03-1998	E 27	73	68	E 50	53	73	125	E 26	E 47
18	08-10-1998	<50	<50	<50	<50	<50	<50	<50	<50	E 18
19	08-05-1998	63	95	108	73	61	139	207	E 40	87
Minimum reporting level		50	50	50	50	50	50	50	50	50

Table A-1. Concentration of organic compounds detected in streambed sediment for sites in the Great Salt Lake Basins study unit—Continued

Site number (fig. 1)	Date	Indeno(1,2,3-*cd*) pyrene (µg/kg)	1-methyl-pyrene (µg/kg)	Phenanthrene (µg/kg)	4*H*-cyclopenta [*d,e,f*]phen-anthrene	*cis*-Chlordane (µg/kg)	*trans*-Chlordane (µg/kg)	*p,p'*-DDD (µg/kg)	*p,p'*-DDE (µg/kg)
1	08-12-1998	<50	<50	<50	<50	<1	<1	<1	<1
2	08-12-1998	<50	<50	E 14	<50	<1	<1	<1	<1
3	07-20-1999	<50	<50	<50	<50	<1	<1	<1	<1
4	08-11-1998	<50	<50	<50	<50	<1	<1	<1	<1
5	08-07-1998	<50	<50	<50	<50	<1	<1	<1	<1
10	08-13-1998	<50	<50	<50	<50	<1	<1	<1	<1
11	08-06-1998	<50	E 16	E 16	<50	<1	<1	E 1.5	E 2.5
12	07-26-1999	E 5	<50	53	<50	<1	<1	<1	E 1.5
13	07-27-1999	<50	<50	<50	<50	<1	<1	<1	<1
14	07-29-1999	<50	<50	<50	<50	<1	<1	<1	<1
15	08-14-1998	<50	<50	E 6	<50	<1	<1	<1	<1
16	08-04-1998	E 14	E 9	<50	<50	<1	<1	<1	<1
17	08-03-1998	E 48	57	108	E 28	<1	<1	E 4.5	E 3.3
18	08-10-1998	<50	<50	<50	<50	<1	<1	<1	<1
19	08-05-1998	56	E 30	141	E 48	2.8	3.3	E 4.9	8.2
Minimum reporting level		50	50	50	50	1	1	1	1

Table A-2. Concentration of selected organic compounds in fish tissue for sites in the Great Salt Lake Basins study unit

[All concentrations reported in micrograms per kilogram, wet weight, unless expressed otherwise; <, less than; E, estimated; NA, not applicable]

Site number	Location	Date	Fish species	Lipids (percent)	Total PCB	*trans*-Nonachlor
1	Bear River above Reservoir, near Woodruff, Utah	09-08-1998	Redside shiner	7.4	<50	<5
2	Bear River below Smiths Fork, near Cokeville, Wyoming	08-12-1998	Utah sucker	6.6	<50	<5
3	Cub River near Franklin, Idaho	07-20-1999	Carp	6.3	<50	<5
4	Cub River near Richmond, Utah	08-11-1998	Carp	4.2	300	<5
5	Bear River near Corinne, Utah	08-07-1998	Carp	6.2	<50	<5
10	Weber River near Coalville, Utah	09-08-1998	Mountain whitefish	7.4	<50	<5
11	Weber River Middle Fork near Ogden Bay Dike	08-06-1998	Carp	12	650	16
11	Weber River Middle Fork near Ogden Bay Dike	08-06-1998	Carp	6.7	<50	13
11	Weber River Middle Fork near Ogden Bay Dike	08-06-1998	Carp	8.1	437	8.8
12	Provo River at Provo, Utah	07-26-1999	Rainbow trout	8.8	53	E 4.4
13	Jordan River below Utah Lake at Pumping Station	07-27-1999	Carp	9.9	84	E 3.6
14	Jordan River at 90th South near Midvale, Utah	07-29-1999	Carp	8.9	82	E 3.8
15	Little Cottonwood Creek at Crestwood Park, Salt Lake City, Utah	08-25-1998	Sucker	5.7	<50	<5
16	Little Cottonwood Creek at Jordan River, near Salt Lake City	08-04-1998	Sucker	5.6	80	9.8
17	Jordan River at 1700 South, Salt Lake City, Utah	08-03-1998	Carp	8.6	300	35
18	Red Butte Creek at Fort Douglas, near Salt Lake City, Utah	08-10-1998	Cutthroat trout	5.2	<50	<5
19	Jordan River at Cudahy Lane near Salt Lake City, Utah	08-05-1998	Carp	11	270	E 26
19	Jordan River at Cudahy Lane near Salt Lake City, Utah	08-05-1998	Carp	12	450	E 23
19	Jordan River at Cudahy Lane near Salt Lake City, Utah	08-05-1998	Carp	13	340	17
	Fish-tissue method reporting limit			NA	50	5

Table A-2. Concentration of selected organic compounds in fish tissue for sites in the Great Salt Lake Basins study unit—Continued

Site number	*cis*-Nonachlor	*delta*-BHC	Hexa-chloro-benzene	Dieldrin	*p,p'*-DDE	*o,p'*-DDE	*o,p'*-DDD	*p,p'*-DDD	*p,p'*-DDT	*cis*-Chlordane	*trans*-Chlordane
1	<5	<16	<5	<5	6.9	<5	<5	<5	<5	<5	<5
2	<5	<55	<5	<5	<5	<5	<5	<5	<5	<5	<5
3	<5	<5	<5	<5	15	<5	<5	<5	<5	<5	<5
4	<5	<5	<5	<5	37	<5	<5	<5	<5	<5	<5
5	<5	<5	<5	<5	24	<5	<5	<5	<5	<5	<5
10	<5	<43	<5	<5	12	<5	<5	<5	<5	<5	<5
11	<5	<5	<5	<5	73	<7.8	<8.2	24	<5	15	6.5
11	<5	<5	<5	<5	42	<9.3	<5	17	<5	12	<5
11	<5	<5	<5	<5	87	<5	18	64	<5	8.4	6
12	<5	<5	<5	<5	49	<5	<5	<5	<5	<5	<5
13	<5	<5	<5	<5	85	<5	<5	7.1	<5	<5	<5
14	<5	<5	<5	<5	298	<5	<5	12	<5	<5	<5
15	<5	<5	<5	<5	6	<5	<5	<5	<5	<5	<5
16	E 5.8	<5	6.4	<5	91	<5	<5	<5	E 13	5.8	<5
17	10	<5	<5	<5	290	<5	<5	E 22	<5	20	20
18	<5	<8	<5	<5	<5	<5	<5	<5	<5	<5	<5
19	<5	<5	<5	7.2	89	<5	<5	22	<5	29	9.7
19	<5	<5	5.4	6.7	72	<5	<5	19	<5	23	7.7
19	<5	<5	6.7	8.2	50	<5	<5	13	<5	21	7.7
	5	5	5	5	5	5	5	5	5	5	5

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