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Mercury in the Carson River Basin, California and Nevada

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This report provides a summary of mercury (Hg) data in the Carson River Basin, Nevada, USA, one of the most Hg-contaminated sites in the world. An overview of Hg chemistry, fate and transport, current global sources, and toxicity are presented along with a summary of Hg data and research performed in this watershed basin. The original sources of Hg contamination in the Carson River Basin are from historical gold and silver mining of the Comstock Lode near Virginia City, Nevada. Runoff and erosion from mining and refining deposited a large amount of contaminated sediments in the Carson River Basin from Dayton, Nevada, into the closed terminal basin of the Carson River in the Carson Desert. This area is now the primary source of Hg pollution in the basin. During runoff and flood events, the Carson River laterally cuts through the contaminated sediments and transports Hg on suspended sediments, with concentrations rising with higher flow. When Lahontan Reservoir was built in 1915, it became a settling basin for suspended Hg from the Carson River, and while it retains up to 90 percent of influent sediments, the reservoir continues to pass significant concentrations of suspended and dissolved inorganic Hg and methylmercury (Me-Hg) downstream to the Carson Sink. Literature and other source Hg data are summarized for surface waters, sediments, and biological tissues.

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Mercury in the Carson River Basin, California and Nevada

by

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EXECUTIVE SUMMARY

This report summarizes the story of mercury (Hg) in the Carson River Basin of eastern Nevada, and provides background information about the global Hg cycle, natural and anthropogenic sources and emissions; the chemistry, movement, and transformation of Hg in the aquatic environment; and the wildlife and public health risks of Hg exposure. We have summarized most of the Hg data measured in water, sediments, and biota collected from the Carson River Basin, and relevant research studies performed on the Carson River, Lahontan Reservoir, and areas downstream from Lahontan Dam. We have also included appendices containing a glossary and a summary of fish tissue Hg data from Lahontan Reservoir.

This report is intended to provide an information overview and reference source on Hg for water resources managers and researchers working in the Carson River Basin. It also has pertinent information for water resource managers in many western watersheds that have Hg-enriched geology and historical mining. This section and the data tables provide a general overview.

Why is Hg an issue in the Carson River Basin? The Carson River Basin below Dayton, Nevada, is *the most heavily Hg-contaminated region in the world* (Cooper et al., 1985; Gustin et al., 1994; Bonzongo et al., 1996b; Hoffman and Taylor, 1998, and others). Hg concentrations in surface waters, soils, sediments, plants, and wildlife from Dayton, Nevada, through the middle and lower Carson River watershed are all several orders of magnitude higher than background and often exceed biological effect and regulatory levels. The Environmental Protection Agency (EPA) has included the Middle Carson and Carson Desert Sub Basins as part of the Carson River Mercury Site, a Superfund cleanup project on the National Priority List.

For comparison, consider another Superfund site also polluted by Hg from mining, Clear Lake, California. Maximum Carson River water total Hg is almost 300-times more concentrated than Clear Lake maximum levels (28,000 vs. 69 nanograms per liter [ng/L]). Maximum sediment Hg in the Carson River below Dayton is almost 4-times Clear Lake maximum concentrations (600,000 vs. 159,000 micrograms per kilogram [µg/kg]). Elevated Hg levels as seen in the Carson River Basin have created significant water quality, wildlife, and human health issues that will continue to pose challenges for water managers and decisionmakers.

Toxicity – Most people are aware that Hg is toxic and can be poisonous. All forms of Hg attack neural tissues, and in elevated dosages Hg can cause symptoms from confusion and tremors to serious birth defects and death. The developing fetus and small children are especially sensitive compared to adults, and can experience developmental impairment, gross abnormalities, or other symptoms at much lower dosages.

Hg is toxic to aquatic life at much lower concentrations than most other trace elements, on the order of 5–10 ng/L (0.005 to 0.010 micrograms per liter [µg/L]) – levels that require special water sampling precautions to prevent contamination and analyze correctly. Levels on the order of 10 ng/L are not directly toxic to humans who might drink Hg-contaminated water, but fish and other aquatic organisms that live in such waters may experience toxic effects over time through bioaccumulation.

Stability, Persistence, and Mobility – Because Hg is an element, once it is released into the environment, it cannot be broken down into non-toxic byproducts, so it is stable as a pollutant. Hg is the only liquid element at ambient temperatures, so it is volatile, forms a gas and can enter the atmosphere and be transported long distances. It is also soluble in water and attaches readily to sediments, so it will move throughout watersheds in both surface and groundwaters. Hg can enter and be transported in organisms. Finally, because Hg will recycle, or exchange back and forth between the ecosystem components of air, water, soil, sediments, vegetation, and animals, it can have an extended environmental residence time.

Bioaccumulation and Methylation – While inorganic or elemental Hg is toxic, it becomes a bigger problem to living systems through the process of bioaccumulation. Also called *bioconcentration* or *biomagnification*, this is the process where concentrations of Hg increase through the predator-prey food chain pyramid. When Hg enters aquatic systems, even at low concentrations, aquatic plants and microbes will adsorb or ingest Hg from water. Microbes then convert inorganic forms of Hg into a much more toxic form, methylmercury (Me-Hg). Microbes containing Me-Hg are eaten by plankton and insects, which are in turn eaten by forage fish, which are then eaten by predator fish and birds, and finally by people. Biotic Hg increases because each organism on a higher trophic (or size) level will eat many smaller organisms from the lower trophic levels. Humans are the top predator of the food chain pyramid, and most cases of human Hg poisoning have occurred through the eating of contaminated fish or other food, a problem recognized for many years in the Carson River Basin. The State of Nevada has issued public consumption advisories for fish and game in waters downstream from Lahontan Reservoir because of Hg bioaccumulation.

Natural vs. Anthropogenic Sources – While there are natural sources of Hg in most volcanic geology, the biggest global sources are now anthropogenic. Currently, the largest global source of Hg is the combustion of fossil fuels, and this source, increasing with population and development, helps create a background level of Hg around 1–4 nanograms per cubic meter (ng/m^3) in the atmosphere. Even fairly remote and pristine wilderness areas have detectable Hg in soils, water, and vegetation. In the

Carson River Basin, the primary source of Hg contamination is local – from historical gold and silver mining and the use of Hg to refine ore. This *artisanal*, or small scale prospector mining, while no longer common in the United States, is still widely practiced in the developing world and now represents the second largest human source of Hg.

Mercury in the Carson River Basin – Current Hg inputs to the Carson River Basin are from historic mining and milling contamination during extensive gold and silver mining in the late 1800s. This mining occurred in and around Virginia City and Silver City, Nevada, site of the historic Comstock Lode. The Hg pollution arose from the Hg amalgamation process (the Washoe Process) that was used on transported milled rock in refining operations located along the Carson River and nearby tributaries near Dayton, Nevada. Large amounts of refining wastes were discharged into the local streams and then transported downstream into the Middle Carson River Basin and Carson Desert by runoff and flood events.

This waste transport created a meter-thick layer of Hg-contaminated sediment downstream in the Carson River Valley from below Dayton into the Carson Sink, that buried the original Carson River channel. Since the cessation of most mining in 1915, the Carson River has been laterally cutting through the contaminated waste sediment layer during spring runoff and flood events, providing an inexhaustible source of Hg to the downstream aquatic environment (Miller et al., 1995, 1998). Almost all Hg is transported attached to bed and bank sediments suspended in river flows. The higher the runoff volume, the greater the amount of Hg transported downstream. A significant flood in January 1997 produced some of the highest Hg concentrations ever recorded in the Carson River Basin (Hoffman and Taylor, 1998).

Data Summaries – Tables ES-1, -2, and -3 provide overall summaries of Hg data we collated from Web sites and the research literature. Table ES-1 covers surface water data, table ES-2 stream and reservoir sediment data, and ES-3 the data from plant and animal tissue analyses. (More detailed summaries and references are summarized in tables 3–5 in the body of this report.) Each Executive Summary table begins with expected background levels, levels of concern or effect identified by researchers, and any applicable environmental standards. The collected Hg values in each table are then arranged to follow general regions in the Carson River Basin from the upper elevation headwaters in Alpine County, California, downstream to the Carson Desert. These regions are (1) Carson River above Dayton, Nevada, (2) Carson River from Dayton to Fort Churchill, Nevada, (3) Lahontan Reservoir, and (4) Below Lahontan Reservoir.

Carson River above Dayton, Nevada – In this region, Hg levels in water, sediment, and biota are only slightly elevated above normal background levels for the volcanic geology of the Sierra Nevada mountains and the Great Basin and Range. The Leviathan Mine, an abandoned sulfur pit mine, contributes some Hg to the East Fork of the Carson River by way of acid mine drainage; however, this area is also a Superfund Site and is being remediated.

Table ES-1.— Summary of Hg and Me-Hg concentrations in surface waters from the Upper Carson Sub Basin to below Lahontan Dam, including the Carson River and Lahontan Reservoir. Averages are from reported average values – refer to table 3 for references

Regulations and Background Concentrations

Source	***Unfiltered Total Hg, ng/L***	***Source***	***Unfiltered Total Hg, ng/L***
Nevada Water Quality Criteria (State of Nevada, 1994)	12 aquatic life 2,000 drinking water 10,000 livestock water	National Primary Drinking Water Standard (EPA 2002)	2,000
Uncontaminated Background (Gustin et al., 1994)	1–3	Clear Lake Superfund Site, California (Gustin et al., 1994)	5.5–69
Truckee Basin Alpine Creeks (Wayne et al., 1996)	1.3–1.6	Truckee Canal at Dam (Wayne et al., 1996)	4.0–4.4

	Unfiltered Total Hg, ng/L	***Filtered Total Hg, ng/L***	***Unfiltered Me-Hg, ng/L***	***Filtered Me-Hg, ng/L***
Carson River Above Carson City, Nevada				
Average	8.27	4.55	0.409	0.271
Range	2.80–22.0	0.580–13.5	0.305–0.512	0.161–0.380
Carson River From Dayton to Fort Churchill, Nevada				
Average	1,330	16.9	2.20	0.665
Range	48–28,000	3.24–46.1	0.360–7.20	0.090–3.13
Lahontan Reservoir				
Average	421	23.6	0.472	0.142
Range	76.0–1,580	1.90–113	0.400–0.544	0.135–0.149
Below Lahontan Dam				
Average	498	9.85	2.14	0.125
Range	< 5.00–2,500	< 5.00–26.0	0.450–2.73	0.040–1.08

Table ES-2.— Summary of Hg concentrations in sediments from the Upper Carson Sub Basin to below Lahontan Dam, including the Carson River and Lahontan Reservoir. Unless otherwise noted, concentrations are on a dry-weight basis, and data are for bed sediments. Refer to table 4 for references and specific data sets

Biological Effect and Background Concentrations

Source	***Total Hg or Me-Hg, μg/kg***	***Source***	***Total Hg or Me-Hg, μg/kg***
Bioassay Exposure Level of Concern (Long and Morgan, 1991)	150 total Hg	Bioassay Exposure Effect Level (Long and Morgan, 1991)	1,300 total Hg
Uncontaminated Background (Gustin et al., 1994)	<100 total Hg 10–50 total Hg	Virginia Range Rock Background (Gustin et al., 1994)	10–50 total Hg
Contaminated Lake Owyhee, Oregon (< 178 micrometer [µm]) (Craft et al., 2000)	152–410 total Hg 2.39–5.39 Me-Hg	Clear Lake Superfund Site, California (Gustin et al., 1994)	900–159,000 total Hg

	Total Hg, μg/kg	***Me-Hg, μg/kg***
Carson River above Carson City		
Range	< 20–6,100	2.80–6.62
Carson River from Dayton to Fort Churchill, Nevada		
Range	50–881,000	4.20–14.5
Lahontan Reservoir		
Range	10–103,000	–
Below Lahontan Dam		
Range	< 250–23,750	–

Table ES-3.— Summary of Hg concentrations in biota from the Upper Carson Sub Basin to the Carson Sink Sub Basin. Unless otherwise noted, concentrations are on a whole-body wet-weight basis. Refer to table 5 for references and specific data sets

Biological Effect and Background Concentrations				
Source		*Total Hg, mg/kg*	*Source*	*Total Hg, mg/kg*
EPA Recommendation for Fish Consumption Advisory (EPA, 1994a)		0.60	U.S. Food and Drug Administration Consumption Action Levels (FDA, 1984)	1.0 fish 3.6 edible wildlife
Uncontaminated Tissue Background (Gustin et al., 1994)		0.02–0.20	Fernley Water Management Area (FWMA) Nevada Background (Gustin et al., 1994)	Fish < 0.5
Levels of Concern (Tuttle and Thodal, 1998)		Fish 0.17	Effect Levels (Heinz, 1979)	Diet > 0.4, Fish > 0.67 Avain Eggs > 0.83 Avian Liver > 4.3
	Species and Tissue Type	*Range, Tissue Total Hg, mg/kg*	*Species and Tissue Type*	*Range, Tissue Total Hg, mg/kg*
Carson River above Carson City, Nevada				
Range	Stonefly	0.038–0.126	Unspecified Biota	0.167–0.500
Carson River from Dayton to Fort Churchill, Nevada				
Range	Crayfish, wet weight	0.100–0.969	Unspecified Biota	4.9–10
Range	Non-predator fish	0.19–2.07	Predator fish	1.18–3.19
Lahontan Reservoir				
Range	Non-predator fish	0.22–4.22	Predator fish	0.211–16.0
Range	Fish-eating bird livers	5.01–222	Fish-eating bird eggs	0.81–1.8
Below Lahontan Dam				
Range	Aquatic plants	< 0.2–2.40	Insects	0.30–5.4
Range	Forage fish	0.16–2.4	Predator fish	0.72–5.7
Range	Duck livers	0.15–25	Bird eggs	0.20–6.2
Range	Duck muscle	0.40–16		

Carson River from Dayton to Fort Churchill, Nevada – Total Hg concentrations between Dayton and Fort Churchill increase exponentially in water during spring runoff (Bonzongo et al., 1996b). Almost all the Hg is associated with suspended sediments, and total Hg concentrations closely follow river flow rates. Me-Hg concentrations, however, increase in a more linear manner, and are greater in the Carson River when flows are low and biotic processes are given more time to convert inorganic forms to Me-Hg (Bonzongo et al., 1996a, 1996b; Hoffman and Taylor, 1998). While Me-Hg *concentrations* may rise during low river flows, it should be noted that Me-Hg *mass loading* into Lahontan Reservoir is low during low-flow conditions.

Lahontan Reservoir – The loading of Hg from the Carson River and its movement and transformation within Lahontan Reservoir water and sediments is strongly influenced by suspended particles. Research suggests that reservoir sediments release dissolved forms of Hg, and sediment resuspension from wind mixing and flood events may be an ongoing source for suspended Hg. However, the adsorption and exchange surface that is associated with the ever-present particulates in Lahontan Reservoir may limit and regulate dissolved concentrations of both total Hg and Me-Hg.

The shallow upper (southern) basin of Lahontan Reservoir acts as a settling basin for Carson River sediments and Hg, and has the highest concentrations of Hg, with significantly lower concentrations in the lower (northern) basin behind the dam. Inflows from the relatively Hg-clean Truckee Canal also dilute Hg concentrations near the dam. Lahontan Reservoir retains 90 percent of the total Hg loading from the Carson River and has generally lower Me-Hg concentrations compared to the Carson River above the reservoir, but the dam continues to discharge Hg and Me-Hg at elevated levels downstream to the Carson Sink, and some data suggest that Me-Hg above inflow concentrations may be discharged below the dam..

Hg in Lahontan Reservoir Fish – Fish in Lahontan Reservoir have highly elevated Me-Hg concentrations in their tissues, and higher body levels are seen in older and bigger predator species. Because of the extreme Hg concentrations in sediments and water, 30–35 percent of forage fish that prefer the shallower Upper Basin of Lahontan Reservoir, such as carp and blackfish, have tissue Hg higher than the 1.0 milligrams per kilogram (mg/kg) action level set by the U.S. Food and Drug Administration (FDA). These fish are harvested commercially and sold to markets in San Francisco. Figure ES-1 shows concentration ranges measured for Lahontan Reservoir fish by the State of Nevada and the Bureau of Reclamation (Reclamation) (NDOW, 2004b; Reclamation, 2004d).

Analysis of Nevada Division of Wildlife (NDOW) and Reclamation Hg data for individual fish (n = 385, all species) suggests that over 90–95 percent of fish from Lahontan Reservoir contain Hg above the 0.6 mg/kg EPA advisory level, and from 70–75 percent above the 1.0 mg/kg FDA action level. These data clearly show that Hg bioaccumulation in Lahontan Reservoir fish is a serious issue.

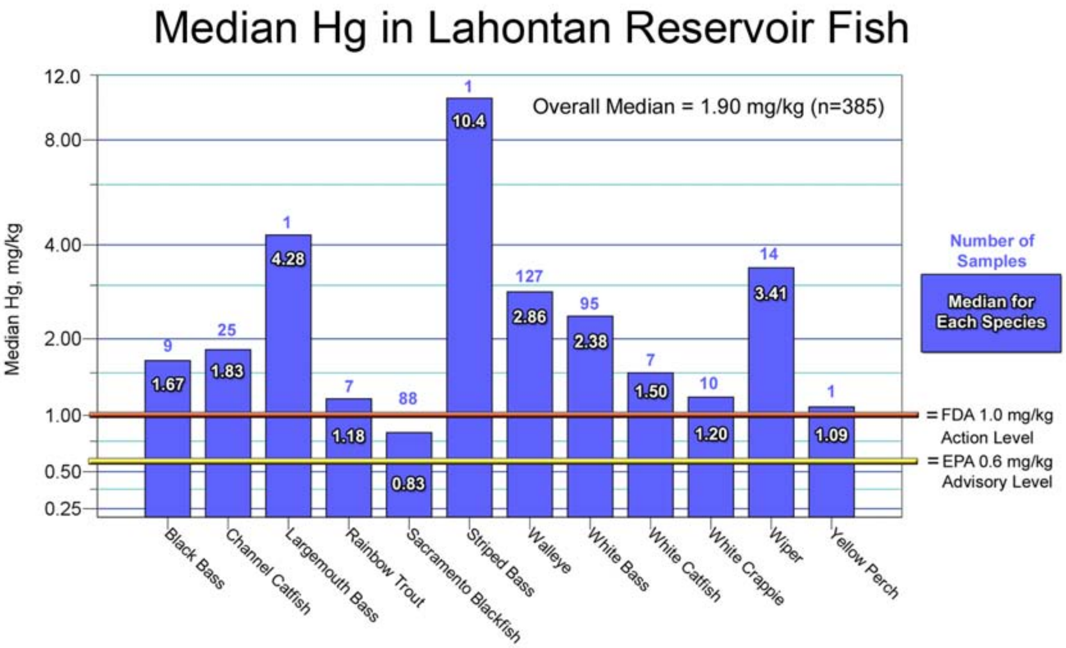


Figure ES-1.— Median concentrations of Hg in fish collected from Lahontan Reservoir. Data from the State of Nevada and Reclamation (NDOW, 2004b; Reclamation, 2004d).

Below Lahontan Reservoir – As expected, Hg concentrations in sediments and surface waters are highly elevated below Lahontan Dam. While large deposits of Hg were deposited in the lower Carson River reaches in sediments and soil prior to dam construction, discharges from Lahontan Reservoir continue to contribute elevated Hg to downstream areas. Hg bioaccumulation has been observed in fish-eating birds (egrets, cormorants) around and below Lahontan Reservoir, and in detritus, aquatic plants, insects, fish, and ducks in the Carson Lake, Indian Lakes Recreation Area, and the Stillwater Wildlife Management Areas. Edible tissue concentrations in many birds exceed FDA action levels of 3.6 mg/kg.

Despite considerable research and data collection efforts, many questions surrounding the transformation and movement of Hg in Lahontan Reservoir remain unresolved. Additional research and information will be needed both to better understand the dynamics of Hg interactions in the reservoir, and to help make informed decisions to minimize Hg bioaccumulation. Some of the important questions include:

- Where are the specific source areas for Me-Hg and methylation-reactive inorganic Hg for Lahontan Reservoir? Does the reservoir delta contribute to the methylation of Hg?

- Do suspended and bottom sediments in Lahontan Reservoir create additional Me-Hg above that delivered from river inflows? Does summer reservoir stratification in the Lower Basin enhance Me-Hg production?

- Does Hg become more mobile and bioavailable after reservoir draw down and subsequent re-flooding of dried and oxidized sediments in the Upper Basin "overflow" areas? What variables affect these processes?

- What factors account for the elevated Hg found in forage fish in the Upper Basin?

INTRODUCTION

Background and Purpose

This report, prepared by the Bureau of Reclamation (Reclamation), is intended to provide an interdisciplinary information overview for water resource managers regarding mercury (Hg) issues affecting water resources and biota in the Carson River Basin. Subjects to be covered include: a review of the environmental and analytical chemistry of Hg; a survey of the physiography, hydrology, geology, and water quality in the Carson River Basin; a summary of available Hg and methylmercury (Me-Hg) data in Carson River water, sediments, and wildlife; and research performed to date by other agencies and universities in the Carson River Basin and Lahontan Reservoir.. A bibliography of pertinent references, a glossary, and supplemental data tables are also included.

Some of the questions to be considered by this report include:

- How is Hg deposited and transformed in ecosystems, and what are its effects on biota and human health?
- What are the important global Hg sources and what factors enhance the mobilization and methylation of Hg?
- What areas constitute important sources of inorganic Hg and Me-Hg in the Carson River Basin?
- If samples for Hg and Me-Hg are collected by interested researchers, what sampling techniques, analytical methods, detection limits, and quality assurance procedures should be specified?
- What questions have not been answered by research and data collection efforts to date?

Mercury in the Environment

Why is Hg Important? Hg is a significant global contaminant. The reasons are simple and compelling:

- **Toxicity** – Hg is highly toxic in its elemental, inorganic, and organic forms, often at very low exposure levels.
- **Stability** – Because it is an element, Hg cannot be broken down into harmless components. Once released into the environment, it will remain a toxic contaminant for long periods.

- **Mobility** – Because of its ability to vaporize and form gaseous Hg, adsorb onto dust and other particulates, and the solubility of its forms in water, Hg emitted into the atmosphere can potentially be transported across hemispheres by weather systems and ocean currents.

- **Persistence** – Once Hg enters the environment, it is able to reversibly move between the atmosphere, land, water, and biota. This recycling, or flux, between and within these ecosystem components prolongs its residence time and makes Hg a persistent pollutant.

- **Widespread Distribution** – Hg is everywhere. Global background Hg reaches even remote wilderness ecosystems including polar regions. Almost every western drainage basin has been contaminated from historical use of Hg in mining.

- **Increasing Global Hg Contamination** – Hg is geologically associated with fossil fuels, and is released to the atmosphere when these fuels are burned. Increasing population, development, and world demand for energy means that background levels of Hg contamination will also increase over time.

- **Public Health** – Because Hg bioaccumulates and biomagnifies in the aquatic food chain, becoming more concentrated in predator species, humans eating fish from water bodies contaminated with Hg are at risk from Hg poisoning.

- **Reclamation Resources are Contaminated** – The Carson River Basin downstream from Dayton, Nevada, including Lahontan Reservoir and all downstream wetlands, may be the most Hg-contaminated region in the United States (U.S.) (Bonzongo et al., 1996a, 1996b, 2002; Gustin et al., 1994).

Properties and Chemistry of Hg – The element Hg (atomic number 80, atomic weight 200.59), also known as quicksilver, exists as a dense (13.53 grams per milliliter [g/mL]) shiny liquid metal in its elemental state (denoted as Hg^0); however, it is rarely observed in its pure liquid form in nature (Winter, 2004). Because Hg is a liquid and has a high vapor pressure relative to solid transition metals (0.00185 millimeter [mm] at 25 °C), it is a volatile element that will readily enter the gas phase. For example, volatilized Hg can be measured in air above ore bodies and contaminated mine tailings (Gustin et al., 1995,1996; Coolbaugh et al., 2002; Zhang et al., 2001, 2002).

Mercury readily combines with metals, such as gold, silver, zinc cadmium, and tin, forming alloys called amalgams. Hg also forms charged ionic species, such as the mercuric ion (Hg^{2+}, Hg in the +II oxidation state), and the mercurous ion (Hg_2^{2+}, Hg in the +I oxidation state). These ions will combine with other inorganic and organic compounds, such as humic and fulvic acids (Hintelmann et al., 1995), and can adsorb directly onto soils, fugitive dust in the atmosphere, and particulate matter suspended in water. Chemical equilibrium modeling data from Craft et al. (2000) suggest that the dominant dissolved Hg species in alkaline oxygenated western freshwaters is mercuric hydroxide, Hg $(OH)_2$.

In soils and sediments, microbial activity will convert inorganic Hg to alkyl mercury compounds, the most important form being methylmercury, or the methylmercurous ion, CH_3Hg^+ (Me-Hg). This form of Hg is fairly stable, fat soluble binds to protein, and will bioconcentrate in higher trophic levels of the food chain—the reason for the public health concern regarding human consumption of fish. Table 1 summarizes the common species (chemical forms), and reactions of Hg in the aqueous environment (Jensen and Jernelöv, 1972) that are important to the mobility and transformation of Hg.

Table 1.— Some common chemical forms and reactions for mercury in the environment. From Jensen and Jernelöv, 1972.

Major Inorganic Forms:		
Hg^0 Elemental	**Hg^{2+}** Mercuric	**Hg_2^{2+}** Mercurous
$HgCl^+$	**$HgCl_2$** chloride formation depends on concentration	
$HgOH^+$	**$Hg(OH)_2$** hydroxide formation is pH sensitive	
Major Organic Forms:		
CH_3Hg^+ Methylmercuric ion	**$(CH_3)_2Hg$** Dimethylmercury	
Common Reactions and Comments:		
$Hg^{2+} + 2e^- \leftrightarrows Hg^0$	Reduction of mercuric ion to elemental mercury is redox sensitive and abiological in anoxic waters at reducing potentials. *Pseudomonas* can reduce Hg^{2+} under aerobic conditions.	
$Hg^0 \leftrightarrows Hg^{2+} + 2e^-$	Oxidation of elemental mercury to mercuric ion is redox and so depends on dissolved oxygen (DO). Aerobic waters will slowly oxidize dissolved and particulate Hg^0.	
$Hg^{2+} + S^{2-} \leftrightarrows HgS$	Formation of mercuric sulfide will occur under anaerobic, reducing conditions. Dissolved oxygen will slowly oxidize HgS in reservoirs during overturn and mixing, and when sediments are exposed, thus releasing Hg^{2+}.	
$Hg^{2+} \Rightarrow CH_3Hg^+$	Methylmercury will form from a large number of biotic reactions in sediments and water—usually when organic carbon, nitrogen and phosphorus are available to stimulate microbiological growth. Under severely reducing conditions in sediments, sulfide formation is favored.	
$CH_3Hg^+ \Rightarrow Hg^{2+}$	Oxidation of methylmercury will proceed in aerobic waters and exposed lake sediments. Alkyl mercuries with longer chains will be less stable relative to methylmercury.	

Natural Sources of Hg – Geologically, Hg mostly occurs in volcanic deposits as solid minerals such as cinnabar, (mercuric sulfide [HgS]), with smaller amounts as minerals weathered from cinnabar and evaporites associated with hydrothermal groundwater deposits (Rytuba, 1995; United Nations Environment Program – UNEP, 2003). The weathering and erosion of these volcanic minerals and soils contributes to Hg entering surface waters. Volcanic eruptions and forest and range fires also represent a natural source of Hg to the atmosphere.

The natural abundance of Hg in the crust was estimated during the 1970s at 0.085 milligrams per kilogram (mg/kg), and in the ocean at 0.03 micrograms per liter (µg/L) (Nriagu, 1979). Degassing of Hg from continental sources has made the atmosphere an Hg reservoir, or compartment, with residence times estimated to range from 5.5 to 90 days. More recent modeling suggests atmospheric residence times of up to a year (Andren and Nriagu, 1979; UNEP, 2003). Subsequent wet and dry deposition from the atmosphere has in turn made the oceans a Hg reservoir with a residence time estimated at over 2,000 years (Andren and Nriagu, 1979). Thus, both oceans and continents act as natural Hg sources to the atmosphere.

Anthropogenic Sources and Emissions of Hg – While natural sources of Hg cannot be ignored, anthropogenic sources are now the dominant component of global Hg emissions (Nriagu, 1979; Nriagu and Pacyna, 1988; Nriagu, 1989; UNEP, 2003). Analysis and chronostratigraphy of lake sediments suggest that global Hg emissions have increased from 2 to 5 times precultural levels (Andren and Nriagu, 1979), so ongoing and historical human activity now contributes a significant proportion of total Hg emissions to the environment.

Hg has been known to and used by man for a long time, having been found in 3,500 year-old Egyptian tombs. Though the trend in developed countries has been to gradually eliminate the commercial use of Hg in products, it continues to be used in existing consumer products and industrial processes. Here are some common commercial uses:

- Thermometers, barometers, electrical switches, electrodes, scientific instruments, and thermostats containing liquid Hg are in widespread current use.

- A variety of Hg compounds (mercuric chloride, $HgCl_2$ and calomel, Hg_2Cl_2) were used medically as disinfectants and thimerosal is still used as a vaccine preservative. Silver amalgam is used for dental fillings.

- Organo-Hg compounds are being phased out, but were widely used as fungicides in paint and as pesticides and fungicides as late as the 1970s.

- Mercuric oxide (HgO) and amalgams of zinc and cadmium are used in dry-cell and alkaline batteries.

- Hg vapor is used in mercury vapor lamps and fluorescent and neon lighting.
- HgS is used in the paint pigment vermillion.
- The chlor-alkali process, where elemental Hg is used as the electrode in an electrochemical process to produce chlorine and caustic soda ash from brines, remains in use, though emission controls and phase-outs are now being enforced in developed countries.
- The amalgamation process, which polluted the Carson River Basin in the 19th century, is still widely used to remove gold and silver from ore in the developing world (UNEP, 2003).

Despite a significant decline in worldwide consumption of liquid Hg, it is still mined and produced in Spain, Italy, Kyrgyzstan, and Algeria, where between 24,700 and 30,600 metric tons (54.4-million to 67.4-million pounds [lb], 1 metric ton = 1,000 kilogram [kg]) were produced from 1981 to 2000. Additional quantities are recovered from mine tailings and smelter operations along with redistribution of Hg from phased-out industrial uses into the global commodity market (UNEP, 2003).

Historically, the industrialized northern countries contributed the bulk of Hg emissions through mining, smelting, and industrial chemical activities. Since the 1970s, however, awareness of the health risks posed by Hg have resulted in a shift in industrial processes and pollution abatement technology that have lowered Hg emissions in developed countries. At the same time, increased third world economic activity and energy demand has shifted Hg emissions to developing regions. Figure 1 shows 1995 summary data from the UNEP *Global Mercury Assessment*, of the proportions and amounts (in metric tons/yr) emitted by continent (left pie chart) and by economic activity (right pie chart).

The majority of today's anthropogenic emissions (around 2,200 metric tons/yr, 4.8 million lb/yr—1 metric ton = 1000 kg) are from the burning or heating of materials containing trace amounts of Hg. This source constitutes a worldwide "background" level of Hg deposition that will be unavoidable, and will contaminate even relatively pristine and remote watersheds. Combustion of fossil fuels, especially coal, is now the largest source (66.5 percent, 1,470 metric tons/yr) of global anthropogenic Hg emissions. Economic development and demand for fossil fuels in Asia, combined with poorly regulated stack emissions, will likely increase the amount of Hg from this category. As of 1995, Asia accounted for 56.3 percent of global Hg emissions; however, energy demand and Hg emissions in developed countries are also projected to increase with population in these regions.

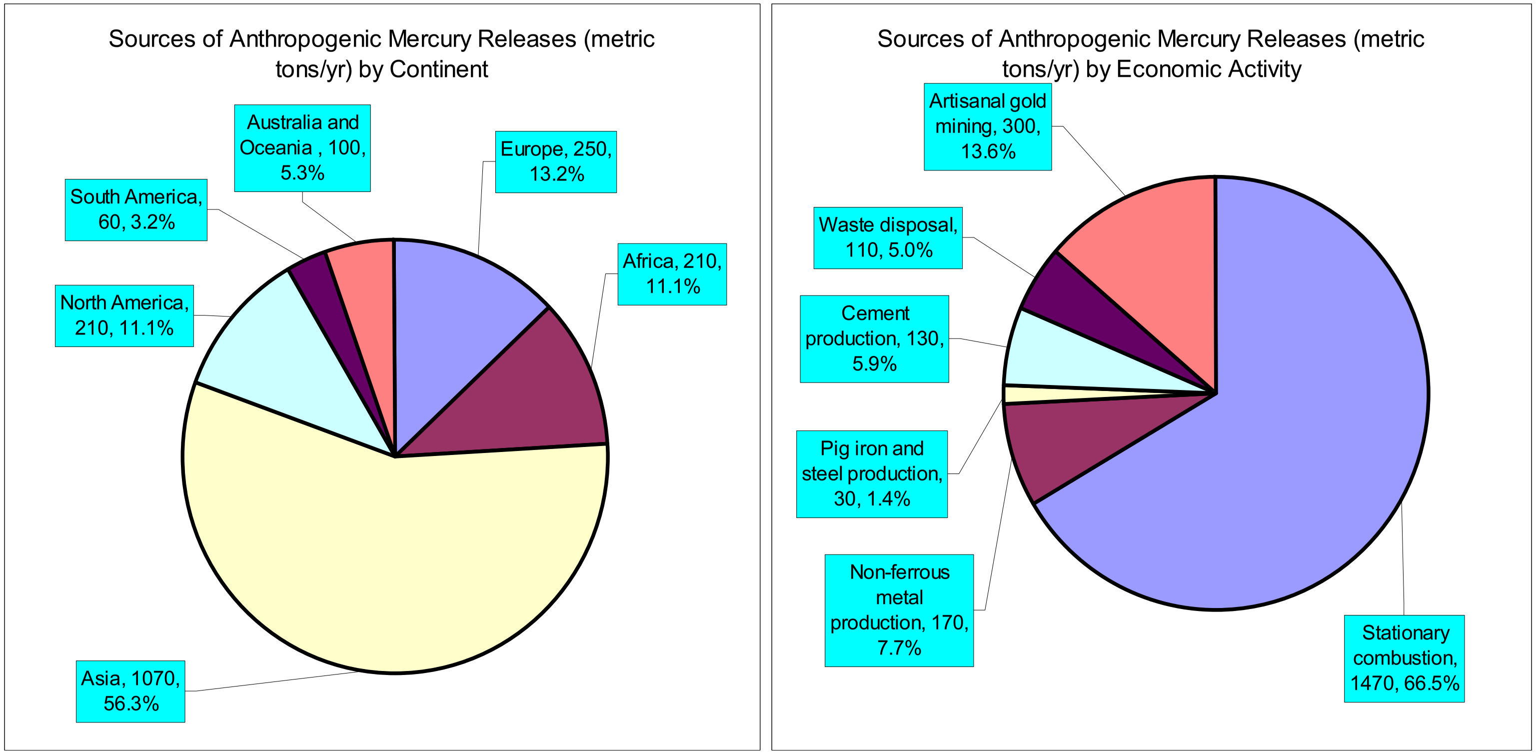


Figure 1.— Pie charts showing global anthropogenic sources of Hg released to the environment, in metric tons/yr, from 1995 estimates. The left chart shows releases and percentages by source continent, and the right chart show releases by economic activity (UNEP, 2003; Pirrone et al., 2001; Lacerda, 1997).

Artisanal gold mining (small-scale operations by prospectors) is the next largest Hg source (13.6 percent, 300 metric tons/yr), where liquid Hg is often used in the amalgamation process to remove gold and silver from ore. This type of mining and precious metal recovery, which was widely practiced in the American west during the 19th century, is now largely located in the developing world where this Hg source activity is projected to increase (UNEP, 2003). Historical mining is, by far, the largest continuing source of Hg emissions into the Carson River Basin.

The remainder of global Hg emissions are from metals smelting and processing (9.1 percent, 200 metric tons/yr), cement production (5.9 percent, 130 metric tons/yr), and waste incineration and disposal (5.0 percent, 110 metric tons/yr).

Fate and Transport of Hg in the Environment

The main features of the global Hg cycle are: emission into atmosphere, transportation, deposition, chemical and biological conversion, and recycling. A large part of the story of Hg behavior in the environment involves the recycling, or fluxes, between the storage compartments of atmosphere, land, water, and biota. These fluxes within and between compartments account for the persistence of Hg as a contaminant before it reaches final long-term sinks in deep ocean and lake sediments and the earth's crust (UNEP, 2003; Andren and Nriagu, 1979). Refer to the diagram in figure 2 showing a simplified version of the global Hg cycle.

After emission into the atmosphere, Hg and its species will be transported and then deposited from the atmosphere as wet or dry deposition. These Hg species, estimated to be > 95 percent as Hg^0 in the atmosphere (Ericksen et al., 2002), then adsorb onto soil particles, vegetation, and also enter surface waters. A portion of this deposition can re-enter the atmosphere as Hg gas or as adsorbed Hg on re-suspended dust (Sorensen et al., 1990), and directly repeat the emission, transportation, and deposition process. Gustin et al. (1994) reported atmospheric Hg concentrations at Lahontan Reservoir from 2.0 to 2.6 nanograms per cubic meter (ng/m^3) during October. These levels correspond to global background levels of 1 to 4 ng/m^3.

The role of plants and the flux of Hg between forests and atmosphere in the global Hg cycle has not been determined completely, but some research suggests that terrestrial plants may act as both a source and sink for Hg (Lindberg, 1996). Ericksen et al. (2002) recently suggest that foliage appears to be an effective adsorption sink for atmospheric Hg and that litterfall may represent an important source of Hg to terrestrial environments and surface waters. This work also suggests that most of the Hg remains in the elemental form within terrestrial foliage.

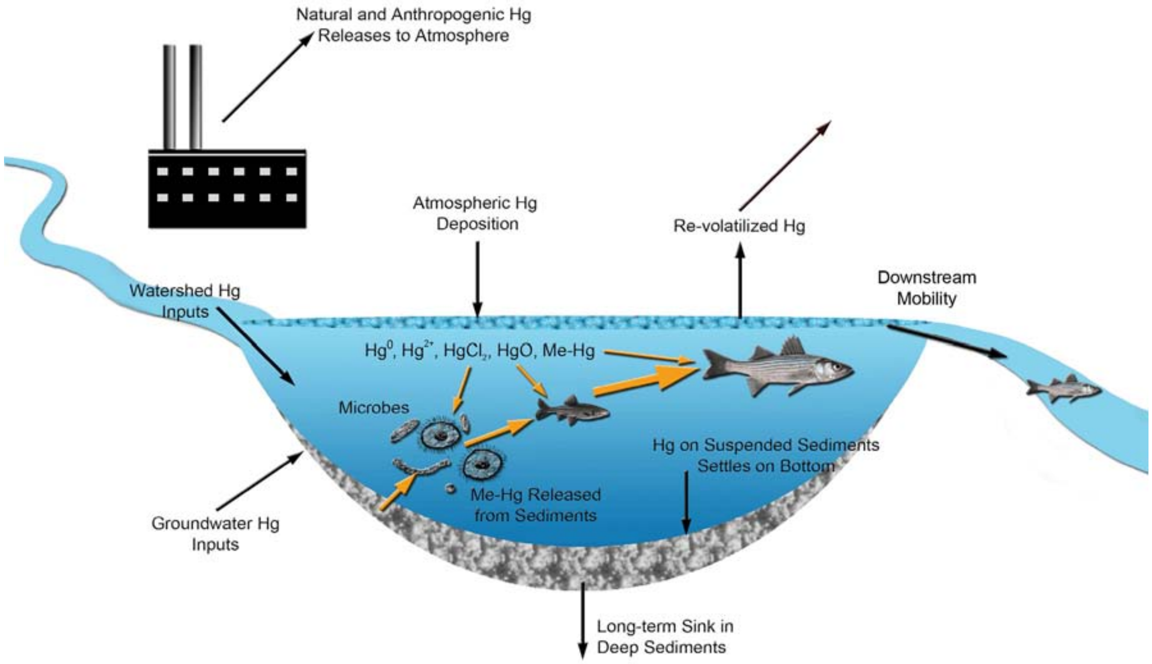


Figure 2.— A snapshot of part of the global mercury cycle showing atmospheric deposition of Hg species, conversion by microbes into methylmercury, and food chain bioaccumulation. Fish photos by Rene Reyes. Diagram by the authors.

Concern with the global Hg cycle begins when global background Hg is combined with local natural and anthropogenic Hg sources and enters freshwater systems (figure 2). Hg enters surface waters either directly from atmospheric deposition, through soluble species in local groundwater, or both soluble and adsorbed (particulate) forms from surface waters contacting Hg adsorbed on watershed surfaces. Worldwide, increased sedimentation from increasing erosion is a major component of adsorbed Hg inputs into streams and lakes (UNEP, 2003). Flood events will also mobilize particulate-adsorbed Hg in stream banks and soils (Lindberg et al., 1999). Some of the transported inorganic Hg will be converted to Me-Hg and enter the food chain while most will remain adsorbed to sediments. Dissolved and suspended forms of Hg will be mobile and will be transported downstream in water bodies. Recycling of Hg and Me-Hg will occur as organisms die and decompose releasing stored Me-Hg back into the ecosystem. Some of this Me-Hg will be oxidized and demethylated (via photo degradation and bacterial processes) and re-enter the global atmospheric Hg background (Oremland et al., 1995), while some will re-cycle through the food chain.

The transformation and transport, cycling within lakes, methylation, food chain bioaccumulation, and the Me-Hg sub-cycle are complex subjects and are covered in more detail elsewhere (Bloom, 1990; Jensen and Jernelöv, 1969; Zhang and Planas, 1994; Nriagu, 1979; Andren and Nriagu, 1979; Oremland et al., 1995).

Hg Methylation – Once Hg enters the aquatic environment, it readily enters the food chain when suspended particulate Hg species directly adsorb onto, or dissolved species (mostly containing Hg^{2+}) diffuse through, the cell membranes of bacteria, algae, and other unicellular microbes (either free-floating in water or in the upper layers of bottom sediments) (figure 2). Sulfate reducing bacteria are currently thought to be the dominant contribution to methylation in sediments (Oremland et al., 1995). Abiotic methylation in soils and sediments has also been reported (Rogers, 1977), but most methylation occurs via biotic processes.

Once inside the cell, inorganic forms of Hg can be bound and methylated by all trophic level organisms (Zhang and Planas, 1994; Beijer and Jernelov, 1979; Wiener and Spry, 1996). It appears that the proportion of Me-Hg in aquatic organisms increases from primary (microscopic) producers to fish (Watras and Bloom, 1992; Francesconi and Lenanton, 1992). For a more detailed review of the biochemistry of Hg in living organisms, refer to Carty and Malone (1979).

One of the biggest problems with Hg contamination is that methylation and bioaccumulation can occur in waters with very low total Hg concentrations (on the order of < 10 nanograms per liter (10 ng/L = 0.010 µg/L) where enough organic carbon is present to support microbial activity (Grieb et al., 1990; Craft et al., 2000; Weiner and Spry, 1996). Environmentally, methylation is favored by the same conditions that favor microbial growth: warmth, presence of nutrients, and time for incubation. This implies that the inflow deltas, shallows, and littoral zones of lakes and reservoirs, wetlands, or the hyporheic sediment zone and innundated banks of streams will provide an environment conducive to methylation. This process will be enhanced for shallow and more stagnant lakes with high productivity (eutrophic waterbodies having algal blooms). Methylation is also more active in lakes during summer when water temperatures are higher and predator fish are more active.

It also appears that general mobilization of Hg and methylation will be encouraged when new reservoirs or rainfalls flood soils, or existing reservoir fluctuations re-wet Hg-containing sediments exposed by previous water releases (Hecky et al., 1991; Jackson, 1991; Verdon et al., 1991; Lindberg et al., 1999). Riverbank erosion and sediment transport during spring runoff are also going to mobilize Hg and provide reactants for methylation processes (Miller et al., 1995, 1998, 1999). Most Reclamation reservoirs experience these conditions, and many, such as Lahontan Reservoir, also have inflow deltas and wetlands that encourage methylation.

Another potential methylation opportunity common to Reclamation water resources is reservoir stratification during summer and winter. During stratification, water near the bottom (the hypolimnion) becomes depleted of dissolved oxygen by bacterial respiration and a lack of mixing with oxygenated surface waters (the epilimnion). As these conditions persist methylation can occur. While fairly shallow as a lake, the lower (northern) basin of Lahontan Reservoir is known to stratify during summer.

Hg Bioaccumulation – As microbes containing Hg and Me-Hg are consumed in the aquatic food chain, the Hg bioaccumulates and biomagnifies, up the food chain into commercial and sports fish as well as aquatic birds and wildlife (Eisler, 1987; Tuttle and Thodal, 1998). Fish can ingest Hg and Me-Hg directly across the gills, as well as through diet. Uptake rates of Me-Hg in food vs. diet will vary with time of year and species (Post et al., 1996; Cech Jr. et al., 2003); however, most of the bioaccumulation of Me-Hg in planktiverous and predator fish species is though food (Philips and Buhler, 1987; Weiner and Spry, 1996), and almost all of the body burden of Hg remains as Me-Hg in fish tissues (Bloom, 1990; Henny et al., 2002). Because humans form the top trophic level in the food chain, they are especially vulnerable to Hg exposure from fish and waterfowl consumption.

Toxic Effects of Hg

While inorganic forms of Hg are toxic, Me-Hg is much more toxic and is a more widespread human health threat because of bioaccumulation in fish and wildlife. Almost all human exposure to Me-Hg is from consumption of fish (Wiener and Spry, 1996). This is especially true for specific populations whose diets are dominated by fish and seafood.

Human Health Effects – Besides industrial accidents and acute poisoning of workers (usually involving elemental Hg vapor exposure), the most notable recent Hg poisonings of human populations occurred in Japan and Iraq and involved Me-Hg exposure from food. From the early 1950s through the early 1970s, Me-Hg pollution from a chemical plant making acetaldehyde bioaccumulated in fish and shellfish in Minimata Bay, Japan. Minimata residents were poisoned when they ate the local seafood, a staple item in their diet. There were 78 fatalities and over 59 percent of the local population suffered neurologic damage and other serious symptoms (Irukayama, 1966). In 1972, around 6,500 rural people in Iraq were poisoned from eating bread made from seed grain coated with Me-Hg as a seed treatment fungicide. This poisoning resulted in 459 reported fatalities as well as large numbers of neurological symptoms and birth defects (UNEP, 2003).

Fat-soluble Me-Hg directly attacks the nervous system. These two poisoning incidents caused significant neurotoxic effects that were caused by direct brain atrophy (cystic cavities and spongy foci) and nerve damage (peripheral neuropathy). These primary atrophies led to symptoms such as ataxia (inability to coordinate movement), blurred vision, impaired hearing, dysarthria (slurred and slow speech), paresthesia (tingling, numbness or itching in the extremities), along with headaches, arthritic pain, and seizures (UNEP, 2003). Because the fetal central nervous system is even more sensitive to Me−Hg, and Me-Hg readily crosses the placenta, infants exposed to Me-Hg during pregnancy developed cerebral palsy-like birth defects (microcephaly, hyperreflexia, gross motor and mental impairment, sometimes associated with blindness or deafness), altered muscle tone and deep tendon reflexes, and showed delayed developmental milestones (Harada, 1995; Takeuchi and Eto, 1999).

Besides the neurotoxic and teratogenic effects, Hg also causes damage to other organs including the respiratory system (interstitial, or pulmonary connective tissue pneumonitis), the kidneys (glomerulonephritis, proteinuria, nephrosis, and renal swelling), the cardiovascular system (anemia and micronuclei in peripheral lymphocytes, strokes and other ischemia, and tachycardia), and the digestive system (stomatitis and other mucosal inflammations) (Takizawa, 1979; Skerfving, 1991; UNEP, 2003).

Public Health Responses to Hg – In recognition of the public health danger from eating quantities of fish containing elevated levels of Me-Hg, the U.S. Environmental Protection Agency (EPA), established guidance and procedures for analyzing and evaluating Hg in fish tissues. The EPA currently recommends that public fish consumption advisories be issued when tissue concentrations exceed 0.6 milligrams per kilogram (mg/kg) (EPA, 1993, 1994a). The U.S. Food and Drug Administration (FDA) has established action levels of 1.0 mg/kg in fish and 3.6 mg/kg in edible duck tissue (FDA, 1984).

Since most of the Hg in contaminated fish and wildlife is Me-Hg, the EPA and FDA guidance and action levels are based on wet-weight total Hg analysis results. One 8-ounce (oz) (227-g) meal of fish per week contaminated at the 0.6 mg/kg EPA guideline would expose a person to 136 µg/wk of Hg. For a 50-lb (22.7-kg) child this would represent a dose of 6 micrograms per kilogram per week (µg/kg/wk) while a 150-lb (68.1-kg) adult would ingest 2 µg/kg/wk from fish at the EPA guideline level.

More recently, a joint United Nations committee of the Food and Agriculture Organization (FAO) and World Health Organization (WHO) recommended that the guideline for Me-Hg ingestion dosage be lowered from 3.3 to 1.6 µg/kg body weight per week to protect the developing fetus (UN-FAO/WHO, 2003). Based on these recommendations, a 120-lb (54.5-kg) woman who eats one fish meal per week should reduce consumption if the fish has more than 0.4 mg/kg Hg in tissue. Most fish consumption advisories will conservatively recommend that pregnant women and small children avoid eating any contaminated fish.

In 1994, the Nevada State Health Division (NSHD) issued a fish consumption advisory for fish caught in Carson River below Lahontan Dam and all waters in Lahontan Valley (Sagouspi Dam, Rattlesnake Reservoir, Stillwater Refuge, Sheckler Reservoir, Harmon Reservoir, and Indian Lakes Camp) (NSHD, 1994). The health advisory suggests:

- No one should eat more than one meal (8 oz) per week of fish caught from these waters.
- Children under age 12 should not eat fish from Lahontan Valley waters.
- Children 12- to 15-years-old should eat no more than one four ounce meal per week of fish caught from these waters.

- Pregnant women, nursing mothers and women who may soon become pregnant should not eat fish from Lahontan Valley waters.

Toxic Effects of Hg on Fish and Wildlife – Mortality is not usually observed in wild fish exposed to ambient levels of Hg, even in systems having Hg sources in the watershed. Bioassay data suggest that acute exposure levels of Me-Hg and $HgCl_2$ between the 0.010 µg/L water quality standards and 1 µg/L, have caused behavior changes, histological responses, reduced development, growth, and survival, and reproductive impairment (Weiner and Spry, 1996). Neurotoxic effects have been observed in fish experiencing prolonged dietary uptake and accumulation of Me-Hg. Symptoms included incoordination, inability to feed, and diminished responsiveness. Me-Hg poisoned fish from Minimata bay were sluggish, emaciated, moved abnormally, and also had brain lesions (Wiener and Spry, 1996; Takeuchi and Eto, 1999).

Long-term effects of dietary Me-Hg exposure on 1-yr-old walleyes was studied by Scherer et al. (1975). Fish fed food containing around 8 mg/kg Me-Hg (analyzed and reported as total Hg) showed pronounced behavioral impairment and significant mortality after 42 days compared to control fish fed food containing 0.41 mg/kg Me-Hg. Cumulative mortality was 88 percent in the high exposure group and 27 percent in the low exposure group over 314 days. Armstrong (1979) noted that fish can apparently carry fairly high Me-Hg levels – enough to cause an ill effect in humans who eat such fish – but that above 10 mg/kg bioaccumulated Hg, very few live fish are found.

Birds and mammals experience similar toxic effects from Me-Hg intoxication to humans noted above in the Minimata and Iraq poisoning tragedies (Thompson, 1996). Levels of concern for fish have been reported at tissue concentrations of 0.17 mg/kg, and adverse effects on reproduction and survival have been reported at 0.62 mg/kg (Tuttle and Thodal, 1998). In birds, Heinz (1979) reported reproductive and behavioral effects in mallard ducks when the avian diet exceeded 0.4 mg/kg Hg, egg concentrations exceeded 0.83 mg/kg, and liver concentrations exceeded 4.3 mg/kg (all concentrations are dry-weight). Kidney lesions were seen in starlings when liver concentrations exceeded 1.3 mg/kg Hg (Nicholson and Osborn, 1984). More detailed information on Hg and its effects on fish and wildlife are summarized elsewhere (Eisler ,1987; Wiener and Spry, 1996; Armstrong, 1979; Thompson, 1996).

Specifying Chemical Tests and Methods for Hg in Environmental Samples

This section provides a primer on some of the technical issues surrounding analysis of Hg in water, sediments, and other media. Very few environmental analyses present the kinds of complications and problems as those associated with Hg and Me-Hg sampling and analysis for waters. The appendix 1 Glossary contains definitions of many terms used in this section.

Some Terms from Hg Analysis and Water Quality Regulations – Hg concentrations in water analyzed before the early 1990s often reported detection limits of 0.1 µg/L or higher, and almost all pre-1990s Carson River Basin data were reported "less than" or very near comparable detection limits. In the 1980s, however, researchers began discovering that Hg was present at significantly lower concentrations in water as more reliable analytical methods, sample collection, and laboratory contamination mitigation procedures were developed and followed (Gill and Fitzgerald, 1987; Bloom, 1989, 1990; Bloom and Horvat, 1995). In respose to toxicological research and improved analytical test methods, regulated concentrations for Hg were generally lowered and aquatic water quality standards adopted by most states are currently around 0.010 µg/L (10 ng/L) as *total Hg*. The Nevada Environmental Commission (NEC, 1991) has established regulated Hg concentrations of 0.012 µg/L (12 ng/L) for aquatic life, 2 µg/L (2,000 ng/L) for municipal or domestic water supplies, and 10 µg/L (10,000 ng/L) for watering of livestock.

Total Hg in water quality standards usually refers to an unfiltered (or raw) water sample that is digested or treated to liberate all suspended forms of Hg. The digestion or treatment should also convert all (or mostly all) dissolved Hg species into a single form for analysis—usually Hg^0, elemental Hg. Any water sample, however, can be analyzed for total Hg, and a result reported as "total" may actually be less than "all Hg" depending on the digestion method followed. The term *total recover*able usually refers to a digestion method that does not dissolve all the analyte from the sample matrix. In this report we will use "total Hg" to mean "all Hg species" and specify whether the sample is *filtered* (through a 0.45-µm filter, often called *dissolved*), or *unfiltered* (raw). Suspended Hg can then be calculated by subtracting filtered from unfiltered. Me-Hg data will be similarly treated.

Expected Concentrations in Surface Waters – While local pollution outfalls or mine drains may have elevated total Hg concentrations above 1 µg/L, naturally occurring levels are usually much lower. In uncontaminated or pristine surface waters, unfiltered total Hg has been reported to range from 0.6 to 4 ng/L—the Truckee River at Derby Dam contained 4.4 ng/L in October 1992 (Wayne et al., 1996)—and in watersheds containing sources of Hg, from 5 to 100 ng/L. Me-Hg concentrations typically range two orders of magnitude less than total Hg, from 0.01 to 0.8 ng/L (Wiener and Spry, 1996) in systems exposed to only natural background Hg deposition.

An example of concentrations pertinent to the Carson River Basin is found in a recent study of Lake Owyhee (Craft et al., 2000), a Reclamation reservoir in eastern Oregon located in a watershed containing both natural sources of Hg (extensive volcanic geology), historical mining (Silver City, Idaho), and where the Oregon State Department of Public Health issued fish consumption advisories because of elevated levels of Hg in sports fish.

In the Lake Owyhee study, the highest observed unfiltered total Hg, measured on the reservoir inflow zone during spring runoff, was 140 ng/L (0.140 µg/L). Average concentrations for unfiltered total Hg ranged from 19 to 50 ng/L. Unfiltered Me-Hg ranged from 0.022 to 2.45 ng/L and filtered Me-Hg from < 0.009 to 0.308 ng/L. Chemical equilibrium modeling with the MINTEQA2 program (Allison et al., 1991) using average Lake Owyhee data suggest that 86.3 percent of total Hg is suspended, and dissolved inorganic Hg forms (mostly aqueous $Hg(OH)_2$) account for 12.7 percent of total Hg. Suspended Me-Hg (0.66 percent of total Hg), is about twice dissolved Me-Hg (0.35 percent of total Hg). The implication from the Owyhee study is that around 80 percent of total Hg and around 60–70 percent of Me-Hg is associated with suspended particulates. These results will vary depending on the size distribution of sediments in a watershed and the magnitude of runoff flows.

Ultra Clean Sampling Procedures for Water – The concentrations for dissolved Hg species in surface waters, especially Me-Hg (often < 1 ng/L), are exceedingly low and underscore the need for strict contamination prevention measures during sample collection, preparation, and instrumental analysis. The currently accepted practice for collecting water samples for low concentration Hg, EPA method 1669 (EPA, 1996c), requires field contamination prevention techniques. Field samplers should use disposable clean-room gloves with the 2-person “clean hands – dirty hands” method (figure 3), where the sample is handled only by the “clean hands” gloves, and the sample is sealed inside a ziplock bag after collection. Only certified and traceable ultra-clean sample bottles and subsurface samplers should be used, and trip blanks obtained from the analytical laboratory should be submitted with samples. Field filtration is not recommended and should be performed in the laboratory where clean room standards and statistical blank correction procedures are strictly followed. Samples cannot be preserved, as this can cause contamination, so they must be shipped to the analysis lab by overnight delivery on ice at ~ 4 °C.

Sediment Concentrations – Gustin et al. (2000a) suggested that sediments with total Hg less than 0.1 µg/g (100 µg/kg, dry-weight) are indicative of natural Hg enrichment from uncontaminated watersheds. Sediment samples from the Lake Owyhee study showed minus-80 mesh (< 178 µm) dry weight total Hg ranging from 152 to 410 micrograms per kilogram (µg/kg) and Me-Hg ranging from 2.39 to 5.35 µg/kg. Wet weight sediment concentrations ranged from 69.3 to 178 µg/kg for total Hg and 1.14 to 2.48 µg/kg for Me-Hg. These data suggest that Me-Hg accounts for around 1.3 percent of sediment total Hg. These sediment Hg concentrations are also around *two orders of magnitude* lower in concentration compared to other sediment trace element concentration averages (chromium = 20,900 µg/kg, copper = 49,100 µg/kg, lead = 11,900 µg/kg) (Craft et al., 2000).

Tuttle and Thodal (1998) summarized levels of concern and effect for sediment Hg concentrations based on bioassay exposure data. The sediment level of concern was 150 µg/kg (0.15 mg/kg), and the effect level was 1,300 µg/kg (1.3 mg/kg), both values on a dry-weight basis (Long and Morgan, 1991). Wet weight data will usually be around 40 to 60 percent of dry weight values.

Figure 3.— Clean-hands/dirty-hands sampling of water for low concentrations of Hg and Me-Hg. The clean-hands (person, on the left) touches the Teflon sample bottle. The dirty-hands person (right) only handles the plastic bag which is sealed before shipping.

Sediment samples, where the amount of Hg is much higher than in water samples, do not require extreme contamination minimization measures or very low detection limits; however, good practice cleanliness is always appropriate for personnel and containers during any trace analysis sampling. Because of the heterogeneous nature of sediments, representative samples should be collected. Multiple sediment sub-samples should be collected at each sampling station around the boat using an Eckman dredge or Ponar sampler. These subsamples may be transferred to plastic containers, and a fractional spooning technique (Pitard, 1993; Ramsey, 1998) may be used to collect a small and representative composite station sample for Hg analysis.

Fish and Biological Tissue Samples – The EPA recommends that fish consumption advisories be issued when whole-fish Hg concentrations exceed 0.6 mg/kg (wet weight basis) (EPA, 1993, 1994a), and the FDA (FDA, 1984) has established an action level of 1.0 mg/kg (wet weight basis) for fish muscle and 3.6 mg/kg (wet weight basis) for edible bird tissue (muscle, liver, skin). The EPA has published guidance for collection, preparation, and analysis of fish tissues for Hg fish consumption advisories (EPA, 1993, 1994a).

Collection of fish for Hg analysis should be coordinated through local state wildlife and public health agencies, as the local requirements may be different from EPA recommendations with respect to numbers of fish and representativeness with respect to number of species, as well as analytical method. Field crews should be experienced or certified in the application of electrofishing or netting techniques, and appropriate safety regulations must be followed by researchers collecting fish. Field crews should ensure that each fish collected is identified, photographed, weighed (to 0.1 g), and measured (for total length and fork length) at the time of sampling. Also, any behavioral anomalies, signs of illness, or injury should be noted.

Quality Assurance and Contract Laboratories – Regardless of chosen analytical method or contract lab, it is very important to develop data quality requirements based on the planned use of the data and to tailor laboratory selection, detection limits, and quality assurance reporting requirements appropriately. The lab should operate with a quality plan and be able to provide a quality control report with the data. Preferably, the lab should be visited, audited, and evaluated using blind performance check samples prior to collecting or submitting samples. The lab should also participate in performance evaluation programs, or “round-robins” where they regularly analyze unknown samples with performance scored by an impartial entity (the U.S. Geological Survey [USGS] maintains such a program). After receiving the data, it should be reviewed and “validated” by a chemist or someone familiar with interpretation of quality control information.

Detection Limits – What are They? There is general confusion about reported detection limits and what they represent, and the definition can often vary from lab to lab. Sometimes, a lab will advertise a detection limit based on the lowest reliable signal the detector can read in a clean sample or deionized water. This is called an *instrument detection limit* (IDL), and is a judgement by the analyst of signal to noise ratio in the detector signal.

The problem is that most real world water samples have other inorganic and organic compounds in the water along with suspended sediments and biota—called the *matrix* of the water sample. A water sample with a complex matrix can increase the “real” detection limit, sometimes significantly. Also, Hg analysis methods usually specify sample preparation (homogenization, subsampling, filtration, digestion), and each of these steps in the analysis process introduce the opportunity for error and loss of analyte. For this reason, it is important to know if the lab’s advertised detection limit is based on the whole sample preparation process *and* instrumental analysis, called a *method detection limit* (MDL).

Taylor (1987) and EPA (1986) recommend that detection limits be based on analysis of replicate subsamples (from 7 to 21 replicates) containing the analyte of interest and the *standard deviation* (*s*) calculated from the analysis results. The philosophy here is that you cannot honestly detect concentrations that are below the variability or noise seen with real sub sample replicate values. Taylor (1987) defines the *limit of detection* (LOD) as 3-times *s,* and the *limit of quantitation,* (LOQ), as 10-times *s*. These statistically-based detection limits are especially useful when data must be legally defensible or decisions obligating significant resources are to be based on the data.

A general rule is that you have to know the Hg concentration that needs to be met for your samples, and whether the detection limit applies to the whole sample treatment and analysis process. For example, if there is water quality criteria of 10 ng/L (0.010 µg/L) then the lab's MDL for your type of samples should be in the range of 3 to 4 ng/L for you to be statistically sure the data are above the criteria. Also, consider requesting very low detection limits if the data are going to be used to establish total maximum daily load (TMDL) values or calculate flow-weighted mass loadings of Hg.

Recommended Analysis Methods – Analytical methods that should be specified will vary with the required detection limits. Elevated levels in water (> 1 µg/L) or sediments may be analyzed by cold-vapor atomic absorption spectrophotometry (CVAA—EPA Method 245.1 or 245.2, *Standard Methods* 3112B) (EPA, 1983; American Public Health Association, 1998) or inductively-coupled plasma-mass spectrometry (ICP-MS—EPA Method 200.82) (EPA, 1994b).

Total Hg analyses in water below 0.1 µg/L should specify EPA Method 1631, "Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluoresence Spectrometry" (Bloom, 1996; EPA, 1996b). This method involves oxidation of the sample using bromine monochloride (BrCl), subsequent stannous chloride ($SnCl_2$) reduction, purging the volatilized Hg onto a gold trap and then thermal desorption followed by detection with CVAFS. Analysis of Me-Hg should be performed using the Frontier Geosciences method (Bloom, 1989) or current consensus method. This method uses distillation extraction followed by aqueous phase ethylation, separation by cryogenic gas chromatography and detection with CVAFS.

If total suspended solids (TSS) data are needed to accompany the Hg in water results, do not request the EPA 160.1 method (EPA, 1983) for "Residue, Filterable." This test is intended for water treatment plants where solids are usually bigger and uses a glass fiber filter medium with a pore size of 1.0 µm. Instead, request that TSS be determined using a 0.45-µm filter disk. This advice also applies if you need to collect suspended materials or detritus and analyze them for Hg.

Other consensus methods published by the American Society for Testing and Materials (ASTM), the USGS, or the International Organization for Standardization (ISO) may have to be specified for analysis of Hg in other media such as rock, paints, transformer oils, construction materials, or plant tissues. The U.S. Fish and Wildlife Service Laboratory in Columbia, Missouri, has extensive experience analyzing plant and animal tissues. Refer to the National Environmental Methods Index at <http://www.nemi.gov/> for a convenient information resource on analytical methods. While there are many analytical contract labs that can meet regulatory detection limits for total Hg, the number capable of analyzing total Hg at very low levels (< 10 ng/L), and Me-Hg are limited.

CARSON RIVER BASIN OVERVIEW

Physiography, Hydrology, and Geology

Maps and Geographic Information System (GIS) – The Carson River Basin is shown in the figure 4 topography and feature map, and the figure 5 geology map. These maps are printed output from a GIS data base containing geospatial data specific to the Carson River Basin from several sources. The GIS shape files specific to the region is available on CD-ROM directly from the authors.

Most of the GIS map base data were obtained from the Reclamation Mid-Pacific Region (Reclamation, 2004c) and the Environmental Systems Research Institute (ESRI, 2004), including watershed boundaries, roads, counties, land ownership, urbanized areas, lakes, and the digital elevation model hill-shade base layer. River layers were obtained from the USGS National Atlas of the United States (USGS, 2004c). Additional geospatial information and data layers were obtained from the U.S. Department of Agriculture (USDA, 2004). In some cases, data were converted to standard coordinates (UTM Zone 11 north, NAD 27) for this project from native coordinate systems, and GIS data were displayed and manipulated using the full version of ArcGIS, version 8.3.

Previously collated geology layers and coverages were also obtained from the Mid-Pacific Region (Reclamation, 2004c). The geology map coverages across state borders were adjusted using data avalible from the University of Nevada, Reno (2004) and the Nevada Bureau of Mines and Geology (NBMG, 2004). The Nevada geology layers were attributed to coincide with California's date and rock-origin legend, so that each rock type now displays both. This process was completed for the greater Lake Tahoe region (not the entire state of Nevada). Metadata for all layers are available by contacting the authors.

The Carson River Basin begins approximately 17 mi (28 km) due south of Lake Tahoe at a portion of the Sierra Nevada divide that runs from Luther Pass (7,735 ft) to south of Carson Pass (8,560 ft, m). Originating on the leeward side of the Sierra Nevada divide, the Carson River Basin extends to the northeast around 160 miles (260 km) into the Carson Desert to the north and east of Lovelock, Nevada. Much of the lower elevations of this basin were once lake bottom for Lake Lahontan, a large Quatenary pluvial glacial melt lake that covered a large area of western Nevada during the most recent Ice Age. Pyramid Lake and Walker Lake remain as remnant lakes from this large waterbody (Orndorff et al., 2001; Fiero, 1986).

The basin is hydrologically divided into three sub basins, the Upper Carson, the headwater region, the Middle Carson, location of Lahontan Reservoir, and the Carson Desert, where flows from the Carson River are diverted into several canals terminating in wetlands areas where the water either evaporates or seeps into the aquifer below the Carson Sink. A large portion of the Carson Desert was covered by a shallow lake (Carson Lake) prior to the construction of Lahontan Dam.

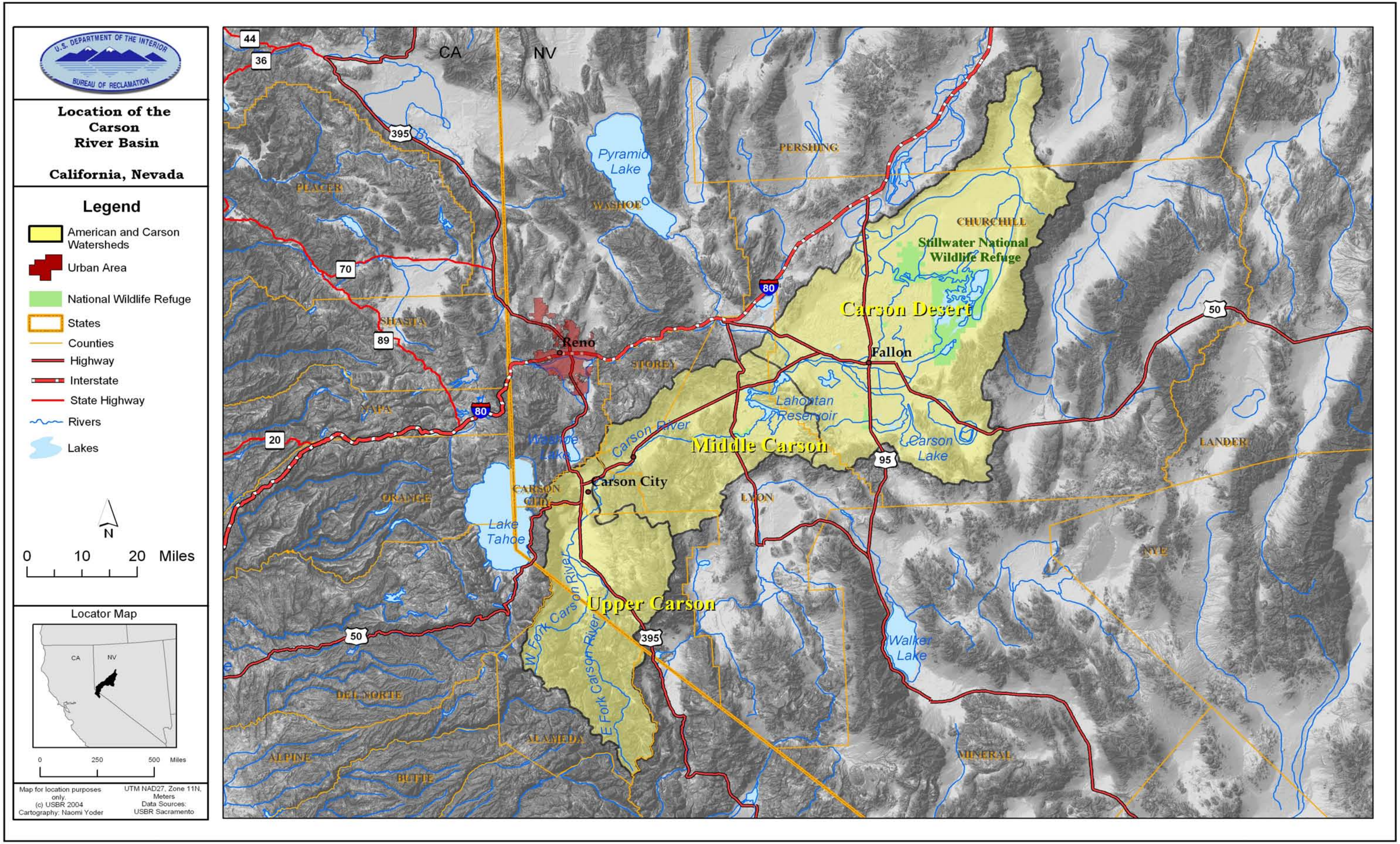


Figure 4.—Map of the Carson River Basin showing general features

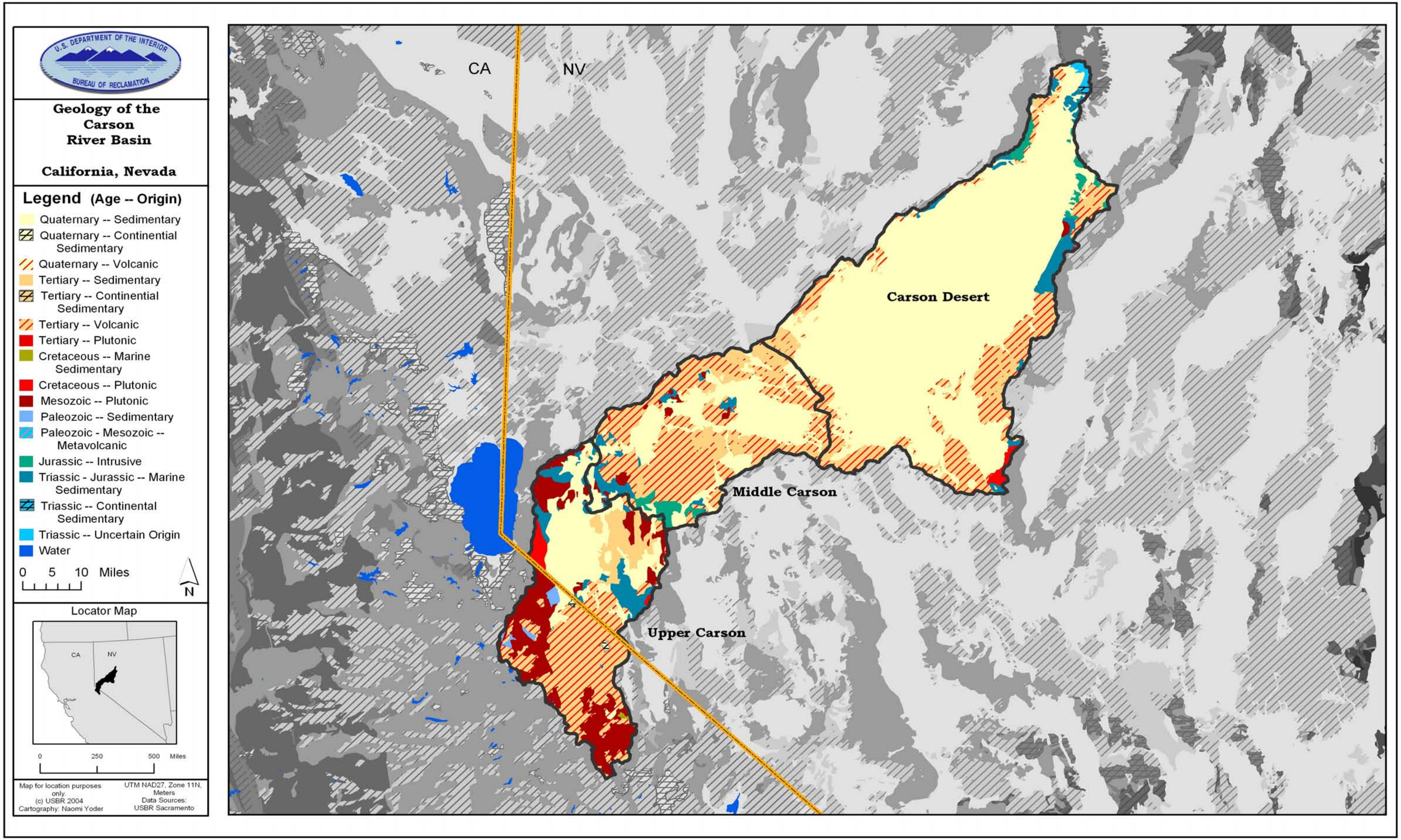


Figure 5.—Map of the Carson River Basin Showing general geological deposits and rock types.

Upper Carson Sub Basin – The Upper Carson Sub Basin, USGS hydrologic unit code (HUC) 16050201, covers an area of approximately 1,090 mi^2 (2,820 km^2) along the border of California and Nevada south and east of Lake Tahoe. Around 52 percent of the surface area of this sub basin is above elevation 5000 ft (1520 m). Headwaters of the Carson River system are in Alpine County, California, with elevations ranging from 7500 ft (2300 m) at the passes to several peaks over 10,000 ft (3050 m). The highest elevation is volcanic Highland Peak (10,935 ft, 3333 m) located in the southern highlands east of Ebbet's Pass (8732 ft, 2662 m) near California Highway 4. Figure 6 shows the Carson River near Genoa, Nevada, an Upper Carson Sub Basin area above Carson City where Hg is fairly low and water quality is comparatively good. This point on the river is a few km downstream from the confluence of the East and West Forks of the Carson River, the two upland tributaries of the Carson River.

Figure 6.— The Carson River near Genoa, Nevada, looking north. This Upper Carson Sub Basin site is several km below the confluence of the East and West Forks of the Carson River, and Hg levels are fairly low here. Reclamation photo by Doug Craft.

The Carson Range forms the western boundary of the Upper Carson Sub Basin with a trio of California mountains: Job's Peak (10,633 ft, 3241 m), Job's Sister (10,823 ft, 3299 m), and Freel Peak (10,881 ft, 3317 m), forming the upper elevations. The eastern boundary of the Upper Carson River Basin is formed by the Pine Nut Mountains, ranging in elevation from 8000 to 9000 ft (2440 to 2740 m).

Highest elevation terraines in the Upper Carson Sub Basin are dominated by intrusive Tertiary plutonic rocks, including granodiorite, granites, and gabbros (figure 5 geology map). These Tertiary igneous intrusions also appear less extensively along the northeastern boundary of the Upper Carson River Basin. At lower southern highland elevations, Tertiary rhyolitic and tuffaceous volcanic rocks are widespread. These volcanic rocks and their associated hydrothermal groundwater systems represent a natural source of Hg to the Carson River (Fischer and Gustin, 2002). Once elevations are below 5000 ft (1524 m) in the Carson River valley, the geology is primarily composed of Quaternary sedimentary deposits, mostly weathered volcanic materials, lake sediments, and evaporite deposits, with older Tertiary sedimentary and marine sedimentary rock in the northeastern portions of this sub basin (Stewart, 1980; Hill, 1975).

A notable pollution point source in the Upper Carson Sub Basin that drains into the East Fork of the Carson River is the Leviathian Mine, an abandoned open-pit sulfur mine operated from 1951 through 1962 by the Anaconda Mining Company. Runoff from this site, which produces acid mine drainage and associated toxic metal pollution, enters the Carson River 9 miles downstream from the mine. Leviathan Mine was listed as a Superfund cleanup site by the EPA in 2000, and remedial activities are continuing at this site (EPA, 2004a, 2004b; Thomas and Lico, 2000). This area, including East Fork tributaries Cottonwood, Leviathan, Poison, Barney Riley, Bryant, and Mountaineer Creeks, is also a reported source of Hg to the Upper Carson Sub Basin (Fischer and Gustin, 2002).

The Carson River Superfund Site – The northern boundary of the Upper Carson Sub Basin is formed by the Flowery Range, with peaks ranging from 6000 to 7000 ft (1830 to 2130 m). The Flowery Range is notable for the Comstock Lode and Virginia City (elevation 6220 ft, 1896 m), location of the gold rush and extensive lode (underground) mining, milling, and refining operations in the late 19th century (figures 7a and 7b). It has been estimated that as much as 200,000 flasks (15-million lb, 6.8-million kg) of Hg were released during Comstock Lode mining in near Virginia City, Nevada, and milling and amalgamation in the Brunswick Canyon mills from 1859 to 1895 (Richins and Risser, Jr., 1975; Cooper et al., 1985). While no longer a primary source area for the Carson River, storm flood events may contribute Hg inputs that are transported to areas downstream from Dayton, Nevada, to Lahontan Reservoir (Miller et al., 1999; Henny et al., 2002).

Figure 7a.— Tailings piles around Virginia City, Nevada, site of the famous Comstock Lode gold and silver strike in the late 19th century. Reclamation photo by Doug Craft.

Figure 7b.— An example of abandoned mining equipment near Virginia City, Nevada. Reclamation photo by Doug Craft.

Figure 7c.— The Carson River above Lahontan Reservoir at the Fort Churchill USGS streamflow gage and sampling station. This location, around 40 km downstream from Dayton, Nevada, is at the northern end of the Carson Plain. This area of the Carson River Valley received the bulk of the sediment Hg contamination from gold and silver refining operations and is now the primary source of Hg to Lahontan Reservoir and the Carson Desert. Some of the highest basin Hg concentrations have been observed at this location. Reclamation photo by Doug Craft.

This extensively mined area and the previously transported sediments that covered the Carson River Valley downstream from Dayton is now a part of an EPA Superfund Cleanup Site (EPA, 2004c). Even though the geographic extent of the Carson River Superfund site is large, extending from mill tailings in the uplands around Dayton, through the Carson River Valley, and finally to the Carson Sink, only relatively minor remedial actions (soil removal) have been implemented around personal residences in Dayton and Silver City, Nevada, and a municipal park in Dayton.

Middle Carson Sub Basin – U.S. Highway 50 eastbound meets the Carson River at the town of Dayton, Nevada, (elevation 4440 ft, 1341 m) which marks the transition from the Upper to the Middle Carson River Basin, USGS HUC 16050202. The area around and downstream from Dayton received a tremendous volume of Hg-contaminated sediment runoff from Comstock Lode refining operations located along the Carson River and other local streams. Runoff and flood erosion contributed to deposition of a layer of sediment approximately 1 m on top of the original Carson River floodplain (Miller et al., 1998) that covers most of the Carson Plains starting approximately 7–8 miles (11–12 km) downstream from Dayton. Before construction of Lahontan Dam, lesser amounts of contaminated sediments were also transported into the Carson Desert Sub Basin. These sediments contain elevated concentrations of mercury and other toxic metals along with organic materials from vegetation and decay washed down into the floodplain (Miller et al., 1995, 1999; Hoffman and Taylor, 1998; Hoffman and Thomas, 2000). Figure 7c shows the Carson River at Fort Churchill, Nevada, the location of a USGS streamflow gaging and water sampling station—a site that has seen some of the highest observed Hg concentrations in the Carson River Basin.

The EPA has funded a considerable amount of research on Hg in the Dayton to Lahontan Reservoir reach of the Carson River Basin (Diamond et al., 2000; Hoffman and Thomas, 2000; Warwick et al., 1997; Oremland et al., 1995). A portion of this research has sought to better understand the dynamics and transport of inorganic Hg and Me-Hg in this polluted reach including role of sediments and mixing in Lahontan Reservoir and Hg transport to downstream areas and waters.

Lahontan Reservoir – The Reclamation waterbody of interest in the Middle Carson River Basin is Lahontan Reservoir (average elevation 4156 ft, 1267 m), located on the border of Churchill and Lyons Counties, near the town of Silver Springs, Nevada. The reservoir is around 17 mi (27 km) in length with a maximum width of 2.5 mi (4.0 km). Lahontan Reservoir covers approximately 10,600 acres (4,300 ha) and has around 65 mi (105 km) of shoreline (NDOW, 2004a). Figure 8a shows a map of Lahontan Reservoir. Figure 8b shows the inflow delta region of Lahontan Reservoir; figure 8c shows the reservoir near the dam; and figure 8d shows inflow from the Truckee Canal into Lahontan Reservoir near the dam.

The reservoir is divided into 3 basins (figure 8a), an upper (southern) and lower (northern) basin separated by a smaller middle basin along the Narrows. Carson River water enters the Upper Basin through the delta (figure 8b) which is intermittantly flooded during runoff. Water elevations at the dam (figure 8c), constructed from 1911 to 1915 as part of the Reclamation Newlands Project, vary from 4070 to 4162 ft (1241 to 1269 m) and the normal reservoir capacity is 295,500 acre-ft (364,500,000 m^3). During 2001, reservoir releases changed the volume from around 260 x 10^6 m^3 (211,000 acre-ft) in May to around 70 x 10^6 m^3 (57,000 acre-ft) in October (Kuwabara et al., 2002). This volume change, around 150,000 acre-ft (190 X 10^6 m^3), suggests that about half of the normal reservoir capacity is exchanged during a normal water year. While Lahontan Reservoir receives Truckee River Basin water from the Truckee Canal (figure 8d) at the dam (approximately 40 percent of the Truckee River discharge at Derby Dam), most of the runoff that fills this desert lake is from the Upper Carson Sub Basin, covering a drainage area of 1,450 mi^2 (3,756 km^2, 375,500 ha) (Reclamation, 1981, 2004a, 2004b; Wayne et al., 1996).

The Narrows feature makes the Upper Basin the primary settling zone for Carson River suspended sediments—and Hg. The Upper Basin covers around 4,100 acres (1.67 x 10^7 m^2), with an average depth of 5 m (10-m maximum), and a maximum volume of 67,300 acre-ft (8.30 x 10^7 m^3, 22 percent of total volume) (Diamond et al., 2000). To the

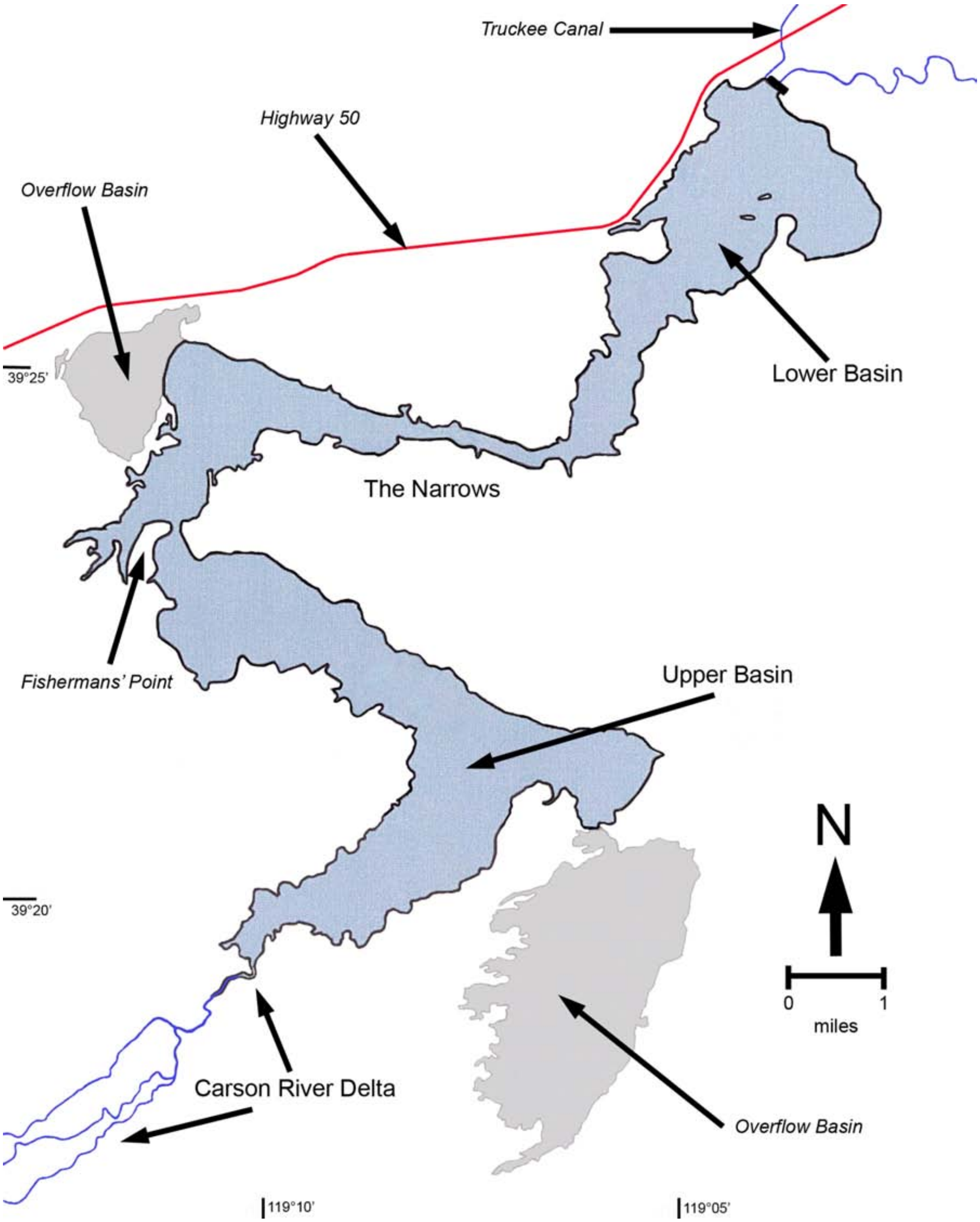


Figure 8a.—Map of Lahontan Reservoir, from Kuwabara et al. (2002).

Figure 8b.— The inflow, or delta region of Lahontan Reservoir, looking west. This wetlands may be an area where Hg is methylated during lower flows. Reclamation photo by Doug Craft.

Figure 8c.— Lahontan Reservoir near the Dam looking towards the northwest. The Truckee Canal flows into the reservoir at the far right of the picture. Reclamation photo by Doug Craft.

Figure 8d.— Water flowing into Lahontan Reservoir from the Truckee Canal. This source of water has very low (around 4 ng/L) unfiltered total Hg, so it dilutes the elevated Lower Basin Hg concentrations. Reclamation photo by Doug Craft.

east of the inflow delta is an area of intermittently flooded sediments approximately half the area of the Upper Basin. Another similar but smaller area can be seen in the figure 8a map as the reservoir bends to the west above the narrows near Highway 50. While not directly studied, these intermittently flooded areas, which receive Hg contaminated sediments during high flood flows, may cause additional local Hg loading to the reservoir during subsequent high runoff, flood, or storm events.

The middle basin starts downstream from Fisherman's Point (around 6 river miles or 9.5 km downstream from the Carson River inflow), and has a surface area of 2,940 acres (1.19×10^7 m^2), an average depth of 7 m, with a volume similar to the Upper Basin.

The Lower Basin (figure 8c) covers 4,670 acres (1.89×10^7 m^2), with an average depth of 11 m (25.9-m maximum), and has a maximum volume of 167,800 acre-ft (2.07×10^8 m^3, 55 percent of total volume) (Diamond et al., 2000).

Lahontan Reservoir is a popular recreation and fishing destination (over 166,000 visitor days logged in 1992) that is administered by the Nevada Division of State Parks and the Truckee-Carson Irrigation District. It has been a managed fishery since 1950, with many introduced game and commercial species. Game fish caught in the warmwater Lahontan Reservoir include wipers , *Morone saxitilis x M. chrysops*, (a hybrid of white bass and striped bass), white bass, *M. chrysops*, walleye, *Stizostedion vitreum*, channel catfish, *Ictalurus punctatus*, white catfish, *I. catus*, black bullhead, *I. melas*, brown bullhead, *I. nebulosus*, largemouth bass, *Micropterus salmoides*, spotted bass, *Micropterus punctulatus*, and crappie, *Pomoxis annularis*. Around 5,600 anglers/yr catch over 100,000 fish/yr, and state trophy records have been recorded for white bass (4.0 lb, 1.8 kg), channel catfish (31.1 lb, 14.1 kg), walleye (15.3 lb, 6.9 kg), and wiper (17.0 lb, 7.7 kg). Despite its popularity with anglers, Hg bioaccumulation in game fish prompted the Fisheries Bureau of the NDOW to advise on its informational Web site that no fish caught in Lahontan Reservoir should be eaten (NDOW, 2004a).

Besides game fish, Lahontan Reservoir is also home to a large population of planktiverous (algae and zooplankton eating) fish including Tahoe sucker, *Catostomus tahoensis*, mountain sucker, *Catostomus platyrhynchus*, speckled dace, *Rhinichthys osculus*, Lahontan redside, *Richardsonius egregius*, non-native carp, *Cyprinus carpio*, and the Lahontan blackfish (introduced to Nevada in 1964), a variety of Sacramento blackfish, *Othhodon microlepidotus* (figure 9) (Cooper et al., 1985; Moyle, 2002; Murphy, 1950).

Figure 9.— The Sacramento blackfish, *Orthodon microlepidotus*, an introduced, commercially harvested fish common in Lahontan Reservoir and downstream waters. These fish are not a predator species, but have levels of Hg in their tissues above EPA advisory levels (> 0.6 mg/kg) and FDA action levels (1.0 mg/kg). Reclamation photo by Rene Reyes.

These forage fish also contain elevated concentrations of Hg in their tissues, and blackfish and carp are harvested commercially by the Murray Fish Company, Silver Springs, Nevada, before being sold to fish markets in the Chinatown district of San Francisco, California. The blackfish harvest, was reported in 1984 to average 353,000 lb/yr (160,000 kg/yr) with carp accounting for around 9 percent of catch (Cooper et al., 1985). Figure 10a shows commercial fish harvesting operations near the delta inflow of Lahontan Reservoir, and figure 10b shows Lahontan blackfish on sale in a San Francisco fish market.

Figure 10a.— Commercial fishing by the Murray Fish Company, Silver Springs, Nevada, in the upper inflow basin of Lahontan Reservoir. The commercial harvest was over 350,000 lb/yr in the mid-1980s. Reclamation photo by Doug Craft.

Figure 10b.— Blackfish from Lahontan Reservoir on sale in a fish market in San Francisco, California. Reclamation photo by Doug Craft.

Carson Desert Sub Basin – Below Lahontan Reservoir, the Carson River eventually disappears into the Carson Sink, with lower elevations around 3850 to 3900 ft (1173 to 1189 m). This region, once lake bottom for the Ice Age Lake Lahontan is relatively flat with wetlands and playa (seasonal dry lake) environments to the south (figure 11a) that eventually become desert towards the north. Before the construction of Lahontan Dam, the northern areas were covered by a large and shallow lake, called Carson Lake. On the south, The Carson Desert Sub Basin is bounded by the Desert Mountains where the old Pony Express trail follows the base of this feature (figure 11b). To the east, this sub basin is bounded by the Stillwater Range, with peaks ranging from 6,500 to 8,800 ft (1,980 to 2,680 m) and to the north it is bounded by the Hot Springs Mountains and the West Humboldt Range. Some of the notable features of this area include Reclamation's Sheckler Reservoir (elevation 3991 ft, 1216 m), the Carson Lake area (figures 11a and 11b), the Indian Lakes Recreation Area (figure 12), the Stillwater National Wildlife Refuge, the Stillwater Wildlife Management Area, and the Fallon National Wildlife Refuge.

Figure 11a.— Mixed playa and wetlands in the Carson Lake area. This popular area is a western hemisphere shorebird preserve and a refuge for ducks and other waterfowl. High levels of Hg have accumulated in the tissues of all resident wildlife. Reclamation photo by Doug Craft.

Figure 11b.— Wetlands in the Carson Lake area. A dust devil whipping up salty playa soil can be seen in the distance. Reclamation photo by Doug Craft.

Figure 12.— One of the many lakes in the Indian Lakes Recreation Area northeast of Fallon, Nevada. Reclamation photo by Doug Craft.

SUMMARY OF DATA AND RESEARCH RESULTS

Water resource managers may benefit from the wealth of water quality and Hg research and data collection being performed in the Carson River Basin by other State and Federal agencies and universities. Completed and ongoing investigations have been funded and performed by Region IX EPA and its contractors, the USGS, the National Science Foundation, the National Institutes of Health, the U.S. Fish and Wildlife Service, the Nevada State Health Division, the NDOW, and the Nevada Department of Conservation and Natural Resources – Fisheries Bureau, the University of Nevada at Reno and Las Vegas, and the Desert Research Institute, Reno, Nevada. Much of the Hg data collected by the USGS, along with other water quality data, are available online (USGS, 2004a, 2004b).

In the following sections, we will summarize available hydrology, general water quality, and Hg concentrations in surface waters, sediments, and biota from the Carson River Basin and Lahontan Reservoir. Groundwater quality and Hg will not be addressed in this report, however, such information is also available from several sources and investigations (Lico, 1992, 1997; Lico and Seiler, 1994; Lico and Pennington, 1997).

Hydrology, Storm Events, and Sedimentation

Basin hydrology and runoff flows are central to the fate and transport of Hg in the Carson River Basin (Van Denburgh, 1973; Richins and Risser, Jr., 1975; Lechler et al., 1995; Miller et al., 1995). Table 2 shows monthly median stream flows for several USGS gage stations in the Carson River Basin (USGS, 2004a). Note the varying periods of record for these summaries. The three stations with the longest periods of record, the East Fork (station 10309000, 1890 to 2003), Carson River near Carson City (station 10311000, 1939–2003), and Carson River at Fort Churchill (station 10312000, 1911 to 2003) show a May–June maximum and an August–November minimum average runoff discharge. Average Carson River inflows into Lahontan Reservoir, measured at the Fort Churchill gage station, are very low during August and September (1–4 ft^3/s), and median monthly high spring flows vary from 1,100 ft^3/s in May to 865 ft^3/s in June (31.1 to 24.5 m^3/s).

The normal seasonal runoff pattern has been interrupted by intermittant winter and early spring precipitation events, the most significant to date happening on January 3, 1997, when the maximum flood wave peaked at 22,300 ft^3/s (632 m^3/s) at the Fort Churchill gage station on the Carson River above Lahontan Reservoir (Thomas and Williams, 1997; Hoffman and Taylor, 1998). This historic flood event has particular relevance to the story of Hg in the Carson River Basin, and the January 1997 monthly average discharge is noted in the lower portion of table 2, first data column, for each of the gage stations.

Table 2.—Station information (top) and monthly median streamflow (bottom) for several Carson River Basin U.S. Geological Survey gage stations (USGS, 2004a)

Station Description	USGS Station Number	Period of Record	Hydrologic Unit Code	Sub Basin Area, mi^2	Station Elevation, ft – m	Latitude	Longitude
East Fork Carson River near Gardnerville NV	10309000	1890–2004	16050201	356	5000	38°50'42"	119°42'13"
West Fork Carson River near Minden NV	10310358	1994–1998	16050201	214	4661	38°58'16"	119°49'00"
Carson River at Genoa NV	10310405	1974–1981	16050201	570	4660	38°59'52"	119°49'41"
Carson River near Carson City NV	10311000	1939–2003	16050201	886	4621	39°06'28"	119°42'44"
Carson River at Dayton NV	10311700	1994–2003	16050202	1090	4350	39°14'16"	119°35'14"
Carson River near Fort Churchill NV	10312000	1911–2003	16050202	1450	4180	39°17'35"	119°15'02"
Carson River below Lahontan Reservoir	10312150	1966–2003	16050203	1801	4040	39°27'50"	119°02'45"
Truckee Canal near Hazen NV	10351400	1966–2003	16050203	na	4167	39°30'14"	119°02'39"
Carson River below Fallon NV++	10312280++	1967–2003	16050203	na	3900	39°40'	118°39'

++ These data from two stations: 10312275 (1967–1985) and 10312280 (1985–2003) with adjoining periods of record

Station Description	Median Monthly Streamflow, ft^3/s												
	Jan 1997 flood Average	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
East Fork Carson River near Gardnerville NV	1789	122	174	252	574	1191	955	292	124	81	79	89	94
West Fork Carson River near Minden NV	219	26	23	26	20	38	55	34	5	8	10	11	16
Carson River at Genoa NV		86	116	219	277	864	614	93	17	14	31	73	83
Carson River near Carson City NV	3171	237	310	353	587	1179	913	96	23	27	81	151	176
Carson River at Dayton NV	3125	384	556	845	912	1607	999	126	34	29	53	154	242
Carson River near Fort Churchill NV	3001	229	317	349	543	1101	865	125	4	1	38	126	189
Carson River below Lahontan Reservoir	1756	4	5	134	624	919	908	940	844	657	328	125	5
Truckee Canal near Hazen NV	21	137	90	179	133	142	111	80	73	109	141	197	148
Carson River below Fallon NV++	660	4	3	3	9	10	12	10	12	9	8	6	3

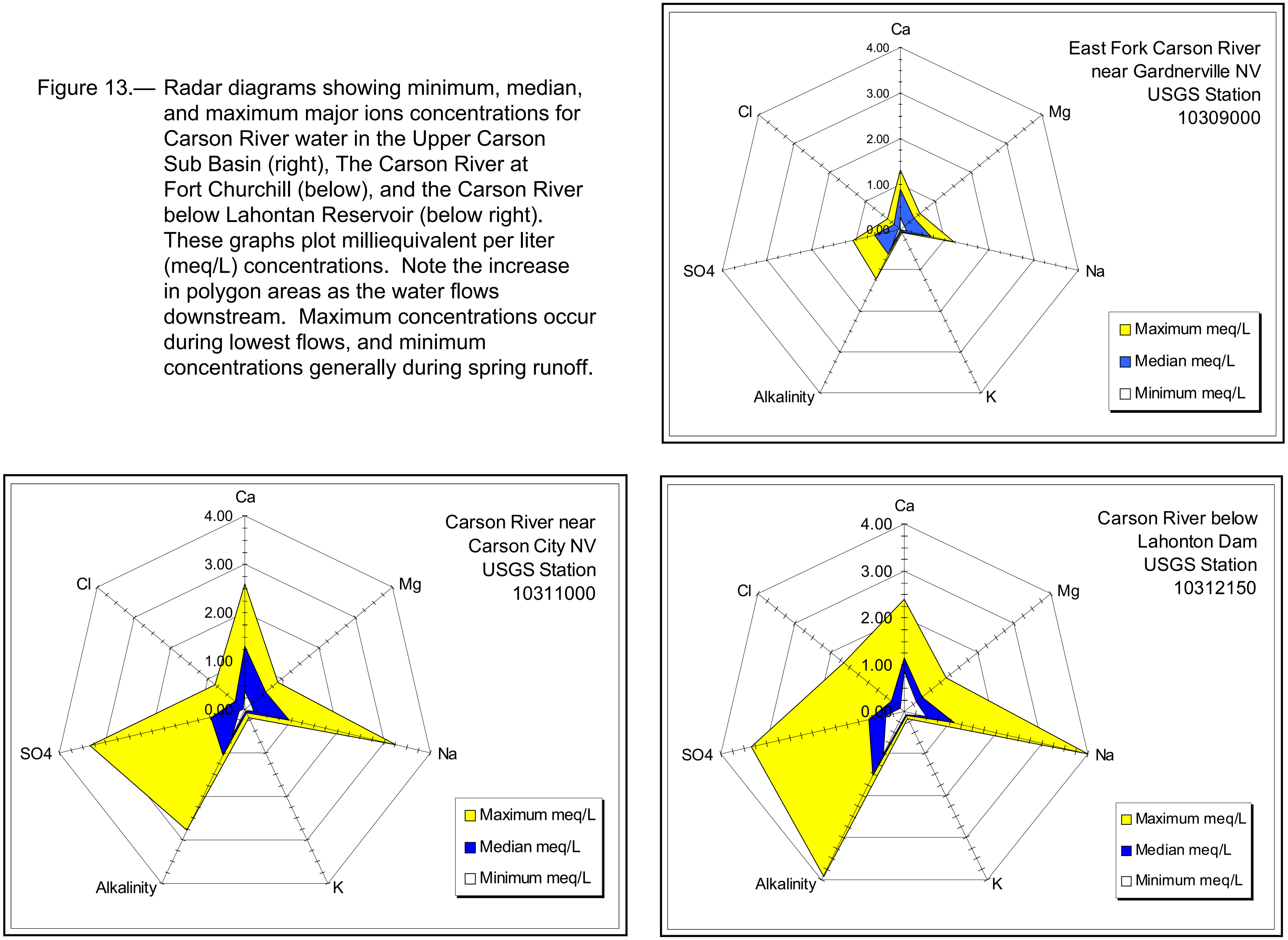
Miller et al. (1998, 1999) noted that the transport and mobility of Hg in the Carson River Basin below Dayton, Nevada, is closely related to streamflow erosion of banks and lateral cutting through the 1-m thick layer of Hg contaminated sediment in Carson Plain. Mobilized suspended sediments in the Carson River will transport Hg downstream during the elevated flows of spring runoff and storm events. Normal Carson River channel capacity is around 8,000 cubic foot per second at Dayton, and flows from 1952–1965 exceeded that level eight times (Hoffman and Taylor, 1998). When channel capacity is exceeded, lateral cutting into contaminated banks and re-channelization can produce significant downstream sediment and Hg transport. In 1982, the USGS estimated that the Carson River deposits an average of around 0.8 in/yr (2 cm/yr) of sediment on the bottom of Lahontan Reservoir behind the dam. During the 1997 flood, over 200,000 lb (90,800 kg) of sediments containing around 3,000 lb (1,400 kg) of Hg were transported past the Fort Churchill gage (figure 8b) into Lahontan Reservoir (Hoffman and Taylor, 1998).

General Water Quality in the Carson River and Lahontan Reservoir

Figure 3 presents radar diagrams showing the major ions concentrations from higher to lower elevations in the Carson River Basin (USGS, 2004a, 2004b). The basin water is generally composed of sodium and calcium as the dominant cations (positively charged ions) and bicarbonate (represented by alkalinity) and sulfate as the dominant anions (negatively charged ions). The pH is alkaline with values up to 9.0 and often reported above 8.0 (Bonzongo et al., 1996a). The minimum concentrations are generally around one-quarter maximum concentrations, suggesting a large range of water quality through the year. While there is a clear increase in area of the polygons from the East Fork to the Carson River at Carson City (marking the transititon from montane to valley regions), the median polygons (blue) do not change much from Fort Churchill to below Lahontan Dam. The maximum polygons, (yellow), however, suggest much more dramatic increases in concentration during the dry season when the chemistry shows much more sodium and sulfate compared to the median calcium-bicarbonate waters. These data suggest a larger influence from local groundwater sources during low surface flows, usually in August through October.

Sediment surveys of chlorophyll-A and macro invertebrates by Kuwabara et al. (2002) and limnological surveys by Cooper and Vigg (1984) suggest that Lahontan Reservoir is an oligotriophc to mesotrophic lake with relatively low algal productivity. This trophic status is likely a result of the overall desert environment in the watershed that contributes lower amounts of dissolved organic materials, a lower population, and the shorter water volume turnover rate for an operating reservoir. However, the popularity of fishing in Lahontan Reservoir argues that productivity is high enough to sustain a large fish population. Productivity may also be higher during dryer runoff years, and algal blooms may occur in more isolated and shallow reaches of the reservoir.

Figure 13.— Radar diagrams showing minimum, median, and maximum major ions concentrations for Carson River water in the Upper Carson Sub Basin (right), The Carson River at Fort Churchill (below), and the Carson River below Lahontan Reservoir (below right). These graphs plot milliequivalent per liter (meq/L) concentrations. Note the increase in polygon areas as the water flows downstream. Maximum concentrations occur during lowest flows, and minimum concentrations generally during spring runoff.



Hg in Surface Waters of the Carson River Basin

Hg data from several literature sources, web-available USGS data, and Reclamation data (Fields, 2004) are summarized in table 3. The top of the table summarizes total Hg concentrations from water quality regulations, and from uncontaminated and contaminated background sites. Below this header, data are arranged by watershed elevation from the Upper Carson Sub Basin down river to the Carson Desert Sub Basin. Higher detection limits reported for samples prior to the mid-1990s do not provide meaningful information, so only the most recent water Hg data with the lowest detection limits are summarized here. The web available Hg data are fairly limited in the upper Carson River reaches—the East and West Forks, and numerous values are not available until the USGS station at Dayton, Nevada, and downstream.

Hg and Me-Hg in the Carson River – The table 3 data from the West Fork Carson River near Woodfords, California, suggest very low concentrations of filtered total Hg (0.58 ng/L) in the uplands of the Upper Carson Sub Basin. Given reported data on Hg species in water (Craft et al., 2000; Bloom and Effler, 1990; Gill and Bruland, 1990), these data would suggest an unfiltered total Hg concentration of 3 to 8 ng/L for the West Fork, suggesting some Hg contamination beyond expected background levels in uncontaminated watersheds. Gustin et al. (1994) reported unfiltered total Hg in Lousetown Creek (which drains into the Truckee River and was defined as a background site for the Carson River Basin in that study) at 10 ng/L with unfiltered Me-Hg at 0.4 ng/L.

While no web-available Hg data were available for waters in the East Fork of the Carson River, Fischer and Gustin (2002) reported unfiltered total Hg in waters near the Leviathan Mine ranging from 2 to 17 ng/L (average = 7.48 ng/L) with highest levels seen in Leviathan Creek (during June) and Mountaineer Creek (during September). Filtered total Hg ranged from 1.8 to 13.5 ng/L (average = 5.65 ng/L). The sources for these Hg inputs were acid mine drainage during spring runoff, and hydrothermal groundwater sources later in summer. Most of the Hg associated with the acid mine drainage is dissolved because of the low pH. These results suggest that dissolved Hg is a major Hg form in upper watershed waters (around 75 percent) and that the Upper Carson Sub Basin has Hg sources that could cause Hg bioaccumulation.

Once the Carson River flows past Dayton, the contamination entry point from Comstock mining, table 3 median concentrations of unfiltered total Hg (120 ng/L) exceed water quality limits by over a factor of 10. The highest table 3 unfiltered total Hg value at the Dayton station was 430 ng/L in June, 1998, suggesting an association with spring runoff. However, elevated unfiltered total Hg was also observed in December, 1998 (328 ng/L), and in August, 1998 (239 ng/L), likely caused by storm events. The August 1998 sample also showed the highest filtered total Hg (13 ng/L) and Me-Hg levels (5.09 ng/L, unfiltered, and 3.13 ng/L, filtered), suggesting that the longer residence times associated with lower flows are conducive to methylation and increased proportions of dissolved

Table 3.— Summary of Hg concentrations in sufrace waters from the Upper Carson Sub Basin to below Lahontan Dam, including the Carson River and Lahontan Reservoir

Regulations and Background Concentrations			
Source	Unfiltered Total Hg, ng/L	Source	Unfiltered Total Hg, ng/L
Nevada Water Quality Criteria (State of Nevada, 1994)	12 aquatic life 2,000 drinking water 10,000 livestock water	National Primary Drinking Water Standard (EPA, 2002)	2,000
Uncontaminated Background (Gustin et al., 1994)	1–3	Clear Lake Superfund Site, California (Gustin et al., 1994)	5.5–69
Truckee Basin Alpine Creeks (Wayne et al., 1996)	1.3–1.6	Truckee Canal at Dam (Wayne et al., 1996)	4.0–4.4

	Unfiltered Total Hg, ng/L	Filtered Total Hg, ng/L	Unfiltered Me-Hg, ng/L	Filtered Me-Hg, ng/L
West Fork Carson River near Woodfords, California				
July 2002 (USGS, 2004b)				
Value (n= 1)	–	0.58	–	–
East Fork Carson River–Tributary Streams				
June to Dec 1999 (Fischer and Gustin, 2002)				
Average (n = 15 to	7.48	5.65	–	–
Range	2.80–15.0	1.80–13.5	–	–
Carson River near Carson City, Nevada				
May and June 1994 (Bonzongo et al., 1996b)				
Average (n= 3)	8.59	4.76	0.409	0.271
Range	4.28–12.9	2.46–7.05	0.305–0.512	0.161–0.380
Oct 1992 to Jul 1993 (Wayne et al., 1996)				
Average (n = 4)	8.73	4.50	–	–
Range	3.00–22.0	2.40–6.60	–	–

Table 3.— Summary of Hg concentrations in sufrace waters from the Upper Carson Sub Basin to below Lahontan Dam, including the Carson River and Lahontan Reservoir–continued

	Unfiltered Total Hg, ng/L	Filtered Total Hg, ng/L	Unfiltered Me-Hg, ng/L	Filtered Me-Hg, ng/L
Carson River near Dayton, Nevada				
Oct 1992 and Jul 1993 (Wayne et al., 1996a, 1996b)				
Average (n = 2)	51.5	18	–	–
Range	48–55	–	–	–
May and June 1994 (Bonzongo et al., 1996)				
Average (n = 3)	90.5	6.39	1.08	0.739
Range	47.0–134	4.79–7.98	0.542–1.61	0.458–1.02
Apr 1998 to Jul 2002–(USGS, 2004b)				
Median (n = 12 to	120	6.08	0.505	0.235
Range	87.7–430	3.24–18.2	0.360–5.09	0.090–3.13
Carson River near Fort Churchill, Nevada				
Oct 1992 and Jul 1993 (Wayne et al., 1996)				
Average (n = 4)	109	26	–	–
Range	49–188	–	–	–
May and Jun 1994 (Bonzongo et al., 1996a, 1996b)				
Average (n = 3)	1,380	27.8	4.50	1.02
Range	646–2,110	9.43–46.1	1.79–7.20	0.844–1.20
Jan to Sep 1997 (Hoffman and Taylor, 1998)				
Average (n= 19 to	6,210	–	2.71	–
Range	260–28,000	–	0.52–5.24	–
Lahontan Reservoir–Upper (Southern) Basin				
Oct 1992 and Jul 1993 (Wayne et al., 1996)				
Average (n = 4)	536	76.5	–	–
Range	105–977	10–113	–	–
Aug and Sep 1993 (Gustin et al., 1994)				
Average (n = 4)	409	8.4	–	–
Range	138–591	1.9–21	–	–
May and Jun 1994 (Bonzongo et al., 1996a, 1996b)				
Average (n = 3 to	1,280	26.3	3.29	0.838
Range	824–1,580	25.3–56.5	1.82–4.33	0.129–1.60

Table 3.— Summary of Hg concentrations in sufrace waters from the Upper Carson Sub Basin to below Lahontan Dam, including the Carson River and Lahontan Reservoir–continued

	Unfiltered Total Hg, ng/L	Filtered Total Hg, ng/L	Unfiltered Me-Hg, ng/L	Filtered Me-Hg, ng/L
Lahontan Reservoir–Lower (Northern) Basin				
Oct 1992 to Jul 1993 (Wayne et al., 1996)				
Average (n = 3)	115	–	–	–
Range	21–293	–	–	–
Aug and Sep 1993 (Gustin et al., 1994)				
Average (n= 2)	76	3.2	–	–
Range	53–99	3.1–3.3	–	–
May and Jun 1994 (Bonzongo et al., 1996a, 1996b)				
Average (n= 2)	108	3.64	0.472	0.142
Range	57.1–158	3.30–3.98	0.400–0.544	0.135–0.149
Carson River Below Lahontan Dam				
Jun 1997 to Aug 2003 (USGS, 2004b)				
Median (n = 37 to	333	6.5	0.280	0.125
Range	57.3–587	3.6–24.2	0.100–2.73	0.040–1.08
Nov 1996 to Aug 2003–(Reclamation, 2004c)				
Median (n=10 to	350	13.2	–	–
Range	<5.00–1,200	<5.00–26.0	–	–
Jan to Sep 1997 (Hoffman and Taylor, 1998)				
Average (n = 8 to	810	–	3.99	–
Range	310–2,500	–	0.45–1.70	–

inorganic Hg forms in water. Gustin et al., (1994) reported that unfiltered total Hg in Six Mile Canyon above Dayton ranged from 3,880 to 35,400 ng/L, with unfiltered Me-Hg ranging from 7.2 to 9.4 ng/L.

Table 3 also summarizes Hg sample data collected from the Carson River below Lahontan Dam by both the USGS (this site and the Fort Churchill site—figure 7b—have been funded by the EPA since 1997) and Reclamation. The USGS unfiltered total Hg data range from 57.3 to 587 ng/L and filtered total Hg from 3.6 to 24 ng/L. Unfiltered Me-Hg ranged from 0.10 to 2.73 ng/L and dissolved Me-Hg from 0.040 to 1.08 ng/L. Reclamation data, except for two non-detect samples collected in November 1997 and February 1998, ranged from 120 to 1,200 ng/L for unfiltered total Hg and from < 5 to 26 ng/L for filtered total Hg. The maximum value was observed in late August 1999.

While the USGS data showed fewer extreme values, the median unfiltered total Hg data from Reclamation (350 ng/L) and USGS (333 ng/L) are comparable, and also suggest that Lahontan Reservoir does pass significant amounts of Hg to downstream areas, and greater amounts may pass the reservoir after peak flood events (Hoffman and Taylor, 1998). This is understandable given that Reclamation will likely release Lahontan Reservoir water during and after a flood event, and cold winter floodwaters will likely submerge and flow along deeper paths directly to the outlet works.

Some Relevant Hg Research Studies in the Carson River

Several informative studies summarize Hg in water and sediments in the reach of the Carson River from Dayton to below Lahontan Reservoir, including work by Bonzongo et al. (1996a, 1996b, 2002), Wayne et al. (1996) and Gustin et al. (1994).

Runoff Mobilization of Hg from Sediments – During and immediately after the 1994 spring runoff event, Bonzongo et al. (1996b) measured Hg species concentrations at Carson River stations from Carson City (upstream from the Comstock contamination) to the inflow of Lahontan Reservoir, and at two Lahontan Reservoir stations. Unfiltered and filtered total Hg and Me-Hg concentrations were measured under high- (15.5 m^3/s, 547 ft^3/s) and low-flow (2 m^3/s, 71 ft^3/s) regimes from Carson City to Fort Churchill. These flows are considerably lower than the median May (1,101 ft^3/s, 31.2 m^3/s), and June (865 ft^3/s, 24.5 m^3/s), flows recorded at Fort Churchill (table 2) (USGS, 2004a).

The Hg data in figure 14 are plotted on a logarithmic concentration scale and show two interesting results. First, the unfiltered total Hg concentrations increase by *two orders of magnitude* over 69 km, from around 10 ng/L to over 1,000 ng/L under high-flow conditions. Filtered total Hg concentrations at lower flows are also consistently lower for stations below Dayton. This demonstrates that greater downstream contact with contaminated sediments is related to higher river concentrations, and that this sediment mobilization represents the primary source of total Hg to Lahontan Reservoir. Second, Me-Hg concentrations do not increase exponentially with river km, but are generally *higher* at lower flows, again suggesting an association of Me-Hg formation at lower flows. We know that water velocity is slower at lower flows, and elevated summer temperatures also promote microbial activity, so methylation reactions are encouraged under these conditions.

Bonzongo et al. (1996a) also reported Hg concentrations for the Carson River sampled above and below the Dayton contamination entry area. Unfiltered total Hg above the tailings ranged from 4 to 39 ng/L (mean = 18.9 ng/L) while below tailings samples ranged from 47 to 7,590 ng/L (mean = 1,454 ng/L). Filtered total Hg above the tailings ranged from 0.4 to 7 ng/L (mean = 3.07 ng/L) while below tailings samples ranged from 4.8 to 88 ng/L (mean = 9.8 ng/L). Unfiltered Me-Hg above the tailings ranged from 0.3 to 0.5 ng/L (mean = 0.38 ng/L) while below tailings samples ranged from 0.5 to 7.2 ng/L

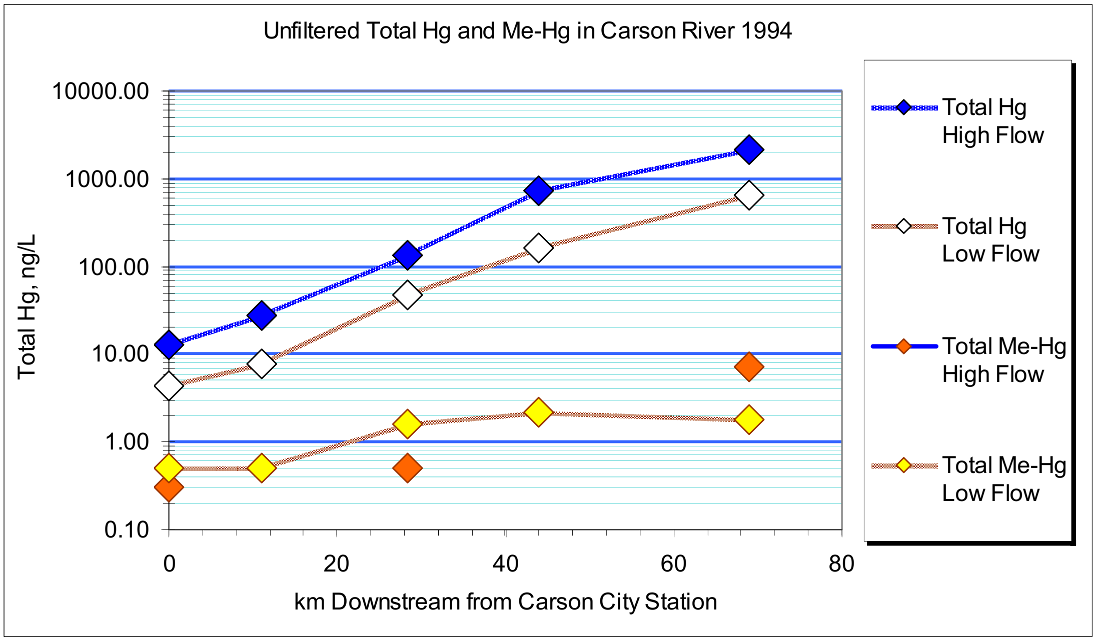


Figure 14.— Reported unfiltered total Hg and Me-Hg in the Carson River from Carson City to Fort Churchill. Data from Bonzongo et al. (1996a).

(mean = 2.56 ng/L). Filtered Me-Hg above the tailings ranged from 0.08 to 0.4 ng/L (mean = 0.24 ng/L) while below tailings samples ranged from 0.25 to 1.3 ng/L (mean = 0.79 ng/L).

Similar results for sediment and water Hg concentrations were found by Wayne et al. (1996) and showed an exponential increase in water Hg concentrations from Dayton into and below Lahontan Reservoir. Average unfiltered total Hg ranged systematically from 3.3 ng/L at Carson City to 188 ng/L at Fort Churchill in July 1993, similar to lower range values for low flows reported by Bonzongo et al. (1996a).

Note that the Carson River at Carson City site (km 0 in Bonzongo et al., 1996b), while uncontaminated by basin standards, exceeded water quality criteria at high flow, but not at low flow. These results suggest that the Upper Basin does contribute a small portion of the Hg inputs to Lahontan Reservoir, perhaps enough (see summary of available tissue data below) to cause bioaccumulation of Hg in fish above the Comstock contamination.

Hg Speciation from Bonzongo et al. – Figure 15 shows pie chart proportions for Hg species defined as dissolved and suspended inorganic Hg and dissolved and suspended Me-Hg, calculated from data reported by Bonzongo et al. (1996b). These charts are arranged from upstream to downstream sites (top to bottom), and high-flow vs low-flow conditions (left vs right). The term inorganic Hg used here also includes Hg bound to

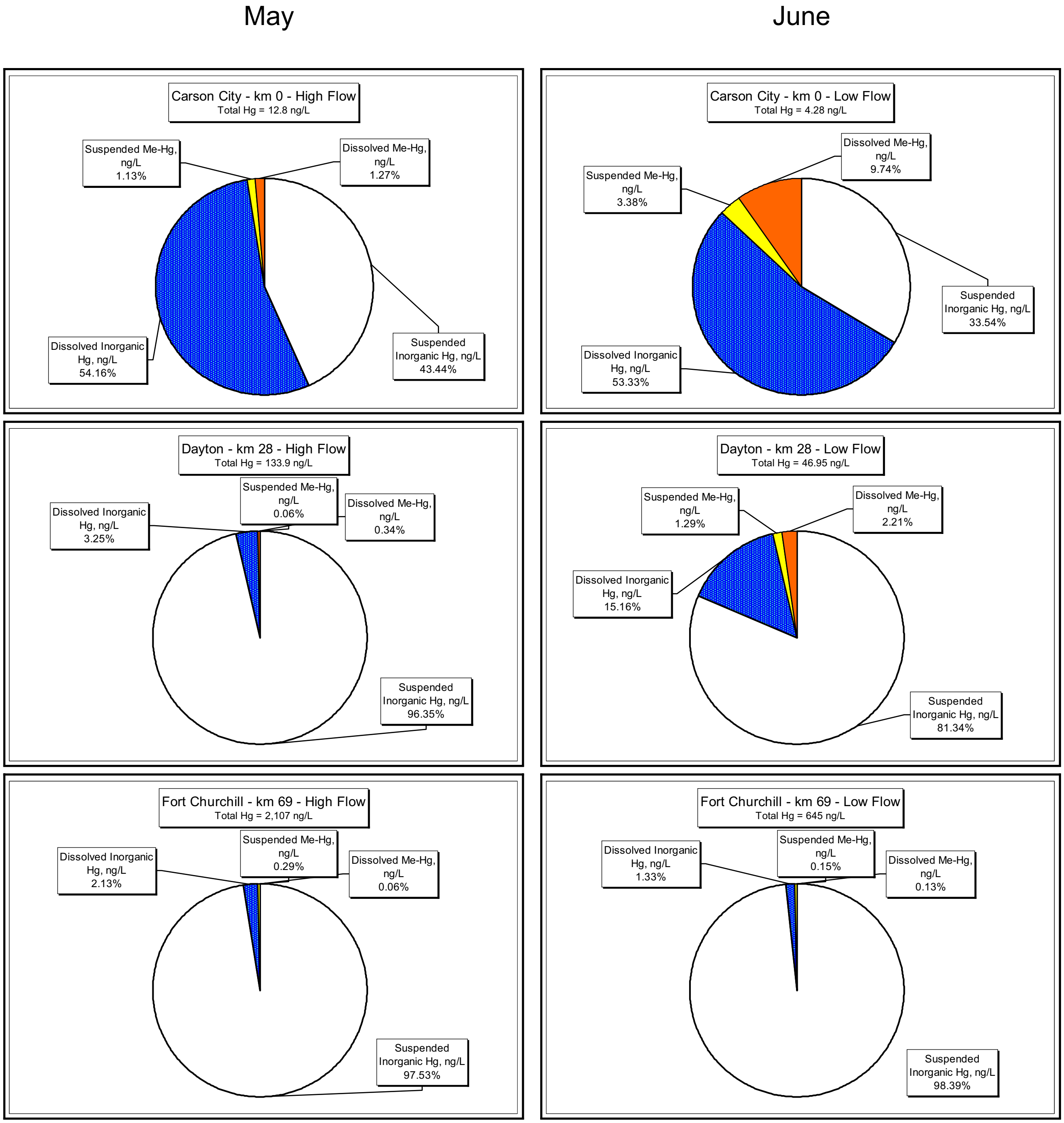


Figure 15.— Proportions of suspended and dissolved total Hg and Me-Hg from the Carson River in 1994 (Bonzongo et al., 1996a, 1996b). From top to bottom, the distance from Carson City increases. Charts on the left side are from May with flow = 15.5 m^3/s. The three charts on the right side are from June with flow = 2.0 m^3/s.

suspended and dissolved humic and fulvic materials, but not methylated forms. The most obvious point is that dissolved forms are much more prominent at Carson City (top charts), though remember that concentrations are also much lower here. At the Dayton station (middle charts, 28 km downstream) we can see that most Hg is suspended, but that percentages of dissolved forms are greater at lower flows (dissolved inorganic Hg increases from 3.25 to 15.2 percent, dissolved Me-Hg increases from 0.34 to 2.21 percent from high to low flows). At Fort Churchill (bottom charts) we actually see a decrease in dissolved inorganic Hg (from 2.13 to 1.33 percent) but dissolved Me-Hg doubles from 0.06 to 0.13 percent (see section on Me-Hg flux from sediments below).

Research in Lahontan Reservoir

Several studies in Lahontan Reservoir have been performed in the past 10 years, many funded by EPA and USGS.

Hg Trends in Lahontan Reservoir and Below the Dam – The Bonzongo et al. (1996b) study also analyzed samples in Lahontan Reservoir, from the inflow delta (station 6, 87 km downstream from Carson City) to the dam (111 km downstream) before and after maximum spring runoff flows. Unfiltered total Hg ranged from 57.06 to 1,583 ng/L, and filtered total Hg ranged from 3.30 to 56.46 ng/L. Unfiltered Me-Hg ranged from 0.4 to 4.33 ng/L, and filtered Me-Hg ranged from 0.129 to 1.597 ng/L. Highest reservoir concentrations for both filtered and unfiltered total Hg were observed at the Upper Basin Fisherman's Point Station 7. Lowest concentrations for almost all Hg species were seen behind the dam in the Lower Basin at Station 8.

Highest filtered (4.33 ng/L) and unfiltered (1.60 ng/L) Me-Hg concentrations, however, were observed in the Station 6 inflow samples at high flow. Figure 16 shows data for suspended inorganic Hg and dissolved Me-Hg vs. lateral distance in Lahontan Reservoir. These averaged values are plotted on a logarithmic scale. Figure 17 shows pie chart percentages for Hg species in Lahontan Reservoir.

The general trends seen in figures 16 and 17 are a decrease in total Hg concentrations from the Carson Delta inflow to behind the dam, and time lags in concentration response caused by a change from river to lake flow and transport environments. During May, average unfiltered total Hg is 1,470 ng/L at the delta, 1,250 ng/L at Fisherman's Point, and 57.0 ng/L at the Dam. In June, Carson Delta average unfiltered total Hg was lower at 824 ng/L conforming to lower river flows and sediment loads, but Fisherman's Point showed the highest lake concentrations at 1,580 ng/L. These results suggest a delayed pulse from earlier higher flows, but may also reflect a natural sediment collection point in the reservoir Upper Basin at the narrows. At the dam, the June sample shows almost three-times higher concentration—unfiltered total Hg was 158 ng/L (Bonzongo et al., 1996b). These results, based on replicate samples, suggest that some Hg is being transported through the reservoir (over 27 km lateral distance) within a month of the spring runoff suspended Hg pulse.

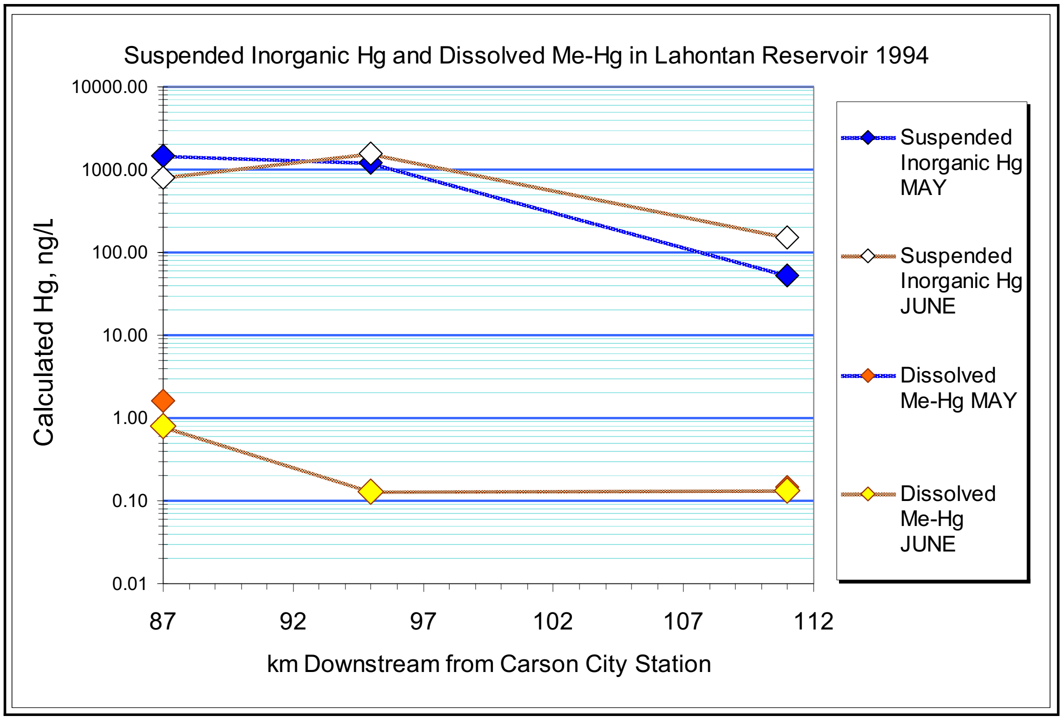
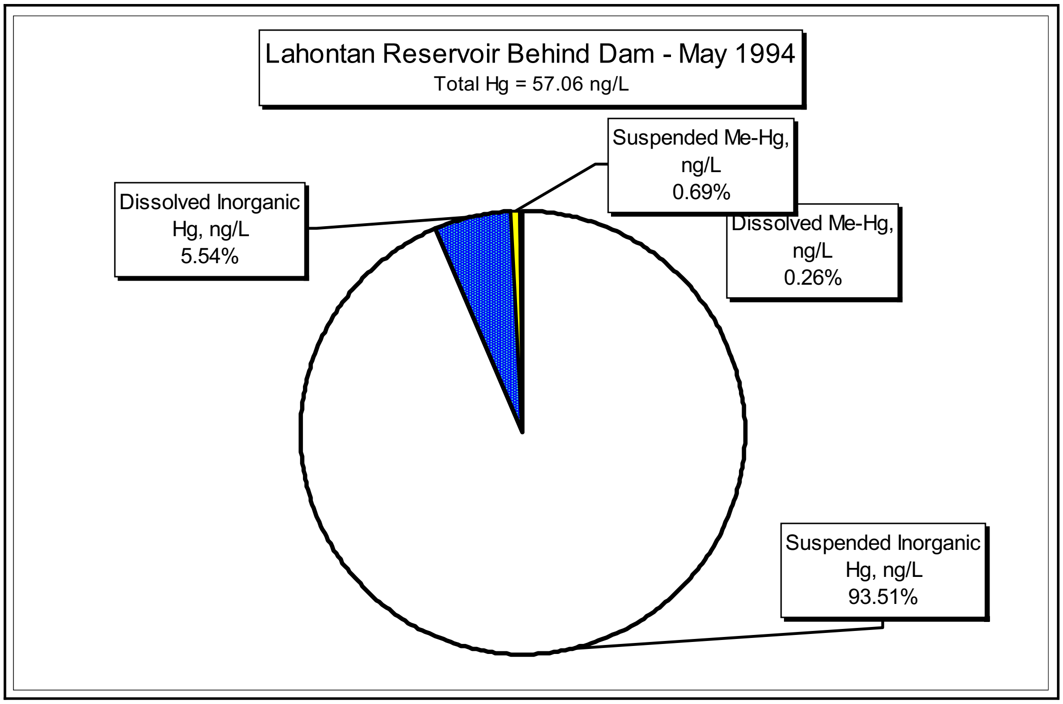


Figure 16.— Calculated suspended inorganic Hg and dissolved Me-Hg in Lahontan Reservoir. The left data points are from the inflow delta sample, the middle data from Fisherman's Point, the right data from behind the dam. Data from Bonzongo et al. (1996a, 1996b).



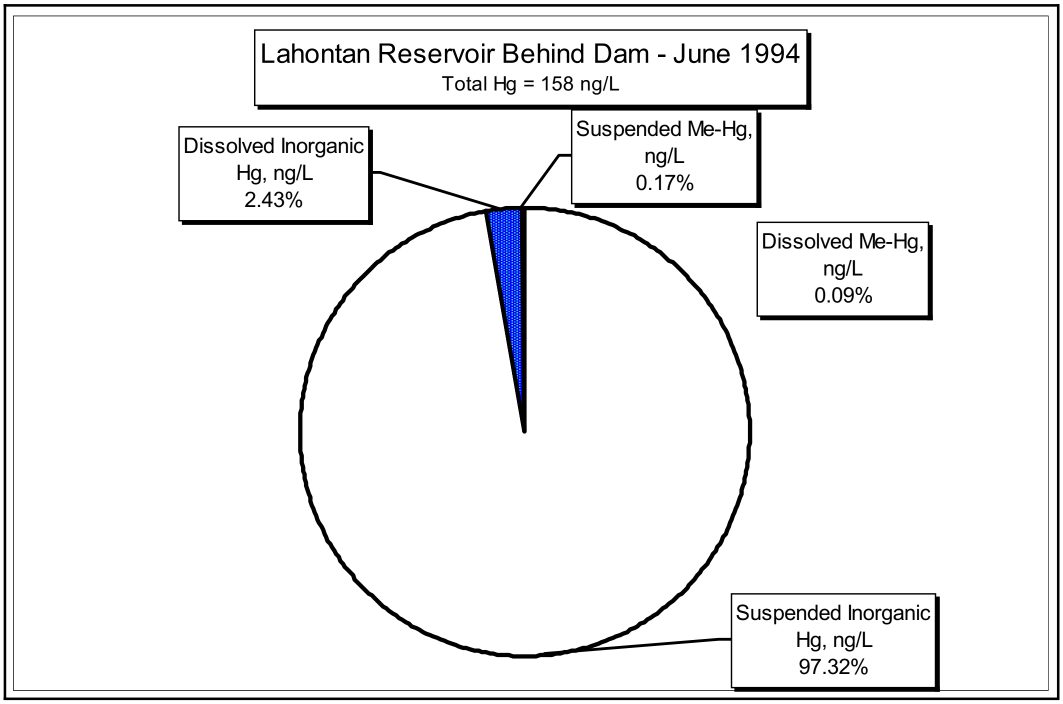


Figure 17.— Percentages of different forms of Hg in Lahontan Reservoir, May and June 1994. Data from Bonzongo et al. (1996a, 1996b).

Truckee Canal inflows measured in this study at the dam reported total Hg at 4 ng/L. These low unfiltered total Hg results are corroborated by 4.4 ng/L reported by Wayne et al. (1996). Those Truckee Canal concentrations would be expected to provide a dilution effect, so another possibility is that suspended sediments and Hg concentrations are heterogeneous in Lahontan Reservoir.

Bonzongo et al. (1996b) reservoir surface sample Hg trends and concentrations corroborated data from Gustin et al. (1994), who reported unfiltered total Hg and Me-Hg concentrations in Lahontan Reservoir sampled in August and September 1993. Unfiltered total Hg ranged from 53 ng/L to 591 ng/L, and concentrations were much higher closer to the inflow delta in the Upper Basin. Unfiltered Me-Hg levels were also highest in the Upper Basin ranging from 5.1 to 21 ng/L. These results, which are around one-third of the Bonzongo et al. (1996b) data, also suggest that suspended Hg levels will decrease through the summer as inflow volume decreases, but that Me-Hg concentrations may increase.

Wayne et al. (1996) were also collecting samples in 1993, reporting a maximum 1,000 ng/L unfiltered total Hg in Lahontan Reservoir, with around 60 percent of Hg associated with suspended particulates > 0.45 µm, and filtered total Hg on one replicated sample at 113 ng/L. April 1993 reservoir samples showed highest average concentrations of unfiltered total Hg in the Upper Delta at 977 ng/L, with only 21 ng/L found at the dam. Post-runoff July 1993 samples were much lower in the Upper Basin, but higher at the dam (32 ng/L). Samples from October 1992 showed average unfiltered total Hg at 293 ng/L behind the dam—once again hinting at possible time lags of earlier runoff season spikes of Hg.

In a previous study, Bonzongo et al. (1996a) reported means and ranges for Hg in Lahontan Reservoir. Unfiltered total Hg ranged from 57 to 1,583 ng/L (mean = 873 ng/L) and filtered total Hg ranged from 0.75 to 6 ng/L (mean = 23.03 ng/L). Unfiltered Me-Hg ranged from 0.4 to 6.7 ng/L (mean = 2.81 ng/L) and filtered Me-Hg ranged from 0.13 to 3.06 ng/L (mean = 1.01 ng/L). Notably, Me-Hg was reported higher for both unfiltered and dissolved concentrations in Lahontan Reservoir compared to the Carson River. Here is a clear indication is that Lahontan Reservoir may encourage methylation.

The Bonzongo et al. (1996a) study also reported profile data collected at depth in Lahontan Reservoir behind the dam in August 1994. The thermocline at 6 m was weak, only 5 °C. between surface (25 °C.) and bottom (20 °C.), and dissolved oxygen (DO) was above theoretical saturation (13 mg/L) at the surface, but zero below 10 m. These results suggest anaerobic activity in the bottom sediments of the Lower Basin, likely encouraged by warm temperatures. pH ranged from 8.9 at the surface (probably indicative of algal photosynthesis), to 7.8 at the bottom, suggesting fairly alkaline conditions. Dissolved organic carbon varied from 5.5 mg/L at the surface to 4.0 mg/L at the bottom (12 m depth).

Bonzongo et al. (1996a) noted a strong correlation ® = 0.92) between unfiltered total Hg and total suspended solids (TSS) in Lahontan Reservoir. TSS increased from surface to bottom, 7.5 mg/L to 46.2 mg/L, and unfiltered total Hg followed this trend ranging from 120 to 140 ng/L in the upper 5 m to 260 ng/L at the bottom. Filtered total Hg ranged from 10.5 to 14.0 ng/L in the upper 5 m, to 5 to 6 ng/L at the bottom.

Unfiltered Me-Hg decreased from 0.88 ng/L at the surface to 0.48 ng/L at the thermocline, and then increased to 0.76 ng/L at the bottom. Dissolved Me-Hg showed no trend with depth, ranging from 0.12 ng/L at the surface and bottom to 0.15 at the thermocline, a result not seen in pristine clear lakes lacking suspended materials where dissolved Me-Hg is an order of magnitude more concentrated in the anoxic hypolimnion (Bloom and Effler, 1990). These results suggest that dissolved Me-Hg adsorbs onto particulate surfaces that increase with depth. Changes in iron (Fe) and manganese (Mn) also suggested interactions between Me-Hg and the oxyhydrates of Fe and Mn at the oxic-anoxic boundary near the bottom (Bonzongo et al., 1996a).

Overall, it appears that suspended forms of Hg are mostly trapped in Lahontan Reservoir—the USGS estimated that around 90 percent of inflow sediments and 80 percent of unfiltered total Hg are retained by Lahontan Reservoir (Hoffman and Taylor, 1998; Cooper et al., 1985). Table 3 USGS filtered Me-Hg data below Lahontan Dam (0.04 to 1.08 ng/L, median = 0.125 ng/L) are in the range of those reported by Bonzongo et al. (1996b), where dissolved Me-Hg was around 1 ng/L at the Carson Delta, but dropped to around 0.10 ng/L by Fisherman's Point and remained at that level to the dam.

It should be noted that the Hg and Me-Hg water concentrations summarized here for Lahontan Reservoir are *significantly* elevated—especially during runoff flows above half median discharges—and even when compared with other watersheds and lakes having Hg bioaccumulation issues in fish (Gustin et al., 1994; Bonzongo et al., 1996a,1996b, 2002). For comparison, Gill and Bruland (1990) reported a range of 15 to 34 ng/L unfiltered total Hg in Davis Creek, California, in the Sierra Nevada, and from 12.0 to 104 ng/L in Clear Lake, California, in the Coastal Range, both heavily mined areas. Lake Owyhee unfiltered total Hg ranged from 4.8 to 140 ng/L (Craft et al., 2000). Bloom and Effler (1990) reported 7.13 to 25.7 ng/L unfiltered total Hg in Onondaga Lake, New York, and 5.0 to 80 ng/L in Clay Lake, Ontario, both lakes directly contaminated by chlor-alkali plants.

Additional research and studies on Lahontan Reservoir have been funded by Region IX EPA as part of the risk assessment for the Carson River Mercury Superfund site. Risk assessment is driven mostly by Me-Hg issues, and the identification of potential remedial actions cannot occur until more is understood about these sources. Several questions remain, including verification of suspected source areas such as the reservoir delta and intermittently flooded Upper Basin sediments, the role of Me-Hg production and flux in Lahontan Reservoir sediments, flux rates between surface water and atmosphere. Results to date from sampling and modeling studies funded by EPA have not fully answered these questions, so there is interest in supporting additional research aimed at understanding Hg dynamic in Lahontan Reservoir and the relative roles of river and internal flux and loading play in bioaccumulation of Hg in fish.

Hg in Carson River Basin Bed, Bank, and Suspended Sediments

Table 4 summarizes literature and web-available total Hg in bed sediments and suspended sediments downloaded from the USGS (USGS, 2004b). Like the table 3 organization, table 4 includes background and biological effects levels for reference to the Carson River Basin data that are also arranged by watershed elevation.

We can assume that suspended sediment concentrations are based on particles > 0.45 µm; however, direct comparison of different sediment concentrations (such as the Owyhee data) should consider the varying size fractions analyzed. The Owyhee sediment data are for minus-80 mesh materials (< 178 µm) while the USGS data are for the sediment fraction < 62.5 µm. We can generally expect the smaller size fractions to have higher Hg concentrations because of the much higher surface area associated with small particles (Hem, 1985; Forstner and Whitmann, 1979; Jackson, 1979; Stumm, 1987; Stumm and Morgan, 1996). A Hg concentration of 100 µg/kg was suggested by Cooper et al. (1985) as a background level for Hg in sediments from pre-mining Nevada watersheds.

Upper Carson Sub Basin Sediment Hg Concentrations – There are limited web-available data for the Upper Carson Sub Basin, but bed sediments containing 2,200 µg/kg reported for the East Fork Carson River near Gardnerville, Nevada, suggest either an anomalous result, or possible areas of significant Hg contamination (perhaps hot spots from localized mine drainage). Fischer and Gustin (2002) reported sediment Hg in East Fork tributaries Leviathan and Bryant Creeks from 100 to 190 µg/kg, and Me-Hg in Upper Mountaineer Creek of 6.62 µg/kg. These levels are only slightly above the background levels noted in table 4.

Middle Carson Sub Basin Sediment Hg Concentrations – Downstream from Carson City, Hg in Carson River bed sediments increases, especially below Dayton. In the early 1970s, Van Denburgh (1973) reported Carson River bed sediment Hg concentrations ranging from 310 to 2,100 µg/kg at Dayton and 3,800 to 11,000 µg/kg at Fort Churchill. Richins and Risser, Jr. (1975) reported somewhat lower Hg in sediments with 722 µg/kg Hg at Fort Churchill and 1,345 µg/kg near the Lahontan Reservoir Delta. Hoffman and Taylor (1998) reported Hg in Carson River bed sediments (wet-weight basis) from Fort Churchill ranging from 260 to 34,000 µg/kg, with a median concentration of 17,000 µg/kg.

Table 4.— Summary of Hg concentrations in sediments from the Upper Carson Sub Basin to below Lahontan Dam, including the Carson River and Lahontan Reservoir. Unless otherwise noted, concentrations are on a dry-weight basis, and data are for bed sediments

Biological Effect and Background Concentrations			
Source	*Total Hg or Me-Hg, µg/kg*	*Source*	*Total Hg or Me-Hg, µg/kg*
Bioassay Exposure Level of Concern (Long and Morgan, 1991)	150 total Hg	Bioassay Exposure Effect Level (Long and Morgan, 1991)	1,300 total Hg
Uncontaminated Background (Gustin et al., 1994)	<100 total Hg 10–50 Total Hg	Virginia Range Rock Background (Gustin et al., 1994)	10–50 total Hg
Contaminated Lake Owyhee, Oregon (< 178 µm) (Craft et al., 2000)	152–410 total Hg 2.39–5.39 Me-Hg	Clear Lake Superfund Site, California (Gustin et al., 1994)	900–159,000 total Hg

	Total Hg, µg/kg	*Me-Hg, µg/kg*	*Total Hg, µg/kg*	*Me-Hg, µg/kg*
Carson River above Carson City				
Source	Fischer and Gustin, 2002		USGS, 2004b	
Range	100–190	6.62	2,200	–
Source	Wayne et al., 1996		Bonzongo et al., 1996a	
Range	30–6,100	–	< 10	2.8–3.0
Source	Cooper et al., 1985		Lechler et al., 1995, 1997	
Range	< 250–970	–	< 100–1,500	–
Carson River from Dayton to Fort Churchill, Nevada				
Source	Wayne et al., 1996		Bonzongo et al., 1996a (river banks)	
Range	50–881,000	–	35,000–600,000	4.2–14.5
Source	Hoffman and Taylor, 1998		USGS, 2004b (bed sediments)	
Range	260–34,000 (wet weight)	–	260–34,000	–
Source	Van Denburgh, 1973		USGS, 2004b (suspended sediments)	
Range	310–11,000	–	200–25,000	–
Source	Richins and Risser, 1975		Gustin et al., 1994	
Range	722	–	1,900–156,000	–
Source	Lechler et al., 1995, 1997		Cooper et al., 1985	
Range	1,800–12,000	–	350–22,850	–
Lahontan Reservoir–Upper (Southern) Basin				
Source	Gustin et al., 1994		Van Denburgh, 1973	
Range	20–103,000	–	12,000–20,000	
Source	Lechler et al., 1995		Wayne et al., 1996	
Range	12,000	–	~3,200–10,500	–
Source	Lechler et al., 1995			
Range	12,000	–		
Lahontan Reservoir–Lower (Northern) Basin				
Source	Hoffman and Taylor, 1998		Wayne et al., 1996	
Range	4,000–15,000	–	~10–60,000	
Carson River Below Lahontan Dam				
Source	Cooper et al., 1985		USGS, 2004b	
Range	650–14,660	–	1,200	–
Carson Lake and Stillwater Wildlife Areas				
Source	Cooper et al., 1985			
Range	< 250–23,750	–		

Bonzongo et al. (1996a) reported river bank Hg levels from the Carson River from Carson City to Lahontan Reservoir. Total Hg above and at Dayton (station 3 in that study) were at low µg/kg concentrations, while levels increased exponentially below this point to Fort Churchill (station 7), where river banks contained up to 600,000 µg/kg. Me-Hg in stream banks followed a more linear trend with concentrations ranging from 2.77 to 14.58 µg/kg over the same Carson River reach. Similar results for sediment Hg concentrations were found by Wayne et al. (1996) and showed an exponential increase in both sediment (and water) Hg concentrations from Dayton into and below Lahontan Reservoir. Sediments from above Dayton ranged from 30 to 6,100 µg/kg, while below this point sediment Hg ranged from 50 to 881,000 µg/kg. Lechler at al. (1995) reported increasing bed sediment concentrations along the same river reach up to 2,500 µg/kg, but at much lower total Hg concentrations compared to Bonzongo et al. (1996a, 1996b) and Wayne et al. (1996).

Suspended sediment concentrations at the Fort Churchill station ranged from 200 to 25,000 µg/kg, and confirm that bed sediment-like concentrations of Hg are suspended in the water column and being transported downstream (Hoffman and Taylor, 1998; Hoffman and Thomas, 2000). For comparison, the Lake Owyhee wet-weight sediments ranged from 69.3 to 178 µg/kg Hg, so this is another indication of the severity of Hg contamination in labile sediments upstream from Lahontan Reservoir.

Once again, the connection between high flows, elevated Hg in water, and sedimentary Hg transport must be mentioned. The extreme bed and suspended sediment Hg concentrations observed after the 1997 flood (around 130-times the concentrations observed in September 1992) and extremely high unfiltered total Hg in water (28,000 ng/L), suggest a significant relationship between high flows and mobilization of Hg from contaminated streambanks in the Carson Plains area east of Dayton into Lahontan Reservoir (Hoffman and Taylor, 1998; Miller et al., 1998, 1999).

Hg in Lahontan Reservoir Sediments – Elevated Hg in sediments from Lahontan Reservoir and the data suggesting a relation between sediment Hg levels, transport, and concentrations in the water column have been reported since the early 1970s (Van Denburgh, 1973; Richins and Risser, Jr., 1975; Cooper et al., 1985; Lechler et al., 1995).

The Upper Basin, separated from the Lower Basin at the Narrows, experiences greater rates of sediment deposition and Hg contamination. Van Denburgh (1973) reported 12,000 µg/kg in surficial sediments from the Upper Basin of Lahontan Reservoir near the delta, 20,000 µg/kg in the Narrows, and 5,300 µg/kg behind the dam. These data support the hypothesis that the Upper Basin has much higher Hg levels in water and sediments because of the isolation of the two basins at the Narrows. Gustin et al. (2003) reported Lahontan Reservoir sediment Hg to range from 20 to 103,000 µg/kg with a mean of 17,000 µg/kg. Notably, these eight samples were collected from the Upper Basin of Lahontan Reservoir and suggest that Upper Basin sediments are generally higher in Hg compared to the Lower Basin. This difference may be a contributing factor as to why Lahontan blackfish, who prefer shallower habitats, have bioaccumulated Hg in their tissues.

Lechler et al. (1995) investigated the speciation of Hg in sediments along the contaminated reach of the Carson River and Lahontan Reservoir using sequential extractions. They reported total Hg in the Upper Basin reservoir sediments at 12,000 µg/kg, with elemental Hg_0 accounting for 50 percent of total, "exchangeable" and "organic" Hg both < 5 percent, and 36 percent as residual, or unreactive forms. Given the volcanic geology of this basin, this residual fraction is likely mercuric sulfide. However, Bonzongo et al. (1996a) reported average Hg_0 in unfiltered Upper Basin reservoir water samples around 0.70 ng/L, representing less than 0.1 percent of average total Hg. These differences may be caused by sediment heterogeneity or the analytical methods used by Lechler et al. (1995).

Hoffman and Taylor (1998) also summarized Lower Basin Hg and isotopic sediment chronostratigraphy performed in 1982 using cesium-137 and lead-210 isotopes for core samples collected from Lahontan Reservoir around 0.5 miles south of the dam. These Lower Basin cores revealed that sedimentation rates vary from 0.9 to 0.6 in/yr (2.3 to 1.5 cm/yr) and these rates are dependent on the magnitude and frequency of peak runoff events. The sediment record revealed that Hg has decreased slightly since the early 1940s from 6,000 to 8,000 µg/kg to the 1982 level of 4,000 µg/kg, with a significant spike to 15,000 µg/L associated with a 1955 flood peak of 9,680 ft^3/s (274 m^3/s) at the Fort Churchill gage. These Lower Basin sediment levels exceed by 30-times those observed in Lake Owyhee.

Hg in Biota and Tissues

Table 5 summarizes the available tissue Hg concentrations (wet weight basis) in the Carson River Basin, and is organized similarly to tables 3 and 4. EPA recommends fish consumption advisories when concentrations reach 0.6 mg/kg, and the FDA (1984) has established an action level of 1.0 mg/kg for fish and 3.6 mg/kg for other edible wildlife. Natural background levels for fish in uncontaminated watersheds range from 0.02 to 0.2 mg/kg. Background levels in fish were less than 0.5 mg/kg from the Fernley Water Management Area (FWMA), just outside the Carson River Basin near Fernley, Nevada, a "background" site for Nevada (Gustin et al., 1994). The higher background levels in Nevada are indicative of the higher abundance of natural sources of Hg in the volcanic geology of the Sierras and the Great Basin and Range.

The general trend for the Hg concentrations in aquatic tissues in the Carson River Basin is that background levels (associated with the FWMA) seen in the Upper Carson Sub Basin begin to increase below Dayton, and become higher as the Carson River approaches Lahontan Reservoir. These high levels in aquatic plants, fish, and waterfowl continue to persist below Lahontan Reservoir in areas such as the Carson Lakes, Indian Lakes Recreation Area, and the Stillwater Wildlife Management Area (WMA) and other wildlife refuge areas in the Carson Sink (Cooper et al., 1985). Larger fish generally have higher the levels of Hg compared to smaller fish.

Table 5.— Summary of Hg concentrations in biota from the Upper Carson Sub Basin to the Carson Sink Sub Basin. Unless otherwise noted, concentrations are on a whole-body wet-weight basis

Biological Effect and Background Concentrations			
Source	*Total Hg, mg/kg*	*Source*	*Total Hg, mg/kg*
EPA Recommendation for Fish Consumption Advisory (EPA, 1994a)	0.60	FDA Consumption Action Levels (FDA, 1984)	1.0 fish 3.6 edible wildlife
Uncontaminated Tissue Background (Gustin et al., 1994)	0.02–0.20	Fernley Water Management Area (FWMA) Nevada Background (Gustin et al., 1994)	Fish < 0.5
Levels of Concern (Tuttle and Thodal, 1998)	Fish 0.17	Effect Levels (Heinz, 1979)	Diet > 0.4 Fish > 0.67 Avain Eggs > 0.83 Avian Liver > 4.3

	Species and Tissue Type	*Range, Tissue Total Hg, mg/kg*	*Species and Tissue Type*	*Range, Tissue Total Hg, mg/kg*
Upper Carson Sub Basin				
Source	Fischer and Gustin, 2002		USGS, 2004b	
Data	Stonefly, dry weight	0.038–0.126	Unspecified Biota	0.167–0.500
Carson River from Dayton to Fort Churchill				
Source	USGS 2004b, (Dayton)		Cooper et al., 1985 (Dayton)	
Data	Unspecified Biota	8.8	Tahoe sucker Mountain sucker	0.33–0.68 1.17–0.19
Source	Richins and Risser, 1975 (Carson River)		USGS, 2004b (Fort Churchill)	
Data	Crayfish Carp	0.10–0.969 0.355–1.36	Unspecified Biota	4.9–10
Source	Cooper et al., 1985 (Fort Churchill)			
Data	Mountain sucker Carp White bass Channel catfish	0.72–1.22 0.89–2.07 3.10–3.19 1.18–2.69		
Lahontan Reservoir				
Source	Richins and Risser, 1975 (Lahontan Reservoir)		Cooper et al., 1985 (Lahontan Reservoir)	
Data	White bass White catfish Brown bullhead Carp	0.501–2.72 0.211–0.769 0.250–1.08 0.382–1.09	Yellow perch Sacramento blackfish While bass While catfish	0.33–0.77 0.72–1.38 0.41–1.80 0.65–4.14
Source	Henny et al., 2002 (Lahontan and Carson Lake)		Reclamation, 2004d and NDOW, 2004b (Lahontan Reservoir)	
Data	Night-heron liver Night-heron eggs Snowy egret liver Snowy egret eggs Cormorant liver Cormorant eggs Fledgling feathers Avian diet	5.01–49.6 0.81–1.8 16.0–110 0.81–1.53 82.5–222 1.07 (average) 14.7–87.3 0.17–2.23 (Lahontan)	Forage fish Predator fish (see tables 6a and 6b for details by species)	0.19–4.22 0.18–16.0

Table 5.— Summary of Hg concentrations in biota from the Upper Carson Sub Basin to the Carson Sink Sub Basin. Unless otherwise noted, concentrations are on a whole-body wet-weight basis—continued

	Species and Tissue Type	*Range, Tissue Total Hg, mg/kg*	*Species and Tissue Type*	*Range, Tissue Total Hg, mg/kg*
Carson Lake, Indian Lakes, and Stillwater Wildlife Areas				
Source	Cooper et al., 1985 (Below Carson Diversion)		Cooper et al., 1985 (Sheckler Reservoir)	
Data	Sacramento blackfish	0.42–0.83	Sacramento blackfish	0.16–0.53
	Yellow perch	0.72–1.82	White bass	0.56–0.74
	Carp	0.71–1.78	White catfish	0.28–2.00
	White catfish	1.16–1.80		
	Walleye	1.54–2.79		
Source	Hoffman et al., 1989 (Carson Lake)		Henny et al. 2002 (Carson Lake)	
Data	Aquatic plants	0.43–2.40	Night-heron food	0.03–0.93
	Insects	0.30–5.4	Snowy egret food	0.20–0.89
	Carp	1.2–2.4		
	Mosquitofish	1.0–2.0		
	Sacramento perch	5.70		
	Smallmouth bass	2.1		
	Coot livers	0.15–25		
	Stilt livers	0.30–21		
	Mallard livers	2.2–16		
	Mallard muscle	0.3–7.9		
	Shoveler liver	4.0		
Source	Hallock and Hallock, 1993 (Carson Lake)			
Data	Coot livers	2.0–8.8		
	Cinnamon teal livers	5.6		
	Mallard livers	1.4–6.0		
	Redhead livers	0.9–5.1		
	Stilt liver	7.9		
	Duck muscle	0.4–16		
	Green-winged teal muscle	0.1–3.7		
Source	Cooper et al., 1985 (Indian Lakes)		Tuttle and Thodal, 1998 (Indian Lakes)	
Data	Channel catfish	0.24–0.67	Pondweed	< 0.2
	Carp	0.66–2 .21	Insects	0.47–2.88
	Sacramento blackfish	0.54–1.09	Brine shrimp	<0.19–1.13
			Avocet eggs	0.58–2.27
			Avocet livers	0.91–31
Source	Hallock and Hallock, 1993 (Stillwater WMA)		Hoffman et al., 1989 (Stillwater WMA)	
Data	Detritus	< 0.04–38.6	Aquatic plants	2.0 median
	Algae	< 0.02–10.4	Insects	0.30–2.0
	Duck eggs	0.20–6.2	Carp	0.40–2.0
	Coot livers	2.0–5.7	Mosquitofish	0.40–0.70
	Redhead livers	2.4–6.4	Coot livers	0.10–8.5
			Stilt livers	0.10–11
			Mallard livers	1.1–14
			Redhead livers	1.2–3.7
			Shoveler liver	2.1–12

Biotic Hg in the Upper Carson Sub Basin – Table 5 tissue wet weight concentrations at the Upper Carson Sub Basin East Fork station (0.2 and 0.5 mg/kg) suggest that there may be some Hg bioaccumulation even in the upper reaches of the Carson River Basin, and these observations are corroborated by the West Fork station biota sample (0.167 mg/kg). However, these reported values are in the range of background values for fish (< 0.5 mg/kg) seen in the FWMA. Fischer and Gustin (2002) reported dry weight Hg and Me-Hg in stoneflies (*Doroneuria baumanni*) from the upper reaches of the East Fork of the Carson River. Tissues from Poison Creek contained total from 0.038 mg/kg in June to 0.064 mg/kg the following September, and similar levels of Me-Hg were observed in September tissues. Stoneflies from Mountaineer Creek varied from 0.038 mg/kg in June to 0.126 mg/kg in September. These results show that a primary fish food species in the Upper Carson Sub Basin contains enough Hg to produce Hg bioaccumulation in fish, but likely below a toxic effects levels (Scherer et al., 1975).

Biotic Hg in the Middle Carson River Basin – Table 5 tissue concentrations, however, are considerably higher downstream at Dayton (8.8 mg/kg) and at Fort Churchill (4.9 to 10 mg/kg). Richins and Risser, (1975) reported similar trends downstream from Dayton, but lower wet-weight Hg levels, in several species in the Carson River and Lahontan Reservoir. Hg in Carson River crayfish at Carson City ranged from 0.100 to 0.520 mg/kg, while near Fort Churchill, levels were 0.534 to 0.969 mg/kg. Carp showed 0.069 to 0.503 mg/kg Hg near Carson City, 0.355–0.650 mg/kg at Dayton, and 0.020–1.360 mg/kg near Fort Churchill. These researchers suggested that fish were swimming upstream from Lahontan Reservoir to the Fort Churchill gage.

Hg in Lahontan Reservoir Fish – Richins and Risser (1975) reported average Hg content for shiners (0.129 mg/kg), suckers (0.245 mg/kg), carp (0.547 mg/kg), white catfish (0.374 mg/kg), brown bullhead (0.554 mg/kg), and white bass (1.3 mg/kg) from Lahontan Reservoir. These researchers also reported a high positive correlation ($r^2 = 0.975$ at $p = 0.001$) between weight and Hg content for white bass, a predator fish. Cooper (1983) also reported significant correlations between fish weight and Hg for yellow perch, white crappie, white catfish, and white bass, with a maximum concentration observed in a 16-year old striped bass of 9.52 mg/kg (Cooper, 1983; Cooper and Vigg, 1984).

In a comprehensive survey of Carson River Basin fish for Hg, Cooper et al. (1985) suggested that some fish from Lahontan Reservoir (carp, white bass, catfish) migrate upstream in the Carson River to Fort Churchill. These fish showed elevated tissue Hg far higher than samples collected at the Dayton river site—88 percent of the 32 Fort Churchill fish exceeded the 1.0 mg/kg FDA action level. White bass (average = 3.14 mg/kg) showed the highest Hg levels, and all Tahoe suckers collected (average = 1.42 mg/kg) exceeded FDA action levels.

In Lahontan Reservoir, Cooper et al. (1985) found that Hg ranged from 0.33 mg/kg in a small yellow perch, up to 4.14 mg/kg in a 4.5-lb (2.0-kg) white catfish. This survey found average tissue Hg in catfish and carp species exceeding levels in predator fish. This range of concentrations seems unexpected assuming food chain bioaccumulation by predators, but this result is likely a sampling artifact of the relative masses of the fish sampled. Commercially harvested non-predator species also showed elevated levels of Hg. Cooper at al. (1985) reported carp ranging from 0.84 to 2.30 mg/kg with 71 percent of the fish exceeding FDA action levels, and blackfish ranging from 0.72 to 1.38 mg/kg with 17 percent exceeding 1 mg/kg. Overall, 41 percent of Lahontan Reservoir fish exceeded FDA action limits (Cooper et al., 1985).

More corroboration that Hg bioaccumulation is a serious issue in Lahontan Reservoir is provided by fish tissue samples collected and analyzed by the State of Nevada and Reclamation for Hg (NDOW, 2004b; Reclamation, 2004d). Summaries of these data, collected since 1980, are provided in table 6a, for forage fish, table 6b for predator fish, and in appendix 2 tables. Analysis of NDOW and Reclamation Hg data for individual fish (n = 385, all species) suggests that over 90–95 percent of fish from Lahontan Reservoir contain Hg above the 0.6 mg/kg EPA advisory level, and from 70–75 percent are above the 1.0 mg/kg FDA action level.

As expected, predator game fish show higher tissue Hg compared to forage fish. Average predator Hg was 3.03 mg/kg (with species averages ranging from 0.56 to 4.81 mg/kg), while forage fish averaged 0.94 mg/kg (with species averages ranging from 0.65 to 1.48 mg/kg). Predators showed 95–97 percent with Hg above the 0.6 mg/kg EPA level, and 90–92 percent above the 1.0 mg/kg FDA level. One 11.1 lb. (30-in) walleye captured in 1996 had 12.4 mg/kg Hg and a smaller (5.5-lb, 25-in) walleye, captured in 1998, showed 16.0 mg/kg. These Hg values approach those reported for fish from Minimata Bay during the 1970s (UNEP, 2003). While extreme, these values are not outliers—the NDOW data suggest that 5 percent of predator game fish have Hg greater than 7.6 mg/kg.

Commercial forage fish harvested from the Upper Basin were analyzed by NDOW and Reclamation. Reclamation sampled 65 Upper Basin blackfish from a fish market in San Francisco, California, in 1996 and 2001 (table 6a, appendix 2, tables A2-1 to A2-3). These fish showed Hg ranging from 0.19 to 4.22 mg/kg with a median concentration of 1.00 mg/kg. Only 4.6 percent of these blackfish showed tissue Hg less than the 0.6 mg/kg EPA advisory level, and 50 percent exceeded the 1.0 mg/kg FDA action level (Reclamation, 2004d). NDOW collected 10 samples from Murray Fish Company in 2004. These 13.0- to 14.4-in fish showed lower Hg concentrations that ranged from 0.47 to 0.81 mg/kg Hg, with a median of 0.64 mg/kg, with only 25 percent below the 0.6 mg/kg EPA level.

Biotic Hg in the Carson Desert Sub Basin – Downstream from Lahontan Dam, Hg continues to bioaccumulate in the Carson Lake area, the Newlands Project irrigation diversions and sloughs, and the Stillwater Wildlife Management Area (WMA). While fewer game fish are found in this area, aquatic plants, forage fish, and waterfowl bioaccumulate Hg in the 15,000 acres of remaining wetlands of the Carson Sink (Hallock and Hallock, 1993). While some elevated tissue concentrations have been reported for

Table 6a.— Summary of Hg in forage fish collected from Lahontan Reservoir by the State of Nevada and Reclamation (NDOW, 2004b; Reclamation, 2004d). Medians and percentages greater than the EPA 0.6 mg/kg and FDA 1.0 mg/kg action levels were calculated only for non-summarized data sets. These data are provided in more detail in the appendix 2 tables

Species	Samples	Hg Range, mg/kg	Median Hg, mg/kg	Average Hg, mg/kg	Percent > 0.6 mg/kg	Percent > 1.0 mg/kg
Forage Fish						
Tahoe Sucker	4 (1985)	0.73–1.08	–	0.97	100	–
Carp	7 (1985)	0.84–2.30	–	1.48	100	–
Sacramento blackfish (Fish Market)	63	0.19–4.22	1.00	1.05	90	50
Sacramento blackfish (Murray Fish Co.)	10	0.47–0.81	0.64	0.65	70	0
Sacramento blackfish (Reservoir)	15	0.20–0.90	0.76	0.66	40	0
Sacramento blackfish (Reservoir)	5 (1981) 6 (1985) 17 (1994) 30 (1995) 20 (1996)	0.441.92 0.72–1.38 0.22–0.94 0.80–1.64 0.59–1.15	– – – – –	0.96 0.88 0.54 1.25 0.83	– 100 – 100 100	– – – – –
Sacramento blackfish **(Summary)**	166	0.19–4.22	0.83	0.94	85	35

Table 6b.— Summary of Hg in predator fish collected from Lahontan Reservoir by the State of Nevada and Reclamation (NDOW, 2004b; Reclamation, 2004d). Medians and percentages greater than the EPA 0.6 mg/kg and FDA 1.0 mg/kg action levels were calculated only for non-summarized data sets. These data are provided in more detail in the appendix 2 tables—continued

Species	Samples	Hg Range, mg/kg	Median Hg, mg/kg	Average Hg, mg/kg	Percent > 0.6 mg/kg	Percent > 1.0 mg/kg
Predator Fish						
Black bass	9	0.60–3.38	1.67	1.85	100	75
Black bullhead	2	0.67–0.75	–	0.71	100	0
Bluegill	11	0.42–0.97	–	0.59	–	0
Green sunfish	3	1.16–1.30	–	1.23	100	100
Channel Catfish	3	2.35–6.25	–	4.81	100	100
	25	0.37–5.34	1.83	2.13	92	85
	5	0.43–2.23	–	1.40	–	–
Largemouth bass	14	0.38–2.88	–	1.29	–	–
	1	4.28	–	–	100	100
Rainbow trout	7	0.18–1.86	1.18	1.02	75	50
Striped bass	1	10.4	–	–	100	100
Walleye	9	0.54–2.07	–	0.97	–	–
	127	0.69–16.0	2.86	3.40	100	95
White bass	13	0.85–3.96	–	2.63	100	–
	23	0.41–1.80	–	1.08	–	–
	95	0.27–13.8	2.38	3.15	90	80
White catfish	3	1.48–1.86	–	1.68	100	100
	10	0.65–4.14	–	1.80	100	–
	7	1.29–2.18	1.50	1.63	100	100
White crappie	2	0.69–0.86	–	0.77	100	–
	10	0.86–2.60	1.20	1.32	100	100
Wiper	14	1.34–6.64	3.41	3.63	100	100
Yellow perch	1	1.09	–	–	100	100
	11	0.33–0.77	–	0.56	–	–
Predator **(Summary)**	297	0.18–16.0	2.36	3.03	97	90

the Stillwater WMA and the Indian Lakes area, the highest tissue Hg levels were found in the Carson Lake area (Hoffman et al., 1990). The results of Hoffman et al. (1990) suggest an enrichment of Hg in biota downstream from Lahontan Dam in the range of 40 to 100 percent above Nevada background levels reported for the Fernley WMA (Gustin et al., 1994).

Hg bioaccumulation was less severe in Sheckler Reservoir, where only 25 percent of white catfish (and only 5 percent of all sampled fish) showed Hg higher than the FDA action limit. The overall range of Hg was 0.16 mg/kg (in a 7.2-in blackfish) up to 2.0 mg/kg in a 10.9-in white catfish. These values are thought to be the result of settling of suspended Hg in the V Canal which feeds Sheckler Reservoir and the location of the Sheckler basin off the main channel Hg contamination of the Carson River downstream from Lahontan Dam. However, average values for all fish except for white crappie were above the 0.6 mg/kg EPA advisory level (Cooper et al., 1985)—better than in Lahontan Reservoir, but still a problem for fish consumption. Additionally, insects analyzed by Hoffman et al. (1989) from Sheckler Reservoir showed Hg above 1.5 mg/kg.

Hoffman et al. (1989) reported dry-weight Hg ranging from 0.43 to 2.40 mg/L in 12 of 102 plants collected from Carson Lake and Stillwater WMA, with much higher levels in drains. Median levels in *Potamogeton* species in the Carson Lake Drain were 6.0 mg/kg. *Hemiptera* species (true bugs), and *diptera* species (two-winged flies) ranged from 0.3 to 5.4 mg/kg. These results suggest that food sources for ducks and other waterfowl are contaminated with effect-level Hg (> 0.4 mg/kg – Heinz, 1979) in specific locations. Carp and mosquitofish were reported to contain from 1.0 to 2.0 mg/kg, and while a Sacramento perch (5.7 mg/kg) and a smallmouth bass (2.1 mg/kg) showed elevated levels similar to Lahontan Reservoir. However, populations of game fish are very low in the Carson Sink waters.

Hallock and Hallock (1993) reported elevated Hg in duck eggs collected from the Stillwater WMA ranging from 0.2 to 6.2 mg/kg, with mean concentrations exceeding the 0.83 mg/kg effect level (Heinz, 1979) for cinnamon teals, mallards, and redheads. Juvenile duck livers were reported to contain Hg ranging from 1.4 to 6.4 mg/kg in the Stillwater WMA and from < 0.1 to 8.8 mg/kg in Carson Lake. The highest liver Hg was found in a stilt from Masala Slough at 13.9 mg/kg. The adverse effect liver criterion of 4.3 mg/kg (Heinz, 1979) was exceeded for mean concentrations from mallards and redheads in the Stillwater WMA, and for coot, teal, and stilts in Carson Lake. Hoffman et al. (1989) reported that the adverse effect criterion was exceeded in 9 of 28 median liver concentrations in coots, black-necked stilts, and mallards and shoveler ducks in the Stillwater WMA and Carson Lake area. The Carson Lake area showed the highest liver concentrations for coots (25 mg/kg), stilts (22 mg/kg), and mallards (16 mg/kg). Mallard ducks also showed median muscle concentrations (4.6 mg/kg) well above the FDA action level of 3.6 mg/kg in the Carson Lake area (Hoffman et al., 1989).

Henny et al. (2002) investigated Hg in piscivorus birds nesting in Lahontan Reservoir and the Carson Lakes areas and found much higher bioaccumulation in Lahontan Reservoir compared to downstream birds. Food in stomachs ranged from 0.17 to

1.96 mg/kg Hg in the Lahontan reservoir area, and from 0.03 to 0.93 mg/kg Hg in Carson Lake. The proportion of Me-Hg in food was also higher in Lahontan Reservoir. Overall, elevated levels of Hg were found in the livers of black-crowned night herons (5.01 to 49.56 mg/kg), snowy egrets (16.00 to 109.86 mg/kg), and double-crested cormorants (82.45 to 222.16 mg/kg). Liver and other tissue Hg levels in adults were high relative to fledglings. Eggs generally contain < 0.83 mg/kg, but nesting success was low relative to reference site birds, especially for snowy egrets.

Biotic Hg in the Indian Lakes Area – In the Indian Lakes Recreation Area, the lack of fish in many lakes makes human exposure to Hg unlikely via this exposure route; however, Tuttle and Thodal (1998) reported < 0.2 mg/kg in pondweed samples, from 0.47 to 2.88 mg/kg in insects, < 0.19 to 1.13 mg/kg in brine shrimp, suggesting potential Hg bioaccumulation in ducks and other waterfowl. Avocet eggs ranged from 0.58 to 2.27 mg/kg and avocet livers ranged from 0.91 to 31.0 mg/kg, suggesting deleterious effect levels are present in shore birds in the Indian Lakes area. Cooper et al. (1985) also reported Hg in channel catfish (0.24–0.67 mg/kg), carp (0.66–2.21 mg/kg), and Sacramento blackfish (0.54–1.09 mg/kg) in the Indian Lakes.

Other Relevant Research in the Carson River Basin

Hg Flux and Transport in Lahontan Reservoir – Given that the vast majority of total Hg input to Lahontan Reservoir is from inflow sediments (Hoffman and Taylor, 1998), the question arises as to whether the sediments within Lahontan Reservoir can also act as a source of Hg and Me-Hg. Computer modelers are also interested in including reservoir sediment Hg flux data into models developed for the Carson River Basin (Warwick, 2004). Understanding the Hg and Me-Hg fluxes in Lahontan Reservoir would be helpful to address potential changes in internal loading from sediments that might occur if inflow Hg is reduced, for example, by streambank remediation along the Carson River above the reservoir.

EPA funded Kuwabara et al. (2002) to investigate dissolved Hg and Me-Hg fluxes from sediments using incubated cored sediments in core tubes with local bottom reservoir water added to form sediment-water microcosms. Microcosms provide a static simulation of the reservoir sediment-water interface and are a valuable and cost-effective means to investigate an otherwise inaccessible study site. Data from static microcosms cannot simulate the dynamic flow and steady state exchange processes between sediments in a real reservoir, but they are valuable providing upper-bound or "worst case" condition scenarios associated with prolonged stratification and stagnant hypolimnetic water flows (Craft, 1985; Craft and Miller, 2001).

Kuwabara et al. (2002) reported dissolved total Hg concentrations in Lahontan Reservoir water sampled above the sediments ranging from 74.8 to 157.8 ng/L, and dissolved Me-Hg ranging from 0.060 to 0.100 ng/L (as Hg) for the Lower Basin cores (northern lobe) nearer the dam. Note that these data are based on 0.7-μm filtration, and seem elevated compared to other dissolved total Hg data summarized here—Kuwabara et al., dissolved total Hg concentrations are only supported by a single surface sample replicate average of 113 ng/L reported by Wayne et al. (1996). Dissolved Me-Hg data are more in line with 0.10 ng/L reported by Bonzongo et al. (1996b) and others. The highest bottom water results were from the Upper Basin (southern lobe) with dissolved total Hg ranging from 129.7 to 391.6 ng/L and dissolved Me-Hg from 0.140 to 0.221 ng/L. These results are consistent with respect to upper and Lower Basin differences reported by Bonzongo et al. (1996a, 1996b), Gustin et al. (1994), and Wayne et al. (1996).

Benthic Me-Hg flux (releases of Me-Hg into the water overlying the sediment core surfaces) were positive for 10 of 12 microcosms, with Upper Basin Site 1 (a shallow, near-shore location) showing both positive and negative fluxes for both May and July. Note that dissolved Hg flux estimates were based on 0.2 µm filtration. Kuwabara et al. (2002) suggest generally *higher* Me-Hg flux in the Lower Basin and lower average dissolved Me-Hg fluxes for Upper Basin microcosms. Fluxes for dissolved total-Hg were generally three orders of magnitude greater than Me-Hg and 10 of 12 microcosms showed positive Hg fluxes. In contrast to Me-Hg, dissolved total Hg fluxes were reported generally *higher* in the Upper Basin compared to the Lower Basin, probably caused by the abundance of higher concentrations of total Hg in Upper Basin sediments. Very different dissolved total Hg fluxes were reported for Upper Basin Site 2 replicates, for both May (-6.8 and +9.8 $\mu g/m^2/d$) and July (+0.236 and +5.7 $\mu g/m^2/d$) microcosms. We would conclude that the heterogeneity of sediment cores makes general comparisons of both total and Me-Hg fluxes between basins problematic.

Kuwabara et al. (2002) also suggest that the Me-Hg fluxes are driven by concentration gradients between sediments and overlying water; however, varying Upper Basin fluxes were reported for similar total and Me-Hg bottom water concentrations—another indication of bottom sediment heterogeneity. Microbial processes may also mediate the Hg and Me-Hg fluxes via iron and manganese oxyhydrate redox reactions (Stone and Morgan, 1987; Stumm and Morgan, 1996). Sediments from deeper settling basins in Lahontan Reservoir would be expected to experience greater hypolimnetic anaerobic bacterial activity, yet dissolved oxygen flux was comparable (negative values suggesting microbial oxygen demand) for May microcosms in both basins. July dissolved oxygen flux was *lower* in the Lower Basin microcosms, once again suggesting sample heterogeneity issues.

Modeling of Basin and Reservoir Hg Processes – Several researchers have studied Hg in the Carson River Basin using computer ecological modeling. These efforts usually involve a combination of hydrodynamic river flow algorithms and inputs coupled with water quality algorithms and inputs. These models are useful in better understanding basin-wide water quality processes and they can be applied to assess the effects of potential remediation activities on Hg concentrations.

Sediment transport and loading into Lahontan Reservoir has been performed by Heim and Warwick (1997) using the EPA hydrodynamic RIVMOD model coupled with the WASP5 water quality model and bedload transport equations. This modeling effort generally predicted downstream concentrations measured by Bonzongo et al. (1996) during and after the 1994 runoff. Carroll et al. (2002) simulated Hg transport and fate in the Carson River using a combination of RIVMOD, WASP5 and MERC4 programs with code modified to address specific processes in the Carson River Basin. In this study, inorganic Hg concentration estimates had an average error of 24 percent with a prediction bias of -88 ng/L. Me-Hg estimates showed an average error of 32 percent with an prediction bias of +0.14 ng/L. Both of these Hg transport studies demonstrate the applicability of modeling to estimate loading of Hg to Lahontan Reservoir under varying flow regimes; however, changes in Carson River bed and bank sediment Hg concentrations suggest that the Carson River system was significantly changed after the 1997 flood event.

In Lahontan Reservoir, Diamond et al. (2000) applied the QWASI fugacity/aquivalence multispecies model to study Hg dynamics under high flow (a 2 percent probability, or 50-year flood event) conditions. This modeling treated the reservoir as three separate basins with 2 sediment layers that included deeper sediment reactions and transport components, but not a biotic uptake component which may represent a significant sink for Me-Hg. Results suggested very little Hg_0 (estimated at less than 1 percent of total system Hg) is volatilized from the reservoir and over 95 percent of the Hg in the system remains in unreactive forms (likely insoluble amalgamated Hg, HgS, and irreversibly bound sediment forms). Nonetheless, dissolved and potentially reactive Hg is extremely high in Lahontan Reservoir.

Diamond et al. (2000) also suggest that the bulk of Hg inputs to the sediments and water are from the Carson River, although sediment resuspension from wet and dry cycles—dominantly from the Upper Basin—was hypothesized as another source. The proportion of Me-Hg was low, from 0.5 percent in water, to 0.1 percent in sediments, and their model calculated a net *loss* of Me-Hg to unreactive fractions of Hg. The low proportions of Me-Hg in Lahontan Reservoir—despite large amounts of dissolved and potentially reactive Hg—may be caused by the unreactive mineralogy of the basin (HgS) suspended sediments, coupled with a toxic inhibitory effect on microbial activity from the extreme Hg concentrations (arsenic, lead, and selenium are also elevated). Bonzongo et al. (1996a, 1996b) reported dissolved organic carbon (DOC) concentrations in the Lower Basin during August to range from 2.4 to 6.4 mg/L—a potentially much more productive reservoir than the low Me-Hg fractions would suggest.

Modeling efforts funded by EPA continue in Lahontan Reservoir. All modeling in the Carson River Basin would benefit from additional research addressing bioaccumulation and the extent of its function as a Hg sink in Lahontan Reservoir. There will also continue to be a need for ongoing field sampling and measurement of inflows, reservoir, and outflows, to provide reliable and current data to calibrate models for continued predictive accuracy.

CONCLUSIONS

1. While Hg concentrations indicate some contamination above background in the Upper Carson Sub Basin, Hg sources in the Carson River Basin are dominated by anthropogenic sources from historical mining runoff that entered the Carson River Valley near Dayton, Nevada. The pollution arose from the Hg amalgamation process used on milled rock during extensive mining during the late 1800s in and around Virginia City and Silver City, site of the Comstock Lode. Runoff and floods from these heavily mined areas eventually deposited a meter-thick layer of Hg-contaminated sediment in the Carson River Valley from below Dayton into the Carson Sink, making this area the most Hg-contaminated system in the world.

2 Since the cessation of most mining in 1915, the Carson River has been laterally cutting through these elevated sediments during spring runoff and flood events, providing a currently inexhaustible source of Hg to the downstream aquatic environment. The reach of river from Dayton to Fort Churchill continues to contribute large quantities of Hg to Lahontan Reservoir and the Carson Desert.

3. Almost all the Hg in the Carson River is associated with suspended sediments, and total Hg concentrations are highest during high river flows. During elevated flows, river total Hg concentrations are significantly elevated, but almost all of the Hg is in inorganic or suspended forms.

4. Me-Hg concentrations are greater in the Carson River when flows are low and biotic processes are given more time to convert inorganic forms to Me-Hg. However, because flows are also much lower, mass loading of Me-Hg is also reduced.

5. The loading of Hg from the Carson River and its movement and transformation within Lahontan Reservoir water and sediments is dominated and probably regulated by suspended particulates. Research suggests that the sediments do release dissolved forms of Hg, but the ever-present suspended particulates account for a large amount of adsorption and exchange surface in reservoir water that may limit dissolved concentrations of both total Hg and Me-Hg. Sediment microbial processes within the reservoir may also contribute to re-releases of Me-Hg.

6. The shallow Upper (southern) Basin of Lahontan Reservoir acts as a settling basin for suspended Carson River sediments and Hg, and has the highest concentrations of total Hg, with significantly lower concentrations in the Lower (northern) Basin behind the dam. Inflows from the relatively Hg-clean Truckee Canal also dilute Hg concentrations near the dam. Lahontan Reservoir retains 90 percent of the Hg load from the Carson River and has generally lower Me-Hg

concentrations compared to the Carson River above the reservoir, but the dam continues to discharge Hg and Me-Hg at highly elevated levels downstream to the Carson Sink.

7. Fish in Lahontan Reservoir have highly elevated Me-Hg concentrations in their tissues (90–95 percent of sampled fish exceed the 0.6 mg/kg EPA Advisory Level), and higher body levels are seen in older and bigger predator species. Bioaccumulation has also been observed in fish eating birds (egrets, cormorants) in and around Lahontan Reservoir, and in detritus, aquatic plants, insects, fish, and ducks in the Carson Lake and Stillwater areas. Edible tissue concentrations in many birds exceed FDA action levels of 3.6 mg/kg.

8. Because of the extreme Hg concentrations in sediments and water, plankton and forage feeders that prefer the shallower Upper Basin of Lahontan Reservoir, such as carp and blackfish, also have tissue Hg higher than the 1.0 g/kg advisory level set by the FDA. These fish are harvested commercially and sold to markets in San Francisco.

9. Several technical questions concerning the chemistry of Hg within Lahontan Reservoir remain unanswered. These questions are important because they represent information needed to more accurately test and apply water quality models and to better understand Hg processes in Lahontan Reservoir. Some of the important questions include:

    - Where are the specific source areas for Me-Hg and methylation-reactive inorganic Hg for Lahontan Reservoir? Does the reservoir delta contribute to the methylation of Hg?

    - Do suspended and bottom sediments in Lahontan Reservoir create additional Me-Hg above that delivered from river inflows? Does summer reservoir stratification in the Lower Basin enhance Me-Hg production?

    - Does Hg become more mobile and bioavailable after reservoir draw down and subsequent re-flooding of dried and oxidized sediments in the Upper Basin "overflow" areas? What variables affect these processes?

    - What factors account for the elevated Hg found in forage fish in the Upper Basin?

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Appendix 1

Glossary of Technical Terms and Unit Conversion Factors

for

Mercury in the Carson River Basin, California and Nevada

Technical Memorandum TSC-2005-8290-001

by

Doug Craft, John Fields, and Naomi Yoder

Glossary of Technical Terms

+80 mesh	measurement unit – plus-80 mesh, material retained on a U.S. Standard No. 80 Screen sieve
-80 mesh	measurement unit – minus-80 mesh, material passing through a U.S. Standard No. 80 Screen sieve
AA	chemistry – atomic absorption, a spectrophotometric instrumental method used to analyze for trace elements
AAS	chemistry – atomic absorption spectrophotometer
absorption	chemistry – the atomic process whereby an atom or molecule absorbs energy at a given wavelength, causing an electron to move to a higher-energy orbital; the opposite of emission; this term should not be confused with adsorption
accuracy	statistics/quality assurance – the closeness of a measured value to the true value
acid mine drainage	geology – acidic water associate with mining activities, created when sulfide minerals such as pyrite are exposed to oxygenated water, creating sulfuric acid
acre	measurement unit – English unit for land area, (1 acre = 2,471 ha)
acre-ft	measurement unit – English volume unit for water, 1 acre-ft = 12,335 m^3 = 325,851 gallons
acute	toxicology – short-term or immediate, usually applied to toxicity or exposure to toxic compounds
adsorbed	chemistry – analytes chemically bound or otherwise attached to the surface of a particle
adsorption	chemistry – the process whereby a chemical compound attaches to a surface; adsorption may involve several attractive forces, including van der Waal's forces, electrostatic attraction, or chemical bonding; this term should not be confused with absorption
aerobic	biology/chemistry – with oxygen
AFS	American Fisheries Society
agglomerates	geology – clumps of loosely consolidated solid materials
albite	geology – a plagioclase feldspar enriched with sodium: $NaAlSi_3O_8$
alevin	biology – fish fry still having visible yolk sac, especially for salmonids
algae	biology – microscopic aquatic plants that contain chlorophyll
alkalinity	chemistry – the acid neutralizing components in water, usually carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) and hydroxide (OH^-); often reported in mg/L as $CaCO_3$
allochthonous	limnology – having an origin or formed outside the system of interest, usually applied to organic materials
alluvium	geology – unconsolidated gravel, silt and sand deposited in recent geological times by flowing water: alluvial deposit, alluvion
alteration, altered	geology – change in the mineralogical composition of rock by physical or chemical means, usually applied to hydrothermal solution processes
anaerobic	biology/chemistry – without oxygen

analyte	chemistry – the chemical compound or constituent being detected or analyzed
anions	chemistry – negatively charged ions, usually the major anions: HCO_3^-, CO_3^{2-}, SO_4^{2-}, and Cl^-
anorthite	geology – a plagioclase feldspar enriched with calcium: $CaAl_2Si_2O_8$
anoxic	biology – an environment without oxygen; synonym for anaerobic
ANSI	American National Standards Institute
apatite	geology – a group of calcium phosphate-containing minerals, also containing carbonate, fluoride, chloride, or hydroxide
APHA	American Public Health Association
arkose, arkosic	geology – a feldspar-rich sandstone derived from rapid disintegration of granite
As	chemistry – the element arsenic
ASCE	American Society of Civil Engineers
ASQC	American Society for Quality Control
ASTM	American Society for Testing and Materials
atm	chemistry – atmosphere, SI unit, equal to the atmospheric pressure at mean sea level
autochthonous	biology – pertaining to organic materials produced within an aquatic system
AWWA	American Water Works Association
basalt	geology – an igneous volcanic rock
benthic	limnology – associated with sediments below the water column, or the bottom of a stream or lake
bias	statistics/quality assurance – a consistent deviation of measured values from the true value caused by a systematic error
bioaccumulation	biology – the process whereby toxic compounds are taken up by living organisms and become concentrated in animal tissue over time, or magnify in organisms feeding at higher levels of the food chain
bioassay	biology/toxicology – an experiment where multiple populations of organisms are exposed to a toxic chemical at zero concentration (the control group) and a series of increasing concentrations (exposure groups) to determine the toxicity of the chemical
bioavailability	biology – a property of chemical compounds that describes how well the compound is taken up by living organisms
biomass	biology – the weight of biological matter in a system, usually expressed as weight of carbon per unit area (g/m^2) or weight of carbon per volume (mg/m^3)
biotic	biology – associated with biological organisms
blank	chemistry-QA/QC – a clean check sample used to test for contamination during an instrument run
blind	chemistry-QA/QC – a check sample or standard submitted to a lab disguised as a normal sample
BOD	chemistry – biological oxygen demand; the degree to which algae and organisms in a natural water sample will deplete dissolved oxygen in a given length of time

breccia	geology – a coarse-grained rock composed of angular broken rock fragments held together with mineral cement
C	chemistry – the element carbon; coulomb, SI unit for electric charge
Ca, Ca^{2+}	chemistry – the element calcium, or calcium ion
calcite	geology – calcium carbonate, $CaCO_3$
calibration verification	chemistry-QA/QC – a known concentration certified standard, different from the standards used to calibrate an instrument, that is analyzed after calibration and during the period the instrument is analyzing samples. Used to independently verify initial (ICV) and continuing calibration (CCV).
Cambrian	geology – rocks formed during the older period of the Paleozoic Era, from 570 to 510 million years ago
carbonate	geology – minerals containing carbonate, such as calcite or dolomite
carboxylate	chemistry – a charged, deprotonated carboxylic acid group, -COO-
carboxylic acid	chemistry – an organic acid containing -COOH functional groups, such as acetic acid (CH_3-COOH)
carcinogen	biology – a chemical or influence that causes cancer
carnivorous	biology – meat eating
catabolism	biology/biochemistry – the process whereby large molecules are broken down; decomposition
cations	chemistry – positively charged ions, usually Ca^{2+}, Mg^{2+}, Na^+, and K^+
Cd	chemistry – the element cadmium
Celsius, °C	SI metric temperature scale with 0° set to the freezing point of water, and 100° to the boiling point of water at 1 atm pressure; formerly called centigrade
centrarchid	biology – fish classified in family Centrarchidae, including bluegill, crappies, sunfish, and black basses
CERCLA	regulatory – Comprehensive Environmental Response, Compensation and Liability Act, Public Law PL 96-510, 40 CFR 300, 1980; the federal environmental law that regulates cleanup of hazardous waste sites; the Superfund program
certified	chemistry-QA/QC – as applied to a standard, having documentation attesting to the precision, accuracy, and traceability of a reported concentration.
cfs, ft^3/s	measurement unit – cubic feet per second, English and engineering unit for flow discharge, 100 ft^3/s = 28,317 liters per second
check sample	chemistry-QA/QC – a sample analyzed during an instrument run having known concentrations, not necessarily certified or traceable.
chlorite	geology – a group of clay-like minerals of the general formula: $(Mg, Fe^{2+}, Fe^{3+})_6AlSi_3O_{10}(OH)_8$
chlorophyll	biochemistry – the green pigment in most plants
chronic	toxicology – long-term or of extended duration, usually applied to toxicity or exposure to toxic compounds
cinnabar	geology – mercuric sulfide: HgS
Cl, Cl^-	chemistry – the element chlorine, or the chloride ion

clastic	geology – pertaining to a rock or sediment composed of broken fragments of rocks and minerals transported some distance from their points of origin. Sandstone and shale are considered “clastics”
clay	geology – a class of finely crystalline or amorphous single and multi-layered aluminosilicate minerals formed from the weathering of feldspars, pyroxenes, and amphiboles; or soil and sediment particles smaller than 0.004 µm containing clay minerals such as illite, smectite, or montmorillonite
clinoptilolite	geology – a zeolite mineral rich in potassium: $(Na,K,Ca)_{2-3}Al_3(Al,Si)_2Si_{13}O_{36}\cdot 12H_2O$
CO_2	chemistry – carbon dioxide gas
CO_3^{2-}	chemistry – carbonate, or carbonate ion
COD	chemistry – chemical oxygen demand
colloid	chemistry – very small particles suspended in water that do not settle
colorimetric	chemistry – a spectrophotometric analytical method that uses a chemical to react with the analyte to form a colored compound The intensity of the colored compound is related to concentration
complex	chemistry – a compound formed between a metal and a ligand, usually called a “trace metal complex”
composite	sampling/QA – a single sample composed of many combined individual subsamples, used to represent a larger population or area
composite sample	sampling/QA – a combined sample containing subsamples collected from different locations, depths, or times
conglomerate	geology – a coarse-grained clastic sedimentary rock composed of granules, pebbles, and cobbles larger than 2mm in diameter (gravel) in a matrix of fine sands and silts
cortisol	biochemistry – a hormone produced by vertebrate organisms when exposed to stress
Cretaceous	geology – rocks formed during the final period of the Mesozoic era, covering the span of time from 65 to 135 million years ago
CVAA	chemistry – cold vapor atomic absorption
CVAFS	chemistry – cold vapor atomic fluorescence spectrophotometry
CWA	regulatory – Clean Water Act, Public Law PL 92-500, 1972, 40 CFR 100-140, and 400-470; the federal environmental law regulating pollutant discharges into surface waters
cyprinid	biology – fish classified in family Cyprinidae including minnows, carps, chubs, splittails, and daces
delta	geography – the area where a river empties into a bay, ocean, or lake
detritus	biology/limnology – nonliving particulate matter
diatoms	limnology – microscopic, single-celled plant plankton that form cell walls of silica, called frustules
diel	biology – a 24-h period, referring to a daily pattern or behavior
dikes	geology – a vertical igneous intrusion that cuts across the bedding or foliation of the country rock: also sill, dyke

diorite	geology – a group of plutonic rocks of intermediate acid-base composition containing visible hornblende, acid plagioclase (oligoclase, andesine), pyroxene, and some quartz Also andesite
dissolved	chemistry – an operationally defined term applied to water analysis results, usually meaning that the sample is filtered through a 0.45-µm pore-size membrane filter before analysis
diversion, diversion dam	engineering – a structure that diverts water from a river or other water body; a dam that partially blocks a river or stream to allow diversion of water into canals or other conveyance structures
DL	chemistry-QA/QC – detection limit.
DO	chemistry – dissolved oxygen, mg/L
DOC	chemistry – dissolved organic carbon
dolomite	geology – a carbonate mineral containing both calcium and magnesium: $Ca_aMg_b(CO_3)_{a+b}$
DRI	Desert Research Institute, University of Nevada, Reno
EA	regulatory – Environmental Assessment, a preliminary study of the environmental effects of a proposed development or construction project that is required by the National Environmental Policy Act (NEPA) The EA is the initial disclosure of environmental impact and economic cost to benefit analysis If concerned parties dispute the EA findings, a more involved Environmental Impact Statement (EIS) may be required
EC	chemistry – electrical conductivity, measured in microsiemens per centimeter, µS/cm; also electron capture detector, a detector on a gas chromatograph that is sensitive to halogens in organic compounds
egg	biology – female gamete; on this site usually refers to fish egg
Eh	chemistry – redox or oxidation-reduction potential, measured in millivolts, mV
EIS	regulatory – Environmental Impact Statement; a comprehensive technical report and disclosure of the environmental impacts and costs of a proposed construction project, development, or alteration in use of land or water resources, required by the National Environmental Policy Act (NEPA)
electrometric	chemistry – analysis using measurement of electrical potential (voltage), as with an electrode that measures pH
electroneutrality	chemistry – a property of natural waters where positive ions (sum of cations) and negative ions (sum of anions) have equal concentrations (in meq/L); this principle can be used to independently check analysis results for major ions; see ion balance
endangered species	regulatory – a class of species protected under the Endangered Species Act, (ESA); species in imminent danger of extinction
endocrine	biology – relating to the system of glands in vertebrates that secrete hormones to regulate metabolism and reproduction
endocrine disruptor	chemistry – a chemical compound in the environment suspected of imitating hormones or blocking the proper functioning of hormones in organisms
Entrada Sandstone	geology – a sedimentary rock formation deposited during the middle Jurassic period, usually observed below the Morrison shale and above the Navajo Sandstone

entrainment	transporting fish out of their native ecosystem by way of water passed through a conduit, penstock or diversion at dams or irrigation canals
Eocene	geology – the Eocene Epoch; rocks deposited or formed 55 to 35 million years ago, between the Oligocene (more recent) and the Paleocene (older) strata
EPA	U.S. Environmental Protection Agency
epilimnion	limnology – the surface layer of a thermally stratified lake
epiphyton	biology – plants that grow on other plants or nonliving structures
epithermal	geology – pertaining to hydrothermal mineral deposits formed in the upper 1 km of the earth's surface at temperatures of 50°-200°C
EPRI	Electric Power Research Institute
eq/L	chemistry/measurement unit – equivalents per liter
equilibrium	chemistry – the state in a chemical reaction when the forward and reverse reaction rates are equal
equivalent	chemistry/measurement unit – a chemical concentration unit based on reactivity, equal to the molar weight divided by the valence of the compound or ion
ESA	regulatory – Endangered Species Act, PL 93-205, 16 USC 1531, 1988, the federal law that identifies and protects endangered and threatened plant and animal species
estuary	biology – aquatic transition zone where fresh water and salt water mix, influenced by tides
eutrophic	limnology – trophic state of a lake having high productivity, generally low water transparency, abundant nutrients for plankton, and elevated concentrations of organic carbon
evaporite	geology – a mineral formed when water evaporates
exotic species	biology – species not native or indigenous to an ecosystem; an invasive species
Fahrenheit, °F	Non-SI temperature scale with 32° set to the freezing point of water, and 212° to the boiling point of water
fault	geology – a crack or fracture in rock, or a zone of fracturing with displacement of sides parallel to the fracture
fault block	geology – a crustal unit bounded by faults that tectonically behaves as a single unit
Fe	chemistry – the element iron
Fe^{2+}	chemistry – the ferrous ion, a reduced form of iron in the +II oxidation state; the stable form of iron found in anaerobic waters and sediments
Fe^{3+}	chemistry – the ferric ion, an oxidized form of iron in the +III oxidation state; the stable form of iron in oxygenated waters
feldspar	geology – a class of metamorphic aluminosilicate minerals
felsic	geology – pertaining to a group of igneous rocks composed of light colored minerals such as quartz, feldspars, feldspathoids, or muscovite
ferrihydrite	geology – an iron hydroxide mineral: $Fe(OH)_3$
filtrate	chemistry – the liquid passed through a filter

fluorescence	chemistry – the emission of light caused by incident light, a spectrophotometric analysis method based on fluorescence
fork length, FL	fish biology – the length of a fish measured from the snout to the fork in the tail along the lateral line
fractional spooning	sampling/QA – a procedure for collecting representative subsamples using many small, randomly selected scoops of solid material
fugitive dust	meteorology – wind-blown dust, fine soil, and sediment transported away from its point of origin
fulvic acid, fulvic materials	chemistry – a heterogeneous and polydisperse class of organic compounds with molecular weights from 600 to 2,000 amu, found in natural soil and water environments, that includes fatty acids, proteins, polysaccharides, and their hydrolysis products Fulvic materials account for most of the DOC in natural waters Like humic materials, fulvic materials are formed by the decomposition of living matter, but are usually more soluble than the higher molecular weight humic materials
functional group	chemistry – a reactive site on a molecule
FWS, USFWS	U.S. Department of the Interior – Fish and Wildlife Service
G	SI unit prefix for giga, or 10^9
g	measurement unit – gram, SI mass unit
gabbro	geology – a group of dark colored intrusive igneous rocks composed of calcium plagioclase and other minerals; a coarse-grained equivalent of basalt
GC	chemistry – gas chromatograph
geothermal	geology – pertaining to heat from the interior of the earth
GFAA	chemistry – graphite furnace atomic absorption
gill	biology – the breathing organ of fish
glacier, glaciation	geology – a large mass of ice formed mostly on land from the compression and recrystallization of snow, which slowly flows downhill; the process of glacier formation
glass	geology – a non-crystalline rock formed from the rapid cooling of magma
gneiss	geology – a foliated textured rock formed by regional metamorphism
grab sample	chemistry-QA/QC – a randomly selected single sample
granite	geology – a hard plutonic rock, containing mostly quartz and feldspar
granodiorite	geology – a coarse-grained plutonic rock intermediate in composition between quartz diorite and quartz monzonite; a diorite containing quartz and alkali feldspar
H_2S	chemistry – hydrogen sulfide, a gas that smells like rotten eggs, usually associated with stagnant water and prolonged anaerobic conditions
HA	chemistry – humic acid
ha	measurement unit – hectare, SI area unit (1 ha = 1.00 X 10^4 m^2)
hardness	chemistry – the sum of divalent ions in a water sample, usually calculated as calcium + magnesium, and often reported in mg/L as $CaCO_3$

HCO_3^-	chemistry – bicarbonate, or bicarbonate ion, the dominant form of alkalinity in most natural surface waters
head	hydrology – hydrostatic potential, or pressure difference between two water surfaces or depths, usually expressed in feet or inches of water
head differential	hydraulic engineering – water pressure difference across the surface of a screen, louver, or other positive barrier structure, usually measured in inches of water
hematite	geology – an iron oxide mineral: $\alpha\text{-}Fe_2O^3$
hepatotoxin	biology/toxicology – a toxic compound or agent that damages liver tissue or interferes with normal liver biochemistry
herbivorous	biology – plant eating
heterogeneous	chemistry – poorly mixed and having different phases, such as a solid dispersed nonuniformly in a liquid, or as with soil composed of many minerals in a random mixture
Hg	chemistry – the element mercury
histogram	statistics – a graph of ranked and grouped data that shows the distributional properties of the variable; a graph of number of observations within ranked groups (called cells, based on an arbitrary range of data values) vs value
Holocene	geology – an epoch of the Quaternary period, after the Pleistocene, approximately 8,000 years ago to the present
homogeneous	chemistry – completely and uniformly mixed, as with dissolved constituents in water
hornblende	geology – the most common mineral in the amphibole group, having a general formula: $Ca_2Na(Mg, Fe^{2+})_4(Al, Fe^{3+},Ti)$
humic acid, humic materials	chemistry – a heterogeneous and polydisperse class of high average molecular weight (> 2,500 amu) organic compounds found in natural soil and water environments that includes fatty acids, proteins, polysaccharides and their hydrolysis products Humic materials are formed by the decomposition of living matter, and are usually less soluble than the lower molecular weight fulvic materials
hydrated	geology – a mineral or compound containing water
hydrodynamics	limnology – the study of water flows and currents
hydrology	the study of surface and ground water hydrodynamics
hydrolysis	chemistry – a reaction, usually in aqueous solution, in which hydroxide reacts with C-C bonds causing cleavage (lysis) of molecules; a common reaction that breaks down organic compounds in natural waters, especially at higher pH
hydrothermal	geology – processes in igneous rock involving heated or superheated water
hypolimnion	limnology – the cold and dense water pool in a thermally stratified lake, next to sediments and below the thermocline
hyporheic	biology – pertaining to benthic environments in streams including the porous subflow zone and the oxic-anoxic boundary
IC	chemistry – ion chromatograph
ICP-ES	chemistry – inductively-coupled plasma – emisssion spectrograph

ICP-MS	chemistry – inductively-coupled plasma – mass spectrometer
ICV	chemistry-QA/QC – initial calibration verification.
IDL	chemistry-QA/QC – instrument detection limit.
IEC	International Electrotechnical Committee
igneous	geology – a rock or mineral formed from cooling of molten or partly molten material, such as magma
illite	geology – a general name for a group of triple-layer clays commonly found in marine shales
in	English length unit, 1 inch = 2.54 cm,
interbedding	geology – layering of different kinds of sedimentary rock or minerals
interquartile range	statistics – a rank based statistic defined as the range of values from the 25th to the 75th percentile value.
intrusive	geology – a rock different from surrounding rock that formed within or forced its way into the surrounding rock
invasive species	biology/regulatory – a non-native species that reduces species diversity when introduced into an ecosystem
invertebrate	biology – an animal lacking a backbone
ion	chemistry – an element or molecule dissolved in water with a net positive or negative electrical charge
ion balance	chemistry – a percentage calculation used to check major ions data that compares cations to anions; values near zero suggest that the analysis results are accurate and confirm electroneutrality in the water sample,
ion exchange	chemistry – the chemical reaction process where one ion will replace another in a reaction with a mineral, such as a clay, or a medium containing ionic binding sites
ISO	International Organization for Standardization
IUPAC	International Association of Pure and Applied Chemistry, the organization establishing standardized atomic weights and chemical constants
Jurassic	geology – the second period of the Mesozoic era, after the Triassic and before the Cretaceous, covering a span of time from 135 to 190 million years ago
juvenile	biology – lifestage before adult
k	SI unit prefix kilo, or 10^3
K, K^+	chemistry – the element potassium, or potassium ion
kaolinite	geology – a common clay mineral of the kaolin group: $Al_2Si_2O_5(OH)_4$
Kelvin, °K	chemistry/physics – thermodynamic temperature scale with 273° set to the freezing point of water, 373° to the boiling point of water, and 0 °K called absolute zero
K_{eq}, K	chemistry – the equilibrium constant for a given balanced chemical reaction, based on the stoichiometry of the reactions and ratio of product concentrations to reactant concentrations at chemical equilibrium
kg	measurement unit – kilogram, SI mass unit, 1 kg = 1,000 g
L	measurement unit – liter, SI volume unit

lacustrine	limnology – associated with a lake environment
lamellae	biology – the small vaned structures on gills that facilitate oxygen uptake
laminar flow	hydraulic engineering – flow that is slow and uniform
Laramide Orogeny	geology – the period of time when the eastern Rocky Mountains were uplifted and formed, from the late Cretaceous to the end of the Paleocene
larvae	biology – newborn fish; first fish lifestage after hatching from egg
lat/long	measurement unit – latitude/longitude
LC_{50}	toxicology – lethal concentration that kills 50 percent of the test organisms within the exposure period of the bioassay
LD_{50}	toxicology – lethal dosage that kills 50 percent of the test organisms within the exposure period of the bioassay
lentic	biology/limnology – pertaining to still water
ligand	chemistry – a compound or functional group on a molecule, usually negatively charged, that forms a chemical bond with a positively charged trace element
limestone	geology – a sedimentary rock containing more than 50 percent by weight of calcium carbonate; specifically, a carbonate mineral containing at least 95 percent calcite and less than 5 percent dolomite
limnetic	biology/limnology – associated with a lake environment
limnology	the study of the biology, chemistry, morphology, and hydrodynamics of lakes
listed species	regulatory – plant and animal species designated as threatened or endangered under the Endangered Species Act (ESA)
littoral	biology/limnology – shallow lake or estuarine enviroment that supports aquatic plants
LOD	chemistry-QA/QC – limit of detection, a statistically based estimate of the lowest statistically valid measurement concentration for an instrument or analytical method
loess	geology – small particle-sized wind-blown deposits
log(AP/(KT)	chemistry – see saturation index
LOQ	chemistry-QA/QC – limit of quantitation, statistically based. 10 times the standard deviation calculated from repeated same-sample results.
lotic	biology/limnology – flowing water environment as in streams and rivers
LR	statistics – linear regression
m	meter, SI length unit, ; also SI unit prefix for milli, or 10^{-3}
M	chemistry – molarity, moles per liter, ; also SI unit prefix for mega, or 10^{6}
m/s	measurement unit – meters per second, SI velocity unit,
macrophyte	biology – any plant visible to the unaided eye
mafic	geology – pertaining to an igneous rock composed of dark-colored ferromagnesian minerals
magma	geology – naturally occurring mobile molten rock material generated within the earth and capable of extrusion and intrusion; parent material of all igneous rock

magnesite	geology – a carbonate mineral containing magnesium: $MgCO_3$
major ions	chemistry – higher concentration elements dissolved in water, usually: Ca^{2+}, Mg^{2+}, Na^+, K^+, CO_3^{2-}, HCO_3^-, SO_4^{2-}, and Cl^-
Mancos Shale	geology – a sedimentary shale rock formation deposited from inland seas during the middle Cretaceous period, observed throughout the great basin and Colorado, usually observed above the Dakota Sandstone and below the late-Cretaceous to early Tertiary Mesaverde Group coal, sandstones, and mudstones
marble	geology – a metamorphic rock formed from re-crystallized calcite and/or dolomite
marsh	biology – wetland, swamp
matrix	chemistry-QA/QC – the sum of all chemical components in the sample besides the analyte being tested.
matrix spike	chemistry-QA/QC – a real sample to which a known amount of an analyte is added, sometime denoted MS.
MCL	regulatory – Maximum Contaminant Level; federal regulated concentrations defined under the Safe Drinking Water Act and adopted by CERCLA for Superfund site cleanups
MDL	chemistry-QA/QC – method detection limit.
mean	statistics – the arithmetic average, an estimate of central tendency applied to variables having normal distributions, denoted as x-bar, or $\bar{x}$.
media	chemistry – the type of material associated with a sample: water, wastewater, groundwater, soil, sediments, rock, tissue, etc
median	statistics – an estimate of central tendency that does not depend on the distribution of the data; the middle value in a data set that has been ranked (arranged, or sorted) from minimum value to maximum value; the 50th percentile
Me-Hg	chemistry – methylmercury, the methylmercuric ion, $CH_3\text{-}Hg^+$
meq/L	measurement unit – milliequivalents per liter, 10^{-3} equivalents per liter
mesh	geology/sedimentology measurement unit – a size standard unit based on the diameter of space between the wire mesh in a screen, used to separate and quantify size fractions of solid materials
mesolimnion	limnology – the depth region in a thermally stratified lake where temperature drops to a lower limit in the hypolimnion
metabolism	biochemistry – the biochemical process whereby organisms convert food and nutrients into energy for survival and reproduction
metamorphic	geology – previously formed rock that is transformed in structure and mineralogy at higher pressure and temperature
metazoa	biology – multicellular animals
methylation	chemistry – the chemical process of adding a methyl group(-CH3) to an inorganic or organic compound
mg	measurement unit – milligram, SI mass unit, (1 mg = 10^{-3} g)
Mg, Mg^{2+}	chemistry – magnesium, or magnesium ion
mg/kg	measurement unit/chemistry – milligrams per kilogram (1,000 g), SI concentration unit applied to solid samples and liquid samples with high salinity

mg/L	measurement unit/chemistry – milligrams per liter, SI concentration unit
mi^2	measurement unit – square mile
mica	geology – a group of clay-like, layered aluminosilicate minerals that form elastic sheets and flakes in igneous or metamorphic rock
microfauna	biology – the collection of microscopic animals in an ecosystem
microflora	biology – the collection of microscopic plants in an ecosystem
mineralization	geology – the processes whereby minerals are introduced into rock, and may involve hydrothermal solution processes, fissure filling, impregnation, or replacement
MINTEQ, MINTEQA2	chemistry/geochemistry – a computer chemical equilibrium model developed by EPA that calculates all the possible chemical species in solution based on equilibrium constants for the competing reactions; also calculates mineral saturation indices based on concentrations entered into the model
minus No. 10 mesh	geology/sedimentology – solid material smaller than 0.079 in (2,000 μm), passing through a No 10 U.S. Standard screen
minus No. 80 mesh	geology/sedimentology – solid material smaller than 0.007 in (178 μm), passing through a No 80 U.S. Standard screen
mL	measurement unit – milliliter, SI volume unit, (1,000 mL = 1.000 L)
mm	measurement unit – millimeter (10^{-3} m), SI length unit
mM/L, mmol/L	measurement unit – millimoles per liter, 10^{-3} moles per liter
Mn	chemistry – the element manganese
Mo	chemistry – the element molybdenum
mol/L, M/L	measurement unit/chemistry – moles per liter
molal	measurement unit/chemistry – moles per 1,000 g of solution,
mole	measurement unit/chemistry – a chemical concentration unit based on the empirical formula of a chemical compound, equal to the mass of Avogadro's number (6.023×10^{23}) of molecules of a chemical compound, or atoms of an element
monzonite	geology – a group of intrusive plutonic rocks intermediate in composition between syanite and diorite, containing equal amounts of alkali feldspar and plagioclase, and very little quartz
morbid, morbidity	biology – lack of vitality, indicative of sickness or injury
mortality	biology – death
MP	Mid-Pacific Region, Bureau of Reclamation
mucous, mucus	biology – a slippery polysaccharide and protein mixture secreted by fish that covers all surfaces exposed to the environment
mutagenic	biology/toxicology – referring to a chemical compound or environmental influence that causes cell mutations
mV	measurement unit – millivolt, (10^{-3} volts) SI voltage unit
mw	chemistry – molecular weight
N	chemistry – the element nitrogen; chemistry – normality, expressed in equivalents/liter; Newton, SI unit for force, 10 N = 10 kg-m/s^2,

n	SI unit prefix nano, or 10^{-9}
N	chemistry – the element nitrogen
n	statistics – number of data points.
N/m^2	Newtons per square meter, SI unit for pressure,
Na, Na^+	chemistry – the element sodium, or sodium ion
native	regulatory – a species naturally occuring in an ecosystem; an indigeneous species not introduced by humans
NCDC	National Climate Data Center, NOAA
ND	chemistry-QA/QC – not detected, also U, undetected, or <(number), meaning less than the detection limit.
NDEP	Nevada Department of Conservation and Natural Resources, Division of Environmental Protection
NDOW	Nevada Department of Conservation and Natural Resources, Division of Wildlife
NEPA	regulatory – the National Environmental Policy Act of 1969, 42 USC §§ 4321-4370c; the federal environmental law that established the Council on Environmental Quality and requires federal agencies to formally consider environmental impacts of planned actions or decisions potentially affecting the quality of the human environment
ng	measurement unit – nanogram, SI mass unit, (1 ng = 10^{-9} g)
ng/kg	measurement unit/chemistry – nanograms (10^{-9} g) per kilogram (1,000 g), an SI concentration unit applied to solid samples and liquid samples with high salinity
ng/L	measurement unit/chemistry – nanograms per liter, SI concentration unit
NH_3	chemistry – ammonia; nitrogen in the -III oxidation state
NH_4^+	chemistry – ammonium ion
NIH	U.S. Department of Health, Education, and Welfare – National Institutes of Health
NIST	U.S. Department of Commerce – National Institute of Standards and Technology; formerly the National Bureau of Standards
nm	measurement unit – nanometers, (10^{-9} m), usually applied to spectral wavelengths
NMFS	NOAA – National Marine Fisheries Service
NO_2^-	chemistry – nitrite, or nitrite ion, nitrogen in the +III oxidation state
NO_3^-	chemistry – nitrate, or nitrate ion, nitrogen in the +V oxidation state
NO_3+NO_2	chemistry – nitrate plus nitrite
NOAA	U.S. Department of Commerce – National Oceanic and Atmospheric Administration
non-native	regulatory – a species introduced by human activity into an ecosystem; an exotic or invasive species
non-point source	regulatory – a diffuse source of pollution
normal	statistics – a data distribution having symmetrical tails; the "bell-curve"

NPDES	regulatory -National Pollution Discharge and Elimination System; the permitting system for regulating polution discharge point sources, administered by the states based on national guidelines developed under the Clean Water Act
NSF	National Science Foundation
NTIS	U.S. Department of Commerce – National Technical Information Service
NTU	measurement unit/chemistry – nephelometric turbidity units
nutrients	chemistry/water quality – a term referring to all nitrogen and phosphorus species, usually includes total-P, ortho-P, TKN, NH_3, NO_2, and NO_3
OH^-	chemistry – hydroxide, or hydroxide ion
Oligocene	geology – an epoch of the early Tertiary period, after the Eocene and before the Miocene
oligoclase	geology – a plagioclase feldspar mineral enriched with sodium, but containing more calcium than albite
oligotrophic	limnology – trophic state of a lake having low productivity, generally higher water transparency, and low concentrations of nutrients and organic carbon
olivine	geology – a group of ferromagnesian silicate minerals formed from igneous rock: $(Mg,Fe,Mn,Ca)_2SiO_4$
omnivorous	biology – plant and meat eating
ON	chemistry – organic nitrogen
o-P, ortho-P	chemistry – orthophosphate
organic	chemistry – referring to compounds containing carbon, excluding inorganic carbon as in carbonates
Organic-N	chemistry – nitrogen bound to organic matter in water, calculated as TKN – NH_3
orogeny	geology – the process of mountain formation
ORP	chemistry – oxidation-reduction potential; Eh
orthoclase	geology – an alkali feldspar enriched with potassium
oversaturated	chemistry – the temporary condition in a two-phase (solid-solution) system when the reactants in solution that form a chemical compound exceed concentrations required to form the solid compound at equilibrium Oversaturated solutions tend to form the solid product and precipitate out of solution
oxic	biology – an environment containing oxygen; synonym for aerobic
oxidation	chemistry – chemical combination or reaction with oxygen, or removal of electrons to increase oxidation state
oxidizing	chemistry – a chemical environment where oxygen is present and/or excess electrons are unavailable; in natural waters, an aerobic environment where dissolved oxygen is present and compounds may undergo oxidation from a lower oxidation state to a higher oxidation state, such as ferrous iron, Fe^{2+} (Fe in the +II oxidation or valence state), being oxidized to ferric iron, Fe^{3+} (Fe in the +III oxidation or valence state); a natural water environment with positive Eh
oxyhydrate	geology – hydrated oxide/hydroxide minerals usually containing iron and/or manganese
p	SI unit prefix for pico, or 10^{-12}

P	chemistry – the element phosphorus; statistics – probability
parameter	statistics – a coefficient for a random variable derived from a statistical analysis.
particulate	chemistry – analytes bound to, or strongly associated with suspended particles in water
Pb	chemistry – the element lead
pCO_2	chemistry – the partial pressure of carbon dioxide, measured in atm, Pa, or mm of Hg (torr),
pelagic	biology – referring to organisms and habitats in open oceanic environments
percent H_2O	measurement unit – weight percent water
Percent R, %R	chemistry-QA/QC – percent recovery, in general, (observed value)÷(true value) X 100
percent RSD	statistics – percent relative standard deviation, the ratio of the standard deviation to the mean, expressed as a percentage.
percentile	statistics – a rank based statistic, a data value corresponding to the percentage of the data set below the value associated with the percentage. Examples: the 50th percentile, called the median, is the boundary value below which 50 percent of the data values will fall, or 50 percent of the data will be less than the value of the 50th percentile; a test score in the 97th percentile means that the score is higher than 97 percent of the scores, and less than only 3 percent of the scores.
periphyton	biology – sessile organisms covering surfaces in freshwater aquatic environments
Permian	geology – rocks formed during the last period of the Paleozoic era, covering a span of time from 225 to 280 million years ago
petrography	geology – the branch of geology that determines the mineralogy of rock and soil
pH	chemistry – hydrogen ion concentration as activity, defined as the negative logarithm (base 10) of the hydrogen ion activity; an indicator of the acidity or alkalinity of water that follows a unitless scale (called su, or standard units) of 0 to 14
phreatic surface	hydrology – the surface of groundwater in an aquifer or earth-fill dam
PHREEQE	chemistry/geochemistry – a computer chemical equilibrium model developed by the USGS that calculates all the possible chemical species in solution based on equilibrium constants for competing reactions based on concentrations and reactions entered into the model
physiography	geology – a description of the surface features and landforms of the earth
phytoplankton	limnology – microscopic plants suspended in water, usually algae and diatoms
plagioclase	geology – a group of triclinic feldspar minerals of the general formula: $(Na,Ca)Al(Si,Al)Si_2O_8$
plankton	limnology – microscopic plant and animal organisms suspended in water
Pleistocene	geology – rocks and deposits formed during the Quaternary period, covering a span of time from 2-3 million to 8,000 years ago
pluvial	geology – referring to a rainy climate
pO_2	chemistry – the partial pressure of oxygen, measured in atm, Pa, or mm of Hg (torr),

PO_4^{3-}	chemistry – orthophosphate, phosphate, or phosphate ion
PO_4^{3-}	chemistry – orthophosphate, phosphate, or phosphate ion
*p*OH	chemistry – hydroxide ion concentration as activity, defined as the negative logarithm (base 10) of the hydroxide ion activity; an indicator of the acidity or alkalinity of water that follows a unitless scale of 0 to 14; pOH = 14 – pH
point source	regulatory – a localized, well defined source of pollution
porosity	hydraulic engineering – the ratio of open area to total area of a screen or other porous barrier structure
potamon zone	biology – a stream reach with very slow flow, elevated temperatures and low dissolved oxygen
ppb	measurement unit/chemistry – parts per *billion*, equivalent to µg/kg and usually applied to solid samples and liquid samples with high salinity or density,
ppm	measurement unit/chemistry – parts per *million*, equivalent to mg/kg and usually applied to solid samples and liquid samples with high salinity or density,
ppt	measurement unit/chemistry – parts per *trillion*, equivalent to ng/kg and usually applied to solid samples and liquid samples with high salinity or density; may also be parts per thousand, $^{0}/_{00}$, a unit for salinity
PQL	chemistry-QA/QC – practical quantitation limit.
Precambrian	geology – very old rock formed 570 million years ago, or older, before the Paleozoic Era, and composed of the Archeozoic (oldest rocks on the Earth) and Proterozoic (younger rocks)
precipitate	chemistry – to change phase from solution (liquid) to solid or to form an insoluble compound that settles out of solution n a solid compound that settles out of solution
precision	statistics/quality assurance – the repeatability or variability of measurements, usually expressed as a standard deviation or other error
predator	biology – an animal that eats other animals
primary productivity	biology – total biomass per unit time produced by organisms in a given habitat, such as plankton in water
productivity	limnology – the degree of biological activity in an ecosystem
profile	any collection of a measurements made over several cross-sectional units (depth, altitude, elevation, etc); limnology – a plot of water quality variables such as T, DO, or pH with depth, measured at a specific time and location in a water body
protozoa	biology – single celled animals
pyrite	geology – an iron sulfide mineral, FeS, which creates acidic mine drainage and sulfuric acid when oxidized by exposure to air
q, or Q	hydraulic engineering/hydrology – water flow, measured in volume per unit time, such as m^3/s or ft^3/s (cfs)
QA	chemistry-QA/QC – quality assurance, overall efforts, audits, and tests performed to make sure that sample collectors and the analysis lab are following the QC requirements. These could include lab and field sampling audits, or submission of known concentration samples as blind check samples.

QC	chemistry-QA/QC – quality control, efforts and tests undertaken in the lab to check or document analysis data quality.
qualification	chemistry-QA/QC – a code or commentary describing QA/QC non-conformance and its effect on data usability.
qualitative	chemistry-QA/QC – detected, but not at a high level of precision and/or accuracy.
quantitative	chemistry-QA/QC – detected with a higher degree of precision and accuracy.
quartz	geology – a crystalline silicon dioxide mineral: SiO2
quartzite	geology – a very hard but unmetamorphosed sandstone consisting chiefly of cemented quartz grains
Quaternary	geology – rocks formed during the second period of the Cenozoic Era, following the Tertiary, covering the span of time from 2-3 million years ago to the present time
raw sample	chemistry – a sample that is untreated, unpreserved, or otherwise processed
RCRA	regulatory – Resource Conservation and Recovery Act, Public Law 94-580, 40 CFR 240-271, 1976; federal law regulating hazardous waste disposal
recovery	chemistry-QA/QC – observed concentration divided by theoretical or true concentration, usually expressed as a percentage.
redox	chemistry – REDuction-OXidation; referring to oxidation-reduction conditions
reducing	chemistry – a chemical environment where oxygen is absent and/or excess electrons are available; in natural waters, an anaerobic environment where compounds may undergo reduction from a higher oxidation state to a lower oxidation state, such as nitrate, NO_3^- (N in the +V oxidation state), being reduced to nitrite, NO_2^- (N in the +III oxidation state), or sulfate SO_4^{2-} (S in the +VI oxidation state), being reduced to sulfide S^{2-} (S in the +II oxidation state); a natural water environment with negative Eh
reduction	chemistry – the chemical removal of oxygen from a compound, or the addition of electrons to lower the oxidation state
regression	statistics – a statistical analysis that compares one or more independent variables, xi, to predict a dependent variable, y
respiration	biology – the process by which an organism obtains oxygen needed to process food into energy
rhyolite	geology – an extrusive igneous rock containing quartz and alkali feldspar
riverine	limnology – associated with a river or flowing stream environment
RPD	chemistry-QA/QC – relative percent difference, a way to calculate precision from duplicate analysis data.
R-squared, R^2	statistics – adjusted correlation coefficient, a measure of linear correlation.
s	statistics – sample standard deviation
s^2	statistics – *s*-squared, the sample variance
S^{2-}	chemistry – sulfide ion, a reduced form of sulfur in the +II oxidation state, found only in anaerobic and reducing natural waters
salmonid	biology – fish classified in family Salmonidae, that includes trouts, salmons, chars, and whitefishes

sandstone	geology – a medium-grained clastic sedimentary rock containing large amounts of quartz, with some clay and cementing minerals
saturated	chemistry – the condition when a chemical compound is in equilibrium with its solid and solution forms
Saturation Index	chemistry/geochemistry – a unitless number pertaining to the chemical reaction of a mineral compound with water, calculated as log(AP/KT), where AP is the activity product, K is the equilibrium constant, and T is the Kelvin temperature The saturation index, calculated by several computer chemical equilibrium models such as MINTEQ and PHREEQE, indicates whether a given natural water is oversaturated (positive numbers), undersaturated (negative numbers), or near equilibrium (values near zero) with a particular mineral phase
screen, sieving	geology/sedimentology – the process of separating solid samples into defined size fractions by sifting the sample through a series of mesh screens
SDWA	regulatory – Safe Drinking Water Act; Public Law PL 93-523, 42 USC 300f, 1974; federal environmental law regulating toxic chemicals in drinking water; SDWA defines the National Primary Drinking Water Stanards (40 CFR 141) and the National Secondary Drinking Water Standards (40 CFR 143)
Se	chemistry – the element selenium
sediment	geology – mineral particles carried by stream flows
sessile	botany – stalkless leaves attached at the base; zoology – permanently attached or fixed
seston	limnology – microscopic debris, sediments, and organisms suspended in a water
shale	geology – a fine-grained and laminated detrital sedimentary rock composed of fine silt and clay, or mud; also called claystone, mudstone
Si	chemistry – silicon (element)
SI	measurement unit – Système Internationale d’Unités, the international standard system for metric measurement units
silica	geology – amorphous silicon dioxide mineral: SiO2
silicate	geology – a mineral containing SiO4
sill	geology – a tabular igneous intrusion that parallels the planar structure of the surrounding rock
silt, silt-sized	geology/sedimentology – soil or sediment particles ranging from 0.002 to 0.05 mm in diameter; a particle size class smaller than fine sand but larger than clay-sized particles
SiO_2	chemistry – silica (mineral)
SiO_4, SiO_3^{2-}	chemistry – silicate, silicate ion
slurry	chemistry – a mixture of solid materials in a liquid
smectite	geology – a group of multi-layered clay minerals with swelling properties and high cation exchange capacity Also called montmorillonite
SO_4^{2-}	chemistry – sulfate, or sulfate ion, the dominant form for sulfur in oxygenated natural waters
soil	geology – geological materials capable of sustaining plant growth
solute	chemistry – the chemical that is dissolved into the solvent

solvent	chemistry – the chemical that dissolves the solute
spawning	biology – fish reproductive activity
speciation	chemistry – the description of the different compounds formed by an element in a natural water
species	chemistry – the term applied to different compounds that are formed with elements in natural water
spectrometer	chemistry – an instrument that measures light intensity at different wavelengths
spectrophotometric	chemistry – an analytical technique that determines analyte concentration by measuring light transmission, emission, or adsorption, at given wavelength
spectrum	physics – the collection of light intensity data measured over a continuous range of wavelengths
spike	chemistry-QA/QC – a known amount of an analyte added to a real sample or blank.
spinel	geology – a group of ferromagnesian minerals: AB_2O_4, where A can be any or all of Mg, Fe^{2+}, Fe^{3+}, Zn, or Mn, and B can be oxides of Al, Fe^{2+}, Fe^{3+}, or Cr
SRM	chemistry-QA/QC – standard reference material, a known-concentration standard, usually manufactured and tested by a national standards organization (such as NIST.)
standard deviation	statistics – an statistical estimate of variability about a mean.
stocks	geology – an igneous intrusion that is less than 100 km^2 in size
stoichiometry	chemistry – the set of coefficients for reactants and products in a chemical reaction that produce a balanced algebraic equation and condition of mass balance between reactants and products
STP	chemistry – standard temperature and pressure, equal to 1 atm and 273 °K (0 °C)
su or s.u.	measurement unit/chemistry – standard units, usually applied to pH
subsample	sampling/QA – a portion of a larger sample collected to represent the larger sample or population
supernate	chemistry – the liquid separated from a slurry during centrifugation
suspended	chemistry – an operationally defined term applied to water analysis results; analytes associated with suspended particles larger than 045 μm, usually calculated by subtracting dissolved from total
sustained speed	fish biology – the maximum speed an organism can maintain for periods of time on the order of minutes
T	chemistry – temperature, °C
TDS	chemistry – total dissolved solids, mg/L, also called “filterable residue”
teratogenic	biology/toxicology – referring to a chemical compound or environmental influence that causes developmental defects
Tertiary	geology – the first period of the Cenozoic era, covering the span of time between 2-3 million and 65 million years ago
thermal stratification	limnology – the tendency for deeper lakes to form temperature and density layers in the water column,

thermocline	limnology – the temperature transition zone in a thermally stratified lake, associated with the depth of the mesolimnion
thermodynamic	chemistry – pertaining to the study of heat transfer and the formation and breaking down of chemical compounds
threatened species	regulatory – a class of protected species under the Endangered Species Act (ESA); species that are not in imminent danger of extinction, but show population trends suggesting concern
titration	chemistry – the process of adding a standardized reactant chemical solution to a liquid sample, and monitoring completion of a reaction that forms a detectable product
titrimetric	chemistry – an analytical method that uses a titration
TKN	chemistry – total Kjeldahl nitrogen, an digestion analysis that detects both ammonia and organic nitrogen
TM	chemistry – trace metals
TMDL	regulatory – Total Maximum Daily Load; a flow-weighted average for regulating pollution discharges in watershed reaches under the Clean Water Act
TOC	chemistry – total organic carbon
TON	chemistry – total organic nitrogen
total	chemistry – an operationally defined term applied to water analysis results, usually meaning an unfiltered sample that is digested or extracted prior to analysis
toxicity	toxicology – the degree to which a compound harms a given organism, usually described using a dosage per unit body weight, or a concentration in water that causes mortality to a percentage of a population
t-P, total-P	chemistry – total phosphorus
trace	chemistry – low concentrations, generally from mg/L to many µg/L
trace elements	chemistry – a general term applied to low concentration (less than a mg/L) transition metals such as Fe, Pb, Hg, Cd, Cu, Zn, and other elements such as As, Se, and Mo; sometimes called trace metals or toxic metals
trace metals	chemistry – a general term for low concentration trace elements
traceable	chemistry-QA/QC – usually refers to a check sample or verification sample with known values and a certificate indicating comparison to a standard reference material.
travertine	geology – a carbonate mineral formed by rapid precipitation, usually when groundwater super-saturated with calcium and carbonate contacts a flowing stream
travertine cones	geology – conical solid deposits of travertine that form in stream beds
Triassic	geology – the first period of the Mesozoic era (after the Permian period of the Palaeo and before the Jurassic) ranging from 190 to 225 million years ago
trophic state	limnology – a classification of a lake with respect to biological productivity High productivity lakes are classified as eutrophic, low productivity lakes as oligotrophic
TSC	Technical Service Center, Bureau of Reclamation, Denver, Colorado

TSCA	regulatory – Toxic Substances Conrtol Act, Public Law PL 94-469, 40 CFR 700-799, 1977; federal environmental law regulating chemicals not covered under other regulations; covers testing procedures for chemical fate, and environmental and health effects
TSS	chemistry – total suspended solids, mg/L, also called "nonfilterable residue"
tuff	geology – a general term for consolidated pyroclastic or volcanic rocks
tuffaceous	geology – containing tuff
turbidity	chemistry – particulate matter in water that scatters light causing a cloudy appearance
turbulent flow	hydraulic engineering – flow that is fast, complex, and chaotic
turnover	limnology – the mixing of a thermally stratified lake, usually occurs in spring and fall
TV	chemistry-QA/QC – true value.
ultra-clean	chemistry – special precautions taken to minimize sample contamination
ultra-trace	chemistry – referring to chemical compounds in water at very low concentrations, usually less than 10 µg/L
undersaturated	chemistry – the condition in a two-phase (solid-solution) system when the reactants in solution that form a chemical compound are below concentrations required to form the solid compound Undersaturated solutions tend to dissolve the solid reaction product
uplift	geology – a structurally high area in the crust, produced by movements that raise or upthrust the rock
U.S. Standard Mesh	geology/sedimentology – a defined standard for mesh screens used to size solid particles
USBR, BOR	U.S. Department of the Interior – Bureau of Reclamation
USGS	U.S. Department of the Interior – Geological Survey
valence	chemistry – the oxidation state of an element, usually denoted by Roman numerals, as Fe(+III) or S(+VI); valence is used to calculate equivalent weight
validation	chemistry-QA/QC – the process of checking and documenting the quality of analysis data.
variable	statistics – a measured property that varies.
vermiculite	geology – a group of platey or micaceous clay minerals closely related to chlorite and montmorillonite, also the weathering products of micas Has a general formula: (Mg,Fe,Al)3(Al,SI)4O10(OH)2· 4H2O
vertebrate	biology – an animal having a backbone
volatile	chemistry – a solid or liquid with a tendency to evaporate or sublimate into the gas phase
volcanism	geology – the processes by which magma rises to the surface of the earth's crust and is extruded
weathering	geology – the process whereby one mineral is converted to another
WEF	Water Environment Federation
wetland	biology – an area that collects water during part or all of the year

zeolite	geology – a large group of white or colorless aluminosilicate minerals similar to feldspars, usually associated with volcanic tuffs Zeolites also possess ion exchange capacity
Zn	chemistry – the element zinc
zooplankton	limnology – microscopic animals suspended in water
μ	statistics – Greek letter mu; the population mean; SI metric unit prefix for micro, or 10^{-6}
μeq/L	measurement unit/chemistry – microequivalents per liter, 10^{-6} equivalents per liter
μg	measurement unit/chemistry – microgram, SI mass unit, $1\ \mu g = 10^{-6}\ g$
μg/kg	measurement unit/chemistry – micrograms per kilogram (1,000 g), an SI concentration unit applied to solid samples and liquid samples with high salinity,
μg/L	measurement unit/chemistry – micrograms (10^{-6} g) per liter, SI concentration unit,
μm	measurement unit – micrometer, or micron (10^{-6} m), SI length unit
μM/L, μmol/L	measurement unit/chemistry – micromoles per liter, 10^{-6} moles per liter
μS/cm	measurement unit/chemistry – microsiemens per square centimeter, an SI unit for electrical conductivity,
ρ	Greek letter rho; chemistry/physics – density, measured in g/cm^3 at STP
σ	statistics – Greek letter sigma, the population standard deviation
σ^2	statistics – sigma squared, the variance of the population
$\bar{x}$, x-bar	statistics – arithmetic average or mean

Unit Conversion Factors

Conversion factors are from the Bureau of Reclamation's *Metric Manual*, 1978, by L.D. Pedde, W.E. Foote, L.F. Scott, D.L. King, and D.L. McGalliard, U.S. Government Printing Office, Washington DC. English weights and volumes are *avoirdupois* units, and English volumes are based on fluid ounces.

Metric Prefixes
pico = p = 10^{-12}
nano = n = 10^{-9}
micro = μ = 10^{-6} = 0.000001
milli = m = 10^{-3} = 0.001
centi = c = 10^{-2} = 0.010
hecto = h = 10^{+2} = 100
kilo = k = 10^{+3} = 1,000
mega = M = 10^{+6} = 1,000,000
giga = G = 10^{+9}
tera = T = 10^{+12}
Length
1.0 inch = 0.0254 m = 2.54 cm = 25.4 mm
1.0 foot (ft) = 0.30480 m = 30.480 cm = 304.8 mm
1.0 yard (yd) = 0.91440 m = 91.440 cm = 914.4 mm
1.0 mile (mi) = 1,760 yd = 5,280 ft = 63,360 in = 1.6093 km = 1,609.3 m = 160,934 cm
1.0 cm = 0.010 m = 10 mm = 0.03281 ft = 0.3937 in
1.0 meter (m) = 100 cm = 1,000 mm = 1.0936 yd = 3.2808 ft = 39.370 in
1.0 km = 1,000 m = 100,000 cm = 0.62137 mi = 1,093.61 yd = 3,280.83 ft = 39,370 in
Weight
1.0 gram (g) = 1,000 mg = 1,000,000 μg = 1.000 cm^3 deionized H_2O at STP
1.0 kg = 1,000 g = 2.204622 lb = 35.27396 oz
1.0 ounce (oz) = 0.06250 lb = 28.34953 g = 0.0283495 kg
1.0 pound (lb) = 16 oz = 0.45359 kg = 453.59 g
Time
1.0 hour = 3,600 s
1.0 day = 1,440 min = 86,400 s
1.0 week = 168 hr = 10,080 min = 604,800 s

Temperature

Celsius to Fahrenheit: **°F = (°C x 1.80) + 32**

Fahrenheit to Celsius: **°C = (°F - 32) x 0.5556**

Kelvin to Celsius: **°C = °K - 273.15**

Celsius to Kelvin: **°K = °C + 273.15**

STP - standard temperature and pressure = 273 °K at 1 atm

Area

1.0 in^2 = 0.00064516 m^2 = 6.4516 cm^2 = 645.16 mm^2

1.0 ft^2 = 0.1111 yd^2 = 144 in^2 = 0.092903 m^2 = 929.03 cm^2 = 92,903 mm^2

1.0 yd^2 = 9 ft^2 = 1,296 in^2 = 0.836127 m^2 = 8,361.27 cm^2 = 836,127 mm^2

1.0 acre = 0.0015625 mi^2 = 4,840 yd^2 = 43,560 ft^2 = 4,046.87 m^2= 0.404687 ha

1.0 mi^2 = 640 acres = 27.878 x 10^6 ft^2 = 2,589,988 m^2 = 258.99 ha

1.0 cm^2 = 100 mm^2 = 0.1550 in^2

1.0 m^2 = 10,000 cm^2 = 1.1959 yd^2 = 10.7369 ft^2 = 1,550.0 in^2

1.0 hectare (ha) = 100 m x 100 m = 10,000 m^2 = 0.00385901 mi^2 = 2.47104 acres = 11,959.9 yd^2

1.0 km^2 = 100 ha = 1,000,000 m^2 = 0.3860 mi^2 = 247.104 acres

Volume

1.0 fluid oz = 1.8047 in^3 = 0.029574 L = 29.574 mL

1.0 in^3 = 0.5541 oz = 0.016387 L = 16.387 mL

1.0 pint = 16.0 fluid oz = 0.47318 L = 473.18 mL

1.0 quart = 2.0 pt = 32.0 fluid oz = 0.94635 L = 946.35 mL

1.0 gallon = 4.0 qt = 8.0 pt = 128 fluid oz = 3.7854 L

1.0 ft^3 = 7.4805 gal = 0.028317 m^3 = 28.317 L

1.0 acre-ft = 1233.489 m^3 = 1.233 X 10^6 L = 325,851 gal

1.0 cm^3 = 1.0 mL deionized H_2O at STP = 0.001 L

1.0 liter (L) = 0.001 m^3 = 1,000 mL = 0.264172 gal = 1.0567 qt = 2.1134 pt

1.0 m^3 = 1,000 L = 8.1071 x 10^{-4} acre-ft = 35.315 ft^3 = 264.17 gal

Flow

1.0 gal/min (gpm) = 0.0044191 acre-ft/d = 0.0022280 cfs = 192.5 ft^3/d = 3.7854 L/min= 0.063090 L/s = 227.124 L/hr = 5,451 L/d

1.0 ft^3/s (cfs) = 1.98347 acre-ft/d = 448.831 gal/min = 646,317 gal/d = 0.0283169 m^3/s= 28.3169 L/s = 2.4466 x 10^6 L/d = 2,446.6 m^3/d = 1,699.01 L/min = 101,941 L/hr

1.0 acre-ft/d = 0.504167 cfs = 325,851 gal/d = 14.2764 L/s = 856.584 L/min= 51,395 L/hr = 1.23348 x 10^6 L/d = 1,233.482 m^3/d

1.0 m^3/s = 1,000 L/s = 35.315 ft^3/s = 264.17 gal/s

1.0 L/s = 1,000 mL/s = 0.0010 m^3/s = 0.035315 ft^3/s = 0.264172 gal/s

Chemical Concentrations
1.0 mg/L = 0.001 g/L = 1,000 µg/L = 1,000,000 ng/L
1.0 µg/L = 0.001 mg/L = 1,000 ng/L
1.0 ng/L = 0.001 µg/L = 0.000001 mg/L
1.0 percent = 1.0 g/100g = 10 °/₀₀ (parts per thousand) = 10 g/kg = 10,000 mg/kg(also applies to units/L for dilute waters with low TDS and ρ ~ 1.0 g/cm^3)
1.0 g/kg = 0.10 percent = 1,000 mg/kg
1.0 mg/kg = 0.0010 g/kg = 0.00010 percent = 1,000 µg/kg
1.0 µg/kg = 0.001 mg/kg = 1,000 ng/kg

Molar and Equivalent Weights for Major Ions				
Compound Name	Chemical Formula	Molecular Weight, mg/mMole[1]	Equivalent Weight, mg/meq[1]	Approximate Conductivity Factor, µS/cm per mg/L[2]
Carbonate	CO_3^{2-}	60.0094	30.0047	2.82
Bicarbonate	HCO_3^-	61.0171	61.0171	0.715
Hydroxide	OH^-	17.0073	17.0073	5.56
Calcium Carbonate	$CaCO_3$	100.0874	50.0437	N/A
Sulfate	SO_4^{2-}	96.0636	48.0318	1.54
Chloride	Cl^-	35.4527	35.4527	2.14
Calcium	Ca^{2+}	40.078	20.039	2.60
Magnesium	Mg^{2+}	24.3050	12.1525	3.82
Sodium	Na^+	22.9898	22.9898	2.13
Potassium	K^+	39.0983	39.0983	1.84

[1] Data from 76th edition of the CRC *Handbook of Chemistry and Physics*

[2] Data from 20th edition of APHA-AWWA-WEF *Standard Methods for The Examination of Water and Wastewater*

Appendix 2

Mercury in Fish from Lahontan Reservoir - Data from the State of Nevada and Reclamation

for

The Reclamation Resource Manager’s Manual:
Mercury in the Carson River Basin, California and Nevada

Technical Memorandum TSC-2005-8290-001

by

Doug Craft, John Fields, and Naomi Yoder

Table A2-1.— Summary of available fish tissue Hg data from Lahontan Reservoir. These data are for individual samples, obtained from the State of Nevada and Reclamation (NDOW 2004b, Reclamation 2004d)

Species	Year	Fork Length, in	Weight, oz.	Hg, mg/kg	Sample Location
Black Bass	1987	5.5	2.0	0.60	Narrows
	1987	8.5	6.0	0.97	Narrows
	1987	10.4	11.0	1.53	Narrows
	1987	10.8	13.0	1.40	Narrows
	1987	12.0	15.0	1.94	Narrows
	1987	12.2	17.0	1.67	Narrows
	1987	13.2	23.0	2.14	Narrows
	1987	18.1	77.0	2.98	Narrows
	1987	18.5	68.0	3.38	Narrows
	Minimum	5.5	2.0	0.60	
	Maximum	18.5	77.0	3.38	
	Mean	12.1	25.7	1.85	
	Median	12.0	15.0	1.67	
Largemouth Bass	1987	20.2	90.0	4.28	Narrows
Rainbow Trout	1988	12.9	18.0	1.29	Fishermans Bank
	1988	13.5	17.0	1.00	Fishermans Bank
	1994	13.0	16.0	0.18	Reservoir
	1994	14.4	24.0	0.41	Reservoir
	1994	16.1	33.0	1.20	Reservoir
	1996	13.4	20.0	1.86	Reservoir
	1996	14.8	21.0	1.18	Reservoir
	Minimum	12.9	16.0	0.18	
	Maximum	16.1	33.0	1.86	
	Mean	14.0	21.3	1.02	
	Median	13.5	20.0	1.18	

Table A2-1.— Summary of available fish tissue Hg data from Lahontan Reservoir. These data are for individual samples, obtained from the State of Nevada and Reclamation (NDOW 2004b, Reclamation 2004d)—continued

Species	Year	Fork Length, in	Weight, oz.	Hg, mg/kg	Sample Location
Channel Catfish	1987	3.4		0.37	Virginia Beach
	1987	7.5	3.0	1.22	Catfish Cove
	1987	7.7	4.0	0.90	Narrows
	1987	11.2	10.0	1.52	Silver Springs
	1987	12.0	13.0	1.28	Horsemans
	1987	12.3	13.0	0.81	Catfish Cove
	1987	13.6	18.0	3.68	Catfish Cove
	1987	14.0	20.0	2.34	Horsemans
	1987	15.1	23.0	1.83	Narrows
	1987	15.3	26.0	2.37	Horsemans
	1987	15.4	29.0	1.79	Narrows
	1987	16.0	33.0	2.64	Horsemans
	1987	16.0	34.0	1.36	Horsemans
	1987	16.0	34.0	1.36	Reservoir
	1987	16.5	36.0	1.34	Horsemans
	1987	16.5	36.0	1.34	Reservoir
	1987	17.0	37.0	1.36	Horsemans
	1987	17.1	38.0	3.57	Narrows
	1987	17.5	39.0	2.21	Narrows
	1987	19.2	58.0	2.04	Catfish Cove
	1987	21.0	80.0	1.99	Catfish Cove
	1987	23.5	106.0	5.34	6-Mile
	1987	24.6	126.0	4.75	Virginia Beach
	1987	29.0	226.0	3.78	6-Mile
	1999	16.6	38.0	2.12	Reservoir
	Minimum	3.4	0.0	0.37	
	Maximum	29.0	226.0	5.34	
	Mean	15.8	43.2	2.13	
	Median	16.0	34.0	1.83	

Table A2-1.— Summary of available fish tissue Hg data from Lahontan Reservoir. These data are for individual samples, obtained from the State of Nevada and Reclamation (NDOW 2004b, Reclamation 2004d)—continued

Species	Year	Fork Length, in	Weight, oz.	Hg, mg/kg	Sample Location
Sacramento Blackfish	1982	.	.	0.20	Upper Basin
	1982	.	.	0.40	Upper Basin
	1987	.	.	0.62	Upper Basin
	1987	.	.	0.90	Upper Basin
	1987	.	.	0.90	Upper Basin
	1996	.	.	1.22	Upper Basin
	1996	.	.	1.40	Upper Basin
	1996	.	.	1.23	Upper Basin
	1996	.	.	1.00	Upper Basin
	1996	.	.	1.26	Upper Basin
	1996	.	.	1.22	Upper Basin
	1996	.	.	1.16	Upper Basin
	1996	.	.	1.59	Upper Basin
	1996	.	.	1.64	Upper Basin
	1996	.	.	1.12	Upper Basin
	1996	.	.	1.20	Upper Basin
	1996	.	.	1.17	Upper Basin
	1996	.	.	1.24	Upper Basin
	1996	.	.	1.18	Upper Basin
	1996	.	.	1.06	Upper Basin
	1996	.	.	1.02	Upper Basin
	1996	.	.	1.35	Upper Basin
	1996	.	.	0.80	Upper Basin
	1996	.	.	1.25	Upper Basin
	1996	.	.	1.46	Upper Basin
	1996	.	.	1.35	Upper Basin
	1996	.	.	1.57	Upper Basin
	1996	.	.	1.48	Upper Basin
	1996	.	.	1.21	Upper Basin
	1996	.	.	1.29	Upper Basin
	1996	.	.	1.37	Upper Basin
	1996	.	.	1.33	Upper Basin
	1996	.	.	1.32	Upper Basin
	1996	.	.	1.00	Upper Basin

Table A2-1.— Summary of available fish tissue Hg data from Lahontan Reservoir. These data are for individual samples, obtained from the State of Nevada and Reclamation (NDOW 2004b, Reclamation 2004d)—continued

Species	Year	Fork Length, in	Weight, oz.	Hg, mg/kg	Sample Location
	1996	.	.	1.25	Upper Basin
	1996	.	.	1.15	Upper Basin
	1996	.	.	0.94	Upper Basin
	1996	.	.	0.89	Upper Basin
	1996	.	.	0.85	Upper Basin
	1996	.	.	0.95	Upper Basin
	1996	.	.	0.75	Upper Basin
Sacramento Blackfish	1996	.	.	0.68	Upper Basin
	1996	.	.	0.65	Upper Basin
	1996	.	.	0.79	Upper Basin
	1996	.	.	0.79	Upper Basin
	1996	.	.	0.92	Upper Basin
	1996	.	.	0.73	Upper Basin
	1996	.	.	0.75	Upper Basin
	1996	.	.	0.73	Upper Basin
	1996	.	.	0.94	Upper Basin
	1996	.	.	0.81	Upper Basin
	1996	.	.	0.75	Upper Basin
	1996	.	.	0.59	Upper Basin
	1996	.	.	0.85	Upper Basin
	1996	.	.	0.81	Upper Basin
	1996	.	.	0.32	Upper Basin
	1996	.	.	1.00	Upper Basin
	1996	.	.	4.22	Upper Basin
	1999	13.0	.	0.56	Reservoir
	1999	13.0	.	0.47	Reservoir
	1999	13.5	.	0.77	Reservoir
	1999	14.5	.	0.52	Reservoir
	1999	14.5	.	0.58	Reservoir
	1999	15.0	.	0.77	Reservoir
	1999	15.0	.	0.90	Reservoir
	1999	15.0	.	0.80	Reservoir
	1999	16.0	.	0.80	Reservoir
	1999	16.0	.	0.76	Reservoir

Table A2-1.— Summary of available fish tissue Hg data from Lahontan Reservoir. These data are for individual samples, obtained from the State of Nevada and Reclamation (NDOW 2004b, Reclamation 2004d)—continued

Species	Year	Fork Length, in	Weight, oz.	Hg, mg/kg	Sample Location
	2001	.	.	0.67	Upper Basin
	2001	.	.	0.24	Upper Basin
	2001	.	.	0.90	Upper Basin
	2001	.	.	0.59	Upper Basin
	2001	.	.	0.19	Upper Basin
	2001	.	.	0.78	Upper Basin
	2001	.	.	0.79	Upper Basin
	2001	.	.	0.66	Upper Basin
	2001	.	.	0.77	Upper Basin
	2001	.	.	0.86	Upper Basin
Sacramento Blackfish	2004	13.0	19.0	0.61	Upper Basin
	2004	13.1	19.0	0.69	Upper Basin
	2004	13.3	22.0	0.56	Upper Basin
	2004	13.4	25.0	0.62	Upper Basin
	2004	13.4	21.0	0.63	Upper Basin
	2004	13.6	21.0	0.65	Upper Basin
	2004	13.6	25.0	0.76	Upper Basin
	2004	13.9	24.0	0.47	Upper Basin
	2004	13.9	25.0	0.65	Upper Basin
	2004	14.4	28.0	0.81	Upper Basin
	Minimum	13.0	19.0	0.19	
	Maximum	16.0	28.0	4.22	
	Mean	14.1	22.6	0.94	
	Median	13.8	22.8	0.83	
Striped Bass	1988	39.5	479.0	10.40	Beach 3
Walleye	1986	10.8	6.0	2.41	Reservoir
	1986	11.2	8.0	2.25	Reservoir
	1986	14.8	20.0	1.96	Reservoir
	1986	15.2	26.0	1.99	Reservoir
	1986	16.2	24.0	2.19	Reservoir
	1986	17.3	52.0	1.92	Reservoir
	1986	17.9	40.0	1.85	Reservoir
	1986	18.0	38.0	2.20	Reservoir
	1986	18.0	50.0	2.27	Reservoir

Table A2-1.— Summary of available fish tissue Hg data from Lahontan Reservoir. These data are for individual samples, obtained from the State of Nevada and Reclamation (NDOW 2004b, Reclamation 2004d)—continued

Species	Year	Fork Length, in	Weight, oz.	Hg, mg/kg	Sample Location
	1986	19.2	52.0	2.42	Reservoir
	1986	20.2	51.0	3.01	Reservoir
	1986	21.0	55.0	4.66	Reservoir
	1986	21.2	66.0	3.38	Reservoir
	1986	22.0	70.0	3.56	Reservoir
	1986	22.3	83.0	3.86	Reservoir
	1986	24.0	98.0	5.32	Reservoir
	1986	24.2	95.0	4.02	Reservoir
	1986	24.2	120.0	4.80	Reservoir
	1986	24.3	82.0	3.52	Reservoir
	1986	27.0	136.0	4.70	Reservoir
	1987	8.9	5.0	0.69	Catfish Cove
	1987	15.6	29.0	3.17	6-Mile
	1987	15.6	30.0	1.27	Catfish Cove
Walleye	1987	15.8	24.0	2.30	6-Mile
	1987	16.0	30.0	1.75	Narrows
	1987	17.6	40.0	2.05	Catfish Cove
	1987	20.8	76.0	3.22	Catfish Cove
	1988	9.9	5.0	0.72	Truckee Canal
	1988	14.3	17.0	2.04	Truckee Canal
	1988	15.2	22.0	1.43	Truckee Canal
	1988	16.4	29.0	1.50	Truckee Canal
	1988	16.7	24.0	0.95	Truckee Canal
	1988	17.3	38.0	1.98	Truckee Canal
	1988	17.8	39.0	1.92	Truckee Canal
	1988	18.5	49.0	1.51	Truckee Canal
	1988	18.9	49.0	2.87	Truckee Canal
	1988	19.0	49.0	1.89	Truckee Canal
	1988	20.0	51.0	2.66	Truckee Canal
	1988	20.7	59.0	2.02	Truckee Canal
	1988	20.8	60.0	3.52	Truckee Canal
	1988	21.6	64.0	4.45	Truckee Canal
	1988	21.6	68.0	2.43	Truckee Canal
	1988	22.7	74.0	4.43	Truckee Canal

Table A2-1.— Summary of available fish tissue Hg data from Lahontan Reservoir. These data are for individual samples, obtained from the State of Nevada and Reclamation (NDOW 2004b, Reclamation 2004d)—continued

Species	Year	Fork Length, in	Weight, oz.	Hg, mg/kg	Sample Location
Walleye	1988	24.4	115.0	2.73	Truckee Canal
	1988	26.5	124.0	3.24	Truckee Canal
	1988	27.0	171.0	4.23	Truckee Canal
	1988	27.5	160.0	4.00	Truckee Canal
	1989	17.5	32.0	2.85	Truckee Canal
	1989	17.8	34.0	3.28	Truckee Canal
	1989	18.3	38.0	2.32	Truckee Canal
	1989	19.0	50.0	4.58	Truckee Canal
	1989	19.6	34.0	9.52	Truckee Canal
	1989	20.1	42.0	5.10	Truckee Canal
	1989	21.0	53.0	4.76	Truckee Canal
	1989	21.2	50.0	4.04	Truckee Canal
	1989	13.8	15.0	1.37	Reservoir
	1989	15.8	24.0	2.40	Narrows
	1989	16.0	27.0	1.47	Reservoir
	1990	14.8	25.0	1.57	Reservoir
	1990	16.0	30.0	1.32	Reservoir
	1990	17.8	27.0	1.57	Reservoir
	1990	18.0	43.0	1.50	Reservoir
	1990	20.0	63.0	4.11	Reservoir
	1990	20.3	54.0	2.20	Reservoir
	1990	21.3	61.0	3.06	Reservoir
	1990	21.8	88.0	2.01	Reservoir
	1990	24.7	98.0	4.53	Reservoir
	1990	26.5	124.0	4.77	Reservoir
	1995	14.3	20.0	1.53	Reservoir
	1995	14.6	21.0	2.86	Reservoir
	1995	15.2	28.0	1.76	Reservoir
	1995	18.1	44.0	1.49	Reservoir
	1995	18.9	47.0	2.65	Reservoir
	1996	9.8	7.0	2.21	Reservoir
	1996	10.2	8.0	2.90	Reservoir
	1996	10.4	8.0	2.30	Reservoir
	1996	11.8	11.0	2.80	Reservoir

Table A2-1.— Summary of available fish tissue Hg data from Lahontan Reservoir. These data are for individual samples, obtained from the State of Nevada and Reclamation (NDOW 2004b, Reclamation 2004d)—continued

Species	Year	Fork Length, in	Weight, oz.	Hg, mg/kg	Sample Location
	1996	15.5	28.0	4.80	Reservoir
	1996	16.1	31.0	6.67	Reservoir
	1996	16.3	32.0	4.50	Reservoir
	1996	17.8	42.0	5.21	Reservoir
	1996	18.6	49.0	5.30	Reservoir
	1996	30.0	178.0	12.40	Reservoir
	1997	12.1	9.0	2.40	Reservoir
	1997	12.4	11.0	3.10	Reservoir
	1997	12.7	11.0	3.10	Reservoir
	1997	14.2	18.0	2.20	Reservoir
	1997	14.8	20.0	1.90	Reservoir
	1997	15.3	24.0	2.80	Reservoir
	1997	15.5	28.0	5.20	Reservoir
	1997	17.4	32.0	2.80	Reservoir
	1997	17.5	36.0	3.20	Reservoir
	1997	19.7	57.0	4.50	Reservoir
	1997	21.7	71.0	8.50	Reservoir
	1997	21.9	77.0	4.30	Reservoir
	1997	23.7	93.0	5.60	Reservoir
	1998	13.3	13.0	2.36	Reservoir
	1998	14.1	16.0	3.02	Reservoir
	1998	15.8	25.0	2.75	Reservoir
	1998	18.3	40.0	3.80	Reservoir
	1998	19.7	43.0	7.22	Reservoir
	1998	20.5	45.0	9.42	Reservoir
	1998	20.6	44.0	6.92	Reservoir
	1998	23.0	77.0	7.54	Reservoir
	1998	23.0	95.0	6.76	Reservoir
	1998	25.2	88.0	16.00	Reservoir
	1999	9.4	5.0	1.07	Reservoir
	1999	13.7	21.0	1.90	Reservoir
Walleye	1999	14.6	20.0	1.62	Reservoir
	1999	16.3	29.0	2.14	Reservoir
	1999	17.5	37.0	2.86	Reservoir

Table A2-1.— Summary of available fish tissue Hg data from Lahontan Reservoir. These data are for individual samples, obtained from the State of Nevada and Reclamation (NDOW 2004b, Reclamation 2004d)—continued

Species	Year	Fork Length, in	Weight, oz.	Hg, mg/kg	Sample Location
	1999	18.3	40.0	2.28	Reservoir
	1999	18.6	50.0	3.48	Reservoir
	1999	21.0	68.0	3.12	Reservoir
	1999	23.6	96.0	3.18	Reservoir
	1999	23.7	92.0	3.54	Reservoir
	2000	9.5	4.0	1.74	Reservoir
	2000	12.0	8.0	1.06	Reservoir
	2000	13.2	14.0	1.69	Reservoir
	2000	14.1	17.0	2.36	Reservoir
	2000	16.6	24.0	5.02	Reservoir
	2000	17.0	24.0	2.98	Reservoir
	2000	18.0	32.0	3.98	Reservoir
	2000	19.3	38.0	4.00	Reservoir
	2000	21.2	54.0	3.50	Reservoir
	2000	24.2	84.0	3.64	Reservoir
	2000	27.5	133.0	5.80	Reservoir
	Minimum	8.9	4.0	0.69	
	Maximum	30.0	178.0	16.00	
	Mean	18.2	48.1	3.40	
	Median	18.0	40.0	2.86	
White Bass	1987	7.0	3.0	0.61	Truckee Canal
	1987	7.2	4.0	0.83	Truckee Canal
	1987	8.3	6.0	2.69	Truckee Canal
	1987	8.4	6.0	1.53	Truckee Canal
	1987	8.5	6.0	1.46	Truckee Canal
	1987	8.5	6.0	2.34	Truckee Canal
	1987	2.9	2.0	0.29	Lower Basin
	1987	5.3	3.0	1.24	Narrows
	1987	6.2	2.0	0.51	Narrows
White Bass	1987	6.8	3.0	0.89	Narrows
	1987	8.8	7.0	2.56	Lower Basin
	1987	9.2	8.0	2.26	Lower Basin
	1987	9.8	9.0	2.65	Lower Basin
	1988	8.3	5.0	3.31	Truckee Canal

Table A2-1.— Summary of available fish tissue Hg data from Lahontan Reservoir. These data are for individual samples, obtained from the State of Nevada and Reclamation (NDOW 2004b, Reclamation 2004d)—continued

Species	Year	Fork Length, in	Weight, oz.	Hg, mg/kg	Sample Location
	1988	8.4	6.0	1.17	Truckee Canal
	1988	8.5	6.0	1.11	Truckee Canal
	1988	8.6	5.0	3.22	Truckee Canal
	1988	8.6	6.0	2.38	Truckee Canal
	1988	9.0	6.0	2.76	Truckee Canal
	1988	9.2	7.0	2.41	Truckee Canal
	1988	9.2	6.0	2.80	Truckee Canal
	1988	9.5	7.0	3.03	Truckee Canal
	1988	9.6	7.0	2.91	Truckee Canal
	1988	13.3	20.0	5.10	Truckee Canal
	1988	7.9	5.0	0.68	Upper Basin
	1988	8.0	5.0	1.02	Upper Basin
	1988	8.5	5.0	2.08	Narrows
	1988	8.9	6.0	2.76	Narrows
	1988	9.0	7.0	2.56	Narrows
	1988	9.0	7.0	1.32	Narrows
	1988	9.4	8.0	2.65	Narrows
	1988	11.0	12.0	2.54	Upper Basin
	1989	3.5	1.0	0.27	Reservoir
	1989	4.5	1.0	0.35	Reservoir
	1989	5.4	2.0	0.69	Reservoir
	1989	8.0	5.0	0.77	Reservoir
	1989	8.2	7.0	1.84	Reservoir
	1989	8.4	5.0	1.12	Reservoir
	1989	8.4	6.0	0.94	Reservoir
	1989	8.7	6.0	2.09	Reservoir
	1989	9.1	7.0	2.06	Reservoir
	1989	9.1	7.0	1.33	Reservoir
	1989	9.2	8.0	2.98	Reservoir
	1989	9.3	8.0	1.90	Reservoir
	1989	9.5	7.0	2.79	Reservoir
	1990	5.2	2.0	0.39	Reservoir
	1990	5.6	3.0	0.59	Reservoir
	1990	6.7	7.0	1.58	Reservoir

Table A2-1.— Summary of available fish tissue Hg data from Lahontan Reservoir. These data are for individual samples, obtained from the State of Nevada and Reclamation (NDOW 2004b, Reclamation 2004d)—continued

Species	Year	Fork Length, in	Weight, oz.	Hg, mg/kg	Sample Location
White Bass	1990	7.1	3.0	0.33	Reservoir
	1990	9.2	9.0	1.04	Reservoir
	1990	9.2	8.0	1.92	Reservoir
	1990	9.4	7.0	2.30	Reservoir
	1990	9.5	8.0	0.97	Reservoir
	1990	9.6	9.0	2.06	Reservoir
	1990	9.8	8.0	1.56	Reservoir
	1994	11.2	15.0	9.40	Reservoir
	1994	12.3	23.0	9.50	Reservoir
	1994	12.8	29.0	12.00	Reservoir
	1994	13.2	28.0	12.40	Reservoir
	1994	13.3	31.0	12.20	Reservoir
	1995	10.7	13.0	2.56	Reservoir
	1995	10.9	14.0	1.15	Reservoir
	1995	11.7	16.0	1.66	Reservoir
	1995	13.1	28.0	6.03	Reservoir
	1995	14.3	32.0	1.80	Reservoir
	1996	11.8	18.0	3.93	Reservoir
	1996	11.8	17.0	3.87	Reservoir
	1996	11.8	20.0	3.98	Reservoir
	1996	11.9	19.0	3.29	Reservoir
	1996	12.3	21.0	3.40	Reservoir
	1996	13.7	28.0	10.40	Reservoir
	1997	8.0	5.0	1.50	Reservoir
	1997	9.8	10.0	2.80	Reservoir
	1997	12.4	20.0	7.40	Reservoir
	1997	12.8	20.0	5.50	Reservoir
	1997	14.3	26.0	12.60	Reservoir
	1997	14.5	25.0	13.80	Reservoir
	1998	12.2	15.0	1.89	Reservoir
	1998	12.8	15.0	5.70	Reservoir
	1998	13.1	17.0	3.22	Reservoir
	1998	13.2	15.0	5.84	Reservoir
	1998	13.8	17.0	1.42	Reservoir

Table A2-1.— Summary of available fish tissue Hg data from Lahontan Reservoir. These data are for individual samples, obtained from the State of Nevada and Reclamation (NDOW 2004b, Reclamation 2004d)—continued

Species	Year	Fork Length, in	Weight, oz.	Hg, mg/kg	Sample Location
	1998	14.9	31.0	2.88	Reservoir
	1998	15.4	31.0	3.63	Reservoir
	1999	9.5	8.0	1.47	Reservoir
	1999	12.0	16.0	2.62	Reservoir
	1999	12.1	17.0	2.76	Reservoir
White Bass	1999	12.4	15.0	3.36	Reservoir White Bass
	1999	12.8	21.0	2.26	Reservoir
	1999	13.6	23.0	6.68	Reservoir
	2000	10.3	11.0	1.89	Reservoir
	2000	11.4	12.0	4.62	Reservoir
	2000	11.7	15.0	3.94	Reservoir
	2000	13.2	22.0	2.12	Reservoir
	2000	14.1	25.0	4.36	Reservoir
	Minimum	2.9	0.0	0.27	
	Maximum	15.4	32.0	13.80	
	Mean	10.0	11.7	3.15	
	Median	9.5	8.0	2.38	
White Catfish	1987	8.0	4.0	1.50	Upper Basin
	1987	8.3	5.0	1.29	Upper Basin
	1987	9.3	6.0	1.44	Upper Basin
	1987	9.4	7.0	2.18	Upper Basin
	1987	9.7	8.0	1.98	Horsemans
	1987	9.9	8.0	1.39	6-Mile
	1987	10.6	10.0	1.62	Horsemans
	Minimum	8.0	4.0	1.29	
	Maximum	10.6	10.0	2.18	
	Mean	9.3	6.9	1.63	
	Median	9.4	7.0	1.50	
White Crappie	1987	4.5	2.0	.	Narrows
	1987	7.2	4.0	.	Narrows
	1987	8.3	6.0	1.60	Upper Basin
	1987	8.4	6.0	1.40	Upper Basin
	1987	8.7	8.0	1.11	Upper Basin

Table A2-1.— Summary of available fish tissue Hg data from Lahontan Reservoir. These data are for individual samples, obtained from the State of Nevada and Reclamation (NDOW 2004b, Reclamation 2004d)—continued

Species	Year	Fork Length, in	Weight, oz.	Hg, mg/kg	Sample Location
	1987	9.7	7.0	1.02	Narrows
	1997	11.0	12.0	2.60	Reservoir
	1999	6.2	3.0	0.86	Reservoir
	1999	11.0	8.0	1.29	Reservoir
	2000	8.3	5.0	0.89	Reservoir
	2000	9.5	10.0	1.05	Reservoir
	2000	10.2	8.0	1.38	Reservoir
	Minimum	4.5	2.0	0.86	
	Maximum	11.0	12.0	2.60	
	Mean	8.6	6.5	1.32	
	Median	8.6	6.5	1.20	
Wiper	1994	6.8	3.0	1.60	Reservoir
	1994	7.7	4.0	2.04	Reservoir
	1994	8.2	5.0	2.80	Reservoir
	1995	10.5	15.0	3.45	Reservoir
	1995	10.7	12.0	1.55	Reservoir
	1995	13.2	25.0	1.34	Reservoir
	1995	14.0	31.0	2.77	Reservoir
	1996	13.8	28.0	4.62	Reservoir
	1996	14.9	30.0	3.36	Reservoir
	1996	15.3	38.0	4.98	Reservoir
	1996	15.4	36.0	4.26	Reservoir
	1997	16.9	41.0	4.80	Reservoir
	1998	20.2	66.0	6.60	Reservoir
	2000	20.4	62.0	6.64	Reservoir
	Minimum	6.8	3.0	1.34	
	Maximum	20.4	66.0	6.64	
	Mean	13.4	28.3	3.63	
	Median	13.9	29.0	3.41	
Yellow Perch	1986	7.1	.	1.09	Reservoir
All Fish Summary	***Minimum***	2.9	2.0	0.18	
	Maximum	39.5	479.0	16.00	
	Mean	14.3	32.5	2.55	
	Median	13.8	21.0	1.90	

Table A2-2.—Statistical summary of Hg, mg/kg, from individual samples in Lahontan Reservoir Fish

Species	Statistic		Hg, mg/kg
Black Bass	N		9
	Mean		1.85
	Standard Deviation		0.89
	Median		1.67
	Minimum		0.60
	Maximum		3.38
	Percentiles	25	1.19
		50	1.67
		75	2.56
Channel Catfish	N		25
	Mean		2.13
	Standard Deviation		1.23
	Median		1.83
	Minimum		0.37
	Maximum		5.34
	Percentiles	1	0.37
		5	0.50
		10	0.86
		15	1.19
		20	1.29
		25	1.34
		30	1.36
		35	1.36
		40	1.42
		45	1.71
		50	1.83
		55	2.01
		60	2.09
		65	2.20
		70	2.35
		75	2.51
		80	3.38
		85	3.69
		90	4.17
		95	5.16
		99	5.34

Table A2-2.—Statistical summary of Hg, mg/kg, from individual samples in Lahontan Reservoir Fish—continued

Species	Statistic		Hg, mg/kg
Largemouth Bass	N		1
	Maximum		4.28
Rainbow Trout	N		7
	Mean		1.02
	Standard Deviation		0.56
	Median		1.18
	Minimum		0.18
	Maximum		1.86
	Percentiles	25	0.41
		50	1.18
		75	1.29
Sacramento Blackfish	N		88
	Mean		0.94
	Standard Deviation		0.48
	Median		0.83
	Minimum		0.19
	Maximum		4.22
	Percentiles	1	0.19
		5	0.36
		10	0.56
		15	0.60
		20	0.65
		25	0.67
		30	0.74
		35	0.76
		40	0.79
		45	0.80
		50	0.83
		55	0.90
		60	0.93
		65	1.00
		70	1.13
		75	1.20
		80	1.23
		85	1.28
		90	1.35
		95	1.53
		99	4.22

Table A2-2.—Statistical summary of Hg, mg/kg, from individual samples in Lahontan Reservoir Fish—continued

Species	Statistic		Hg, mg/kg
Striped Bass	N		1
	Maximum		10.40
Walleye	N		127
	Mean		3.40
	Standard Deviation		2.19
	Median		2.86
	Minimum		0.69
	Maximum		16.00
	Percentiles	1	0.70
		5	1.29
		10	1.50
		15	1.70
		20	1.90
		25	2.01
		30	2.20
		35	2.30
		40	2.40
		45	2.74
		50	2.86
		55	3.08
		60	3.22
		65	3.52
		70	3.93
		75	4.23
		80	4.55
		85	4.80
		90	5.38
		95	7.41
		99	14.99
White Bass	N		95
	Mean		3.15
	Standard Deviation		2.96
	Median		2.38
	Minimum		0.27
	Maximum		13.80
	Percentiles	1	0.27
		5	0.38
		10	0.69
		15	0.95

Table A2-2.—Statistical summary of Hg, mg/kg, from individual samples in Lahontan Reservoir Fish—continued			
Species	**Statistic**		**Hg, mg/kg**
		20	1.13
		25	1.33
		30	1.52
		35	1.82
		40	1.98
		45	2.15
		50	2.38
		55	2.56
		60	2.73
		65	2.80
		70	3.07
		75	3.36
		80	3.94
		85	5.34
		90	6.97
		95	12.04
		99	13.80
White Catfish	N		7
	Mean		1.63
	Standard Deviation		0.33
	Median		1.50
	Minimum		1.29
	Maximum		2.18
	Percentiles	1	1.29
		5	1.29
		10	1.29
		15	1.31
		20	1.35
		25	1.39
		30	1.41
		35	1.43
		40	1.45
		45	1.48
		50	1.50
		55	1.55
		60	1.60
		65	1.69
		70	1.84
		75	1.98

Table A2-2.—Statistical summary of Hg, mg/kg, from individual samples in Lahontan Reservoir Fish—continued			
Species	**Statistic**		**Hg, mg/kg**
		80	2.06
		85	2.14
		90	2.18
		95	2.18
		99	2.18
White Crappie	N		10
	Mean		1.32
	Standard Deviation		0.51
	Median		1.20
	Minimum		0.86
	Maximum		2.60
	Percentiles	1	0.86
		5	0.86
		10	0.86
		15	0.88
		20	0.92
		25	0.99
		30	1.03
		35	1.05
		40	1.07
		45	1.11
		50	1.20
		55	1.29
		60	1.34
		65	1.38
		70	1.39
		75	1.45
		80	1.56
		85	1.95
		90	2.50
		95	2.60
		99	2.60
Wiper	N		14
	Mean		3.63
	Standard Deviation		1.76
	Median		3.41
	Minimum		1.34
	Maximum		6.64
	Percentiles	1	1.34

Table A2-2.—Statistical summary of Hg, mg/kg, from individual samples in Lahontan Reservoir Fish—continued

Species	Statistic		Hg, mg/kg
		5	1.34
		10	1.45
		15	1.56
		20	1.60
		25	1.93
		30	2.41
		35	2.78
		40	2.80
		45	3.22
		50	3.41
		55	3.65
		60	4.26
		65	4.53
		70	4.71
		75	4.85
		80	4.98
		85	6.20
		90	6.62
		95	6.64
		99	6.64
Yellow Perch	N		1
	Maximum		1.09

Table A2-3.—Hg in fish data previously summarized by the State of Nevada (individual fish sample data unavailable)

				Fork Length (FL) Summary, in.			Tissue Hg Summary, mg/kg		
Year	Species	Agency	n	FL Minimum	FL Maximum	FL Average	Hg Minimum	Hg Maximum	Hg Average
1986	White Bass	NDEP	13	7.1	9.4	8.44	0.85	3.96	2.63
1986	Channel Catfish	NDEP	3	14.6	21.2	17.6	2.35	6.25	4.81
1986	White Catfish	NDEP	3	8.8	10.8	9.53	1.48	1.86	1.68
1985	White Catfish	NDEP	10	6.8	21.5	10.9	0.65	4.14	1.8
1985	Carp	NDEP	7	7.8	16.5	12.1	0.84	2.3	1.48
1985	Channel Catfish	NDEP	5	8	17.5	12.1	0.43	2.23	1.4
1985	Largemouth Bass	NDEP	14	5	16.8	9.5	0.38	2.88	1.29
1985	Green Sunfish	NDEP	3	4.1	4.8	4.4	1.16	1.3	1.23
1985	White Bass	NDEP	23	4.3	11.5	7.2	0.41	1.8	1.08
1985	Walleye	NDEP	9	9.8	17	12.4	0.54	2.07	0.97
1985	Tahoe Sucker	NDEP	4	9.6	10.5	10.1	0.73	1.08	0.91
1985	Sacramento Blackfish	NDEP	6	10	14.6	12	0.72	1.38	0.88
1985	White Crappie	NDEP	2	6.7	7.1	6.9	0.69	0.86	0.77
1985	Black Bullhead	NDEP	2	6.5	7.5	7	0.67	0.75	0.71
1985	Bluegill	NDEP	11	5.2	6.9	5.6	0.42	0.97	0.59
1985	Yellow Perch	NDEP	11	5.5	7.5	6.8	0.33	0.77	0.56
1981	Sacramento Blackfish	DRI	5				0.44	1.92	0.962
1994	Sacramento Blackfish	NDOW	17				0.22	0.94	0.54
1995	Sacramento Blackfish	NDOW	30				0.8	1.64	1.25
1996	Sacramento Blackfish	NDOW	20				0.59	1.15	0.83