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Mercury and Suspended Sediment, Carson River Basin, Nevada—Loads To and From Lahontan Reservoir in Flood Year 1997 and Deposition in Reservoir Prior to 1983

During the flood on January 3, 1997, about 200,000 tons of sediment and 3,000 pounds of total mercury flowed past the Carson River streamflow gage near Fort Churchill.

During January through September 1997:

- **About 600,000 tons of sediment and 10,000 pounds of total mercury flowed past the Fort Churchill site.**
- **About 2,000 pounds of total mercury was discharged from Lahontan Reservoir.**
- **Lahontan Reservoir retained about 90 percent of the sediment and 80 percent of the total mercury that flowed past the Fort Churchill site.**
- **Concentrations of total mercury and total methylmercury ranged from 28,000 to 260 ng/L, and 5.24 to 1.44 ng/L at the Fort Churchill site, respectively.**

A sedimentation rate of about 0.8 in/yr was measured in a core sample of bottom sediment collected from Lahontan Reservoir in April 1982.

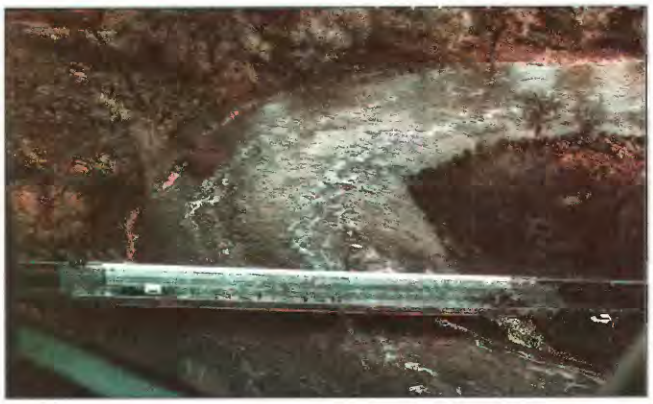
By late December 1996, a huge snow pack (more than 180 percent of normal in some places) had been deposited on the high-altitude eastern slopes of the Sierra Nevada. A carpet of snow had fallen on many of the low-lying valleys in west-central Nevada as well. Coincidently, near the Hawaiian Islands, a subtropical low-pressure system was developing over warm Pacific Ocean waters. Moving rapidly northeastward, the weather system dumped large quantities of unseasonably warm rain on the snow-covered slopes and valleys. During December 30, 1996-January 3, 1997, the rapid release of snowmelt delivered a torrent of water down both main forks of the Carson River in California and Nevada, causing a combined flow that inundated the main channel and flood plain with a deluge of turbulent, debris-carrying water the likes of which few have seen. On January 3, the catastrophic flood wave peaked at 22,300 ft^3/s at the Carson River streamflow-gaging station near Fort Churchill, Nev., about 10 mi upstream from Lahontan Reservoir (Thomas and Williams, 1997). At that gaging station (figs. 1 and 2), the flow exceeded the 100-year peak discharge (16,800 ft^3/s), a flow that, statistically, has a 1-percent chance of happening in any given year (Garcia, 1997). For comparison, the long-term (1911-96) maximum mean flow for January is about 1,500 ft^3/s.

But a flood represents more than just an abundance of water; it also represents an abundance of "things" in water, such as mineral sediment and certain trace elements typically attached to sediment particles—mercury, for example. Inorganic mercury, commonly known as quicksilver, is a metal and in the environment is a potential contaminant hazard to fish and wildlife, and to humans.

Inorganic mercury and its organic compounds, such as methylmercury, have no known biological function, and are potentially toxic to living organisms. Methylmercury (MeHg) is formed by bacteria from inorganic mercury in the aquatic environment.

Figure 1. Location of sampling sites, Carson River Basin, California and Nevada.

The most toxic of the naturally formed mercury compounds, MeHg is known to bioaccumulate and to biomagnify. Bioaccumulation is a biological process wherein an organism accumulates a contaminant in its body at a greater rate than the contaminant is excreted. Biomagnification is a process wherein a contaminant concentration increases incrementally at each level of the food chain, including humans. A local consequence of biomagnification of MeHg is the public-health warnings issued by the State of Nevada for the consumption of game fish from Lahontan Reservoir (Nevada Division of Wildlife, written commun., 1997) and of shoveler ducks from Carson Lake southeast of Fallon, Nev. (Nevada State Health Division, written commun., 1989).



Photograph by Patrick A. Glancy

Figure 2. Sampling site at U.S. Highway 95-A bridge crossing Carson River near Fort Churchill during January 1997 flood.

During the 1800's, large amounts of inorganic mercury were imported from California to the Carson River Basin and used in the milling of gold and silver ore from the Comstock Lode near Dayton, Nev. (fig. 1). About 7,500 tons of the imported mercury were lost from the milling process and became potentially available by erosion to the Carson River system (Smith, 1943, p. 257).

Elevated concentrations of inorganic mercury in the Carson River Basin were first reported by the U.S. Geological Survey (USGS) in 1973 (Van Denburgh, 1973). That study showed concentrations of mercury up to 200-times background concentrations in samples of whole-water (unfiltered) and bottom sediment downstream from areas where inorganic mercury was used during the milling process. Subsequent investigations by researchers at the University of Nevada-Reno have further documented the extent and severity of this human-caused contamination problem (for example, see Gustin and others, 1994). Prior to completion of Lahontan Dam in 1915, much of the mercury stored in mill tailings along stream flood plains was flushed downstream to the Carson Desert wetlands by episodic floods. After 1915, Lahontan Reservoir provided a partial trap for fluvial sediments and adsorbed mercury that settled on the reservoir bottom. In August 1990, the U.S. Environmental Protection Agency (USEPA) listed the Carson River as a Superfund site for possible remediation of mercury contamination from just upstream from Dayton to the river's terminus in the Carson Desert.

What, Where, Why

Streamflow conditions were hazardous near the Fort Churchill gage in the first week of January 1997 as USGS hydrologists collected water samples during the rising and falling stages of the flood wave. Samples also were collected periodically from February through September 1997. All these samples were subsequently analyzed for mercury and suspended-sediment concentrations in the laboratory. These data, and those from samples collected at another gaging station on the Carson River about 1.5 mi downstream from Lahontan Reservoir during January-September 1997, were used to calculate the monthly discharge of suspended sediment (in tons per day) and mercury (in pounds per day) to and from the reservoir. Only water from the Carson River entered the reservoir during the flood. Flow from the Truckee Canal (a diversion from the Truckee River Basin) to Lahontan Reservoir was discontinued during January-September 1997.

The purpose of this paper is (1) to present a contemporary and quantitative perspective on the hydrologic role of a major flood to mobilize and transport large quantities of sediment and associated mercury (as measured just upstream from Lahontan Reservoir) from the active channel and flood plain of the Carson River; (2) to estimate the load of sediment and mercury moving to and from Lahontan Reservoir during January-September 1997; and (3) to provide a historical glimpse of the rate of sediment accumulation and on the concentration of mercury in core samples from bottom sediment in Lahontan Reservoir prior to 1983.

Collection of Data on Surface-Water Quality

Water samples were collected near the Fort Churchill gaging station during rising flood water near the peak flow on January 3, 1997, by grab sampling at three nearly equidistant locations across the channel. Grab samples were collected because emergency conditions existed at the time. These samples were combined and thoroughly mixed to obtain representative subsamples of suspended-sediment and mercury concentrations. Subsequent sample collection was done by the depth-integration method at several verticals across the channel. This method of collection more accurately represents the discharge-weighted sample concentration in each vertical. Water samples from each vertical were combined and thoroughly mixed for obtaining subsamples for chemical analysis. A separate set of depth-integrated water samples was collected for suspended-sediment analysis. Obtaining whole-water samples representative of the river is especially important for high-velocity flows containing appreciable concentrations of suspended particles that are typically poorly mixed within the stream channel.

Water samples for mercury analysis were chilled at 39°F or less, sent overnight to the chemical laboratory, and analyzed according to procedures described by Bloom (1989, 1995). The determination of suspended-sediment concentration in whole-water samples was done in the sediment laboratory according to procedures described by Guy (1969, p. 11-18). External laboratory quality-control samples for mercury comprised equipment blanks and field blanks for the flood-peak samples and for subsequent data collection. Results of those analyses, in light of the high environmental concentrations, showed that rigorous quality-control objectives were met. Water samples were collected more frequently at the Fort Churchill site where flow variability is greater compared to the site below Lahontan Reservoir where water release (flow) is controlled. At the downstream site, water samples were collected near-monthly. Load estimates below Lahontan Reservoir were calculated using time-weighted averages of streamflow multiplied by sample concentrations of suspended sediment, total mercury[a] (THg), and total methylmercury (TMeHg).

Load estimates were developed for the Fort Churchill site using linear regression equations of suspended-sediment concentration with streamflow (fig. 3), and of THg concentrations with streamflow (fig. 4). Data used to develop the equations were for the period of USGS record (1975-97). The time-weighted average method was used for estimating loads of TMeHg.

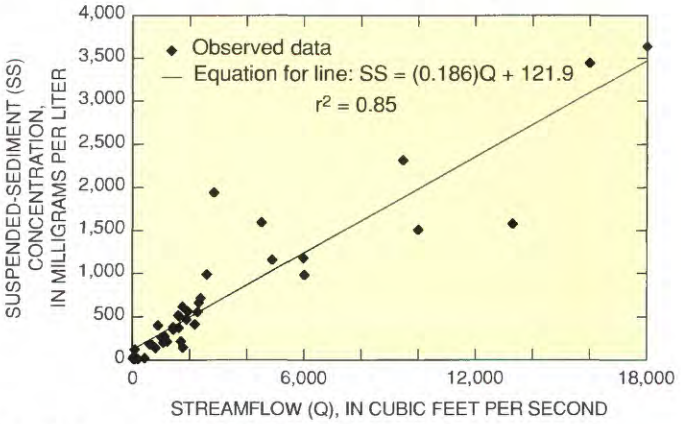


Figure 3. Linear regression of suspended sediment and streamflow for Carson River near Fort Churchill period of USGS record. Symbol: r^2, statistical coefficient indicating decimal percentage of total variation in suspended sediment that can be attributed to streamflow.

[a] Total mercury and total methylmercury refer to all extractable forms of each chemical for a whole-water (unfiltered) sample.

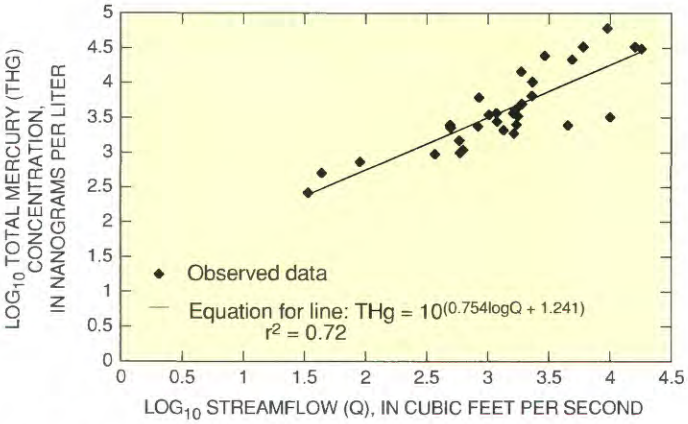


Figure 4. Linear regression of $\log_{10}$ total mercury and $\log_{10}$ streamflow for Carson River near Fort Churchill period of USGS record. Symbol: r^2, statistical coefficient indicating decimal percentage of total variation in total mercury that can be attributed to streamflow.

Results of Surface-Water Data Collection

Streamflow

Daily mean streamflow during January-September 1997 for the gages near Fort Churchill and below Lahontan Reservoir is shown in figure 5. The flow at the Fort Churchill gage represents nearly natural runoff conditions because of the lack of storage reservoirs upstream. The flood wave during the first week of January dominates the 9-month hydrograph (fig. 5). The maximum instantaneous streamflow near Fort Churchill on January 3 was 22,300 ft^3/s. A secondary peak (4,000 ft^3/s) occurred in late January owing to runoff from local thundershower activity. The increase in streamflow from mid-April through June represents spring snowmelt runoff. Lahontan Reservoir was at about 70 percent maximum capacity on December 31. Precautionary releases for flood control from the reservoir were begun at noon January 2 according to Bureau of Reclamation flood control criteria (Bureau of Reclamation, written commun., 1997) and continued to mid-March. From mid-March (fig. 5) to mid-April, the flows were reduced. For the remainder of the period, flows were released for irrigation in the Fallon area.

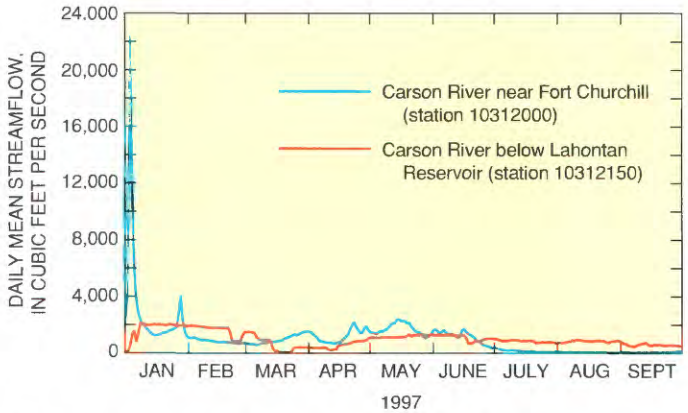


Figure 5. Streamflow at Carson River near Fort Churchill and below Lahontan Reservoir, 1997

[b] Micrograms per liter (µg/L) are equivalent to "parts per billion;" nanograms per liter (ng/L), "parts per trillion;" and milligrams per liter (mg/L) and micrograms per gram (µg/g), "parts per million."

Concentration of Total Mercury and Total Methylmercury

Concentrations of THg in water samples collected periodically at both sites from January through September are shown in figure 6. For the Fort Churchill site, THg concentrations generally correlate positively with flow. The largest concentrations in 1997 were measured near the peak of the flood wave. The 28,000 ng/L[b] (28 µg/L) maximum value shown in figure 6 represents the mean of three discrete samples collected just prior to the peak. After the flood peak passed the Fort Churchill site on January 3-4, the concentrations of measured THg dramatically declined with reduced streamflow. Concentrations ranged from 1,000 to 4,200 ng/L from mid-January to mid-April. Concentrations of THg again increased with increasing flows from spring snowmelt runoff in April. The large concentration of 10,000 ng/L was measured on April 23 during the "first flush" of the snowmelt runoff. Thereafter, throughout the snowmelt runoff period, the concentration of THg varied positively with flow, ranging in concentration from about 2,200 to 6,600 ng/L. During the low-flow period of July through September, the THg concentrations decreased substantially, ranging from about 260 to 960 ng/L throughout the summer. The increase in concentration of THg at the end of September coincided with a slight increase in flow (not readily apparent in figure 5).

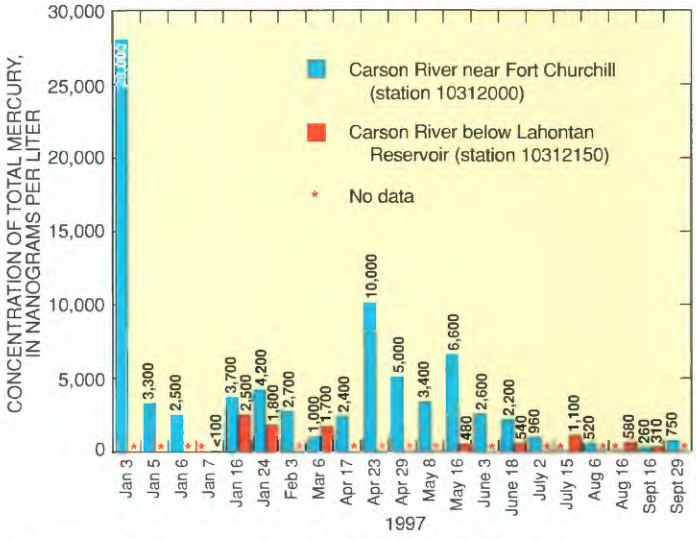


Figure 6. Concentration of total mercury at Carson River near Fort Churchill and below Lahontan Reservoir, 1997

At the sampling site below Lahontan Reservoir, concentrations of THg increased from below the analytical reporting limit (100 ng/L) on January 7 to 2,500 ng/L on January 16, about 2 weeks after the flood peak passed the Fort Churchill site. The January 7 sample represents pre-flood water. Subsequent samples for THg were measured at a minimum reporting limit of 0.1 ng/L. Concentrations of THg stayed near 2,000 ng/L to the beginning of March. However, from the limited data available, during the winter and spring months, THg concentrations typically were less at the site below Lahontan Reservoir than at the upstream sampling site.

To put the above concentrations of THg in perspective, even though the Carson River is not a source of drinking water (at least not for humans), the Nevada standard for THg in public water supplies is 2,000 ng/L (2 µg/L). Upstream from the main source of contamination, THg concentrations in water samples from the Carson River generally are less than 100 ng/L (0.1 µg/L).

Samples for total methylmercury (TMeHg) concentrations (fig. 7) were collected at the Fort Churchill site during spring snowmelt runoff and through the summer of 1997. The data were highly variable throughout the sampling period, with the 11 values ranging in concentration from 5.24 to 1.44 ng/L. The limited TMeHg data for samples collected at the site below Lahontan Reservoir showed an increase in concentration from 0.52 ng/L to 1.70 ng/L from mid-June to mid-September, respectively.

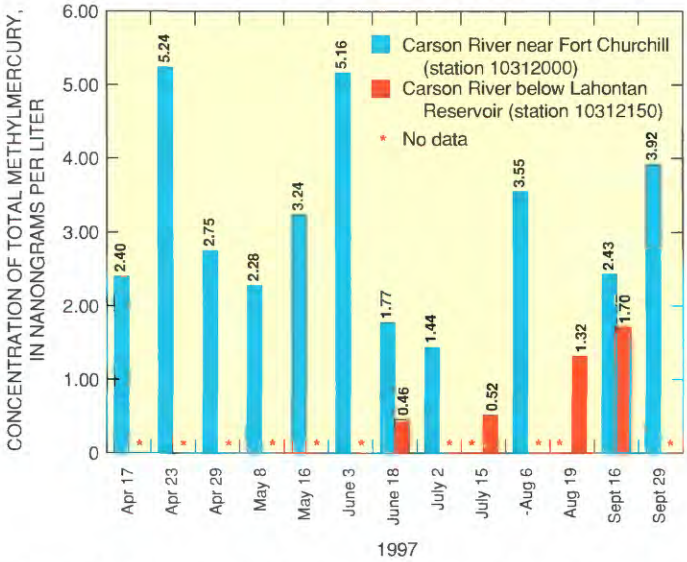


Figure 7. Concentraton of total methylmercury at Carson River near Fort Churchill and below Lahontan Reservoir, 1997

Overall, the Carson River TMeHg concentrations are relatively high. For example, water samples from the Sudbury River, Mass., a stream contaminated with mercury from a nearby Superfund site, contained concentrations of TMeHg ranging from 0.03 to 0.75 ng/L (J.A. Colman, USGS, oral commun., 1997). Surface-water samples from the Sacramento River Basin, Calif., affected by non-point sources of mercury, contained concentrations of TMeHg ranging from 0.065 to 1.3 ng/L (J.L. Domagalski, USGS, written commun., 1997). Alternatively, Bloom (1995) suggests TMeHg concentrations in natural surface water **not** contaminated with mercury typically range from 0.01 to 1 ng/L. Thus, the elevated TMeHg concentrations in the Carson River system have important implications for potential adverse effects on the aquatic ecosystem. For the present work, the minimum reporting limit for TMeHg was less than 0.05 ng/L.

Load of Sediment and Mercury

Because of uncertainties associated with measuring streamflow, including other data-collection and data-analysis activities, for extreme high flows, the summary loading estimates shown in tables 1 and 2 are rounded to one significant figure. The loads of sediment for both sampling sites in terms of monthly values from January to September are shown in figure 8. The total sediment loads for selected periods are given in table 1.

For the Fort Churchill site, the data in table 1 show that about 70 percent of the sediment load for the 9-month period occurred during January *alone*. Of the January load, 50 percent flowed past the site on a single day—January 3, the day of the flood peak.

Table 1. Estimated load of suspended sediment for selected periods at two sampling sites on Carson River, Nev., 1997

Sampling site	Suspended sediment (tons, rounded to one significant figure)			
	January 3 (flood)	January 1-31	April-June (snowmelt)	January-September
Near Fort Churchill (above Lahontan Reservoir)	200,000	400,000	100,000	600,000
Below Lahontan Reservoir	--	10,000	10,000	40,000

Indeed, about 30 percent of the total sediment for the 9-month period occurred on a single, but significant day. For comparison, the 200,000-ton estimate for January 3, is equivalent to about 13,000 standard (six-wheel) dump trucks filled with moist sand.

The data also show that the sediment load below Lahontan Reservoir was only about 10 percent of that measured upstream from the reservoir at the Fort Churchill site for the same 9-month period.

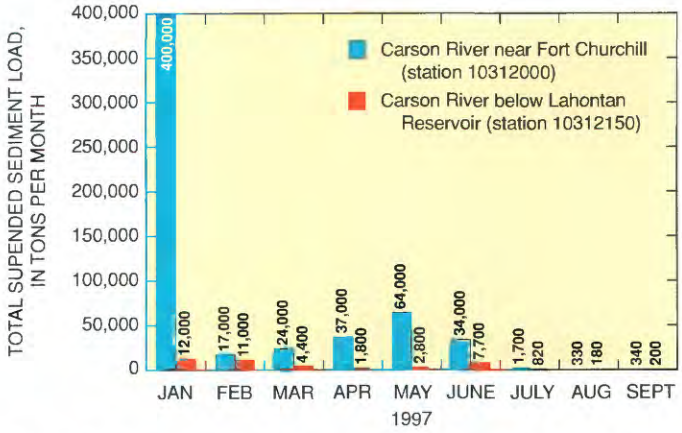


Figure 8. Estimated load of suspended sediment at Carson River near Fort Churchill and below Lahontan Reservoir, 1997.

The loads of THg, in terms of monthly values, from January through September 1997 for both sites are shown in figure 9. The load of THg for selected time periods is shown in table 2. The data in table 2 indicate that about 70 percent of the THg load for the 9-month period (10,000 pounds) occurred during January. Of the January load, about 40 percent flowed past the Fort Churchill site on January 3. For the site below the reservoir, about 2,000 pounds of THg was released from the reservoir for the 9-month period of January through September, or 20 percent of that at the upstream site.

Table 2. Estimated load of total mercury for selected periods at two sampling sites on Carson River, Nev., 1997

Sampling site	Total mercury (pounds, rounded to one significant figure)			
	January 3 (flood peak)	January 1-31	April-June (snowmelt)	January-September
Near Fort Churchill (above Lahontan Reservoir)	3,000	7,000	3,000	10,000
Below Lahontan Reservoir	--	400	300	2,000

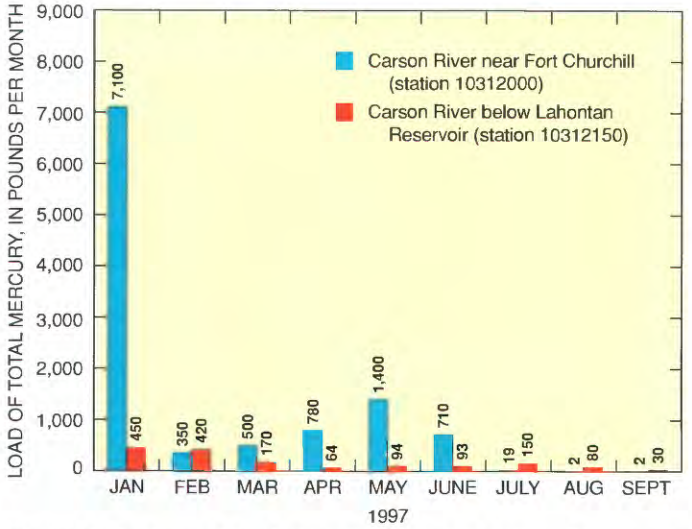


Figure 9. Estimated load of total mercury at Carson River near Fort Churchill and below Lahontan Reservoir, 1997.

Monthly loads of TMeHg (fig. 10) at the Fort Churchill site ranged from 0.3 to 0.7 pound per month, whereas at the site below Lahontan Reservoir, the TMeHg loads ranged from 0.1 to 0.2 pound per month.

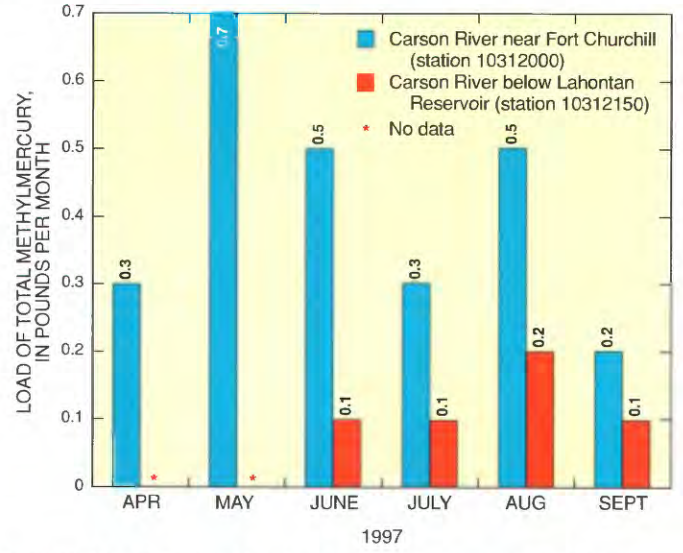


Figure 10. Estimated load of total methylmercury at Carson River near Fort Churchill and below Lahontan Reservoir, 1997.

Mercury Concentrations and Sedimentation Rates From Sediment Cores, April 1982

Vertical core samples of bottom sediments in a reservoir can reveal patterns of natural and human-caused activities in the river's watershed during the last century or more. With the purpose of collecting data on the vertical disposition of mercury and other water-quality variables in bottom sediments of Lahontan Reservoir, core samples were collected April 1982. The samples were collected about 0.5 mi south of the dam using a gravity corer from a water depth of about 80 ft on or near the pre-reservoir channel. To age-date the sediments, three 39.4-in. cores were each sliced horizontally at 3.9-in. intervals from the top of the core to 27.6 in.; the 8th subsample comprised the remainder of the core. Each of the respective subsample intervals was then combined for measurement of the radioisotopes cesium-137 (Cs-137) and lead-210 (Pb-210) in the laboratory. A fourth 39.4-in. core was sliced at 2-in. intervals for measurement of concentrations of mercury.

All cores appeared uniform throughout their length, except about the top 1 in. of brown organic matter, which is typical of the oxygenated conditions observed at the water-sediment contact at the time of collection. The remainder was dark grey with the texture of clay or silt, strong hydrogen sulfide (rotten egg) smell, and no benthic invertebrates nor their burrows seen. Activities of Cs-137 and concentrations of mercury (total recoverable) in bottom sediment are reported in terms of dry weight.

Cesium-137 is a by-product of atmospheric nuclear weapons testing following World War II. Cs-137 is not produced naturally, has a half-life of about 30 years, and is rapidly and almost irreversibly adsorbed onto fine-grained sediments exposed to atmospheric fallout. Over time, sediment particles with adsorbed Cs-137 that enter a reservoir tend to sink and accumulate on the bottom sediment. Measurable concentrations of Cs-137 were first detected in the atmosphere in the early 1950's and peaked at about 1963-64. Atmospheric fallout of this manmade isotope provides a useful age-dating tool for assessing sediment inputs to a reservoir (or a lake) from its watershed (Krishnaswasmi and Lai, 1978, p. 153-177).

The deepest occurrence of measurable Cs-137 along the core composite was in the 23.6- to 27.6-in. subsample and the maximum Cs-137 content was in the 11.8- to 15.7-in. subsample. None of the cores penetrated to pre-reservoir sediments, which were initially covered by water in 1916. Thus, the 25.6-in. core-composite depth was assigned year 1952, and the 13.8-in. depth was assigned year 1964 (fig. 11). The top of the core composite was assigned 1982, the date of collection.

On the basis of analysis for Cs-137, normalized for compaction (P. Van Metre, USGS, written commun., 1997), the average sedimentation rates for 1952-64 and 1965-82 are 0.4 g/in^2/yr and 0.2 g/in^2/yr, respectively, at the coring location. The average linear rates for the same two periods are 0.9 in/yr and 0.6 in/yr, respectively, or an overall average rate of 0.8 in/yr. This overall rate is comparable to the 0.7-0.9 in/yr overall average linear sedimentation rate determined by analysis for Pb-210 from the same core composite (A. Yang, USGS, written commun., 1982). Pb-210 is a naturally occurring radioisotope with a half-life of about 22 years. This isotope is useful for dating sediments less than 150 years old. The reasonable agreement between the two independent dating measurements provides a degree of confidence to accompany the Cs-137 rate. The greater sediment rate during 1952-64 (13 years) than during 1965-82 (18 years), may be due, in part, to the greater number of recorded peak runoffs at the Fort Churchill gage during the earlier period (eight peaks exceeding 8,000 ft^3/s) compared to the later period (zero peaks exceeding 8,000 ft^3/s). The bankfull capacity of the river near Dayton is about 8,000 ft^3/s.

The mercury profile in bottom sediment near the site cored for the Cs-137 and Pb-210 data, is shown in figure 11. With the exception of the abrupt peak concentration of 15 µg/g at the 21.7- to 25.6-in. core interval, the overall concentrations of mercury at the sampled site tend to decrease slightly with time, ranging from about 6-8 µg/g near the bottom of the core to 4 µg/g near the top of core. This

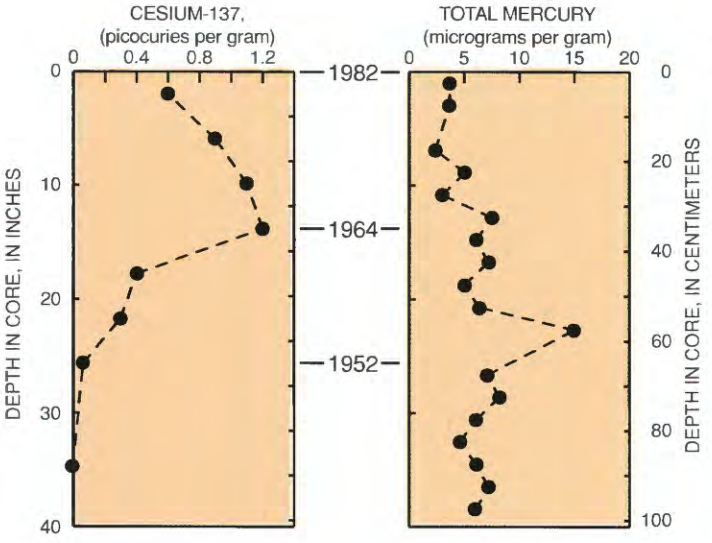


Figure 11. Cesium-137 activities and mercury (total recoverable) concentrations (dry weight) in bottom-sediment cores from Lahontan Reservoir, Nev., April 1982.

overall decrease may be due, in part, to the continued flushing, hence depletion, of human-caused mercury pollution from upstream source areas. The random peak concentrations of mercury concentration along the core probably are due to episodic floods in the basin. The maximum peak mercury concentration of 15 µg/g in the core sample lies just above the 1952 marker and probably corresponds to the flood of late December 1955 with its probable high load of mercury to the reservoir. The 1955 flood had a peak flow of 9,680 ft^3/s at the Fort Churchill site.

Concluding Comments

The reconstruction of historic mercury and sediment deposition in Lahontan Reservoir at the coring site (albeit with limited data) coupled with measurement and analysis of the recent (January 1997) flood flow and its aftermath to and from the reservoir, suggests that episodic floods—infrequent as they may be—play a major hydrologic role in the erosion, transport, and deposition of fluvial sediments and associated mercury in the Carson River. For example, about 200,000 tons of sediment and 3,000 pounds of total mercury moved past the sampling site near Fort Churchill when the Carson River peaked at 22,300 ft^3/s on January 3. Future floods (and spring snowmelt runoff) will again accelerate the flushing of human-caused mercury contamination from the affected reach of the Carson River to Lahontan Reservoir. However, future winter floods having similar physical characteristics as the January 1997 flood also may allow noteworthy discharge of mercury **from** the reservoir. Thus, under certain hydrologic conditions, the reservoir acts as an imperfect trap for mercury.

Acknowledgments

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