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Water-Resources Investigations Report 00-4013

DEPARTMENT OF THE INTERIOR—
NATIONAL IRRIGATION WATER QUALITY PROGRAM and
NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

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

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By Ray J. Hoffman *and* Karen A. Thomas

U.S. GEOLOGICAL SURVEY

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Carson City, Nevada
2000

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
ton (short)	0.9072	megagram
gram (g)	0.03527	ounce avoirdupois
liter (L)	33.82	ounce, fluid

Temperature: Degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the formula °F = [1.8(°C)]+32. Degrees Fahrenheit can be converted to degrees Celsius by using the formula °C = 0.556(°F-32).

Abbreviated water-quality units used in this report:

ng/g, nanogram per gram
µg/g, microgram per gram
ng/L, nanogram per liter
mg/L, milligram per liter

Symbols used in this report:

$\overline{m}$, median
n, number
r^2, coefficient of determination

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ABSTRACT

A reconnaissance survey to evaluate the quantity of total methylmercury (TMeHg) in water and bottom sediment along the Carson River system, Nevada and California, occurred in September 1998. The 3-day survey was made during warm, low-flow conditions about 20 months after a major flood of the river in January 1997. Data were collected at 19 sites representing the mainstem river, its East Fork, and selected agricultural drains, canals, and wetlands upgradient from Stillwater National Wildlife Refuge (NWR) in Lahontan Valley. Methylmercury, an organic compound, is a known neurological toxin that biomagnifies up the food chain in aquatic ecosystems.

The maximum observed concentration of TMeHg in water (7.83 ng/L (nanograms per liter)) was found in the deltaic transition zone where the Carson River enters Lahontan Reservoir. Downstream from the reservoir, maximum observed concentrations of TMeHg were about 3 ng/L at the outflow of two shallow reservoir sites that represent wetland ecosystems. For comparison, the upstream reference concentration for TMeHg in water was 0.2 ng/L. Upstream from Lahontan Reservoir, the maximum observed concentration of TMeHg in bottom sediment (7.35 ng/g (nanograms per gram, dry weight)) was found at the Fort Churchill site in the reach that is highly contaminated with mercury. Downstream from the reservoir, maximum concentrations of TMeHg in sediment (13.4 and 22.3 ng/g) were recorded for two agricultural drains entering Stillwater NWR. The upstream reference concentration for TMeHg in sediment was 3.0 ng/g.

Total mercury (THg) concentrations in water upstream from Lahontan Reservoir were highest at the delta site (9,040 ng/L); downstream from the reservoir, the maximum concentration was 782 ng/L, at the inflow site to Stillwater Point Reservoir. For sediment, upstream from Lahontan Reservoir, the maximum concentration found was 4,130 ng/g, at the Fort Churchill site. Downstream from the reservoir, the maximum concentration was 13,100 ng/g, at the Stillwater Slough site entering Stillwater NWR.

For inorganic mercury in water, the Nevada chronic standard (12 ng/L) for the protection of aquatic life was exceeded at 16 of the 19 sites sampled; the acute standard (2,000 ng/L) was exceeded only at the delta site where the river enters Lahontan Reservoir.

Regression analysis between selected chemical constituents and water-quality properties revealed the following: (1) for water, positive but weak correlations between TMeHg concentration and water temperature, pH, and total organic carbon; and a positive, moderate correlation between TMeHg and THg concentrations; (2) for bottom sediment, a positive but weak correlation between the ratio of TMeHg:THg and organic matter; and a positive, moderate correlation between TMeHg and THg; and (3) a positive, strong correlation between TMeHg in water and THg in sediment.

Comparison of data from two Carson River mainstem sites with historic data (1970-97), showed substantially lower (50 percent or more) concentrations of THg in bottom sediments at the time of this survey compared to preflood sediments. Extrapolating these results to other parts of the river is unadvisable because of uncertainties associated with the heterogeneous distribution of

mercury-bound sediment, and of differences in sampling and analytical techniques used in past and present investigations. Rational time-trend analyses of constituent concentrations in bottom sediments requires data comparability. To this end, the implementation of consistent sample collection, sample processing, and analytical protocols in future data-collection programs is desirable.

INTRODUCTION

Since 1973, much has been written in scientific literature about mercury contamination in the reach of the Carson River, Nev. (fig. 1), downstream from Dayton (Van Denburgh, 1973; Richins and Risser, 1975; Cooper and others, 1985; Hallock and others, 1993, p. 39-53; Gustin and others, 1994; Miller and others, 1995, 1998; and Ecology and Environment, Inc., 1998). Resource managers are concerned because certain sampled fish and waterfowl in the contaminated area contain tissue concentrations of mercury that exceed the 1-µg/g (microgram per gram), wet weight, human-health warning level (U.S. Food and Drug Administration, 1984). Furthermore, elevated concentrations of mercury in body tissue may adversely affect certain other aquatic organisms.

Background

Historically, from mid- to late-1800s, large quantities of mercury were imported from several mercury mines in northern California for use in the amalgamation of gold and silver ores of the Comstock mining area near Virginia City (fig. 1). Bailey and Phoenix (1944, p. 5) estimated that about 200,000 flasks of liquid mercury, each weighing 76 pounds, were imported. Although attempts were made by mill owners to recover the mercury from the amalgam during the milling process, most escaped to the environment in mill tailings. The tailings were deposited along several ravines tributary to the Carson River and along the river itself, in the reach between Carson City and Fort Churchill. About 7,500 tons of mercury are estimated to have been "lost" in the exposed tailings and became available to the Carson River through fluvial processes (Smith, 1943, p. 257). Abandoned mines and geothermal springs that discharge to the river upstream from the Dresslerville site (site 2; fig. 1) also are potential sources of mercury contamination. Prior to the construction of Lahontan Dam in 1905, episodic floods in the Carson River Basin probably flushed much of the available mercury-laden tailings downstream to the Carson Desert (known locally as Lahontan Valley; Glancy and Katzer, 1976, p. 42-47), specifically to Carson Lake, Carson Sink, and wetlands in Stillwater NWR (Hoffman, 1994, p. 8). More recently, however, and partly as a result of the New Years flood of 1997[1], Hoffman and Taylor (1998) showed that 20 percent, or about 1 ton, of the THg load entering Lahontan Reservoir from January through September 1997, flowed past the dam. The spilled water subsequently was distributed throughout Lahontan Valley by way of the vast network of agricultural canals, laterals, and drains, including several shallow regulating reservoirs inside and outside of Stillwater NWR.

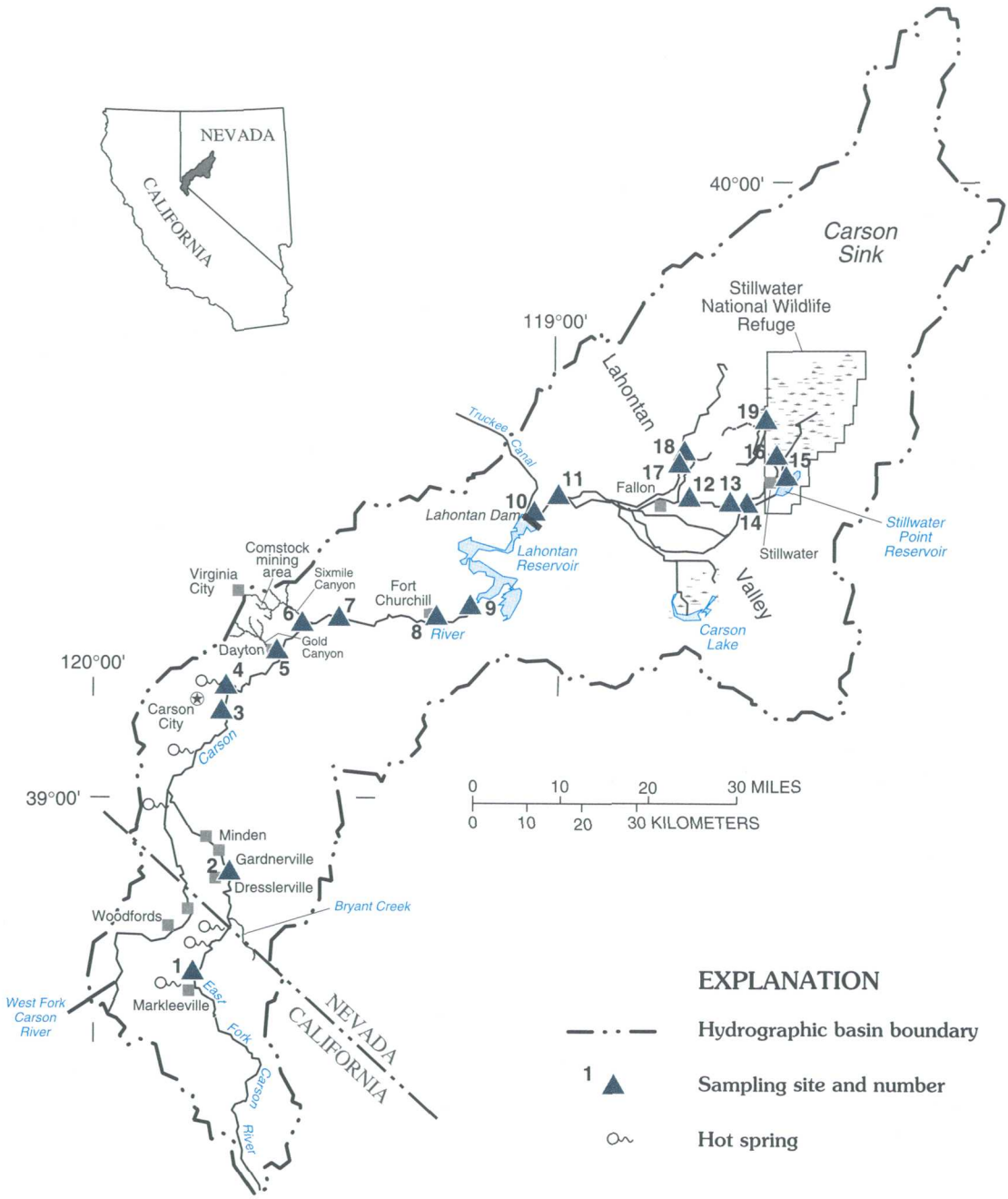
Most of the scientific papers cited above document the distribution and magnitude of THg (and few report MeHg) in samples of water, bottom sediment, and biota along the Carson River system. For this study, little or no data were readily available on the direct determination of MeHg in water and bottom sediment concurrently in Lahontan Valley downstream from Lahontan Reservoir.

Methylmercury

Inorganic mercury, a known toxin and the most common form of mercury in Carson River sediments, is a source material for MeHg, an organic compound. MeHg is a neurotoxin known to bioaccumulate in aquatic organisms and to biomagnify up the food chain (Hoffman and Taylor, 1998). Although mercury can chemically exist in several forms in aqueous systems, MeHg, and possibly ionic mercury (Hg^{+2}), are considered the more important chemical species to biological receptors. Sulfate-reducing bacteria in reducing environments are implicated in the conversion of inorganic mercury to a methylated form making it readily available for uptake by aquatic organisms at successively higher trophic levels (Gilmour and Henry, 1991).

---

[1]Near the Fort Churchill site during the flood of 1997, the peak discharge was 22,300 ft^3/s, which exceeded the 100-year peak discharge of 16,800 ft^3/s. The 100-year peak discharge is one that, statistically, has a 1-percent change of happening in any given year (Garcia, 1997).



Base from U.S. Geological Survey digital data; 1:100,000 scale, 1977-85
Albers Equal Area Conic Projection
Standard Parallels 29°30' and 45°30', central meridian 119°00'

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

Biotic methylation in aquatic systems is a slow process typically enhanced by warm, acidic waters rich in organic carbon. Gill and Bruland (1990) reported that methylation in slightly alkaline systems also is important, whereas in strongly alkaline systems, it appears to be less important. In a previous study, Hoffman and others (1990, p. 89-90) reported that surface waters in Lahontan Valley ranged from slightly alkaline to strongly alkaline with pH ranging from 7.7 to 10.0 (n=75 measurements at 22 agricultural drain and lakes sites during 1986-87).

Demethylation, or biotic degradation of MeHg to an inorganic form, also is known to occur in the study area (Oremland and others, 1995). The importance of the demethylation process in highly mercury-contaminated alkaline waters is the subject of ongoing research.

For the protection of aquatic life, the Nevada standards for inorganic mercury in water are: (1) chronic (96-hour average), 12 ng/L, a value well below the analytical reporting limit of most laboratories (Nevada Legislative Counsel, 1997); and (2) acute (1-hour average), 2,000 ng/L, dissolved. Nevada has no standard for MeHg in water nor for MeHg and THg in bottom sediment.

Purpose and Scope

The purpose of this report is to document and describe selected data collected during the survey. Data on specific conductance and dissolved oxygen are presented by Preissler and others (1999, p. 472).

To obtain additional data on ambient MeHg concentrations, water and bottom-sediment samples were collected during a reconnaissance survey of the Carson River system during September 14-16, 1998. This time period corresponded to (1) low streamflow conditions in the mainstem of the Carson River (daily mean flow less than 140 ft^3/s, with the exception of 400-600 ft^3/s release from Lahontan Dam); (2) active irrigation and relatively warm water temperatures in Lahontan Valley (19-26°C); (3) the coincidence of a scheduled sampling round for TMeHg and THg in water (only) by U.S. Geological Survey (USGS) personnel for an ongoing monitoring program in the reach of the river from Carson City to the streamflow gage 1.1 mi downstream from Lahontan Dam; and (4) a 20-month lapse following the 100-year flood of January 1-3, 1997 (Thomas and Williams, 1997).

During the survey, water samples were collected at 19 sites and bottom-sediment samples were collected at 14 sites (fig. 1; table 1). The sampling sites represent diverse water and sediment types that comprise two on the East Fork Carson River, nine on the mainstem (including one deltiac zone just upstream from Lahontan Reservoir; fig. 2), five in shallow (less than 10 ft) reservoirs/wetlands, and three in agricultural canals or drains. Ancillary data include onsite measurements of streamflow, water temperature, specific conductance, pH, and dissolved oxygen; and laboratory determinations of organic matter.

Acknowledgments

The following individuals are gratefully acknowledged for assistance in the field: Bill Henry (U.S. Fish and Wildlife Service), for piloting an airboat to collect samples from Stillwater Point Reservoir; Angela Paul (University of Nevada, Reno); and Kip Allander, Hugh Bevans, Art Johnson, Steve Lawrence, Armando Robledo, Tim Rowe, and Carl Thodal (USGS).

The authors also thank David Krabbenhoft and Mark Olson of the USGS mercury research laboratory, Middleton, Wisc., and Nicholas Bloom of Frontier Geosciences, Inc., Seattle, Wash., for their cooperation during analytical determination of mercury species in their respective laboratories.

METHODS OF STUDY

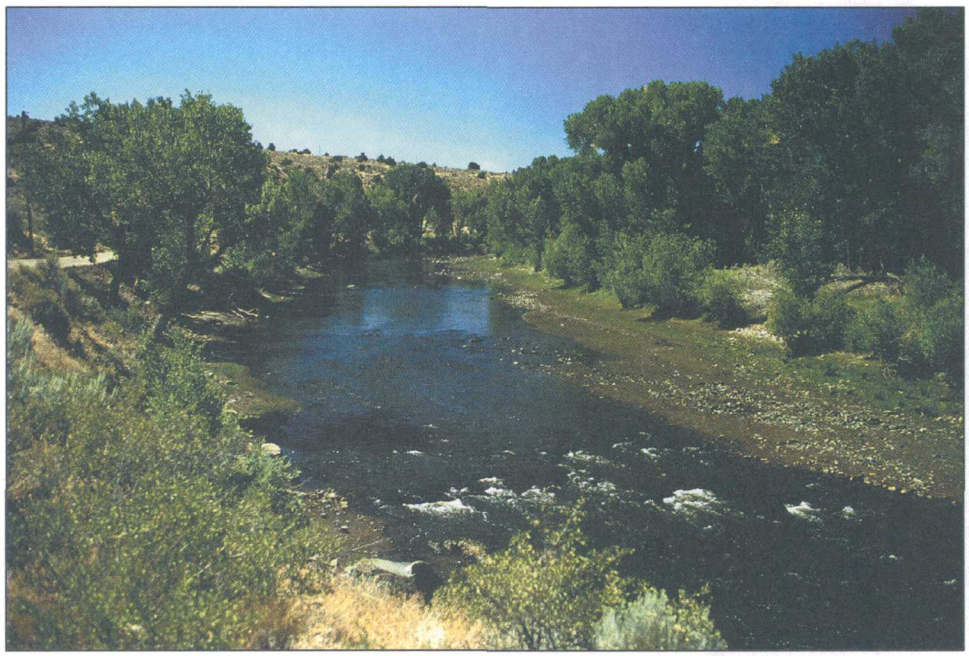
Sampling sites (fig. 1) were based on (1) available hydrologic data from the USGS, National Water Quality Assessment (NAWQA) Program (sites 1-4 and 18), from the concurrent U.S. Environmental Protection Agency (USEPA)/USGS Carson River Mercury (Superfund) study (sites 3-10), and from the Department of the Interior National Irrigation Water Quality Program (sites 14-16, 18, and 19); and (2) where MeHg data from regulated wetland environments (reservoirs) in Lahontan Valley were thought to be nonexistent (for example, sites 11-13, 15, and 17). For these sites, water samples were collected at the outflow from each reservoir; bottom-sediment samples were collected from depositional areas of impounded water just upgradient from the reservoir outflow.

Table 1. Sampling site designations, onsite measurements, and data on mercury and organic matter collected along the Carson River system, September 14-16, 1998

[Abbreviations and symbol: ft^3/s, cubic feet per second; E, estimated; mg/L, milligrams per liter; ng/L, nanogram per liter; ng/g, nanogram per gram; Hg, mercury; LOI, loss on ignition; MeHg, methylmercury; TOC, total organic carbon; –, no data. Analysis by U.S. Geological Survey Research Laboratory, Middleton, Wisconsin, except as noted]

Site number (see fig. 1)	USGS station number (downstream order number)	Station location (latitude/ longitude)	Station name	Water						Bottom sediment, dry weight		
				Discharge, instantaneous (ft^3/s)	Temperature (degrees Celsius)	pH whole field (standard units)	Total MeHg (ng/L)	Total Hg (ng/L)	TOC (mg/L)	Total MeHg (ng/g)	Total Hg (ng/g)	LOI (percent)
1	10308200	384250 1194550	East Fork Carson River below Markleeville Creek, near Markleeville, Calif.	130	16.0	8.3	0.08	4.74	1.3	0.55	45.3	5.7
2	10309010	385242 1194118	East Fork Carson River near Dresslerville, Nev.	150	20.0	8.3	.16	3.42	1.5	2.73	66.2	5.5
3	10311008	390831 1194215	Carson River at Lloyds Bridge near Carson City, Nev.	135	17.5	8.1	[a].99	[a]8.35	--	--	--	--
4	10311400	391052 1194140	Carson River at Deer Run Road near Carson City, Nev.	140	21.0	8.1	.68 [a].68	31.1 [a]20.8	6.9	1.21	78.4	1.7
5	10311700	391416 1193514	Carson River at Dayton, Nev.	110	21.0	8.4	[a,b]5.09	[a]239	--	--	--	--
6	10311715	391656 1193201	Carson River below Dayton, Nev.	140	19.0	7.9	[a,b]5.09	[a]266	--	--	--	--
7	10311860	391728 1192723	Carson River at Chaves Ranch near Clifton, Nev.	140	21.5	8.1	[a,b]5.09	[a]624	--	--	--	--
8	10312000	391735 1191502	Carson River near Fort Churchill, Nev.	89	24.5	8.3	5.12 [a]4.86	1,110 [a]1,110	4.7	7.35	4,130	3.3
9	392024119074801	392024 1190748	Lahontan Reservoir Sample Point near Carson River Mouth, Nev.	--	24.5	9.2	[a]7.83	[a]9,040	--	--	--	--
10	10312150	392750 1190245	Carson River below Lahontan Reservoir, near Fallon, Nev.	420	20.0	7.9	2.44 [a]2.73	374 [a]333	3.2	1.80	1,180	1.2
11	10312155	392931 1185930	Carson River Diversion Dam Outflow at V-Canal near Fallon, Nev.	[c]338	19.0	7.8	3.01	370	3.1	1.38	4,110	1.3
12	1031220120	392900 1184258	S-Line Reservoir Outflow near Fallon, Nev.	E50	23.0	--	.78	223	3.5	.56	204	2.9
13	1031220130	392830 1183745	Harmon Reservoir Outflow near Fallon, Nev.	25	26.0	8.3	.85	221	5.1	5.44	1,040	9.0
14	10312210	392825 1183550	Stillwater Point Reservoir Diversion Canal near Fallon, Nev. (inflow)	22	21.5	7.7	.73	782	7.7	1.88	1,640	2.0
15	10312216	393106 1183038	East-West Canal Outflow from Stillwater Point Reservoir, Nev. (outflow)	55	22.5	7.8	3.14	103	12	5.34	2,540	14.0
16	10312220	393305 1183140	Stillwater Slough Cutoff Drain near Stillwater, Nev.	22	20.5	7.7	1.52	693	7.5	13.4	13,100	6.1
17	10312256	393224 1184401	D-Line Canal Outflow at Sagouspe Dam near Fallon, Nev.	[c]15	21.0	7.0	.93	202	5.3	.74	1,370	.93
18	10312275	393332 1184330	Carson River at Tarzyn Road near Fallon, Nev.	14	26.0	8.4	1.34	205	5.5	1.34	778	.82
19	10312277	393638 1183304	Paiute Diversion Drain below TJ Drain near Stillwater, Nev.	1.7	21.5	8.1	2.40	48.9	6.6	22.3	654	15.0

[a] Analyzed by Frontier Geosciences, Inc., Seattle, Wash.
[b] Identical concentration for three sites verified by laboratory.
[c] Flow data provided by Truckee-Carson Irrigation District, Fallon, Nev.



A.S. VAN DENBURGH, U.S. GEOLOGICAL SURVEY

Figure 2. Carson River mainstem about a mile south of (upstream from) Lloyds Bridge (sample site 3) near Carson City, July 18, 1999. Discharge about 120 ft^3/s. Site of photograph is well above farthest upstream mercury contamination from Comstock Lode ore mills.

Water Column

Measurements of water temperature, specific conductance, pH, and dissolved oxygen were made in the field using the procedures of the USGS (1998). Streamflow measurements were made using the procedures described by Rantz (1982). Water samples were collected using the equal-width-increment sampling method (Shelton and Capel, 1994, p. 16). The water samples collected at each vertical were combined and thoroughly mixed in an 8-liter plastic churn splitter to obtain representative subsamples (Horowitz and others, 1994) for subsequent analyses of TMeHg, THg, and total organic carbon (TOC). During sampling, crews wore plastic gloves and executed ultra-clean techniques (Olson and DeWild, 1999). For mercury determinations, at sites 1, 2, 4, 8, and 10-19, whole-water samples were withdrawn from the churn splitter into acid-rinsed Teflon bottles contained in double zip-lock bags as received from the laboratory. In the field, the samples were frozen using dry ice, then shipped within 24 hours of collection to the USGS mercury research laboratory in Middleton, Wisc. Water samples were collected at sites 3, 4, and 5-10 and processed as above but shipped chilled at 4°C within 24 hours of collection to the Frontier Geosciences, Inc., laboratory in Seattle, Wash., as part of the collaborative USEPA/USGS Superfund study mentioned earlier. Thus, replicate samples were collected at sites 4, 8, and 10 for TMeHg and THg and the results are shown in table 1. Of the replicate data, only those concentrations from the USGS mercury research laboratory were used in the graphs presented herein, to maintain a degree of consistency within the dataset. Considering sample-processing and analytical errors over a wide range of ambient mercury concentrations, the replicate results showed relatively good agreement between the two laboratories. With the exception of the high relative percent difference (39 percent) for THg from site 4, the replicate results ranged from less than 1 to 12 relative percent difference (median ($\overline{m}$)=5.2 percent, number (n)=5 pairs).

Water samples for TOC were collected from the churn splitter into baked glass bottles that were pre-rinsed with sample water, and kept chilled at 4°C until analyzed by the USGS mercury research laboratory.

Bottom Sediment

Bottom-sediment samples were collected using the NAWQA trace-element sampling protocols (Shelton and Capel, 1994). Field personnel wore plastic gloves and used a precleaned Teflon or plastic scoop to collect approximately 0.8 in. of the top fine-grained sediment in depositional areas. At each site, samples were taken from at least five locations and then combined in a glass bowl, mixed, and subsampled. In the field, samples for mercury and ash-free, loss-on-ignition (LOI) determinations were frozen using dry ice, then shipped within 24 hours of collection to the USGS mercury research laboratory. LOI is a measure of total organic matter, as ash-free dry weight, reported in percent of total dry weight.

Laboratory Analyses

Details of analytical procedures used by the USGS mercury research laboratory for MeHg, THg, and TOC in water and MeHg, THg, and LOI in bottom sediment are given by Olson and others (1997) and Olson and DeWild (1999). Analytical procedures used by Frontier Geosciences, Inc. (Bloom, 1989; Gill and Bruland, 1990), were similar to those used by the USGS mercury research laboratory. Minimum analytical reporting limits for TMeHg, THg, and TOC in water were (depending on the laboratory) equal to or less than 0.02 ng/L, 0.04 ng/L, and 0.1 mg/L, respectively. Minimum reporting limits for TMeHg, THg, and LOI in dry-weight sediment were 0.1 ng/g, 0.1 ng/g, and 0.01 percent, respectively. Analyses of TMeHg, Hg, and LOI in sediment were on bulk, unseived samples to avoid affecting the partitioning (percent association) coefficients of mercury that might occur with sieved samples (M.L. Olson, U.S. Geological Survey, written commun., 1999).

External laboratory quality-control samples for mercury consisted of field blanks, a source solution blank, and comparison of replicate samples (subsampled from the churn splitter) that were analyzed by each laboratory (Horowitz and others, 1994).

RESULTS AND DISCUSSION

Data collected during the September 1998 survey are shown in table 1 and figures 3, 6-7, and 9-11. Upstream from and including Lahontan Reservoir, instantaneous streamflow of the Carson River ranged from 89 to 150 ft^3/s ($\bar{m}$=138 ft^3/s); water temperature ranged from 16.0 to 24.5°C ($\bar{m}$=21.0°C), and pH ranged from 7.9 to 9.2 ($\bar{m}$=8.3). Downstream from Lahontan Reservoir, flow in agricultural canals and drains, and mainstem sites ranged from 1.7 to 420 ft^3/s ($\bar{m}$=24 ft^3/s); water temperature ranged from 19.0 to 26.0°C ($\bar{m}$=21.5°C); and pH ranged from 7.0 to 8.4 ($\bar{m}$=7.8). Without exception, the sample results for mercury in water and sediment greatly exceeded the respective minimum reporting limits. The data on TMeHg and THg are reported to as many as three significant figures, in conformance with USGS mercury research laboratory protocols.

Water Column

Mercury concentrations in water (fig. 3*A*) generally increased in a downstream direction from Markleeville (site 1; fig. 1) to the point where the Carson River empties into Lahontan Reservoir (site 9). Downstream from the reservoir, the concentrations declined somewhat but were, for the most part, still elevated. The highest concentrations (7.83 ng/L and 9,040 ng/L for TMeHg and THg, respectively) were measured at site 9. This site represents a deltiac transition zone where river water mixes with reservoir water. The low-gradient, 5-mile reach of the river upstream from site 9 broadens laterally to form a deltaic plain containing many oxbows and rivulets with intervening marsh lands. The lowest mercury concentrations, as expected, were found at the two most upstream sites (reference sites 1 and 2) on the East Fork Carson River, more than 50 river-miles upstream from the historic Comstock milling operations. For purposes of this report, TMeHg less than 0.2 ng/L and THg less than 5.0 ng/L in water are considered reference concentrations and are used herein for comparison to respective data collected at the other sites. These reference concentrations are about threefold higher than median "background" concentrations (0.06 ng/L MeHg and 1.90 ng/L THg, n=17), but less than maximum background concentrations (0.61 ng/L TMeHg and 9.78 ng/L THg) reported by David P. Krabbenhoft and coworkers (U.S. Geological Survey, written commun., 1999) during a nationwide survey of mercury at 21 NAWQA study basins in 1998.

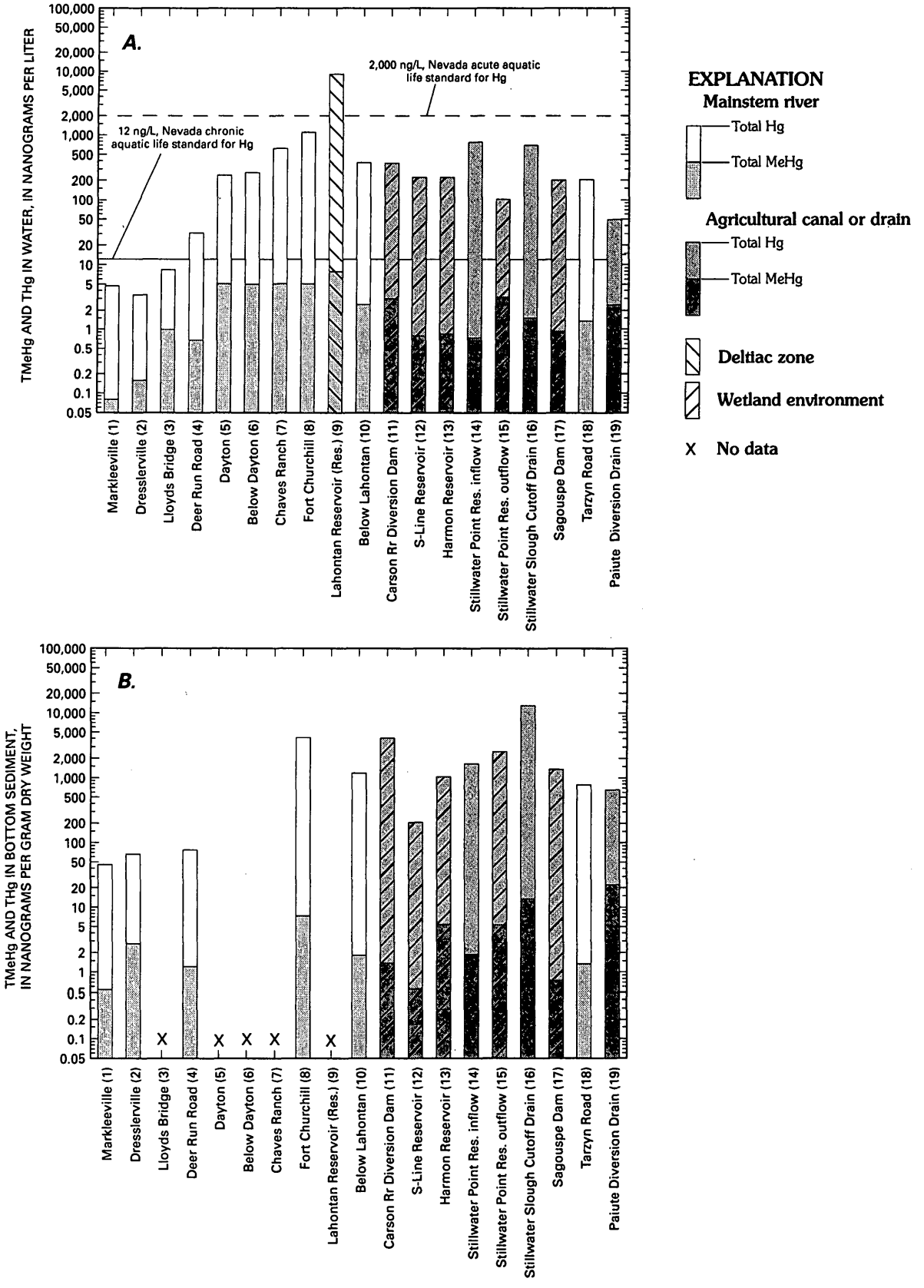


Figure 3. Total methylmercury (TMeHg) and total mercury (THg) concentrations in water column (*A*) and bottom sediment (*B*), Carson River system, September 1998. For water, to obtain an equivalent dissolved concentration, multiply the ambient THg concentration by a factor of 0.85 (Environmental Protection Agency, 1998).

The 26-mile reach of the river from Dayton (site 5) to Lahontan Reservoir (site 9) tended to have the highest concentrations of both TMeHg and THg (fig. 3*A*) compared to other sampling sites in the present survey. These results are not surprising as similar trends were reported by Cooper and others (1985) and Bonzongo and others (1996b). THg at 6 of the 9 sites upstream from Lahontan Reservoir (sites 4-9) exceeded the State of Nevada chronic standard of 12 ng/L for the protection of aquatic life (fig. 3*A*). The acute standard of 2,000 ng/L, dissolved, was exceeded (3.8 fold[2]) only where the Carson River enters Lahontan Reservoir (site 9).

Of the 10 sites downstream from Lahontan Reservoir (fig. 3*A*), TMeHg ranged from 0.73 ng/L in the inflow to Stillwater Point Reservoir (site 14; fig. 4) to 3.14 ng/L in the East-West Canal outflow from the same reservoir (site 15). In general, TMeHg concentrations downstream from Lahontan Reservoir were lower than those in the most contaminated reach of the river upstream from the reservoir, but were still 14- to 16-fold greater than the reference concentration of 0.2 ng/L. The highest TMeHg concentrations, about 3 ng/L, were found at the outflow of Carson Diversion Dam (site 11) and the outflow from Stillwater Point Reservoir (site 15; fig. 5), both of which represent wetland areas. THg at all sites downstream from Lahontan Reservoir exceeded the 12 ng/L (chronic) standard for the protection of aquatic life. However, during this survey the acute standard was not exceeded at any of the 10 sites (fig. 3*A*).

A loglog scatterplot of TMeHg as the dependent variable and THg as the independent variable (fig. 6) shows a weak positive correlation of TMeHg with THg (r^2=0.56). A regression equation for the data in figure 6 can be expressed as a power function $TMeHg=0.14\ THg^{0.46}$. The equation indicates that, within the range of data presented, the concentration of TMeHg in water appears to increase about 3-fold for a 10-fold increase in THg concentration in water. However, the data also suggest that TMeHg does not increase in relation to THg when TMeHg is greater than 1,000 ng/L. This tentative observation probably reflects the complex interplay of several environmental factors in the net production of MeHg. These factors are, for example, the flux of MeHg across the water-sediment interface, demethlylation within the aerobic water column, and differences in water chemistry among the various types of water sampled (Gilmour and Henry, 1991).

For all sites, the percentage of TMeHg to THg ranged from 11.8 (site 3) to 0.09 (site 14), with an overall median of 0.81. For the 10 sampling sites downstream from Lahontan Reservoir, the median of 0.65 percent was about threefold lower than that for the 9 sites upstream from the reservoir ($\overline{m}$=1.9 percent). The overall median of 0.81 percent in this survey corresponds to that reported by other researchers (Ecology and Environment, Inc., 1998, p. 3-15); however, the median of 1.9 percent for sites upstream from Lahontan Reservoir in the present survey is nearly twofold the maximum percentage reported in the earlier study.

A loglog scatterplot of TMeHg relative to TOC (fig. 7) shows two distinct groups of data: relatively low concentrations of TMeHg where TOC is less than 2 mg/L at the 2 upstream reference sites (sites 1 and 2); and the relatively high concentrations of TMeHg where TOC ranges from 3.1 to 12 mg/L ($\overline{m}$=5.4; table 1) at the 17 downstream sites (sites 3-19). A poor relation between mercury and organic carbon in the water column was reported in an earlier study (Bonzongo and others, 1996a) for mainstem sites in the Carson River upstream from Lahontan Dam.

For the present survey, regression analyses (not shown) with data from all sites also revealed that TMeHg correlated poorly with water temperature (r^2=0.06) and with pH (r^2=0.18). These results are in agreement with those reported by Bonzongo and others (1996b, table 4).

Bottom Sediment

Mercury concentrations in bottom sediments (fig. 3*B*) of the mainstem of the Carson River increased sequentially in the downstream direction, peaking near the Fort Churchill (site 8), and declined downstream from that location. The highest THg concentration found on the mainstem was 4,130 ng/g at site 8 (table 1). As expected, the lowest THg concentrations were found at the two farthest upstream sites (reference sites 1 and 2).

[2]Derived by multiplying conversion factor of 0.85 by ambient whole-water concentration for equivalent dissolved concentration (Environmental Protection Agency, 1998).

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Figure 4. Eastward view of Stillwater Point Reservoir (sampling site 15 for bottom sediment) and Stillwater Range near Fallon, Nev., September 1998.

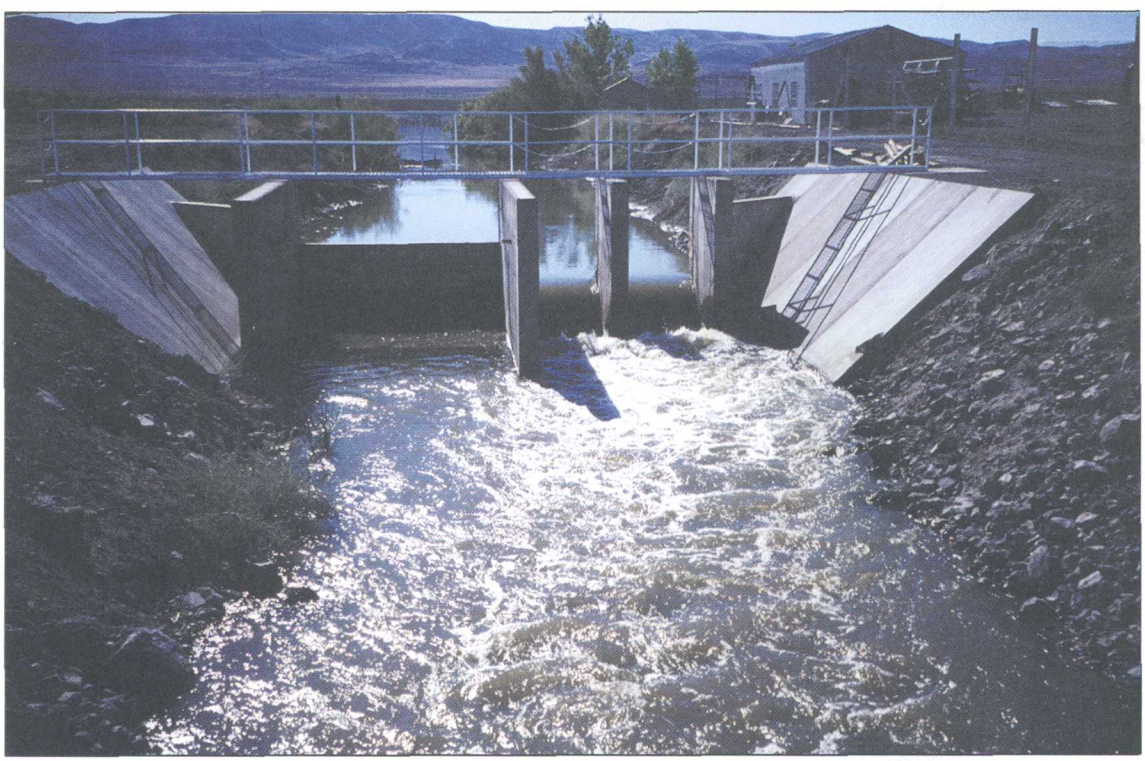

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Figure 5. Upstream view of the East-West Canal outflow from Stillwater Point Reservoir near Fallon, Nev. (sampling site 15 for water). Discharge about 22 ft^3/s, September 1998.

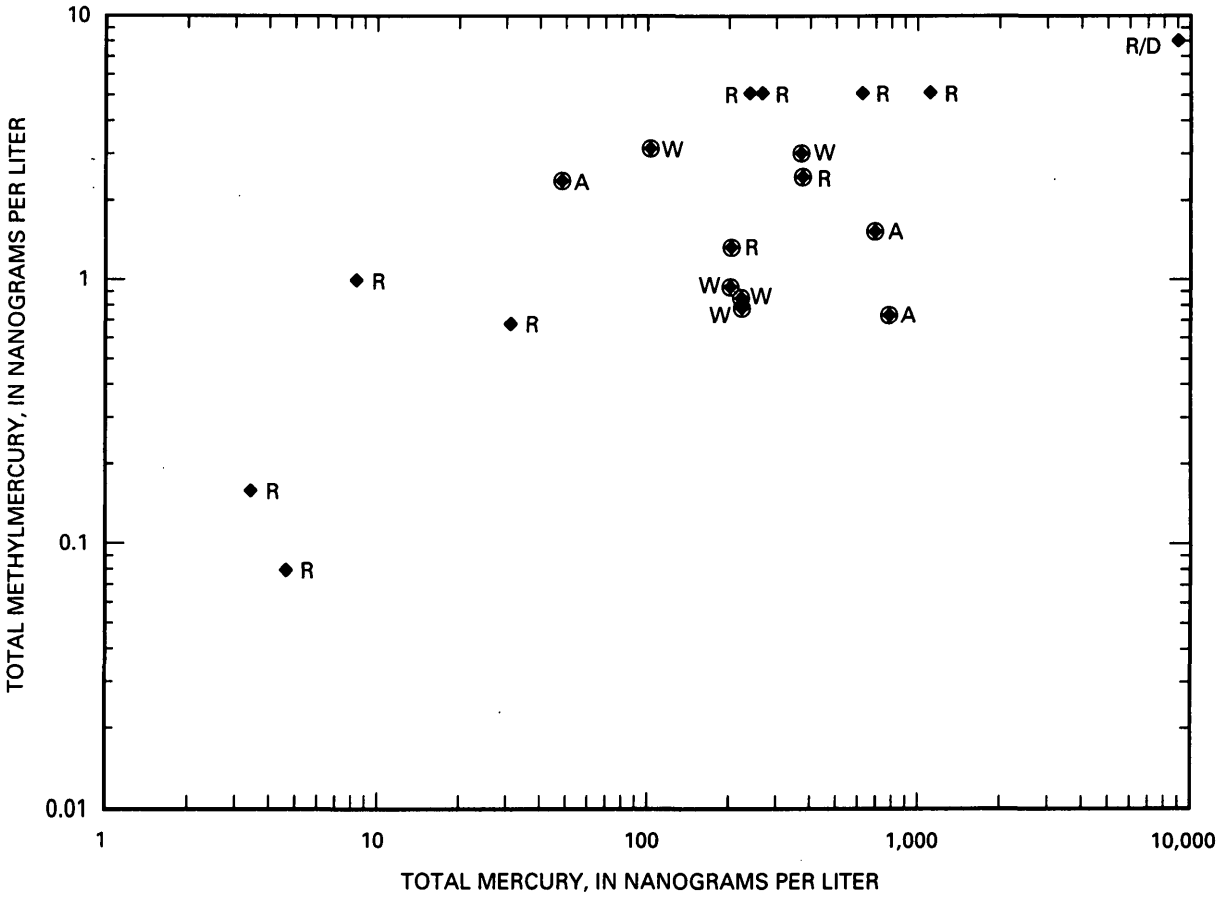

Figure 6. Correlation between total methylmercury and total mercury in water column, Carson River system, September 1998.

The concentration of TMeHg in sediment was highly variable from one site to the next. The lowest concentration (0.55 ng/g) was found at site 1 near Markleeville, whereas the highest concentration (22.3 ng/g) was found near the terminus of the Carson River system in Paiute Diversion Drain below TJ Drain near Stillwater (site 19), hereafter referred to as Paiute Diversion Drain. The elevated concentration of 2.73 ng/g of TMeHg at site 2 near Dresslerville may reflect inputs of mercury from geothermal springs that discharge to the river and an abandoned mercury mine in a tributary basin, Bryant Creek (Lawrence, 1998). For purposes of this report, TMeHg less than 3.0 ng/g and THg less than 70 ng/g in sediment are considered reference concentrations. For comparison, both reference concentrations are higher than median "background" concentrations (1.40 ng/g TMeHg and 61.6 ng/g THg, n=18), but less than maximum background concentrations (7.80 ng/g TMeHg and 288 ng/g THg) reported by David P. Krabbenhoft and coworkers (U.S. Geological Survey, written commun., 1999).

Sampling sites downstream from Lahontan Dam, off the mainstem of the Carson River, had TMeHg and THg concentrations ranging from 0.56 ng/g and 204 ng/g, respectively, for S-Line Reservoir outflow (site 12), to 22.3 ng/g of TMeHg at Paiute Diversion Drain (site 19; fig. 8) and 13,100 ng/g of THg at the Stillwater Slough (site 16). Stillwater Slough is

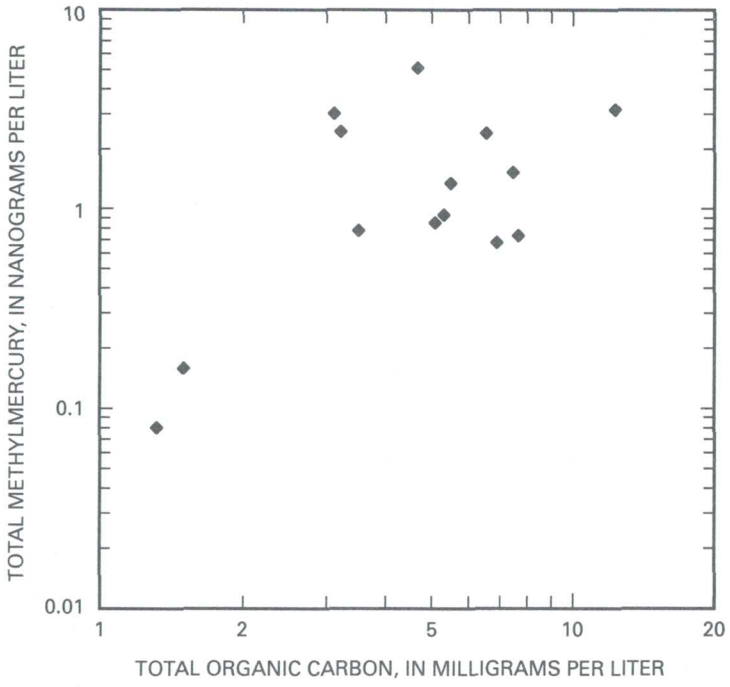

Figure 7. Correlation between total methylmercury and total organic carbon in water column, Carson River system, September 1998.

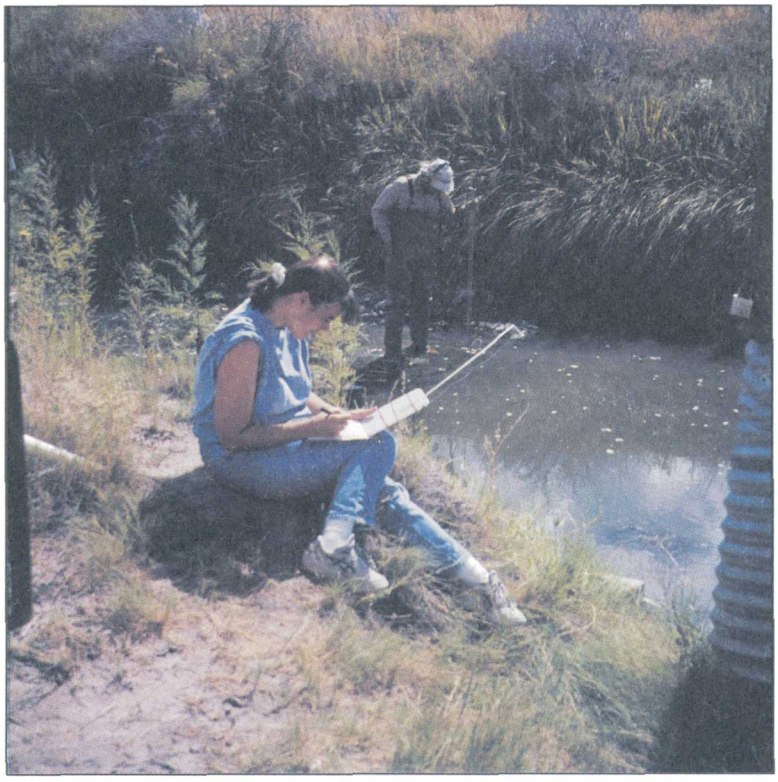

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Figure 8. Paiute Diversion Drain below TJ Drain near Stillwater, Nev. (sampling site 19 for water and bottom sediment). Drainflow measurements by USGS hydrographers Armando Robledo (background) and Angela Paul. Flow, from right to left, is about 1.7 ft^3/s, September 1998.

considered a highly mercury-contaminated channel based on historical streamflow patterns in the area (Hoffman, 1994, p. 8 and fig. 5). Sites 9, 11, 13, 15, and 17 represent wetland environments which may tend to favor mercury methylation (Hurley and others, 1995). For example, David P. Krabbenhoft and coworkers (U.S. Geological Survey, written commun., 1999) found that surface area occupied by wetlands in sampled NAWQA study basins was the most important basin-scale factor controlling MeHg production. Their observations suggest that mercury methylation is greatest for subbasins with substantial wetlands, organic-rich sediments, and low surface-water pH. Of the wetland sites in Lahontan Valley, the highest concentrations of TMeHg in sediment were found in Harmon Reservoir (5.44 ng/g; site 13) and in Stillwater Point Reservoir (5.34 ng/g; site 15). In fact, these TMeHg concentrations are among the four highest that were found for the 10 Lahontan Valley sites. For these two sites, however, the ratios of TMeHg:THg were relatively low compared to those for uncontaminated sediments in the far upstream reach of the river. For the present survey, TMeHg overall represented about 0.2 percent of THg concentration. With the exception of the anonymously high TMeHg:THg ratio for site 19 (3.4 percent), the highest ratios (1.2 to 4.1 percent) were in the mercury-poor, upstream reach of the river system, as represented by sites 1, 2, and 4. Excluding the data from site 19, the lowest ratios were found at the 10 sampling sites in the mercury-rich downstream part of the river system; for the most part, these ratios were substantially less than 1 percent ($\overline{m}$=0.16 percent). Other researchers (Oremland and others, 1995; Chen and others, 1996) have suggested that TMeHg production appears to be directly proportional to the quantity of THg present at low THg concentrations. At high THg concentrations, little additional MeHg evidently is produced with increased loading of THg.

Total organic matter in sediment samples was measured as LOI by ashing at 550°C for 2 hours. LOI was used as a surrogate measure for organic carbon content of the sediment. Organic carbon in sediments is important as a substrate and as an energy source for bacteria involved with increased methylation (Gilmour and Henry, 1991). Sites above Lahontan Reservoir contained low organic content (1.7-5.7 percent), which agrees with results by Chen and others (1996). Sites below Lahontan Reservoir have an organic content that varies from about 1 to 15 percent. A semilog scatterplot of TMeHg:THg ratio relative to LOI percent (fig. 9) suggests that the ratio of TMeHg:THg increases somewhat with increasing carbon content in bottom sediments. However, the relation is not strong (r^2=0.22), with the data widely dispersed about the trend line. Because only 22 percent of the variance of the TMeHg:THg ratio is explained by the effect of LOI (organic matter), other complex biotic and abiotic factors must be involved.

A scatterplot of TMeHg in the water column relative to THg in sediment is shown in figure 10. Anomalous among the data are the appreciably high THg concentration in sediment yet low TMeHg concentration in water at Stillwater Slough (site 16). As mentioned earlier, this slough is a relic channel that probably received substantial loading of mercury during the Comstock era. Interestingly, when the mercury concentrations for site 16 are excluded from the dataset, regression analysis of the remaining data indicate a positive and moderately strong relation (r^2=0.70) between the concentration of TMeHg in water and the concentration of THg in sediment when THg is less than 4,000 ng/g. This observation, however, should be viewed with caution because the limited amount of available data that were used to make such a comparison. For example, Stillwater Slough (site 16) had a TMeHg concentration of 1.52 ng/L in water when drainflow was 22 ft^3/s, whereas Paiute Diversion Drain (site 19) had a TMeHg concentration of 2.40 ng/L when flow was only 1.7 ft^3/s. The lower MeHg concentration in water at Stillwater Slough compared to the extraordinarily high concentration of THg in bottom sediment (13,100 ng/g) simply may reflect a dilution effect on mercury in water with increased flow, or reflect the net amount of TMeHg available as a result of active demethylation process in Stillwater Slough (M.C. Marvin-DiPasquale, U.S. Geological Survey, oral commun., 1999), or possibly both.

A comparison between a loglog scatterplot of TMeHg and THg concentrations in sediment (fig. 11), reveals a positive and moderate correlation (r^2=0.26, n=14). Removing the anomalous data from the computational dataset for Paiute Diversion Drain (site 19), the relation is improved, as indicated by r^2=0.40.

The most recent pre-1997-flood data on THg in unseived, near-surface bottom sediments (G.C. Miller, University of Nevada, Reno, oral commun., 1999) for the active channel appear to be those collected in January and June 1995 by Chen and others (1996, fig. 2a).

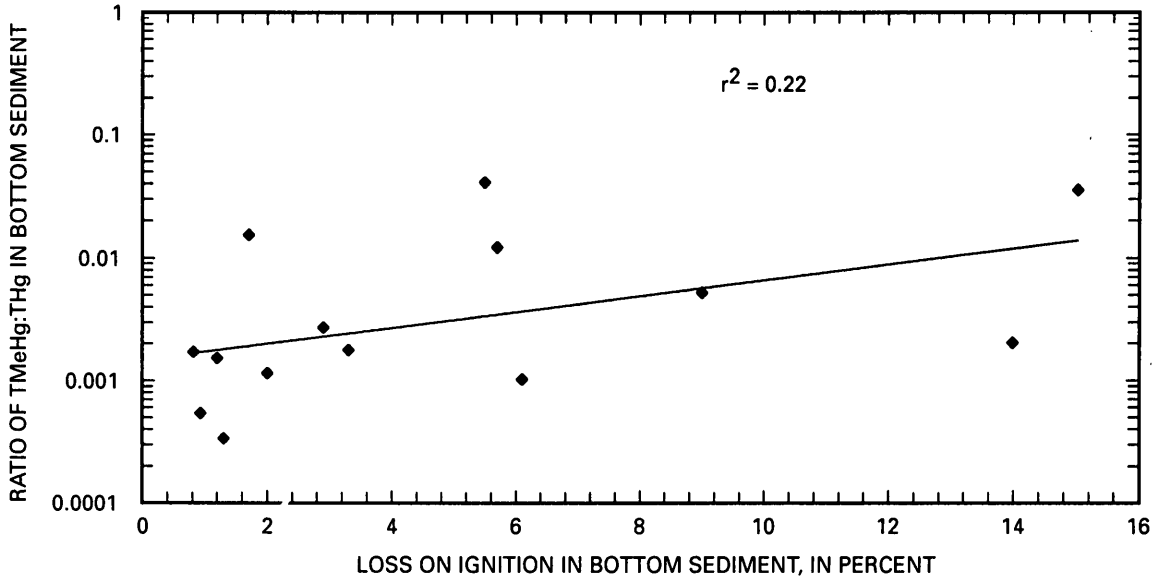

Figure 9. Relation between ratio of total methylmercury and total mercury (TMeHg:THg) and percent of loss on ignition in bottom sediment, Carson River system, September 1998.

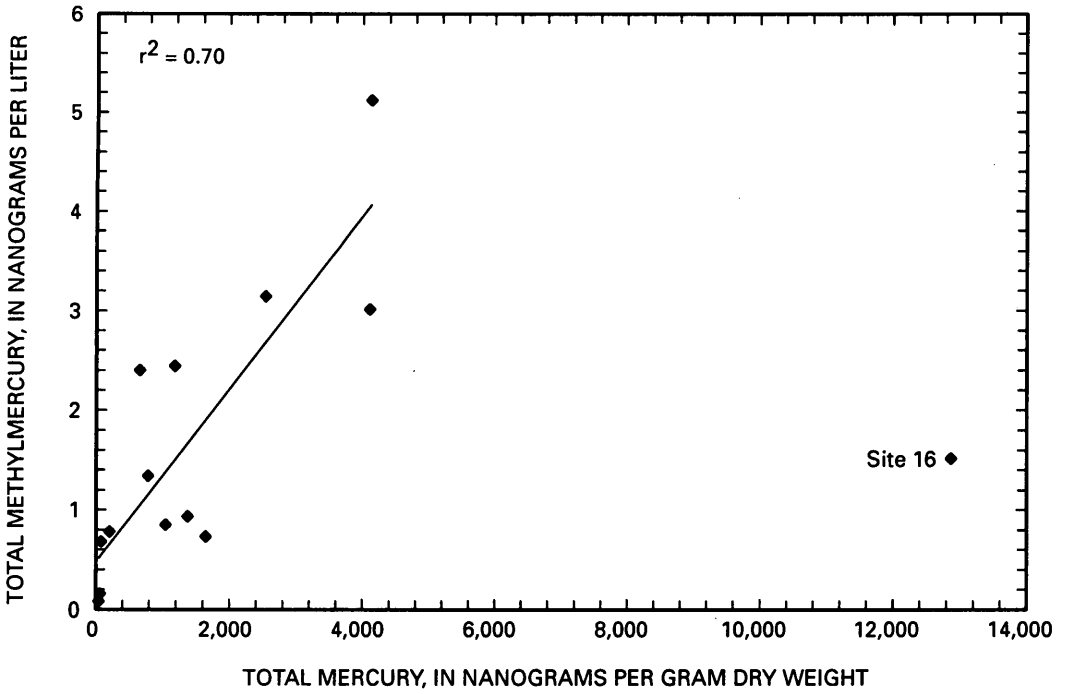

Figure 10. Relation of total methylmercury in water and total mercury in bottom sediment, Carson River system, September 1998. Anomalous data from Stillwater Slough Cutoff Drain (site 16) were excluded from statistical regression.

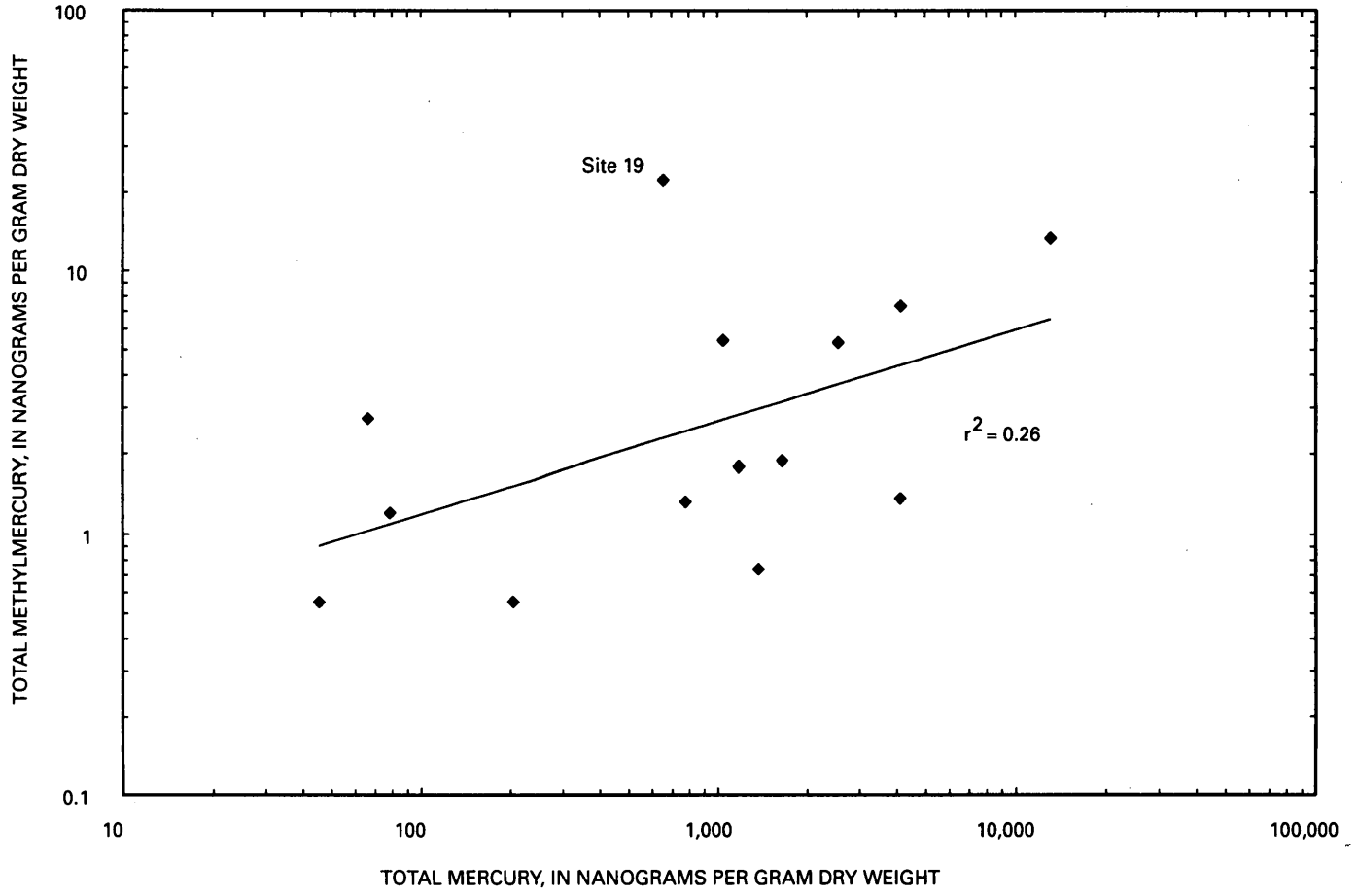

Figure 11. Relation of total methylmercury and total mercury in bottom sediment, Carson River system, September 1998.

Of the sampling sites in the present survey, only Deer Run Road (site 4) and Fort Churchill (site 8) had sediment data to compare with the preflood concentrations in 1995. The data indicate that THg concentrations in sediment samples collected in 1998 at these two sites were substantially lower (50 percent or more) than in those collected in 1995. The 1998 data also were lower than the historic (1970-98) median concentrations for these two sites (site 4, $\overline{m}$=710 ng/g, n=11; site 8, $\overline{m}$=6,870 ng/g, n=7). The apparent reduction of concentration in the 1998 samples may have been caused naturally owing to the scouring action of the flood and the two subsequent spring runoffs of 1997 and 1998, and succeeding sediment deposition. Another possibility is an artifact owing to differences in sampling and analytical methodologies (for example, particle-size class on which chemical analysis was done), or both. However, the true cause of this reduction of concentration is difficult to discern with available data.

Extrapolating these results to other parts of the river is unadvisable because of uncertainties associated with the heterogeneous distribution of mercury-bound sediment, and of differences in sampling and analytical techniques used in past and present investigations. Because of these uncertainties and differences, future sampling programs for time-trend analysis of trace elements in bottom sediment in the Carson River system should establish, implement, and document consistent data-collection protocols.

SUMMARY

In September 1998, a reconnaissance survey of THeHg, THg, and organic matter in the water column and bottom sediment was done upstream and downstream from Lahontan Reservoir along the Carson River system. Measurements were made at 19 sites about 20 months after the 100-year flood of January 1997. The sites included (1) the mainstem river and its East Fork, and (2) shallow reservoirs/wetlands and agricultural canals and drains upgradient from Stillwater NWR in Lahontan Valley. During the 3-day survey, samples were collected from warm, low flows and coincident with active irrigation in Lahontan Valley.

Mercury in water increased in the downstream direction through the highly contaminated reach of the river from Dayton to Lahontan Reservoir, confirming the results of previous studies. Downstream from the reservoir, mercury concentrations tended to decrease in the downstream direction, but still were greatly elevated compared to upstream reference concentrations.

In water upstream from Lahontan Reservoir, maximum concentrations of TMeHg (7.83 ng/L) and THg (9,040 ng/L) were found at the site where the river enters the reservoir. Downstream from the reservoir, maximum concentrations of TMeHg (about 3 ng/L) were found at the outflow of Carson River Diversion Dam and the outflow of Stillwater Point Reservoir, each of which represents a wetland ecosystem. A maximum concentration of THg (782 ng/L) in water was found at the inflow site to Stillwater Point Reservoir. For comparison, the upstream reference ("background") concentrations in water were 0.2 ng/L of TMeHg and 5.0 ng/L of THg, respectively. For the present survey, the Nevada 12 ng/L (chronic) THg standard for the protection of aquatic life was exceed at 67 percent of the mainstem sites upstream from Lahontan Reservoir (n=9) and at all sites downstream (n=10). The acute standard (2,000 ng/L) was exceeded only at the site where the river enters Lahontan Reservoir.

For bottom sediment upstream from Lahontan Reservoir, maximum concentrations of TMeHg (7.35 ng/g) and THg (4,130 ng/g) were found at the Fort Churchill site. For sites downstream from the reservoir, the maximum concentration of TMeHg in sediment (22.3 ng/g) was found at the Paiute Diversion Drain site entering Stillwater NWR. The maximum concentration of THg (13,100 ng/g) was found in the Stillwater Slough site entering wetlands on private land within Stillwater NWR. For comparison, the upstream reference concentrations in bottom sediment were 3.0 ng/g and 70.0 ng/g, respectively

Of the wetland sites in Lahontan Valley, the highest concentrations of TMeHg in sediment were found in Harmon Reservoir (5.44 ng/g) and Stillwater Point Reservoir (5.34 ng/g). These concentrations are among the highest found in the valley, but less than concentrations found in the Stillwater Slough (13.4 ng/g) and Paiute Diversion Drain (22.3 ng/g).

Regression analysis between selected chemical constituents and water-quality properties revealed the following:

- For water, positive but weak correlations between TMeHg concentration and water temperature, pH, and total organic carbon; and a positive, moderate correlation between TMeHg and THg concentrations;

- For bottom sediment, a positive but weak correlation between the ratio of TMeHg:THg and organic matter; and a positive, moderate correlation between TMeHg and THg; and
- A positive, strong correlation between TMeHg in water and THg in sediment (with the exception of one sample).

A comparison of selected pre-1997-flood data on THg in sediment with data collected during the present survey at two sites on the mainstem of the Carson River above Lahontan Reservoir show a 50 percent or greater reduction in the concentration of THg in the 1998 samples. Because of natural variability in the deposition of sediment in time and space and owing to differences in data-collection methods among researchers, this apparent reduction should be viewed with caution.

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