Mercury Characterization in Lahontan Valley Wetlands
Carson River Mercury Site
Lyon and Churchill Counties, Nevada, 1999

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CONTENTS

Tables

Tables (*continued*)

Figures

Figures (*continued*)

EXECUTIVE SUMMARY

In 1999, the Nevada Fish and Wildlife Office of the U.S. Fish and Wildlife Service and the Superfund Division, U.S. Environmental Protection Agency, Region 9 initiated a joint investigation to evaluate extent and severity of mercury contamination in ecologically important wetlands in Lahontan Valley, Churchill County, Nevada. Total mercury (HgT) and methylmercury (MeHg) concentrations were determined in water and sediment in principal wetlands on Stillwater and Fallon National Wildlife Refuges (NWR). HgT and MeHg concentrations were also determined in aquatic invertebrate samples collected from important wetlands throughout Lahontan Valley. A single invertebrate species of the genus *Corisella* (corixid) was selected as a representative aquatic invertebrate species.

Previous investigations found that HgT is widely distributed in sediment in Lahontan Valley. Severe sediment contamination in the agricultural drainage system generally corresponded to Carson River channels that existed between the mid-1800's and the construction of Lahontan Dam in 1915. We found the greatest HgT concentrations in sediment from wetlands that historically received inflow from Carson River channels that existed prior to dam construction. HgT concentrations progressively declined in sequential wetlands in this flow-through wetland system. However, HgT concentrations in all wetlands on Stillwater NWR, including those created in the 1940's, exceeded background concentrations. A gradient of HgT concentrations in sediment was also apparent in constructed wetlands. MeHg concentrations in sediment generally corresponded to HgT concentrations in sediment with MeHg concentrations generally decreasing with distance from wetland inflow. The proportion of MeHg of HgT (e.g., percent MeHg) declined with increasing HgT concentrations. No statistical difference in sediment MeHg concentrations was found between historical and constructed wetlands. A weak negative relationship was found between MeHg concentrations in sediment and water column pH. The bulk of HgT and MeHg in the water column existed in a particulate phase. The proportion of HgT and MeHg in the water column increased with turbidity. Accordingly, HgT in the water column corresponded with turbidity and with HgT in the underlying sediment. Factors controlling MeHg in the water column were not apparent. Similar to sediment, no difference in water column MeHg was found between historical and constructed wetlands.

Most of the HgT in corixids existed as MeHg. The statistically significant relationship between MeHg in corixids and MeHg in sediment suggests that sediment plays a key role in the biological availability of mercury in Stillwater NWR wetlands. As with sediment, we found a weak negative relationship between MeHg in corixids and water column pH. As such, alkaline conditions may provide aquatic organisms some level of protection from mercury in Lahontan Valley wetlands. Bioaccumulation factors (BAFs) for MeHg from sediment to corixids ranged from less than 100 to more than 2,000 times. Within Stillwater NWR, BAFs and subsequently corixid MeHg concentrations were significantly greater in constructed wetlands. MeHg concentrations in other Lahontan Valley wetlands followed a similar pattern with the highest concentrations found in corixids collected from created wetlands.

The transport of HgT to Stillwater NWR in wetland supply water is continuing. Concentrations in agricultural drainwater tend to be greater than in irrigation-quality water. Loads entering Lahontan Valley wetlands may substantially increase following flood events in the Carson River. Transport and deposition of HgT through sequential wetlands is evidenced by

concentration gradients. Because existing water control structures prevent the migration of bottom sediment, the redistribution of HgT on the refuge is likely attributed to movement of particulate Hg in the water column.

HgT and MeHg concentrations in water, sediment, and corixids present a risk to fish and wildlife on Stillwater NWR, Fallon NWR, and other wetlands in Lahontan Valley. In 1999, MeHg concentrations in about half of the corixid samples exceeded concentrations associated with long-term reductions in avian productivity. However, concentrations were well below levels associated with major toxic effects. MeHg concentrations in corixids and, therefore, risk to insectivorous fish and birds appears to be greater in constructed wetlands despite having significantly lower HgT concentrations in sediment. Long-term variability in HgT concentrations in biota has been observed. As such, risks to migratory birds and other wildlife may vary over time. Causal mechanisms are uncertain.

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INTRODUCTION

In the latter half of the 19th century, mercury amalgamation was used in the milling of gold and silver ore from the Comstock Mining District in and around Virginia City in the Virginia Mountain Range, west-central Nevada (Figure 1). Bailey and Phoenix (1944) estimated that at least 7,500 tons of elemental mercury were lost during these operations. Much of this mercury was discarded in mill tailings or discharged to the Carson River or its tributaries in mill effluent. Mercury has since become widely distributed in the lower Carson River basin. Investigations by the Department of the Interior have documented extensive mercury contamination in Lahontan Valley, including some wetlands on Stillwater National Wildlife Refuge (NWR), Churchill County, Nevada (Hoffman et al. 1990, Rowe et al. 1991, Hallock and Hallock 1993, Hoffman 1994, Tuttle et al. 1996, Tuttle et al. 2000). The degree of contamination varied widely with location. These investigations revealed that mercury concentrations in water, sediment, food chain organisms, fish, and migratory birds consistently exceeded levels associated with adverse effects to invertebrates, fish, and wildlife in other investigations.

In 1999, the Nevada Fish and Wildlife Office of the U.S. Fish and Wildlife Service (Service) and the Superfund Division, U.S. Environmental Protection Agency, Region 9 (EPA) initiated a joint investigation to evaluate mercury contamination in the Lahontan Valley. The objective of this cooperative effort is to identify wetlands in Lahontan Valley where fish and wildlife are at high risk of mercury-related effects. The study included three objectives: 1) Review and interpretation of existing information on mercury concentrations in biotic and abiotic media in Lahontan Valley; 2) evaluate total mercury (HgT) and methylmercury (MeHg) concentrations in water, sediment, and aquatic invertebrates in major wetlands on Stillwater NWR; and 3) assess the biological availability and severity of contamination in major wetlands in Lahontan Valley. This report provides the findings of objectives 2 and 3.

STUDY AREA

Background

Lahontan Valley is the terminus of the Carson River. The Carson River basin encompasses 10,300 square kilometers in west-central Nevada and east-central California. The Carson River originates from the east slopes of the Sierra Nevada approximately 80 km to the west of the study area. Historically, the Carson River flowed through a series of shallow marshes in Lahontan Valley to ultimately discharge to the Carson Sink, a playa to the north of

Stillwater and Fallon NWRs.

Wetlands in Lahontan Valley, including those on Stillwater NWR, are the most ecologically important in Nevada (Hallock et al. 1981). The value of the wetlands is largely attributed to the expanse and diversity of wetland habitats, which provide for the largest and most diverse assemblage of migratory and wetland-dependent birds in Nevada. As many as 206 avian species, most of which are migratory, have been identified in Lahontan Valley. Lahontan Valley wetlands provide foraging, nesting, and staging habitat for waterfowl, shorebirds, and colonial nesting birds on the Pacific Flyway. Because of its central location, wetlands in Lahontan Valley have been identified as a key point on this migratory route. Since the early 1970's, peak waterfowl counts in Lahontan Valley wetlands have ranged from 6,000 to more than 300,000 birds (USFWS 1996). Waterfowl usage of Stillwater NWR has dropped from 27 million annual bird use-days in the early 1970s to almost 15 million bird use-days in recent years. Under optimal conditions up to 5,000 waterfowl are annually produced on Stillwater NWR. Shallow wetlands in the valley are also critically important to a large variety of shorebirds. As many as 250,000 shorebirds and numerous other wading and aquatic birds may use Lahontan Valley wetlands annually (USFWS 1996). Because of their productivity, diversity, and importance to migratory birds on the Pacific Flyway, Lahontan Valley wetlands are recognized as wetlands of regional and international significance. Lahontan Valley wetlands have been designated as one of 15 sites of the Western Hemispheric Shorebird Reserve Network. These wetlands have been nominated for designation as a Wetland of International Importance under the Ramsar Convention. However, because of uncertainties with future water supplies and concerns with environmental contaminants (including mercury and irrigation drainwater-related contaminants), this nomination was postponed until these issues were resolved (Richard Smith, Assistant Director of the Fish and Wildlife Service, 1990, written comm.).

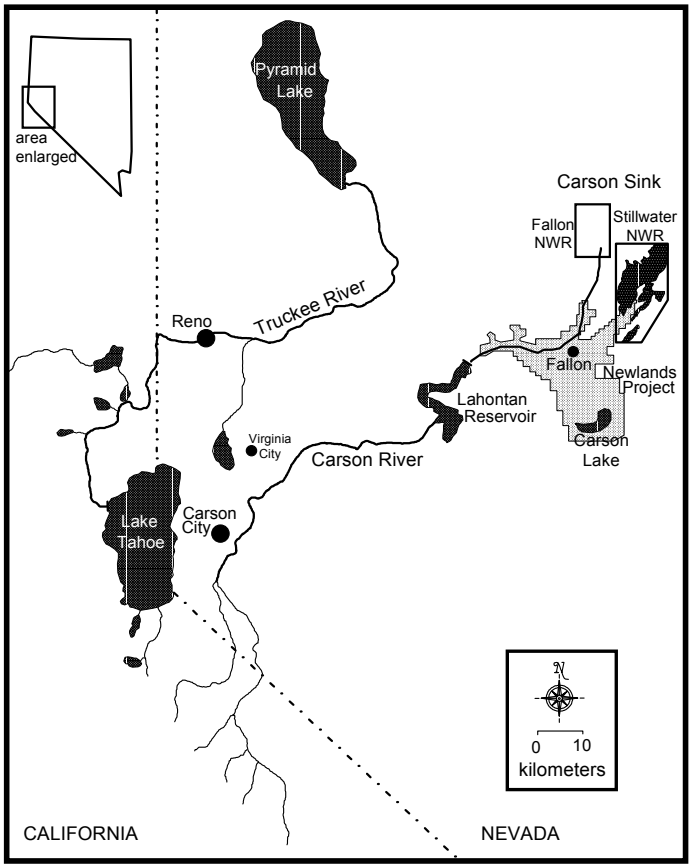


Figure 1. Map of the Carson and Truckee River drainages showing Stillwater and Fallon National Wildlife Refuges (NWR), Churchill County, Nevada.

In 1990, Congress enacted the Truckee-Carson-Pyramid Lake Water Rights Settlement Act (Title II of Public Law 101-618) to resolve conflicts associated with increasing water demands in the Truckee and Carson River basins. Section 206 of the Act directed the Secretary of the Interior to acquire sufficient water and water rights to restore and maintain a long-term average of 25,000 acres of wetland habitat in Lahontan Valley, including 14,000 in Stillwater

NWR. The acquisition of water rights will guarantee a long-term water supply for wetlands in Lahontan Valley.

Hydrology

Wetland hydrology and, subsequently, biological conditions in Lahontan Valley wetlands are highly dynamic. Prior to regulation, the Carson River in Lahontan Valley flowed uncontrolled through a network of natural channels, sloughs, and sequential marshes toward the Carson Sink (Kerley et al. 1993). Because the Carson River originated primarily from snow melt from the eastern slopes of the Sierra Nevada, flows were seasonally variable, with the highest flows coinciding with spring runoff and the lowest flows occurring in late summer. With increased spring runoff, flow through sequential wetlands increased and wetland size consequently expanded. As spring runoff declined, flow through sequential wetlands diminished and wetland size declined with high evapotranspiration rates during warm summer months. Dissolved solids concentrations in wetlands varied through this hydrologic cycle. Because of mixing with residual water from the previous cycle and dissolution of soluble materials upon reflooding of desiccated areas, dissolved solids concentrations would have increased as water progressed through sequential wetlands. Increased seasonal flow through the wetlands would have served to flush much of the dissolved and suspended solids load through sequential wetlands toward the Carson Sink. Annual variability and more long-term climatic cycles would have amplified the magnitude of expansion or contraction of the marsh system, and the concentration of dissolved solids. Flooding of the Carson Sink during the early 1980's followed by regional drought conditions during the early 1990's serve as examples of recent extremes driven by climatic conditions. During this period, wetland acreage in Lahontan Valley ranged from more than 200,000 acres to less than 1,000 acres.

Regulation of the Carson River and agricultural development in the early 1900's substantially altered hydrologic characteristics and water quality in Lahontan Valley wetlands. As a result the inflow of higher quality water directly from the Carson River was reduced and the inflow of irrigation drainage containing elevated dissolved solids concentrations was increased. Increased irrigation efficiencies mandated under the Operational Criteria and Procedures have further reduced the inflow of fresh water since 1970 (Hoffman 1994). Because of reduced inflows, wetland acreage declined. Kerley and others (1993) estimated about 10 percent of the historical wetland acreage remained during the late 1980's. However, because of increased dependence on irrigation drainage, concentrations of dissolved solids in wetlands increased. Dependence on drainwater resulted in a shift in water delivery patterns to wetlands, with inflows to wetlands corresponding to the release of irrigation water from Lahontan Reservoir over the agricultural growing season (March 15 to November 15).

The Carson River flow path in Lahontan Valley has changed over time. Between the mid-1800's and construction of Lahontan Dam in 1915, the Carson River flowed in three distinct channels (Hoffman 1994). Upon entering Lahontan Valley, the river most often flowed south to Carson Lake. Overflow from Carson Lake then flowed north to Stillwater Marsh via Stillwater Slough (Figure 2). Overflow from Stillwater Marsh entered the Carson Sink. The Carson River

flow path changed in response to flood events in the 1860's. In the early 1860's, the channel changed course and proceeded directly northward to the Carson Sink. In the late 1860's, the channel altered course to flow directly east to Stillwater Slough and then to Stillwater Marsh.

As a result of agricultural development, Stillwater NWR has received water from numerous flow paths (Figure 2). In recent years, the historical portion of the Stillwater Marsh has received agricultural drainwater through Stillwater Slough via the Canvasback Gun Club. Water is also delivered to the Canvasback Gun Club from Stillwater Point Reservoir and to Lead Lake through the D-Line Canal. As a result of the river course change in the early 1860's, the river flowed northward to enter the Carson Sink at what is now Fallon NWR. In recent years, Fallon NWR has received water during flood events and excess irrigation water. Development of Stillwater Marsh for wetland and wildlife management purposes has also modified the flow of water through the historical Stillwater Marsh. Perhaps most importantly was the construction of wetlands in the southeastern portion of the refuge in the 1940's. These wetlands have primarily received water from Diagonal Drain (Figure 2). Portions of the historical Stillwater Slough were incorporated in the construction of Diagonal Drain. More recently, irrigation-quality water has been received from S-Line Canal. Flow through constructed wetlands has proceeded in a northeasterly direction to rejoin the historical Stillwater Marsh in the vicinity of Goose Lake and South Nutgrass Lake. To assist in the management of available water, a system of canals and several dikes were constructed on Stillwater NWR. Currently, refuge managers primarily use natural flow through sequential wetlands to convey water to wetlands. However, canals are also used to supply water to wetlands as required to meet management objectives.

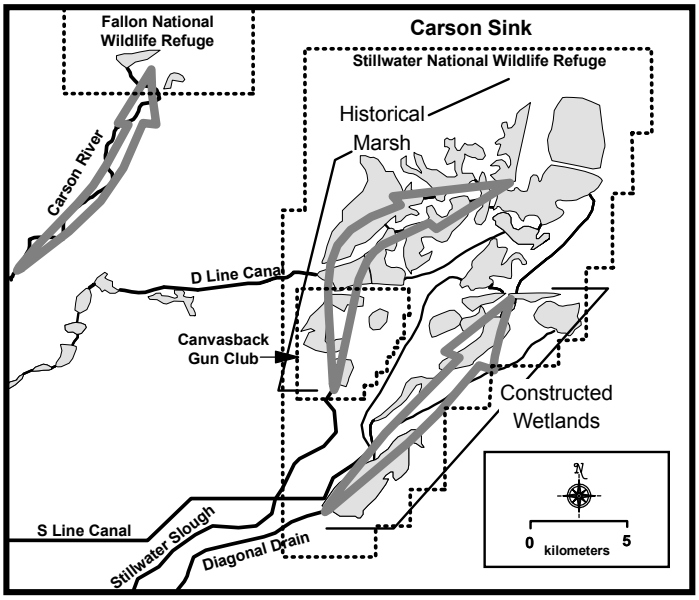


Figure 2. Dominant flow paths of water through historical and constructed wetlands in Stillwater Marsh and the northern Carson River channel to Fallon National Wildlife Refuge, Churchill County, Nevada.

ENVIRONMENTAL CONTAMINANT CONCERNS

Concerns with several environmental contaminants have been identified on Stillwater NWR and other wetlands in Lahontan Valley. Concerns are primarily related to agricultural development and anthropogenic mercury.

Agricultural Drainwater

The modification of wetland water supplies, natural hydrologic characteristics, and wetland processes in the lower Carson River basin have contributed to declines in habitat quantity, water and habitat quality, and the numbers of wetland-dependent fish and wildlife occurring in Stillwater Marsh and other wetlands in Lahontan Valley (Kerley et al. 1993). Following regulation of the lower Carson River in 1915, inflow of higher quality water directly from the Carson River to Stillwater NWR was reduced and drainage from agricultural areas became an increasingly larger component of the wetland water supply. Drainage from agricultural areas, including operational spills, surface runoff from fields, and subsurface drainage, commonly contains elevated concentrations of total dissolved solids, including a variety of major and trace elements, which have been mobilized from soils or local groundwater (Hoffman 1994). The discharge of irrigation drainage to wetlands has contributed to substantial changes in the biogeochemical cycling of major and trace constituents in the wetlands (Lemly et al. 1993). Increased irrigation efficiencies mandated under the Operational Criteria and Procedures in the 1970's further reduced the inflow of fresh water since 1970 and dependence on drainwater resulted in a shift in water delivery patterns to wetlands, with inflows to wetlands corresponding to the release of irrigation water from Lahontan Reservoir over the agricultural growing season (March 15 to November 15). Reduced inflow of water resulted in the hydrologic isolation of some wetlands while diking and flow regulation within the wetlands disrupted the flow-through character and increased the hydrologic retention time of other wetlands. Such changes reduced the frequency and efficiency of flushing of dissolved solids through the wetlands. The high rate of evaporative water loss in this hydrologically isolated basin has contributed to accumulation and concentration of dissolved constituents in wetlands (Seiler 1995). A chronology of physical and hydrologic modification of Lahontan Valley is found in Hoffman (1994).

Hoffman et al. (1990) found that water in Stillwater NWR contained concentrations of arsenic, boron, dissolved solids, sodium, and un-ionized ammonia in excess of baseline conditions or Federal and State criteria for the protection of aquatic life or the propagation of wildlife. Sediment from some affected wetlands contained elevated levels of arsenic, lithium, mercury, molybdenum, and zinc. Additionally, concentrations of arsenic, boron, copper, mercury, selenium, and zinc in biota collected from some affected wetlands exceeded levels associated with adverse biological effects in other studies. Organochlorine compounds were detected in sediments collected from wetlands of Stillwater NWR. Of greatest concern was lindane which exceeded the EPA's sediment quality criteria in three samples. This study concluded that arsenic, boron, mercury, and selenium were of primary concern to human health and fish and wildlife in and near Stillwater NWR. Subsequent studies have generally supported these findings (Lico 1992, Hallock and Hallock 1993, Tuttle et al. 1996, Tuttle et al. in preparation).

The acquisition of water rights as authorized under Public Law 101-618 will guarantee a long-term water supply for wetlands in Lahontan Valley. Additional water is also expected to reduce concerns with agricultural drainwater-related contaminants. The acquisition of water rights is not expected to be completed until at least 2020.

Mercury

Mercury contamination in Lahontan Valley is believed to have resulted from the release of elemental mercury during precious metal milling which occurred in and near the Virginia range from about 1860 to 1900. Mercury released during these operations was subsequently transported to Lahontan Valley via the Carson River. Transport occurred primarily in particulate form (Bonzongo et al. 1996, Hoffman and Thomas 2000). A previous investigation (Hallock et al. 1993) found that the highest concentrations of mercury in detrital material in Lahontan Valley were generally associated with the Carson River channels that existed between about 1850 and the regulation of the Carson River in 1915 (Figure 3).

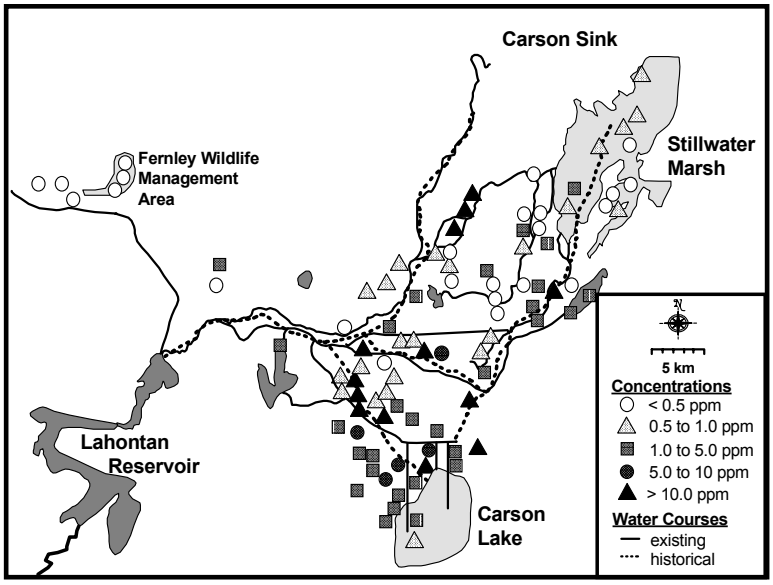


Figure 3. Total mercury concentrations (parts per million, dry weight) in detrital matter from agricultural drain and wetlands in Lahontan Valley, 1988-89. Data from Hallock et al. 1993.

Currently, mercury appears to represent the greatest hazard to wetland species in Lahontan Valley (Tuttle et al. 2000). Concentrations in sediment frequently exceeded levels associated with effects to aquatic invertebrates. Not surprising, HgT in sediment was correlated with differences in aquatic invertebrate community structure in Lahontan Valley (Tuttle et al. 2000). HgT concentrations in a majority of fish and invertebrate samples and a smaller number of aquatic vegetation samples exceeded dietary concentrations associated with behavioral effects in avian species. A large number of these samples also exceeded concentrations associated with histopathology and reproductive effects in birds. Mercury was transferred to higher trophic levels, and HgT concentrations in a large number of the avian eggs and juvenile livers exceeded concentrations associated with behavioral effects in birds. A smaller number of these samples exceeded concentrations associated with histopathology and reduced survival. The relationship of HgT in sediment with HgT in pondweed and invertebrates suggests that food chain contamination is originating from sediment. Although relationships were not significant, HgT concentrations in avian eggs and juvenile livers were generally higher in wetlands with higher concentrations of HgT in sediment. Because mercury-contaminated sediments act as both a sink and a source of mercury in aquatic systems, the acquisition of water authorized under P.L. 101-618 is unlikely to provide a direct positive effect to mitigate mercury contamination.

METHODS

Water, bottom sediment, and aquatic invertebrate samples were collected from 18 major wetlands on Stillwater NWR and 2 wetlands on Fallon NWR to assess the severity of mercury contamination, gauge biological availability, and evaluate the interaction of HgT and MeHg in biotic and abiotic media. Additionally, aquatic invertebrate samples were collected from 20 other major wetlands in Lahontan Valley to assess the biological availability and severity of contamination (Figure 4, Table 1). Sampled wetlands included the existing and historical Carson River corridors, marshes in Carson Lake and Stillwater Marsh, constructed wetlands on the Fallon Paiute Shoshone Indian Reservation, and Newlands Project water management reservoirs. Additionally, invertebrate samples were collected from two isolated sites in Lahontan Valley that are unaffected by mercury from the Carson River and from one site, Mason Valley Wildlife Management Area (WMA) in the Walker River basin. All samples were analyzed for HgT and MeHg.

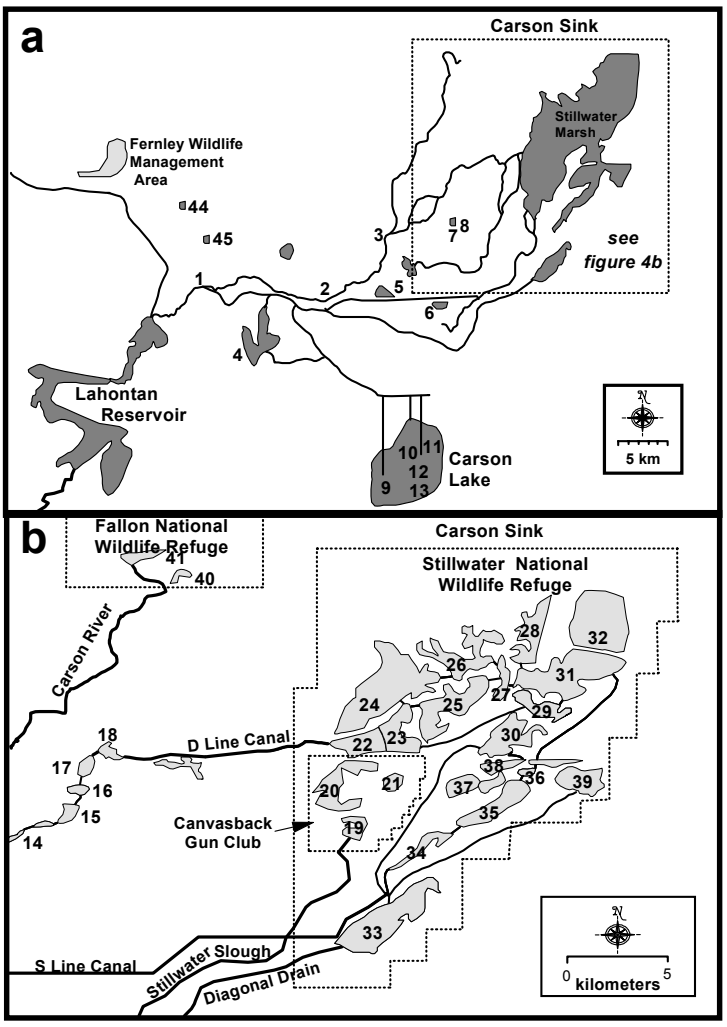


Figure 4. Sample collection sites in Lahontan Valley, Churchill County, Nevada, 1999. Sites include: a) aquatic invertebrate (e.g., corixid) collection sites throughout Lahontan Valley, and b) water, sediment, and aquatic invertebrate collection sites in the Indian Lakes Area, Canvasback Gun Club, and Stillwater and Fallon National Wildlife Refuges. Site numbers correspond with numbers in Table 1.

Samples were collected from June to August 1999. Sampling during this period coincided with migratory bird nesting and juvenile rearing in Lahontan Valley wetlands. Additionally, 15 invertebrate (corixid) samples collected in October and November 1998 were submitted for HgT and MeHg analyses. Sampling during this time period enabled assessment of the potential exposure of migrating birds which pass through Lahontan Valley during the fall migration. Analysis of invertebrate samples collected during both periods also enables the evaluation of seasonal (i.e., Spring and Fall) differences in mercury methylation, biological availability, and biological exposure.

Samples were collected from three locations within each wetland, including: 1) near the wetland inflow, 2) near the wetland outflow, and 3) an intermediate point between inflow and outflow points. In 38 of the sampled wetlands, corixids from the three locations were

Table 1. Water (wat), sediment (sed), and aquatic invertebrate (inv) collection sites in Lahontan Valley, Churchill County, Nevada, 1999. Site numbers correspond to Figures 4a and 4b, "ns" indicates that the site is not shown in Figure 3.

site	site no.	fig. no.	sample types
Carson River (CR)			
Carson Dam	1	4a	inv
Coleman Dam	2	4a	inv
Sagouspi Dam	3	4a	inv
Newlands Project Reservoirs (NP)			
Sheckler Reservoir	4	4a	inv
S-Line Reservoir	5	4a	inv
Harmon Reservoir	6	4a	inv
Tribal Wetlands (TW)			
Wetland 1	7	4a	inv
Wetland 2	8	4a	inv
Carson Lake (CL)			
Sprig Pond	9	4a	inv
York Unit	10	4a	inv
Rice Unit	11	4a	inv
Big Water	12	4a	inv
Sump	13	4a	inv
Indian Lakes (IL)			
D-Line Marsh	14	4b	inv
Upper Lake	15	4b	inv
Likes Lake	16	4b	inv
Papoose Lake	17	4b	inv
Big Indian Lake	18	4b	inv
Canvasback Hunting Club (SM)			
Freeman Lake	19	4b	inv
Dutch Bill Lake	21	4b	inv
Stillwater National Wildlife Refuge (SM)			
South Lead Lake	22	4b	inv, wat, sed
North Lead Lake	23	4b	inv, wat, sed
Willow Lake	24	4b	inv, wat, sed
Tule Lake	25	4b	inv, wat, sed
Swan Lake	26	4b	inv, wat, sed
Swan Check	27	4b	inv, wat, sed
Pintail Bay	28	4b	inv, wat, sed
South Nutgrass	29	4b	inv, wat, sed
Goose Lake	30	4b	inv, wat, sed
North Nutgrass	31	4b	inv, wat, sed
Big Water	32	4b	inv, sed
Stillwater Point Res.	33	4b	inv, wat, sed
Upper Foxtail Lake	34	4b	inv, wat, sed
Lower Foxtail Lake	35	4b	inv, wat, sed
Doghead Pond	36	4b	inv, sed
West Dry Lake	37	4b	inv, wat, sed
Cattail Lake	38	4b	inv, wat, sed
East Alkali Lake	39	4b	inv, wat, sed
Fallon National Wildlife Refuge (FN)			
Duck Lake	40	4b	inv, wat, sed
Battle Ground Point	41	4b	inv, wat, sed
Background Sites (BK)			
Massie Slough	42	4a	inv
Mahala Slough	43	4a	inv
Mason Valley WMA	44	ns	inv

composited to form a single sample for mercury analyses. In five wetlands corixids collected from each of the locations were analyzed as separate samples to enable evaluation of within-wetland variability of mercury concentrations.

The location of each sample collection site was determined with a Rockwell International Precision Lightweight Global Positioning Receiver (PLGR+96). Ambient and water temperatures, dissolved oxygen concentration, pH, turbidity, and specific conductivity were measured at the time of sample collection. Temperature was measured with a Yellow Springs Instruments model 33 S-C-T meter. The meter temperature calibration was verified with a

Fisher Scientific Company model 15-041A thermometer with a manufacturer's certification to the National Institute for Standards and Technology. Dissolved oxygen concentrations were measured with a Yellow Springs Instruments model 57 oxygen meter. The dissolved oxygen meter was calibrated to elevation and water temperature before each use each day. A Cole Parmer model 59000-25 pH meter was used to measure pH. The pH meter was calibrated using pH 7 and 10 buffers prior to use each sampling day. Specific conductivity was measured with a Yellow Springs Instruments model 33 S-C-T meter. Meter calibration was checked using 1,413 microsiemens per centimeter (µS/cm) reference solution prior to use each sampling day.

Total (e.g., dissolved plus particulate) HgT and MeHg concentrations were determined in a total of 18 unfiltered water samples. Additionally, dissolved HgT and MeHg concentrations were determined in six samples. Water samples for mercury analyses were collected in certified clean 500 ml glass bottles. Samples were collected from mid-water column depth from undisturbed areas near the wetland outflow. Samples were collected by immersing a closed bottle then opening under water. Each sample bottle was rinsed three times using the above collection technique prior to collection of the sample. Rinsate was disposed of away from the sample collection site. Samples were stored on blue ice in the field and shipped to the analytical laboratory within 6 hours of collection. One field blank consisting of deionized water exposed to sample collection and processing conditions was collected. This blank was treated as an individual sample and submitted for analysis. Additionally, two duplicate water samples were collected and analyzed. No preservatives were added to water samples.

HgT and MeHg concentrations were determined in sediment samples collected from 20 wetlands on Stillwater NWR. Sediment samples consisting of surficial materials (i.e., top 3 cm of sediment) were collected using a Wildco model number 2422 H12 core sampler (5 cm diameter). Each sample consisted of a minimum of five subsamples collected within a 10-m reach of a central sampling point. Subsamples were composited in a certified clean 500 ml nalgene jar and mixed with a stainless steel knife. A sample of composited material was placed in a certified clean 125 ml glass jar with teflon-lined closures. Sediment samples were stored on blue ice in the field and transferred to a freezer within 8 hours of collection. Samples remained frozen before and during shipment to the analytical laboratory. Prior to use at each site, sediment collecting and processing equipment was washed with a brush and mild detergent, rinsed with deionized water, rinsed with a dilute nitric acid solution, triple rinsed with deionized water, and submerged in site water for at least one minute prior to use. Between collection of subsamples at each site, collection equipment was brushed to remove sediment and rinsed with site water.

Aquatic invertebrate samples collected from 43 sites were analyzed for HgT and MeHg. The aquatic invertebrate *Corisella* spp., a genus within the order Hemiptera (Corixidae) was selected for sampling because this representatives of this genus are widely distributed and present in all wetland types in the Lahontan Valley and because it is are sufficiently mobile to reflect contamination over a broad portion of its immediate environment, but still reflect the level of contamination in the wetland in which they are collected. Species of the genus *Corisella* are widespread in western North America and typically occur in littoral areas of lakes and ponds (Thorp and Covich 1991). *Corisella* spp. often occur in brackish and saline waters (Usinger 1956). Species of the genus *Corisella* are predatory (Merrit and Cummings 1984), primarily feeding on chironomids, mosquito larvae, or other small invertebrates. Previous investigations

in Lahontan Valley wetlands found HgT concentrations in this free-swimming, predaceous invertebrate ranged from <0.2 to 10.8 ppm, dry weight (Tuttle et al 1996, Tuttle et al. 2000), thus confirming that representatives of this genus acquires and retains mercury. Corixids were collected using kick nets. Upon collection, invertebrates and debris were placed in a pre-cleaned stainless steel pan containing water from the site. Selected corixids were separated from debris and non-target invertebrates and placed into certified clean 60 ml glass containers with Teflon lined closures. We attempted to collect a minimum of 5 grams, but some samples contained less than the targeted amount. Because adult *Corisella* spp. are flight-capable, sub-adult individuals (3-7 mm) were targeted for collection. Invertebrate samples were stored on blue ice in the field and transferred to a freezer within 8 hours of collection. Samples remained frozen before and during shipment to the analytical laboratory. Prior to use at each site, kicknets were washed with a brush and a mild detergent-deionized water solution and rinsed with deionized water. Other collection and processing equipment were washed with a brush and mild detergent-deionized water solution, rinsed with dilute nitric acid, and triple-rinsed with deionized water.

Water and sediment samples were submitted to Frontier Geosciences, Inc. in Seattle, Washington for HgT and MeHg analyses. Water samples for determination of dissolved Hg concentration were filtered in the laboratory. HgT in water was determined by BrCl oxidation, $SnCl_2$ reduction, dual gold amalgamation, and cold vapor fluorescence (CVAFS) detection (EPA method 1631 modified). MeHg in water was determined by distillation, aqueous phase ethylation, isothermal gas chromatography separation, and CVAFS detection (EPA draft method 1630 modified). HgT in sediment was determined by aqua regia digestion, $SnCl_2$ reduction, dual gold amalgamation, and CVAFS detection (EPA method 1631 modified). MeHg was extracted from sediment samples with methylene chloride. Following preparation, an aliquot of each extract was analyzed by aqueous phase ethylation, isothermal GC separation, and CVAFS detection (EPA draft method 1630 modified).

Aquatic invertebrate samples were submitted to Toxscan Inc., Watsonville, California for HgT analyses. MeHg analyses were performed by Battelle Marine Sciences Laboratory. Samples were freeze-dried and ball-milled prior to digestion. Samples for MeHg determination were homogenized and digested with a KOH/methanol mixture. An ethylating agent was added to form a volatile methyl-ethylmercury derivative, and then purged onto graphite carbon traps as a means of preconcentration and interference removal. The sample was then isothermally chromatographed, pyrolitically broken down to elemental mercury, and detected using CVAFS.

Concentration data received from the laboratory was log-transformed (base10) to acheive equal variance about the regression line. Pearson's chi-square test was used to examine differences in HgT and MeHg concentrations and water quality variables between historical and constructed wetlands on Stillwater NWR. The relationship among HgT and MeHg concentrations in water, sediment, and corixids and among other environmental variables were examined using regression analyses. Significance was assigned at the p#0.05 level.

In the following discussions, HgT and MeHg concentrations in water are given as total concentrations (e.g., dissolved plus particulate) unless otherwise noted. HgT and MeHg concentrations for sediment and corixids are given in dry weight unless otherwise noted.

RESULTS

HgT concentrations in bottom sediment varied considerably among sites within Stillwater and Fallon NWR (55 to 21,80 ng/g; Table 2, Figure 5). The highest HgT concentrations were found in the two Fallon NWR sites (Duck Lake and Battle Ground Point). Both locations are closely associated with the northern Carson River channel (Figure 2). Within the historical Stillwater Marsh, HgT concentrations were highest in the wetlands closest to the point of inflow from Stillwater Slough (e.g., Lead Lake) and generally declined along the flow path (Figure 3). HgT concentrations in sediment were significantly lower (p=0.018) in wetlands constructed in the 1940's. A gradient of HgT concentrations is also apparent in constructed wetlands, with the highest concentrations occurring in Stillwater Point Reservoir, the initial unit in this series. No statistical relationships (p$0.234) were found between HgT concentrations in sediment and dissolved oxygen concentrations, specific conductivity, or pH. Concentration gradients for MeHg in sediment along the flow paths in the historical and constructed wetlands are discernable, but less pronounced than those for HgT (Figure 6). However, MeHg concentrations were not statistically different between the historical and the constructed wetlands (p=0.188).

When all data were examined a poor relationship (p=0.54, r^2=0.20) was found between HgT and MeHg concentrations in sediment (Figure 7).

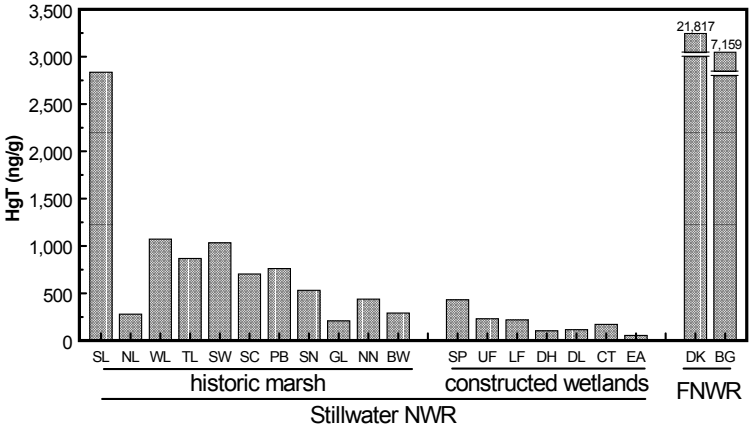


Figure 5. Total mercury (HgT) concentrations (ng/g, dry weight) in sediment from wetlands on Stillwater National Wildlife Refuge (NWR) and Fallon National Wildlife Refuge (FNWR), 1999. Site abbreviations are given in Table 2.

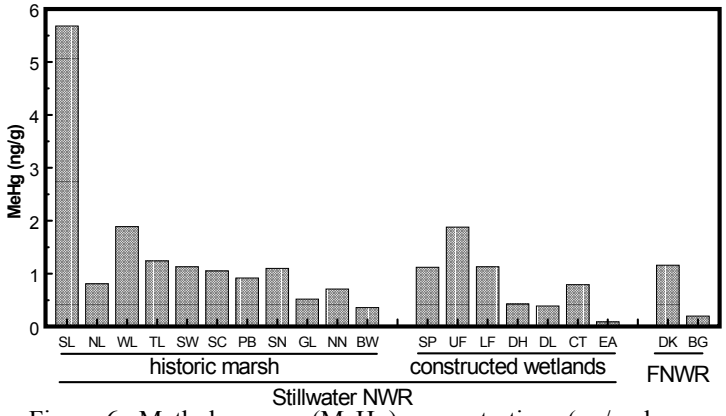


Figure 6. Methylmercury (MeHg) concentrations (ng/g, dry weight) in sediment from wetlands on Stillwater and Fallon NWRs, 1999.

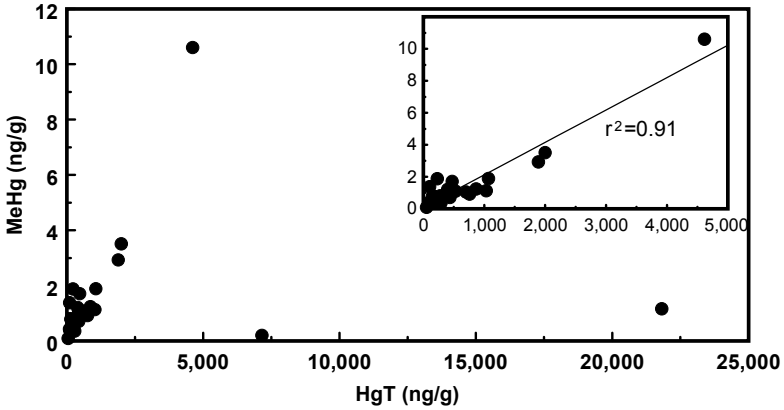


Figure 7. Total and methyl mercury concentrations (ng/g) in sediment from wetlands on Stillwater and Fallon NWRs, 1999. The inset includes only data from Stillwater NWR.

Table 2. Percent solids, total (HgT) and methylmercury (MeHg) concentrations (nanograms per gram; ng/g, dry weight), percent MeHg in bottom sediment and aquatic invertebrates (*Corisella* spp.), and MeHg bioaccumulation factors (BAF) from Stillwater and Fallon National Wildlife Refuges (NWR), 1999. "-" indicates not calculated.

	site	sediment				aquatic invertebrates				
location	abbrev-iation	percent solids	HgT (ng/g)	MeHg (ng/g)	percent MeHg	percent solids	HgT (ng/g)	MeHg (ng/g)	percent MeHg	BAF
Stillwater NWR - Historical Marsh										
South Lead Lake 1	SL	54	2,000	3.5	0.2	20	600	770	128	220
South Lead Lake 2	SL	24	4,620	11	0.2	23	700	660	94	60
South Lead Lake 3	SL	58	1,890	2.9	0.2	20	800	850	106	290
North Lead Lake	NL	63	280	0.8	0.3	18	600	480	80	600
Willow Lake	WL	56	1,070	1.9	0.2	15	600	740	123	390
Tule Lake	TL	53	870	1.2	0.1	19	700	810	116	680
Swan Lake	SW	53	1,040	1.1	0.1	18	700	490	70	450
Swan Check	SC	46	705	1.1	0.2	17	<600	320	-	290
Pintail Bay	PB	47	762	0.9	0.1	20	600	380	63	420
South Nutgrass	SN	51	532	1.1	0.2	18	<600	400	-	360
Goose Lake	GL	34	209	0.5	0.2	16	<600	300	-	600
North Nutgrass	NN	54	439	0.7	0.2	21	800	500	63	710
Big Water	BW	51	292	0.4	0.1	20	<500	130	-	330
Stillwater NWR - Constructed Wetlands										
Stillwater Point Res.	SP	51	433	1.1	0.3	22	1,400	1,450	104	1,320
Upper Foxtail Lake	UF	44	231	1.9	0.8	20	1,400	1,140	81	600
Foxtail Lake 1	LF	52	106	1.4	1.3	18	1,000	1,330	133	950
Foxtail Lake 2	LF	54	152	0.8	0.5	21	900	1,060	118	1,330
Foxtail Lake 3	LF	57	402	1.2	0.3	23	900	1,220	136	1,020
Doghead Pond	DH	55	105	0.4	0.4	19	<500	730	-	1,830
West Dry Lake	DL	46	116	0.4	0.3	17	<600	370	-	930
Cattail Pond	CT	46	173	0.8	0.5	26	500	690	138	860
East Alkali Lake	EA	54	55	0.1	0.2	21	<500	140	-	1,400
Fallon NWR										
Duck Lake	DK	60	21,800	1.2	0.005	20	1,300	600	46	500
Battle Ground	BG	49	7,160	0.2	0.003	17	1,000	450	45	2,250

However, the relationship was stronger (r^2=0.66) when data from Fallon NWR were excluded. The relationship was still stronger ($p<0.001$, r^2=0.91) for non-transformed data. The percent MeHg of HgT appeared to inversely correspond to HgT concentrations. The greatest MeHg percentages were generally found in wetlands with low HgT concentrations. This resulted in a higher mean percent MeHg (p=0.015) in constructed wetlands (0.49 %) than in historical wetlands (0.19 %). MeHg concentrations in the historical and the constructed wetlands were not significantly different (p=0.188). Percentages of MeHg were lowest in Battleground Point (0.003 %) and Duck Lake (0.005 %) which had the highest HgT concentrations (7,200 and 22,000 ng/g, respectively). The relationship between MeHg in sediment and pH was significant

(p=0.016), although the r^2 was low (r^2=0.30). Relationships between MeHg in sediment and dissolved oxygen concentration and specific conductivity were not significant (p$0.518).

HgT and MeHg concentrations in water from Stillwater NWR were highly variable (Table 3). The highest HgT concentrations were found at Fallon NWR at the terminus of the northern Carson River channel. In Stillwater Marsh, HgT concentrations in historical wetlands were significantly greater (p=0.019) than constructed wetlands. No significant difference (p=0.144) was found between historical and constructed wetlands when MeHg was examined. HgT or MeHg concentration gradients were not apparent along the flow paths in each wetland series (Figures 8 and 9).

Analyses of total and dissolved HgT indicated that the bulk of HgT in the water column occurred in a particulate form (Table 3). The proportion of dissolved HgT ranged from 1 to 49 percent with a mean of 16 percent. A strong relationship was found between dissolved HgT and total HgT in water (p<0.001, r^2=0.96). The proportion of dissolved MeHg in the water column for corresponding samples ranged from 10 to 78 percent with an arithmetic mean of 35 percent. A significant relationship was found between dissolved MeHg and total MeHg (p=0.018), but the r^2 (0.48) was low. Significant relationships were found between HgT concentrations in water and HgT

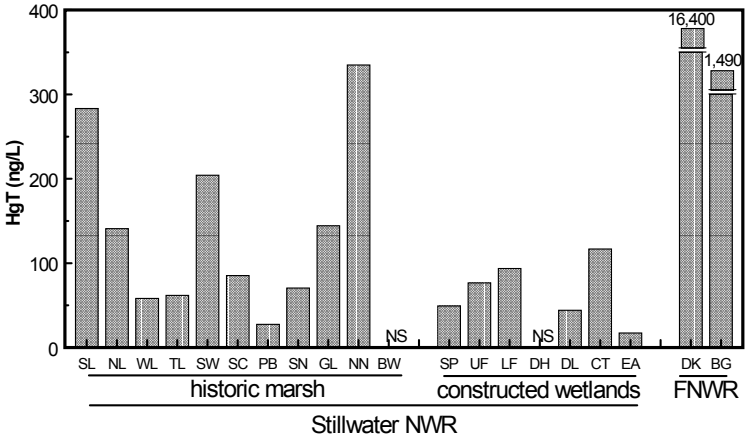


Figure 8. Total mercury (HgT) concentrations (ng/L) in unfiltered water from wetlands on Stillwater and Fallon NWRs, 1999. NS indicates that samples were not collected.

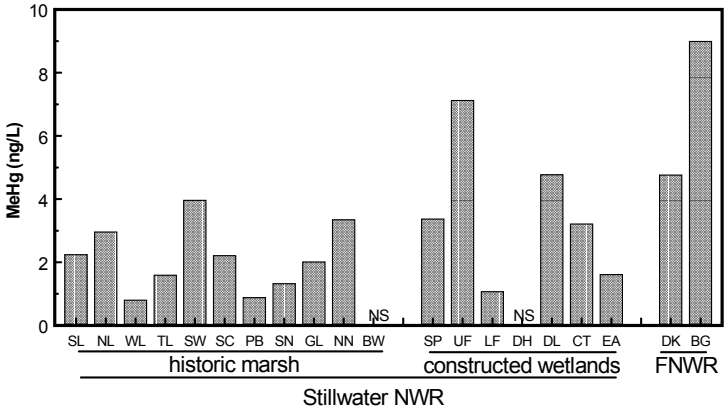


Figure 9. Methylmercury (MeHg) concentrations (ng/L) in unfiltered water from wetlands on Stillwater and Fallon NWRs, 1999.

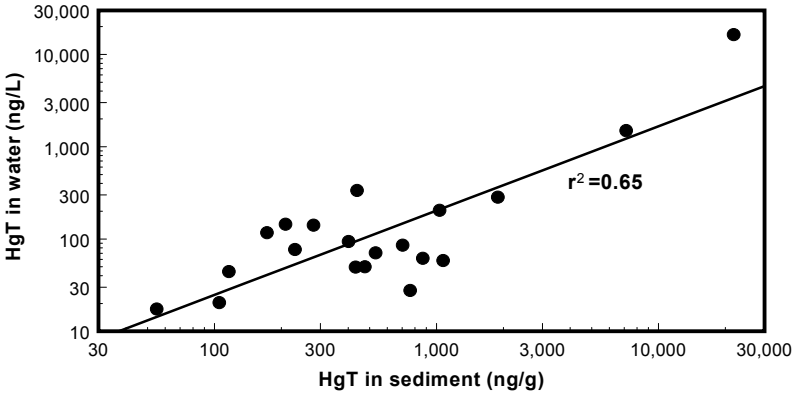


Figure 10. Total mercury (HgT) concentrations (ng/L) in unfiltered water and sediment (ng/g) from wetlands on Stillwater and Fallon NWRs, 1999.

respectively) were low in both cases. Relationships between MeHg in unfiltered water and HgT and MeHg in sediment (p=0.39 and 0.46, respectively) were not significant. No significant relationships were found between both HgT and MeHg concentrations in water and dissolved oxygen, specific conductivity, or pH (p$0.09). The overall pH in historical and constructed wetlands was not statistically different (p=0.166).

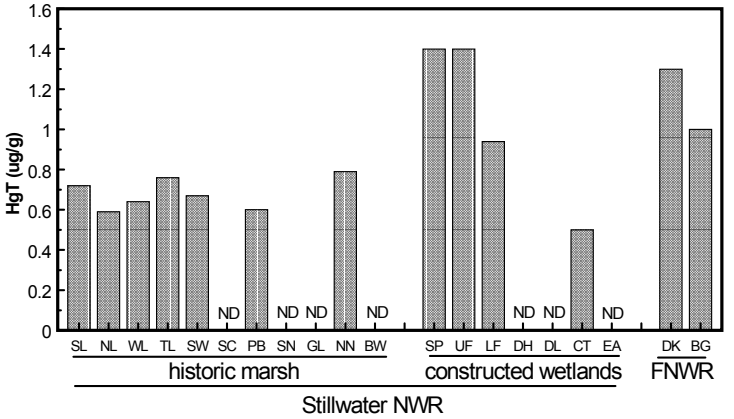


Figure 12. Total mercury (HgT) concentrations (ug/g, dry weight) in aquatic invertebrates (Corisella spp.) from wetlands on Stillwater and Fallon NWRs, 1999. ND indicates that mercury was not detected at a concentration of approximately 0.5 ug/g, dry weight.

HgT and MeHg concentrations in corixids were less than the contract detection limits (0.5-0.6 µg/g, dry weight) in 7 and 9 of 24 samples, respectively, collected on Stillwater and Fallon NWRs. Percent MeHg ranged from 46 to150 percent, with a mean of 105 percent, suggesting that the bulk of HgT in corixids occurs as MeHg. However, the broad concentration range coupled with the high incidence of greater reported MeHg concentrations than HgT concentrations raises some question as to the utility of the data. MeHg concentrations in 9 samples fell between the sample detection limit and the contract required detection limit (0.1 µg/g, wet weight). These values are considered qualitatively acceptable but quantitatively unreliable because of uncertainties in the analytical precision near the limit of detection. These values were included in data analyses and subsequent discussions.

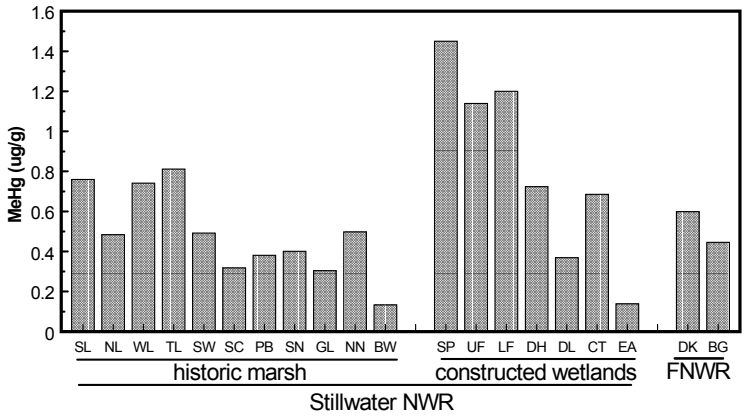


Figure 13. Methylmercury (MeHg) concentrations (ug/g, dry weight) in aquatic invertebrates (Corixid spp.) from wetlands on Stillwater and Fallon NWRs, 1999. Site abbreviations are given in Table 2. Concentrations less than approximately 0.5 ug/g were less than the contract required detection limit and are, therefore, considered estimates.

HgT and MeHg concentrations in corixids varied with location in Stillwater NWR (Table 2). Concentration gradients along the flow paths are not apparent for HgT (Figure 12), but are discernable for MeHg, particularly in the constructed wetlands (Figure 13). MeHg concentrations were significantly greater (p=0.022) in constructed wetlands than in the historical wetlands. A significant statistical relationship was found between MeHg concentrations in corixids and sediment (p=0.002, r^2=0.42). The strength of this relationship increased when

historical and constructed wetlands were examined separately ($p<0.001$, $r^2=0.58$; $p<0.001$, $r^2=0.89$, respectively; Figure 14). A significant statistical relationship was also detected between MeHg concentrations in invertebrates and pH ($p=0.002$), but the r^2 was low ($r^2=0.36$). Statistical strength increased ($p<0.001$, $r^2=0.63$) when MeHg concentrations in corixids were examined using multiple regression with MeHg in sediment and pH as independent variables. No significant relationships were found between MeHg concentrations in corixids and total or dissolved HgT in water or MeHg concentrations in water ($p>0.645$, $r^2<0.01$), HgT concentrations in sediment ($p=0.351$, $r^2=0.05$), or with dissolved oxygen or specific conductivity ($p>0.253$, $r^2<0.07$).

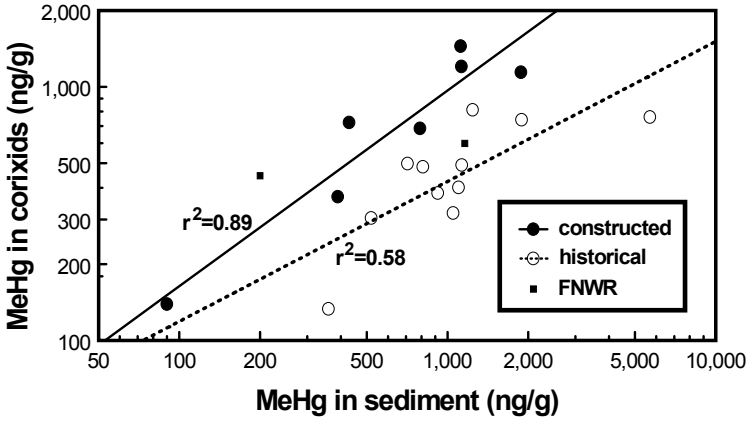


Figure 14. Methylmercury concentrations (ng/g, dry weight) in sediment and aquatic invertebrates (*Corisella* spp.) from wetlands on Stillwater and Fallon NWRs, 1999.

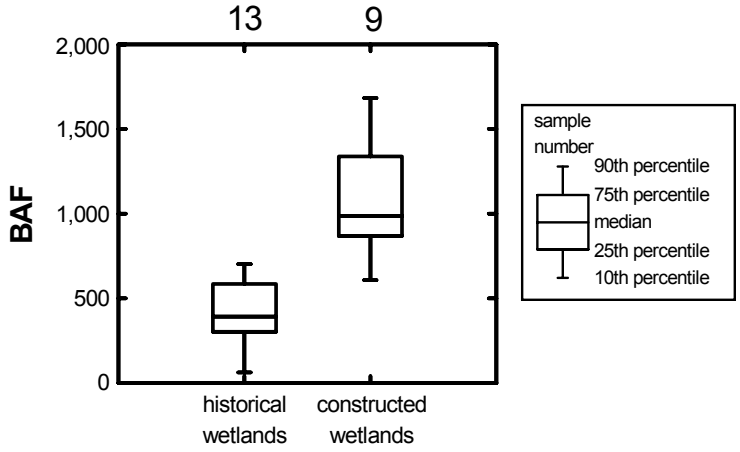


Figure 15. Bioaccumulation factors (BAF) for methylmercury in sediment to methylmercury in aquatic invertebrates (Corisella spp.) from historical and constructed wetlands on Stillwater NWR, 1999.

When MeHg concentration data exceeding the analytical reporting limit are considered, bioaccumulation factors (BAF) from MeHg in sediment to MeHg in corixids ranged between approximately 60 and 1,800 times, with a mean of approximately 750 times. When data less than the analytical reporting limit are considered, BAFs ranged from 60 to 2,200, but the mean (741) remained similar. BAFs were significantly higher ($p<0.001$) in constructed wetlands (mean = 1,135) than in historical wetlands (mean = 415; Figure 15). BAFs for HgT and MeHg in water and HgT in sediment were not calculated because of their poor correlation with concentrations in corixids, .

HgT concentrations in corixids were less than the detection limit (0.1 µg/g, wet weight; ~0.5 µg/g, dry weight) in samples from14 of 40 Lahontan Valley wetlands with concentrations ranging from 0.5 to 1.9 µg/g, dry weight (Table 4). HgT was not detected in two samples from Lahontan Valley not affected by the Carson River (Massie and Mahala sloughs), but was detected at a background site in Mason Valley within the Walker River basin. The highest incidence of detection and the greatest concentrations were generally found in samples from the Carson River sites, Newlands Project reservoirs, and in historical and constructed wetlands on Stillwater NWR. MeHg concentrations in aquatic invertebrate (corixid) samples from 22 of the

Table 4. Dissolved oxygen (DO; milligrams per liter; mg/L), specific conductivity (SpC; microseimens per centimeter; µS/cm), pH, turbidity (turb.; nephroturbidity units; NTU), percent solids, total mercury (HgT), and methylmercury (MeHg) concentrations (nanograms per gram; ng/g, dry weight), and percent MeHg in aquatic invertebrates (*Corisella* spp.) from Lahontan Valley wetlands, 1999. MeHg concentrations less than about 0.5 ng/g are estimated.

	site					aquatic invertebrates			
location	abbrev-iation	DO (mg/L)	SpC (µS/cm)	pH	turb. (NTU)	percent solids	HgT (ng/g)	MeHg (ng/g)	percent MeHg
Carson River (CR)									
Carson Dam	CD	7.2	210	8.4	107	18	1,900	1,100	58
Coleman Dam	LD	6.2	230	7.9	25	16	900	800	89
Sagouspi Dam	SD	7.5	350	7.9	26	19	800	800	100
Newlands Project Reservoirs (NP)									
Sheckler Reservoir	SR	8.9	320	8.7	91	18	1,600	1,200	75
S-Line Reservoir	LR	7.3	250	8.2	39	20	700	800	114
Harmon Reservoir 1	HR	6.3	405	8.1	44	18	900	800	89
Harmon Reservoir 2	HR	9.2	255	8.8	43	18	700	800	114
Tribal Wetlands (TW)									
East Wetland	ET	9.6	320	9.2	12	19	<500	600	-
West Wetland	WT	-	-	-	-	20	1,000	900	90
Carson Lake (CL)									
Sprig Pond 1	CS	16.6	1,550	8.6	92	16	<600	400	-
Sprig Pond 2	CS	7.8	2,400	8.6	164	17	<600	400	-
Sprig Pond 3	CS	8.5	5,000	9.1	150	20	<500	400	-
York Unit	CY	11.5	18,900	9.1	149	22	600	400	67
Rice Unit	CR	5.9	8,000	8.6	172	22	<500	400	-
Big Water	CB	12.6	9,220	8.8	120	13	<700	300	-
Sump	CP	12.2	5,500	9.2	170	18	<600	300	-
Indian Lakes (IL)									
D-Line Marsh	DI	7.2	350	8.6	29	20	<500	400	-
Upper Lake	UI	7.5	440	8.8	83	21	<500	500	-
Likes Lake	LI	6.8	450	8.6	53	21	700	900	129
Papoose Lake	PI	7.0	700	8.7	88	21	600	700	117
Big Indian Lake	BI	5.1	2,115	8.8	39	19	600	900	150
Stillwater Marsh (SM)									
Freeman Lake	FL	4.4	1,065	8.1	89	22	600	900	150
Dutch Bill Lake	DB	13.3	2,615	9.2	147	20	700	400	57
South Lead Lake 1	SL	3.9	2,000	8.3	80	20	600	800	133
South Lead Lake 2	SL	2.9	1,900	8.2	>200	23	700	700	100
South Lead Lake 3	SL	6.9	1,650	8.5	105	20	800	900	113
North Lead Lake	NL	8.7	3,730	8.9	51	18	600	500	83
Willow Lake	WL	9.2	2,880	9.1	-	15	600	700	117
Tule Lake	TL	3.4	7,600	8.9	23	19	700	800	114
Swan Lake	SW	4.8	6,200	8.8	-	18	700	500	71
Swan Check	SC	6.4	4,000	8.6	59	17	<600	300	-

Table 4. *continued*

location	site abbrev-iation	DO (mg/L)	SpC (µS/cm)	pH	turb. (NTU)	aquatic invertebrates percent solids	HgT (ng/g)	MeHg (ng/g)	percent MeHg
Pintail Bay	PB	5.3	5,230	9.4	-	20	600	400	67
South Nutgrass	SN	8.5	1,980	8.9	92	18	<600	400	-
Goose Lake	GL	8.6	2,200	8.9	142	16	<600	300	-
North Nutgrass	NN	14.1	18,670	9.5	72	21	800	500	63
Big Water	BW	15.2	28,000	9.6	124	20	<500	100	-
Stillwater NWR - Constructed Wetlands (CW)									
Stillwater Point Res.	SP	6.7	1,580	8.5	28	22	1,400	1,500	107
Upper Foxtail Lake	UF	9.0	1,100	8.6	34	20	1,400	1,100	79
Foxtail Lake 1	LF	6.2	1,410	8.8	22	18	1,000	1,300	130
Foxtail Lake 2	LF	8.5	1,400	8.9	15	21	900	1,100	122
Foxtail Lake 3	LF	4.7	4,250	8.6	22	23	900	1,200	133
Doghead Pond	DH	10.5	4,765	8.9	38	19	<500	700	-
West Dry Lake	DL	10.3	5,400	8.7	38	17	<600	400	-
Cattail Pond	CT	5.5	4,265	8.3	35	26	500	700	140
East Alkali Lake	EA	8.5	7,900	9.2	30	21	<500	100	-
Fallon National Wildlife Refuge (FN)									
Duck Lake	DK	9.5	1,410	9.5	105	20	1,300	600	46
Battle Ground	BG	9.6	1,115	9.6	>200	17	1,000	500	50
Background Sites (BK)									
Mahala Slough	BA	>20.0	28,000	9.2	144	16	<600	40	-
Massie Slough	BB	8.6	2,350	8.7	28	20	<500	70	-
Mason Valley	BC					26	400	500	125

40 collected throughout Lahontan Valley wetlands and one of the background sites exceeded the contract required detection limits (0.1µg/g, wet weight). The highest incidence of detection and highest concentrations were found in samples from the Carson River sites, Newlands Project reservoirs, and in historical and constructed wetlands in Stillwater NWR. MeHg concentrations in corixids collected throughout Lahontan Valley were significantly greater ($p<0.001$) in constructed wetlands (e.g., reservoirs, impounded areas, and constructed wetlands) than in historical wetlands (Figure 16). The percent MeHg ranged from 46 to 150 percent, with a mean of 99 percent, suggesting that the bulk of the HgT in corixids generally occurs as MeHg.

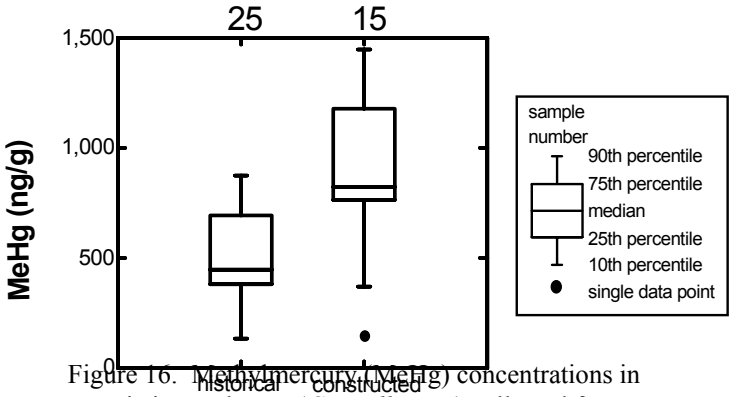
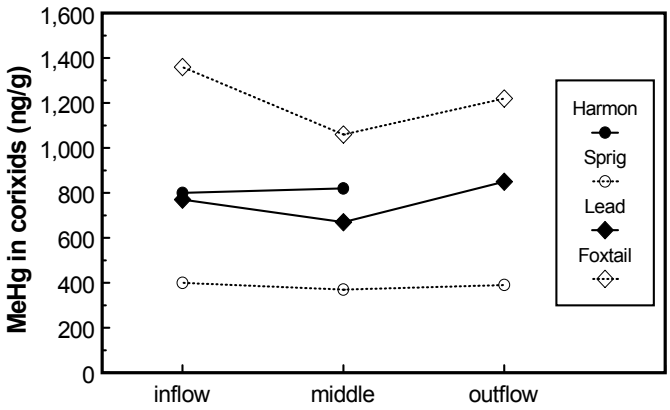


Figure 16. Methylmercury (MeHg) concentrations in aquatic invertebrates (*Corixella* spp.) collected from historical and constructed wetlands in Lahontan Valley, Nevada, 1999.

Figure 17. Methylmercury (MeHg) concentrations (micrograms per gram, ug/g, dry weight) in aquatic invertebrates (corixids; Corisella spp.) relative to location in four wetlands in Lahontan Valley, Churchill County, Nevada, 1999.

Although MeHg concentrations in aquatic invertebrate samples fell below the contract required detection limit, they exceeded the sample detection limit. These values are considered qualitatively acceptable but quantitatively unreliable because of uncertainties in the analytical precision near the limit of detection. These data are included in subsequent discussions.



Statistically significant relationships (p#0.001) were found between MeHg concentrations in corixids collected valley-wide and pH, specific conductivity, and turbidity, but r^2 values were low in all cases (r^2=0.27, 0.31, and 0.21, respectively). Statistical strength increased slightly ($p<0.001$, r^2=0.39) when MeHg concentrations in corixids were examined using multiple regression with pH and turbidity as independent variables. The relationship between MeHg in corixids and dissolved oxygen was not significant (p=0.112).

Within specific wetlands, some variability of MeHg in corixid samples relative to location in the wetland was observed. Differences between samples collected from the same wetland ranged from 2 to 20 percent. No consistent pattern of concentration relative to location in the wetland was apparent (Figure 17).

DISCUSSION

Mercury in Stillwater NWR Sediment

The bulk of the mercury burden within aquatic systems is associated with sediment (Zillioux et al. 1993). Sediment may serve as both a sink and a source of metals in aquatic systems (McIntosh 1991). Sediment also serves as the primary site for mercury methylation in aquatic systems (Morel et al. 1998) . As such, bottom sediment may play a key role in controlling mercury availability in Lahontan Valley. HgT concentrations in sediment of Lahontan Valley are highly variable. Within the Lahontan Valley agricultural area, the most severe HgT contamination generally corresponded to agricultural drains and other water courses that are closely associated with Carson River channels that existed between 1850 and the construction of Lahontan Dam in 1915 (Hoffman 1994). This pattern suggests that significant amounts of mercury were deposited in Lahontan Valley prior to the regulation of the river. Within Stillwater and Fallon NWRs the most severe HgT concentrations in sediment occurred in wetlands most closely associated with historical river channels. The highest concentrations were found near the terminus of the Carson River channel extending to Fallon NWR followed by the portion of the historical marsh occurring on Stillwater NWR. Within the historical marsh, HgT concentrations were greatest in Lead Lake (Figure 5), the initial refuge wetland that received inflow from Stillwater Slough, and progressively declined in sequential wetlands. This pattern generally follows the flow gradient toward the Carson Sink (Figure 3). HgT concentrations in

constructed wetlands were considerably lower than concentrations in the historical marsh. However, HgT concentrations in all wetlands exceeded the estimated background concentration for Lahontan Valley soils of 40 ng/g (Lico 1992). HgT concentrations decrease along a flow gradient in constructed wetlands. These findings indicate that contamination in Lahontan Valley wetlands has also continued to expand since flow regulation. However, lower concentrations in constructed wetlands suggest that water regulation has reduced the rate of expansion.

Like HgT, MeHg concentrations in Lahontan Valley wetland sediments were variable. In Stillwater Marsh, concentration gradients generally mirrored those of HgT. When only Stillwater Marsh was considered, MeHg concentrations correlated with HgT concentrations (Figure 7). However, the percent MeHg generally decreased as HgT concentrations increased. As a result, MeHg concentrations in historical and constructed wetlands were not statistically different. Substantial decreases in the percent MeHg were noted in two sediment samples containing HgT concentrations exceeding 5,000 ng/g. Chen et al. (1996) reported that, at lower HgT concentrations (<15,000 ng/g), mercury methylation rates increased with HgT concentrations. However, this trend was reversed when concentrations increased above this level. These researchers speculated that inhibition of microbial activity by HgT was responsible. Depression of methylation rates may account for the lower percent MeHg observed in Fallon NWR sediments. However, HgT concentrations in the historical Stillwater marsh wetlands were generally well below concentrations associated with significant inhibition of methylation. Therefore, other mechanisms likely account for observed differences.

Bonzongo et al. (1996) reported that rates of MeHg production in Carson River sediment decreased as pH increased. The decrease of methylation rates did not appear to be attributable to differences in microbial activity. We found a weak negative relationship between MeHg concentrations in sediment and pH of the overlying water column. Several studies have found increased MeHg concentrations in aquatic organisms and subsequent increased ecological risk of mercury under conditions of low pH (Wren et al. 1995). Winfrey and Rudd (1990) attributed differences in MeHg concentrations not to a difference in MeHg production, but rather to the a shift in formation from monomethylmercury to dimethylmercury as pH increases. The formation of dimethylmercury is favored at higher pH. Dimethylmercury is more volatile and is therefore more rapidly lost from the aquatic system. Conversely, monomethylmercury is more efficiently retained in aquatic systems. Winfrey and Rudd (1990) also suggested that elevated MeHg accumulation under acidic conditions may also be attributed to pH-mediated differences in MeHg flux from sediments. Miller and Akagi (1979) found that the movement of MeHg from the sediment surface was enhanced as pH declined. More information is needed to determine if the alkaline conditions or related factors affect the retention or availability of MeHg in Lahontan Valley wetlands.

The U.S. Geological Survey (USGS) is currently investigating factors affecting rates of methylation and demethylation in the Carson River basin (Marvin-DiPasquale, USGS, pers. comm., 2000). That investigation, which includes sample sites in Lahontan Valley wetlands, should provide a better understanding of factors and processes controlling the availability of mercury in these shallow, productive wetlands. Preliminary results indicate that acid-reactive Hg concentration and its bioavailability to methylation, the potential for resident bacteria to methylate and demethylate mercury, and the gross rate of demethylation are key factors influencing MeHg production in the Carson River basin. As with previous investigations,

microbial sulfate reduction is recognized as an important factor influencing mercury transformation in Lahontan Valley wetlands.

Mercury in Stillwater NWR Water

Previous investigations in the Carson River basin upstream of Lahontan Dam found that HgT concentrations in the water column were positively correlated with suspended solids (Cooper et al. 1985, Bonzongo et al. 1996). Suspended solids were positively correlated with river discharge. Therefore, HgT concentrations in the water column in the upstream river and reservoir system were largely controlled by river discharge. In the current study, suspended solids were not determined, but turbidity was measured as a surrogate. We found a strong relationship between HgT in water and the combined effect of HgT in sediment and turbidity. Consistent with this, the bulk of HgT occurring in the water column was in a particulate phase. The proportion of HgT in particulate phase increased with turbidity. Dissolved HgT occurring in the water column was strongly correlated with total HgT in the water column and, therefore, appeared to be controlled by HgT in sediment and turbidity. Within the shallow wetlands of Lahontan Valley, turbidity is largely controlled by wind and associated agitation of bottom sediment in the shallow wetlands by wave action (Tuttle et al. 2000). Therefore, wind may be a dominant factor controlling HgT in the water column in wetlands.

Sediment MeHg concentrations in the historical and constructed wetlands were similar. Factors controlling MeHg in the water column on Stillwater NWR are less certain. Hoffman and Thomas (2000) found a strong relationship between MeHg in water and HgT in sediment. Although we found a strong relationship between HgT in sediment and water and a weaker relationship between HgT and MeHg in unfiltered water, our data did not reveal a significant relationship between MeHg in the water and HgT or MeHg in sediment. As indicated previously, turbidity in Lahontan Valley wetlands is largely controlled by wind and associated wave action. As such, HgT concentrations in the water column may change rapidly and overshadow normal MeHg flux from sediment. MeHg concentrations in the water column did not appear to be affected by pH, dissolved oxygen, or specific conductivity.

Mercury in Stillwater NWR Aquatic Invertebrates

Mercury speciation largely determines the toxicity and availability of mercury to aquatic organisms (Zillioux 1993). MeHg is considered the most toxic and is readily accumulated by aquatic organisms (Wren et al. 1995). Aquatic organisms may accumulate MeHg from water, sediment, and food (Clements 1991). Our results suggest that the bulk of HgT in corixids occurs as MeHg. MeHg in corixids was statistically greater in constructed wetlands than in historical wetlands on Stillwater NWR. The relationship between MeHg in sediment and MeHg in corixids suggests that sediment plays a key role in mercury accumulation by aquatic invertebrates in Lahontan Valley. However, the exposure pathway, whether from water, diet, or directly from the sediment, is uncertain. The lack of relationship between both HgT and MeHg in water and HgT and MeHg in corixids would suggest that water is not the primary exposure pathway. However, HgT and, to a lesser degree, MeHg in the water column correlated with turbidity. Turbidity in Lahontan Valley wetlands is largely controlled by wind and associated

wave action and may vary substantially over time (Tuttle et al. 2000). MeHg concentrations in corixids may reflect longer term water column mercury concentrations. Species of the genus *Corisella* are predaceous and may be expected to accumulate significant amounts of mercury from prey.

As with sediment, we found a negative relationship between MeHg in corixids and water column pH. Statistical strength increased when MeHg concentrations in corixids were examined using multiple regression with MeHg in sediment and pH as independent variables. These findings suggest that while MeHg in sediment largely determines MeHg in corixids, pH also plays a role in the availability. As indicated previously, alkaline conditions favor the formation of the more volatile dimethylmercury and may restrict MeHg flux across the sediment-water interface. As such, high alkalinity in Lahontan Valley may reduce the availability of MeHg to aquatic organisms. In this event, natural alkaline conditions in Lahontan Valley wetlands may reduce the potential for adverse effects to fish and wildlife and thereby reduce ecological risk.

Bioconcentration factors for MeHg in sediment to corixids in Stillwater and Fallon NWR ranged from 60 to at least 1,700 times. These levels were generally consistent with BAFs for MeHg from sediment to aquatic invertebrates reported by Mason and Lawrence (1999). While no difference was found between MeHg concentrations in sediment from historical and constructed wetlands, we found that BAFs were significantly greater in constructed wetlands. Aquatic invertebrate bioaccumulation of both HgT and MeHg from sediment may be influenced by organic carbon content in sediment (Mason and Lawrence 1999). In general, BAFs declined as organic carbon concentrations in sediment increased. Organic carbon content in sediment was not determined in our investigation. However, limited data on organic content in Lahontan Valley wetland sediments are available. As might be predicted, organic carbon concentrations were generally greater in historical wetlands than in constructed wetlands. For example, Hoffman et al. (1990) reported that concentrations in historical wetlands ranged from 1.3 to 3.8 percent with a mean of 2.1 percent (n=5) while concentrations in constructed wetlands ranged from 0.4 to 0.8 percent with a mean of 0.6 percent (n=3). Rowe et al. (1991) reported that the organic carbon concentration was higher in Goose Lake (2.1 percent) within the historical marsh than in East Alkali Lake (0.7 percent) which is a constructed wetland. Therefore, low organic matter in constructed wetlands may, at least in part, account for differences in BAFs between historical and constructed wetlands.

Mercury in Lahontan Valley Aquatic Invertebrates

Patterns of HgT and MeHg in corixids from other Lahontan Valley wetlands are similar to those on Stillwater NWR. The bulk of HgT in corixids occurred as MeHg. The highest mean concentrations per site group were found in constructed wetlands on Stillwater NWR followed by Newlands Project reservoirs, the Carson River sites, and the Tribal wetlands. The Newlands Project reservoirs and Tribal wetlands are constructed wetlands. Corixid samples from the Carson River were collected from impounded areas upstream of diversion dams, and therefore may also be considered artificial wetlands. Surprisingly, MeHg concentrations in corixids were lower in samples from Carson Lake, Fallon NWR, Indian Lakes, and the historical Stillwater Marsh, all of which are known to have highly elevated HgT concentrations in sediment (Hoffman et al. 1990; Rowe et al. 1991). A weak negative relationship was found between

MeHg and pH. As indicated previously, it is uncertain if pH, organic carbon in sediment, or both play a role in the availability of mercury in Lahontan Valley wetlands.

Mercury Redistribution in Lahontan Valley

HgT distribution patterns in Lahontan Valley indicate that anthropogenic mercury was transported to and deposited in Lahontan Valley by fluvial processes (Hoffman 1994). Such processes were likely responsible for HgT distribution patterns in Fallon NWR and historical wetlands in Stillwater Marsh prior to regulation of the Carson River. Following the creation of the Newlands Project in the early 1900's delivery routes to Stillwater Marsh were modified. Following that point most water entering the marsh was received through agricultural drains or water delivery canals. Additionally, water flow through the marsh was restricted by the construction of dikes and water control structures. As a result, the role of fluvial processes in the deposition and redistribution of mercury on Stillwater NWR became less significant. However, elevated HgT concentrations in constructed wetlands indicate that HgT deposition on Stillwater NWR has continued within the past 50 years. Similarly, HgT concentration gradients in constructed wetlands indicate that mercury movement between wetlands has also continued.

Significant HgT loads continue to enter Stillwater NWR in irrigation quality water and agricultural drainwater discharged to the wetlands. From 1994 to 1996, HgT concentrations in two agricultural drains entering Stillwater Marsh, Stillwater Slough and Diagonal Drain, ranged from <100 to 3,500 ng/L (Tuttle et al. 2000). During this period, Stillwater Slough delivered a median instantaneous load of 0.009 kilograms of HgT per day (kg/d) and Diagonal Drain delivered 0.027 kg/d to Stillwater Marsh. Diagonal Drain enters the refuge at Stillwater Point Reservoir. Stillwater Slough enters Lead Lake indirectly through wetlands on the Canvasback Gun Club. HgT concentrations in irrigation quality water delivered to the refuge via the S-line canal were generally less than the 100 ng/L detection limit available in this study; therefore, the loads associated with that water source were not calculated. HgT concentrations in drain- and irrigation water entering the Stillwater Marsh in September 1998 ranged from about 200 to more than 500 ng/L and MeHg concentrations ranged from 0.5 to 1.0 ng/L (Hoffman and Thomas 2000).

Loads entering the marsh may increase substantially as a result of high flow events in the Carson River. Hoffman and Taylor (1998) estimated that 4,500 kilograms (kg) of HgT entered Lahontan Reservoir during and following a flood event in 1997. Of this, more than 900 kg was released from the reservoir. The load entering wetlands was uncertain. However, water released during and immediately following the flood were not used for agricultural purposes and, therefore, entered the wetlands. Additionally, Hoffman and Taylor (1998) found that HgT concentrations remained elevated in water released from Lahontan Reservoir for several weeks following the event. It is uncertain whether elevated HgT concentrations observed in water delivered to the refuge in 1998 were a continuing effect of the 1997 flood.

Temporal Variation in Mercury Concentrations

Some variations of HgT concentrations in environmental samples from Lahontan Valley have been observed over the past 13 years. HgT concentrations in sediment from Stillwater Point Reservoir and Dry Lake in 1999 were generally consistent with concentrations found in previous investigations (Hoffman et al. 1990, Rowe et al. 1991, Tuttle et al. 1996, Tuttle et al. 2000). The 1999 HgT concentrations in Lead Lake sediment were consistent with concentrations found in the late 1980's and early 1990's (Figure 18) but were substantially lower than concentrations found from 1993 to 1996. In all investigations, collection methods were similar although depths to which samples were collected (2 to 9 cm) and specific locations within each wetland may have varied. HgT concentrations in corixids collected from Dry Lake, Lead Lake, Stillwater Point Reservoir, and Sprig Pond in 1999 were generally consistent with samples prior to 1993. Like sediment in Lead Lake, HgT concentrations in corixids from these sites were elevated from 1994 to1996 (Figure 19). The 1999 collection sites and methods were similar to previous investigations. Therefore, temporal variation in concentrations is suspected.

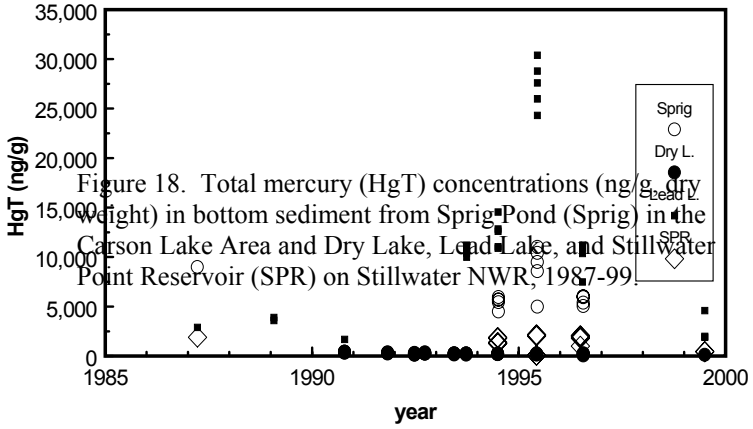


Figure 18. Total mercury (HgT) concentrations (ng/g, dry weight) in bottom sediment from Sprig Pond (Sprig) in the Carson Lake Area and Dry Lake, Lead Lake, and Stillwater Point Reservoir (SPR) on Stillwater NWR, 1987-99.

Mechanisms responsible for temporal variations in concentrations are uncertain. Changes in hydrologic conditions can alter mercury chemistry (Bodaly et al. 1984). A regional drought in the late 1980's and early 1990's caused the desiccation of several Lahontan Valley wetlands and a reduction in water levels in most others. Lead Lake was desiccated from late 1991 to early 1993. The 1993-96 samples were collected following reflooding. It is uncertain if increased sediment concentrations in the 1993-96 samples were due to vertical movement of existing HgT in sediment or if additional HgT was deposited when the wetland was reflooded. Alterations of sediment, such as drying and reflooding, may remobilize mercury from sediment back into the water column (Hecky et al. 1991). Additionally, increases in HgT concentrations in invertebrate samples may have been due to alterations in rates of methylation or demethylation caused by changes in hydrologic conditions (Schwarzbach 1998).

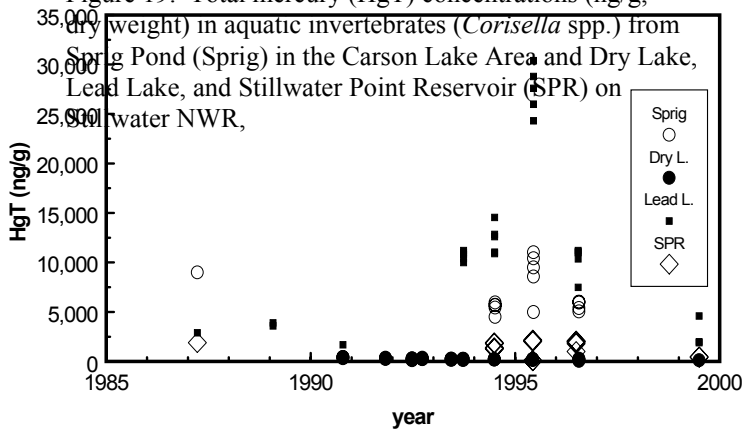


Figure 19. Total mercury (HgT) concentrations (ng/g, dry weight) in aquatic invertebrates (*Corisella* spp.) from Sprig Pond (Sprig) in the Carson Lake Area and Dry Lake, Lead Lake, and Stillwater Point Reservoir (SPR) on Stillwater NWR,

Implications to Fish and Wildlife

Previous investigations identified concerns with HgT in water, sediment, aquatic invertebrates, and fish and in bird forage items, tissues, and eggs in Lahontan Valley (Cooper et al. 1985, Hoffman et al. 1990, Hallock and Hallock 1993, Tuttle et al. 1996, Tuttle et al. 2000). These investigations did not evaluate MeHg in biotic and abiotic samples. Concerns with mercury in water, sediment, and aquatic invertebrates persisted in 1999.

The chronic (96-hour) aquatic life standard for HgT in water (12 ng/L; Nevada Administrative Code 445A.144, 1999) was exceeded in all wetlands on Stillwater NWR. Only one sample (Duck Lake) exceeded the acute (1-hour) aquatic life standard (2,000 ng/L). HgT concentrations at seven sites exceeded a 0.1 µg/L concentration associated with chronic toxicity to fish (Birge et al. 1979). Turbidity was elevated (>50 NTU) in the samples exceeding this effect level. HgT concentrations in corresponding filtered water were well below this level, indicating that the bulk of the mercury was not in a dissolved form. All water samples were well in excess of a 0.05 ng/L MeHg criterion for protection of piscivorous wildlife (Schwarzbach 1998). This criterion is based on bioaccumulation and concentration of mercury in aquatic food chains. HgT and MeHg concentrations in water delivered to the refuge in September 1998 also exceeded the chronic aquatic life standard and effect concentrations for fish and wildlife (Hoffman and Thomas 2000).

HgT in sediment from all wetlands in the historical portions of Stillwater Marsh exceeded sediment effect thresholds for freshwater invertebrates (200 ng/g; Persaud et al. 1993), estuarine and coastal marine invertebrates (150 ng/g; Long and Morgan 1991), and a consensus-based effects threshold concentration for freshwater sediment (MacDonald et al. 2000). Sediment HgT concentrations in constructed wetlands were generally near these threshold concentrations. Severe effect criteria for freshwater sediment (2,000 ng/g; Persaud et al. 1993) and the effect range-median value (1,300 ng/g) for estuarine and coastal marine sediment were exceeded in samples from Lead Lake and the two sites on Fallon NWR. Samples for Willow Lake, Swan Lake, Lead Lake, and Fallon NWR exceeded or approached a probable effect concentration (1,060 ng/g) identified by MacDonald et al. (2000). The probable effect concentration is defined as a concentration at which toxic effects to aquatic organisms is likely. Effect criteria for MeHg in aquatic sediment are uncertain.

Because of the importance of Lahontan Valley wetlands to migratory birds, they are perhaps the ecological endpoint of greatest concern. Diet is likely the most important pathway for avian exposure. At relatively low dietary concentrations, mercury can affect avian reproduction and survival. Reproduction is considered one of the most sensitive toxic endpoints for mercury and effects are observed at very low dietary concentrations (Wolfe et al. 1998). Heinz (1979) found reduced reproductive success in successive generations of mallards maintained on diets containing as little as 0.5 µg/g MeHg. In our investigation, approximately half of the invertebrate samples collected throughout Lahontan Valley (22 of 43 samples) exceeded this dietary effect concentration. The majority of the samples and mean exceeding this dietary effect concentration were collected from artificial wetlands, including the Newlands Project reservoirs, wetlands on the Fallon Paiute-Shoshone Indian Reservation, impounded areas upstream of diversion dams on the Carson River, and constructed wetlands on Stillwater NWR. Conversely, concentrations in samples from wetlands with high HgT concentrations, including Carson Lake, historical Stillwater Marsh, and Fallon NWR were generally lower than this effect

level. All samples were well below a 3.0 µg/g dietary MeHg concentration associated with reduced reproduction in a single generation of black ducks and lesions in nerve tissue of hatchlings (Finley and Stendell 1978).

HgT concentrations in corixids found in our investigation, <0.5 to 1.8 µg/g, were generally lower than concentrations in corixids found in previous Lahontan Valley investigations. Hoffman et al. (1990) reported that HgT concentrations in invertebrates collected from Lahontan Valley wetlands affected by the Carson River ranged from 1.1 to 4.4 µg/g. Tuttle et al. (1996) reported that HgT concentrations ranged from 0.2 to 1.8 µg/g. Tuttle et al. (2000) found that invertebrate HgT concentrations ranged from 0.5 to 10.8 µg/g. As discussed previously, HgT concentrations in corixids were elevated in samples collected from 1994-96. Variations in mercury concentrations in biotic and abiotic matrices may affect ecological risk of mercury in Lahontan Valley. From 1994-96, all corixid samples (n=40) collected from South Lead Lake, Stillwater Point Reservoir, Dry Lake, and Sprig Pond met or exceeded the 0.5 µg/g avian dietary effect concentrations (Tuttle et al. 2000). Thirty percent of the corixid samples exceeded the 3.0 µg/g dietary effect concentration. During this time period, HgT concentrations in 33 percent of aquatic bird eggs and 82 percent of juvenile bird liver samples exceed toxic thresholds identified by Zillioux et al. (1993).

SUMMARY AND MANAGEMENT IMPLICATIONS

Summary

In 1999, the Nevada Fish and Wildlife Office of the U.S. Fish and Wildlife Service and the Superfund Division, U.S. Environmental Protection Agency, Region 9 initiated a joint investigation to evaluate extent and severity of mercury contamination in ecologically important wetlands in Lahontan Valley, Nevada. HgT and MeHg concentrations were determined in water and sediment in major wetlands on Stillwater and Fallon NWR's and in aquatic invertebrates (*Corisella* spp.) collected from important wetlands throughout Lahontan Valley.

Previous investigations found that HgT is widely distributed in sediment in Lahontan Valley. Severe sediment contamination in the agricultural drainage system generally corresponded to Carson River channels that existed between the mid-1800's and the construction of Lahontan Dam in 1915. We found greater HgT concentrations in sediment from wetlands that historically received inflow from Carson River channels that existed during this period. HgT concentrations progressively declined in sequential wetlands. However, HgT concentrations in all wetlands on Stillwater NWR, including those created in the 1940's, exceeded background concentrations. A gradient of HgT concentrations in sediment was apparent in constructed wetlands. MeHg concentrations in sediment correlated with HgT concentrations in sediment and a gradient in concentration was apparent. The percent MeHg declined with increasing concentrations. No statistical difference in sediment MeHg concentrations was found between historical and constructed wetlands. A weak negative relationship was found between MeHg concentrations in sediment and water column pH.

The bulk of HgT and MeHg in the water column existed in a particulate phase. The

proportion of HgT and MeHg in the water column increased with turbidity. Accordingly, HgT in the water column corresponded with turbidity and HgT in the underlying sediment. Factors controlling MeHg in the water column are not apparent. Similar to sediment, no difference in water column MeHg was found between historical and constructed wetlands.

The bulk of HgT in corixids existed as MeHg. MeHg in corixids correlated with MeHg in sediment, suggesting that sediment plays a key role in the biological availability of mercury in Stillwater NWR wetlands. As with sediment, we found a weak relationship between MeHg in corixids and water column pH. As such, alkaline conditions may provide some level of protection from mercury in Lahontan Valley wetlands. Bioaccumulation factors for MeHg from sediment to corixids ranged from less than 100 to more than 2,000 times. Within Stillwater NWR, BAFs and subsequently corixid MeHg concentrations were significantly greater in constructed wetlands. MeHg concentrations in other Lahontan Valley wetlands followed a similar pattern with the highest concentrations found in corixids collected from created wetlands.

The transport of HgT to Stillwater NWR in wetland supply water is continuing. Concentrations in agricultural drainwater tend to be greater than irrigation-quality water. Loads of mercury entering Lahontan Valley wetlands may substantially increase following flood events in the Carson River. Transport and deposition of HgT through sequential wetlands is evidenced by concentration gradients. Because existing water control structures prevent the migration of bottom materials, the redistribution of HgT on the refuge is likely attributed to movement of particulate Hg in the water column.

HgT and MeHg concentrations in water, sediment, and corixids present a risk to fish and wildlife on Stillwater NWR, Fallon NWR, and other wetlands in Lahontan Valley. In 1999, MeHg concentrations in about half of the corixid samples exceeded concentrations associated with long-term reductions in avian productivity. However, concentrations were well below levels associated with major toxic effects. MeHg concentrations in corixids and, therefore, risk to insectivorous fish and birds appears to be greater in constructed wetlands despite having significantly lower HgT concentrations in sediment. Long-term variability in HgT concentrations in biota has been observed. As such, risks to migratory birds and other wildlife may vary over time. Causal mechanisms are uncertain.

Management Implications

Based on the findings of this and other recent studies, several points relevant to the management of Stillwater NWR and other Lahontan Valley wetlands are available.

1) Substantial amounts of mercury were deposited in Lahontan Valley prior to regulation of the Carson River. However, the transport of mercury to Stillwater NWR via water supply is continuing. The redistribution of mercury on the refuge via water movement between wetlands has also continued. The movement of turbid waters between wetlands may promote HgT redistribution.

2) Flood conditions in the Carson River upstream of Lahontan Reservoir may substantially increase the load of HgT transported to wetlands in Lahontan Valley. Selective management of flood waters may reduce HgT deposition in selected wetlands.

3) The availability of mercury to aquatic invertebrates appears to be controlled by MeHg in sediment. HgT concentrations in sediment and water do not appear to provide a suitable indicator of biological risk of mercury in Lahontan Valley wetlands. As such, selective wetland management based on HgT concentrations in sediment does not appear to be an effective remedial strategy for Stillwater NWR.

4) The proportions of MeHg of HgT in sediment and MeHg availability to aquatic invertebrates (e.g., BAF) were greater in constructed wetlands despite having lower sediment HgT concentrations. As a result, mercury risk to fish and wildlife appears to be greater in constructed wetlands.

5) Alkaline conditions in Lahontan Valley wetlands or related factors may provide some degree of protection against mercury availability or toxicity. More information is needed to assess the significance of pH and other related factors and the implications to wetlands management.

6) HgT concentrations in biological samples from Lahontan Valley wetlands have fluctuated over the past decade. Variability may be related to changes in hydrologic conditions within wetlands. The effects of changes in hydrologic conditions on rates of mercury methylation, demethylation, and MeHg retention in Lahontan Valley wetlands are uncertain. More information is needed to assess implications of changes in hydrologic conditions (e.g., moist soil management) to mercury availability and ecological risk in Lahontan Valley.

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