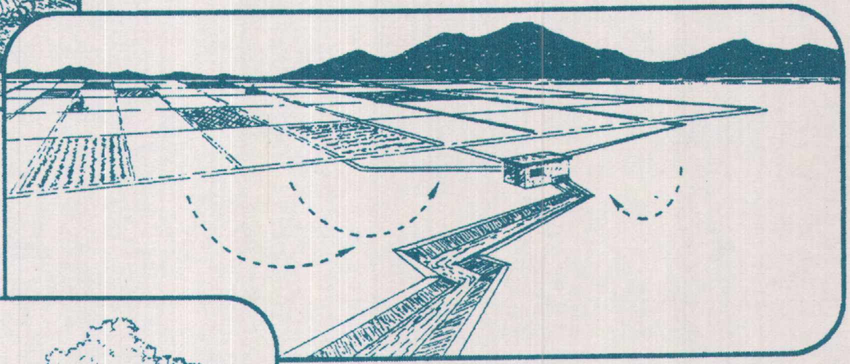
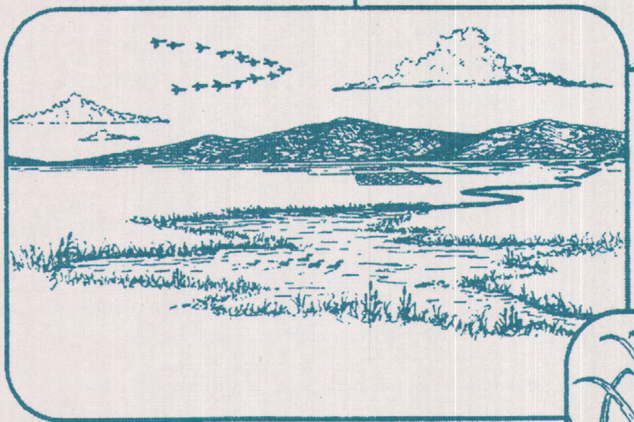
Monitoring of Inorganic Contaminants Associated With Irrigation Drainage in Stillwater National Wildlife Refuge and Carson Lake, West-Central Nevada, 1994–96





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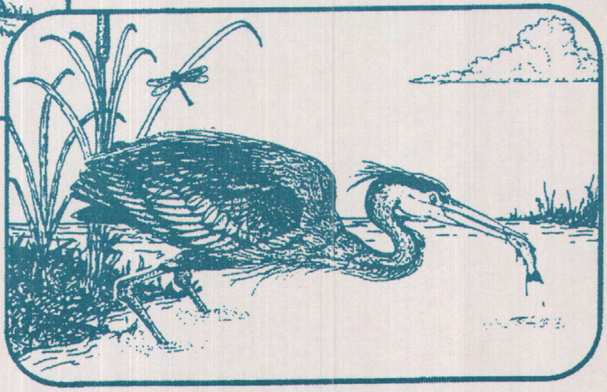

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Monitoring of Inorganic Contaminants Associated With Irrigation Drainage in Stillwater National Wildlife Refuge and Carson Lake, West-Central Nevada, 1994–96

By PETER L. TUTTLE, RAY J. HOFFMAN, STANLEY N. WIEMEYER, and JOHN F. MIESNER

U.S. GEOLOGICAL SURVEY

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Prepared in cooperation:
U.S. GEOLOGICAL SURVEY
U.S. FISH AND WILDLIFE SERVICE
BUREAU OF RECLAMATION
BUREAU OF INDIAN AFFAIRS

Carson City, Nevada
2000

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

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CONVERSION FACTORS, WATER-QUALITY UNITS, VERTICAL DATUM, AND ACRONYMS

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
ounce (oz)	29.57	milliliter
pound (lb)	0.4536	kilogram
pound per day (lb/d)	0.4536	kilogram per day
square mile (mi^2)	2.590	square kilometer
ton	907.2	kilogram
ton per day (ton/d)	907.2	kilogram per day

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).

Water-quality units used in this report:

mg/L	milligrams per liter
µg/g	micrograms per gram
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius

Concentrations of trace elements in unfiltered water are expressed in micrograms per liter; trace-element concentrations in bottom sediment and biological samples are expressed in micrograms per gram on a dry-weight basis unless otherwise indicated herein.

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929, formerly called "Sea-Level Datum of 1929"), which is derived from a general adjustment of the first-order leveling networks of the United States and Canada

ANOVA	Analysis of Variance
IBI	Index of Biological Integrity
NDEP	Nevada Division of Environmental Protection
NDW	Nevada Division of Wildlife
NIWQP	National Irrigation Water Quality Program
NWR	National Wildlife Refuge
USDI	U.S. Department of the Interior
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WMA	Wildlife Management Area

Monitoring of Inorganic Contaminants Associated With Irrigation Drainage in Stillwater National Wildlife Refuge and Carson Lake, West-Central Nevada, 1994–96

By Peter L. Tuttle[1], Ray J. Hoffman[2], Stanley N. Wiemeyer[1], *and* John F. Miesner[1]

Abstract

In 1994, the U.S. Geological Survey and the U.S. Fish and Wildlife Service initiated a 3-year drain-water- and wetland-monitoring program in Lahontan Valley, Nevada, as part of the National Irrigation Water Quality Program of the U.S. Department of the Interior. The purpose of the monitoring was to (1) develop a long-term hydrologic and biologic data base, (2) provide a baseline to evaluate the effects of Federal activities on water quality, wetland quality, and biota in the area, and (3) identify progress toward remediation of contaminant concerns in Lahontan Valley wetlands. Specific data collected included drain-water quantity and quality; trace-element concentrations in water, sediment, and biological samples from wetlands; aquatic-invertebrate and fish diversity and relative abundance in wetlands; fish condition; bird use of wetlands; acreage of major wetland habitat types; and toxicity of water to test organisms.

Consistent with previous National Irrigation Water Quality Program investigations, some inorganic contaminants exceeded applicable beneficial-use criteria or levels of biological concern during 1994–96. Water flowing in some agricultural drains into the wetlands contained concentrations of dissolved boron and molybdenum and total mercury that frequently exceeded applicable beneficial-use criteria. Loads of dissolved solids, boron, and mercury were greatest during the irrigation season coincident with increased flow. In the wetlands of Stillwater National Wildlife Refuge, aluminum, arsenic, boron, lead, mercury, molybdenum, and zinc in unfiltered water samples exceeded State and(or) Federal criteria for the protection of designated beneficial uses of water; arsenic and mercury in sediment exceeded potentially toxic levels; and aluminum, boron, mercury, and zinc in biological tissues exceeded levels associated with lethal or sublethal effects on fish and wildlife. Concentrations of selenium generally were below levels of biological concern in all sample media.

Invertebrate-community species composition and community structure varied among wetlands and among years. Dominant invertebrate taxa were classified as moderately to highly tolerant of pollutants. Concentrations of arsenic, boron, and molybdenum in unfiltered water and arsenic, mercury, and possibly selenium in sediment collected from wetlands correlated with effects on aquatic invertebrate communities. Fish species assemblages, which consisted of one native species and four introduced species, also varied among years and among wetlands. Fish species present were classified as moderately tolerant to tolerant of pollutants. Measures of fish condition were inconsistent among species and among wetlands. The presence of larval fish suggested successful fish reproduction in Lahontan Valley wetlands. Bird use of wetlands also varied among wetlands and among years.

Wetland-habitat acreage increased over the course of this investigation. The increase was attributed to regional climatic patterns and the increase of water flow to wetlands during the 1994–96 study. Corresponding to increased water inflow, the areal extent of open water and associated emergent-vegetation habitats also increased.

Specific conductance, a surrogate measure of dissolved-solids concentration, appeared to be a useful variable to monitor the levels of salinity and certain potentially toxic trace elements in drains and wetlands of Lahontan Valley.

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[1] U.S. Fish and Wildlife Service
[2] U.S. Geological Survey

INTRODUCTION

Background

For the past decade or so, irrigation-induced water-quality problems have been of increasing concern. For example, research by the U.S. Fish and Wildlife Service (USFWS) in the Western United States has related incidents of aquatic-bird and fish mortality, embryo teratogenesis, and reproductive failures to high concentrations of selenium in irrigation drain water (Presser and Ohlendorf, 1987; Seiler and others, 1999). These adverse effects on fish and wildlife were first identified in 1983 at Kesterson National Wildlife Refuge (NWR) in western San Joaquin Valley of California, where irrigation drain-water was impounded (National Research Council, 1989). The embryonic abnormalities at Kesterson NWR were ultimately linked to a combination of human-caused and natural phenomena, specifically by the application of irrigation water to soil naturally rich in selenium. In this instance, selenium as selenate was leached from the soil profile and transported to the surface by subsurface drainage and eventually entered the food chain.

In response to widespread concern about the nature and extent of contamination problems associated with irrigation drainage, the U.S. Department of the Interior (USDI) developed the Irrigation Drainage Program in 1985, later renamed the National Irrigation Water Quality Program (NIWQP), and formed an interbureau Task Group on Irrigation Drainage. This group's charge is to address irrigation-induced water-quality problems in areas where USDI has management responsibilities, including (1) irrigation or drainage facilities constructed or managed by USDI, (2) NWR's that receive irrigation drainage water managed by USDI, and (3) areas that receive water from USDI-funded projects and that are used by migratory birds and (or) endangered species. NIWQP is a five-phase program:

- Phase One: data compilation to identify potential problem areas;
- Phase Two: onsite reconnaissance investigation of water, bottom sediment, and biota in identified areas;
- Phase Three: detailed study of selected areas where further assessment was warranted;
- Phase Four: formulation of a written plan of action to correct identified adverse effects of irrigation drainage; and
- Phase Five: implementation of the corrective action to eliminate or alleviate the identified problems.

Phases One through Three are largely the responsibility of the U.S. Geological Survey (USGS) and USFWS, whereas Phases Four and Five are largely the responsibility of the Bureau of Reclamation. In 1986, 9 areas that warranted immediate reconnaissance-level investigation were identified by the Task Group, and later, 17 other areas were added. All 26 study areas are in the Western United States.

Stillwater NWR in Lahonton Valley of west-central Nevada (fig. 1) was one of the initial nine high-priority areas selected for immediate reconnaissance investigation. The results of that study revealed that concentrations of potentially toxic trace elements (arsenic, boron, mercury, and selenium) and dissolved solids likely pose a threat to human health, fish, and wildlife in areas that receive irrigation drainage (Hoffman and others, 1990). Because the reconnaissance investigation was not designed to determine cause-and-effect relations, a detailed study (Phase Three) of the source, transport, and fate of contaminants began in water year 1988. The results of the detailed study indicated that fish and wildlife in the historic wetlands of Lahontan Valley were affected adversely by elevated concentrations of naturally occurring trace elements that were mobilized in the shallow alluvial aquifer by flood-irrigation practices in the area of the Newlands Project, a USDI-sponsored irrigation project (Rowe and others, 1991; Lico, 1992; Hallock and Hallock, 1993; Hoffman, 1994). These waterborne constituents flowed downslope in the subsurface or by drainflow and eventually entered the wetlands and were concentrated further by evaporation and transpiration. Water from some agricultural drains was acutely toxic to aquatic organisms. The drains in the agricultural area, which eventually discharge to wetlands, were also implicated as sites of uptake of selenium and mercury by aquatic organisms. Other contaminants of concern, either singly or in combination, were arsenic, boron, lithium, molybdenum, and perhaps uranium.

In 1990, Congress enacted the Truckee–Carson–Pyramid Lake Water Rights Settlement Act (Title II of Public Law 101–618) to resolve conflicts associated

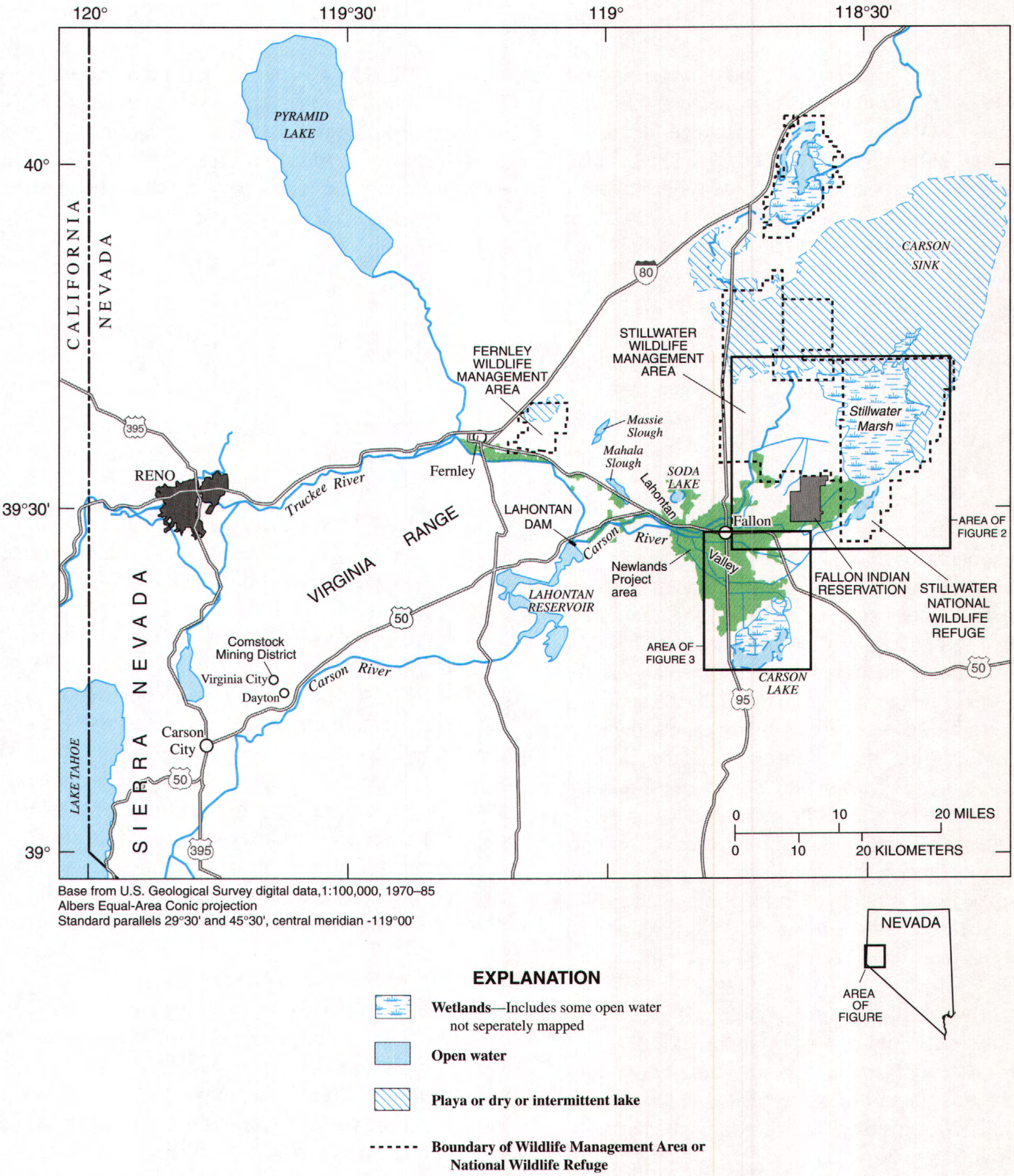


Figure 1. Geographic setting of study area, west-central Nevada.

with increasing water demands in the Truckee River and Carson River Basins. Restoration and protection of ecologically important wetlands in Lahontan Valley was one of many competing uses of water. Section 206 of the law authorized and directed the Secretary of the Interior, in conjunction with the State of Nevada and other parties, 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. Acquired water would be used to support wetlands in the Stillwater NWR, Carson Lake, and the Paiute–Shoshone Indian Reservation at Fallon. Section 206 also authorized the Secretary " * * * to take such actions as may be necessary to prevent, correct, or mitigate for adverse water quality and fish and wildlife habitat conditions attributable to agricultural drain water originating from lands irrigated by the Newlands Project * * * " However, the law also provided for the disposal of agricultural drain water into Stillwater NWR wetlands.

The USFWS began acquisition of water rights under a 1991 "Environmental Assessment and Finding of No Significant Impact," which provided for the acquisition of up to 20,000 acre-ft of water rights from the Newlands Project area. The "Final Environmental Impact Statement" for the Federal Water Rights Acquisition Program was completed in 1996 (U.S. Fish and Wildlife Service, 1996a). Based on analysis of water requirements of various wetland habitat types, the USFWS estimated that 125,000 acre-ft of water was needed to achieve the goal of 25,000 acres of wetland habitat. The "Record of Decision" for water-rights acquisition was signed in November 1996. To achieve that goal, the chosen alternative relies on the acquisition of rights to 75,000 acre-ft of water from the Carson Division of the Newlands Project and the remaining 50,000 acre-ft from the Carson River corridor upstream from Lahontan Reservoir, operational spills from Lahontan Reservoir, treated sewage effluent, water conserved on lands managed by the U.S. Navy, and pumping of ground water near the wetlands. This alternative was chosen because it fulfilled the mandate under Section 206(a)(1) of the law and because it minimized possible adverse effects on farmlands, the local agricultural community, and local ground-water recharge. Under the chosen alternative, an estimated 19,700 acre-ft of Newlands Project drain water would be used to attain the target of 25,000 acres of wetland. Water-quality criteria and water-management practices to minimize contaminant accumulation in wetlands will be addressed in the Stillwater NWR "Comprehensive Conservation Plan" being prepared by the USFWS.

As of August 1998, approximately 29,000 acre-ft of irrigation water rights have been purchased by USDI, the State of Nevada, and other entities. Acquisition of the full amount of water needed to restore and support 25,000 acres of wetlands is not expected to be complete for 15 to 20 years hence.

Purpose and Scope

Federal activities in Lahontan Valley, including the acquisition of water for wetlands and changes in water use within the Newlands Project, are expected to have positive effects on water quantity and quality within the Valley wetlands. Because the type and magnitude of hydrologic changes in the area and the resulting effects on fish, wildlife, and their habitat are uncertain, the NIWQP coordinators indefinitely suspended the Phase Four remedial-planning activities. Additional information was needed to evaluate long-term changes associated with other ongoing activities. Therefore, the coordinators authorized and funded an environmental monitoring program described herein. The objectives of the program are to

- develop a long-term hydrologic and biologic data base for NIWQP;
- evaluate the effects of ongoing Federal activities on water quality, wetland quality, and biota in the area; and
- identify progress toward remediation of contaminant concerns in Lahontan Valley wetlands.

From 1994 through 1996, USGS and USFWS scientists collected physical, chemical, and biological data from surface water at the distal end of the Newlands Project. USGS hydrologists were responsible for collecting data on water quantity and quality from eight sites on principal drains entering wetlands of Stillwater NWR and Carson Lake. These data consisted of (1) instantaneous field measurements of drainflow, water temperature, specific conductance, pH, and dissolved oxygen, (2) continuous measurements of drainflow, water temperature, and specific conductance at selected sites, and (3) concentrations of dissolved solids; dissolved arsenic, boron, lithium, molybdenum; and, at selected sites, total mercury. These data were published by the USGS in the annual water-data reports for water years 1994–96 (Clary and others, 1995; Baurer and others, 1996; Bostic and others, 1997).

USFWS biologists were responsible for collecting hydrologic and biologic data from four representative wetlands, in Lahontan Valley: Dry Lake, Lead Lake, Stillwater Point Reservoir in Stillwater NWR, and Sprig Pond wetland unit of Carson Lake (hereafter may be referred to as Sprig Pond only). These data included (1) trace-element concentrations in water, sediment, and biological samples from wetlands, (2) aquatic-invertebrate and fish diversity and relative abundance, and fish condition, (3) bird use of wetlands, (4) areas of major wetland habitat types, and (5) toxicity of water to test organisms. These data are available from the U.S. Fish and Wildlife Service (1340 Financial Boulevard, Suite 234, Reno, NV 89502–7147) and in "data table" on the Internet at <http://www.usbr.gov/niwqp/datasyn.html>.

This report presents an evaluation of the data collected during the 1994–96 monitoring program.

Acknowledgments

The authors of this report deeply appreciate the assistance provided by Damian Higgins, William Henry, Robert Bundy, and Robert Flores, of the USFWS, and by Rita Whitney, formerly of the USGS, for data collection and data compilation. The initial manuscript was improved greatly by critical-review comments by Kevin Kilbride, USFWS; James Yahnke, Bureau of Reclamation; Thomas Strekal, Bureau of Indian Affairs; and Frank Rinella, USGS.

ENVIRONMENTAL SETTING

A generalized description of the study area, including discussion of history, geology, soils, hydrology, and local climate, were provided by Hoffman and others (1990, p. 3–15) and Hoffman (1994, p. 4–7).

The wetlands of Stillwater NWR and Carson Lake are designated "Class C" waters of the State (Nevada Administrative Code 445A.126), which include "waters or portions of waters located in areas of moderate-to-urban human habitation, [where] industrial development is moderate, agricultural practices are intensive, and the watershed is considerably altered by man's activity." Beneficial uses for Class C waters include "municipal and domestic supply, after complete treatment; irrigation; watering of livestock; aquatic life; propagation of wildlife; recreation involving contact with the water; recreation not involving contact with the water; and industrial supply." Applicable water-quality standards are listed in table 1.

Lahontan Valley is one of the most valuable wildlife areas in the State. The value of the wetlands is largely attributed to their expanse and diversity, which provide habitat for the largest and most diverse assemblage of migratory and wetland-dependent birds in Nevada. Habitat diversity in and wildlife use of Lahontan Valley were described by Thompson and Merritt (1988) and U.S. Fish and Wildlife Service (1996a). One endangered, one threatened, and one candidate bird species for listing as endangered or threatened under the Endangered Species Act of 1973 (16 United States Code–Annotated §§ 1531 to 1544) have been identified in Lahontan Valley (table 2). As many as 70 bald eagles (*Haliaeetus leucocephalus*), a threatened species, commonly winter in Lahontan Valley, and as many as 70 were reported in recent years. In 1997 and 1998, a pair of bald eagles nested at Lahontan Reservoir. Endangered american peregrine falcons (*Falco peregrinus anatum*) have been observed in Lahontan Valley but are considered uncommon migrants in the area (Herron and others, 1985, p. 65). Similarly, mountain plovers (*Charadrius montanus*), a candidate for listing as endangered or threatened, have been sighted only rarely in Lahontan Valley. Of the 19 species of concern (formerly candidates) that have been sighted in Lahontan Valley, 15 commonly are found in wetlands.

Under the Truckee–Carson–Pyramid Lake Water Rights Settlement Act of 1990, Stillwater NWR was expanded to 77,520 acres. Of this acreage, the USFWS estimates that about 14,000 acres will become semipermanent wetland habitat when sufficient water eventually is acquired. However, because of the dynamic nature of wetlands in the Great Basin, owing to human activities and natural climate variability, actual wetland acreage probably will fluctuate. Among other objectives, the refuge is managed for restoration and maintenance of natural biological diversity and for conservation and management of fish, wildlife, and their habitat.

PREVIOUS CONTAMINANT STUDIES

Carson River Mercury

From 1859 to 1900, mercury amalgamation was used in the milling of gold and silver ore from the Comstock Mining District in the Virginia Mountain Range approximately 70 mi west of Stillwater NWR (Smith, 1943). As many as 186 mills, most of which were located near Virginia City and along the Carson River between Carson City and Dayton (fig. 1), were in operation during this period (Ansari, 1989). Nearly 7,500 tons of imported elemental mercury may have been "lost" during milling operations (Bailey and Phoenix, 1944). An unquantified, but probably substantial, amount of mercury entered the river by fluvial processes. Extensive contamination of pre-1900 river channels indicates that a substantial amount of mercury entered Lahontan Valley prior to construction of Lahontan Dam in 1916 (Hoffman, 1994). However, Hoffman and Taylor (1998) demonstrated that transport of mercury into Lahontan Valley is continuing, at least during major floods. An unquantified, but small, amount of mercury is found naturally in the Carson River Basin.

Table 1. Selected regulatory standards applicable to designated waters in Nevada as of 1996

[—, no standard]

Constituent (reporting unit)	Regulatory standard[1]				
	Municipal or domestic supply	Aquatic life	Irrigation	Watering of livestock	Propagation of wildlife
pH (standard units)	5.0–9.0	6.5–9.0	4.5–9.0	6.5–9.0	7.0–9.2
Dissolved solids (milligrams per liter)	1,000	—	—	3,000	—
Chloride (milligrams per liter)	400	—	—	1,500	1,500
Aluminum (micrograms per liter)	—	[2]87	—	—	—
Arsenic (micrograms per liter)	50	[3,4]180	100	200	—
Barium (micrograms per liter)	1,000	—	—	—	—
Beryllium (micrograms per liter)	0	—	100	—	—
Boron (micrograms per liter)	—	—	750	5,000	—
Cadmium (micrograms per liter)	5	([4,5])	10	50	—
Chromium (micrograms per liter)	50	([4,5])	100	1,000	—
Copper (micrograms per liter)	—	([4,5])	200	500	—
Fluoride (micrograms per liter)	—	—	1,000	2,000	—
Iron (micrograms per liter)	—	1,000	5,000	—	—
Lead (micrograms per liter)	50	([4,5])	5,000	100	—
Manganese (micrograms per liter)	—	—	200	—	—
Mercury (micrograms per liter)	2	.012	—	10	—
Molybdenum (micrograms per liter)	—	19	—	—	—
Nickel (micrograms per liter)	13.4	([4,5])	200	—	—
Selenium (micrograms per liter)	50	5	20	50	—
Uranium (micrograms per liter)	[6]20	—	—	—	—
Zinc (micrograms per liter)	—	([4,5])	2,000	25,000	—

[1]From Nevada Administrative Code 445A.119 and 445A.144 except as noted.

[2]Aquatic-life criterion recommended by U.S. Environmental Protection Agency (1998).

[3]Arsenic 96-hour average standards for aquatic life are specific for As^{+3}.

[4]Standard applies to dissolved fraction only.

[5]Standards for aquatic life are based on water hardness, expressed as milligrams per liter of $CaCO_3$. Formulae for 96-hour average standards for specific elements are as follows:

Cadmium:	0.85 exp[0.7852 ln(hardness) – 3.490]
Chromium:	0.85 exp[0.8190 ln(hardness) + 1.561]
Copper:	0.85 exp[0.8545 ln(hardness) – 1.465]
Lead:	0.25 exp[1.273 ln(hardness) – 4.705]
Nickel:	0.85 exp[0.8460 ln(hardness) + 1.1645]
Zinc:	0.85 exp[0.8473 ln(hardness) + 0.7614]

[6]Proposed maximum contaminant level for drinking water.

Elevated mercury concentrations were documented for water, sediment, and biological tissue in the lower Carson River Basin (Van Denburgh, 1973; Richins and Risser, 1975). The contamination extended to the historic wetlands in Lahontan Valley (Cooper and others, 1985, p. 55–57; Hoffman and others, 1990). Although elevated mercury concentrations in the lower Carson River Basin are attributed to historic ore-milling activities upstream, mercury-contaminated sediments have been distributed widely throughout Lahontan Valley by way of canals, laterals, and drains throughout the valley. For example, mercury concentration in various sampled media are elevated in Stillwater Point Reservoir. Constructed in the 1940's, the reservoir primarily received agricultural drainage by way of the Stillwater Point Reservoir Diversion Canal

Table 2. Threatened, endangered, or candidate species and species of concern associated with wetlands in Lahontan Valley, Nevada

Species or subspecies (and common name)	Federal status	Primary habitat
Mammals		
Brachylagus idahoensis (pygmy rabbit)	Species of concern	Riparian areas
Euderma maculatum (spotted bat)	Species of concern	Wetlands, uplands, agricultural fields
Myotis ciliolabrum (small-footed myotis)	Species of concern	Wetlands, uplands, agricultural fields
Myotis evotis (long-eared myotis)	Species of concern	Wetlands, uplands, agricultural fields
Myotis thysanodes (fringed myotis)	Species of concern	Wetlands, uplands, agricultural fields
Myotis volans (long-legged myotis)	Species of concern	Wetlands, uplands, agricultural fields
Myotis yumanensis (yuma myotis)	Species of concern	Wetlands, uplands, agricultural fields
Plecotus townsendii pallescens (pale townsend big-eared bat)	Species of concern	Wetlands, uplands, agricultural fields
Plecotus townsendii townsendii (townsend's big-eared bat)	Species of concern	Wetlands, uplands, agricultural fields
Birds		
Accipiter gentilis (northern goshawk)	Species of concern	Uplands
Athene cunicularia hypugea (western burrowing owl)	Species of concern	Uplands
Buteo regalis (ferruginous hawk)	Species of concern	Uplands
Charadrius alexandrinus (snowy plover)	Species of concern	Wetlands
Charadrius montanus (mountain plover)	Candidate species	Uplands, agricultural fields
Chlidonias niger (black tern)	Species of concern	Wetlands
Falco peregrinus anatum (american peregrine falcon)	Endangered species	Wetlands, uplands, agricultural fields
Haliaeetus leucocephalus (bald eagle)	Threatened species	Wetlands, riparian areas, uplands, agricultural fields
Ixobrychus exilis (least bittern)	Species of concern	Wetlands
Plegadis chihi (white-faced ibis)	Species of concern	Wetlands, agricultural fields
Reptiles		
Clemmys marmorata marmorata (northwestern pond turtle)	Species of concern	Wetlands, riparian areas
Invertebrates		
Limenitus archippus lahontani (nevada viceroy)	Species of concern	Riparian areas
Plants		
Oryctes nevadensis (nevada oryctes)	Species of concern	Uplands

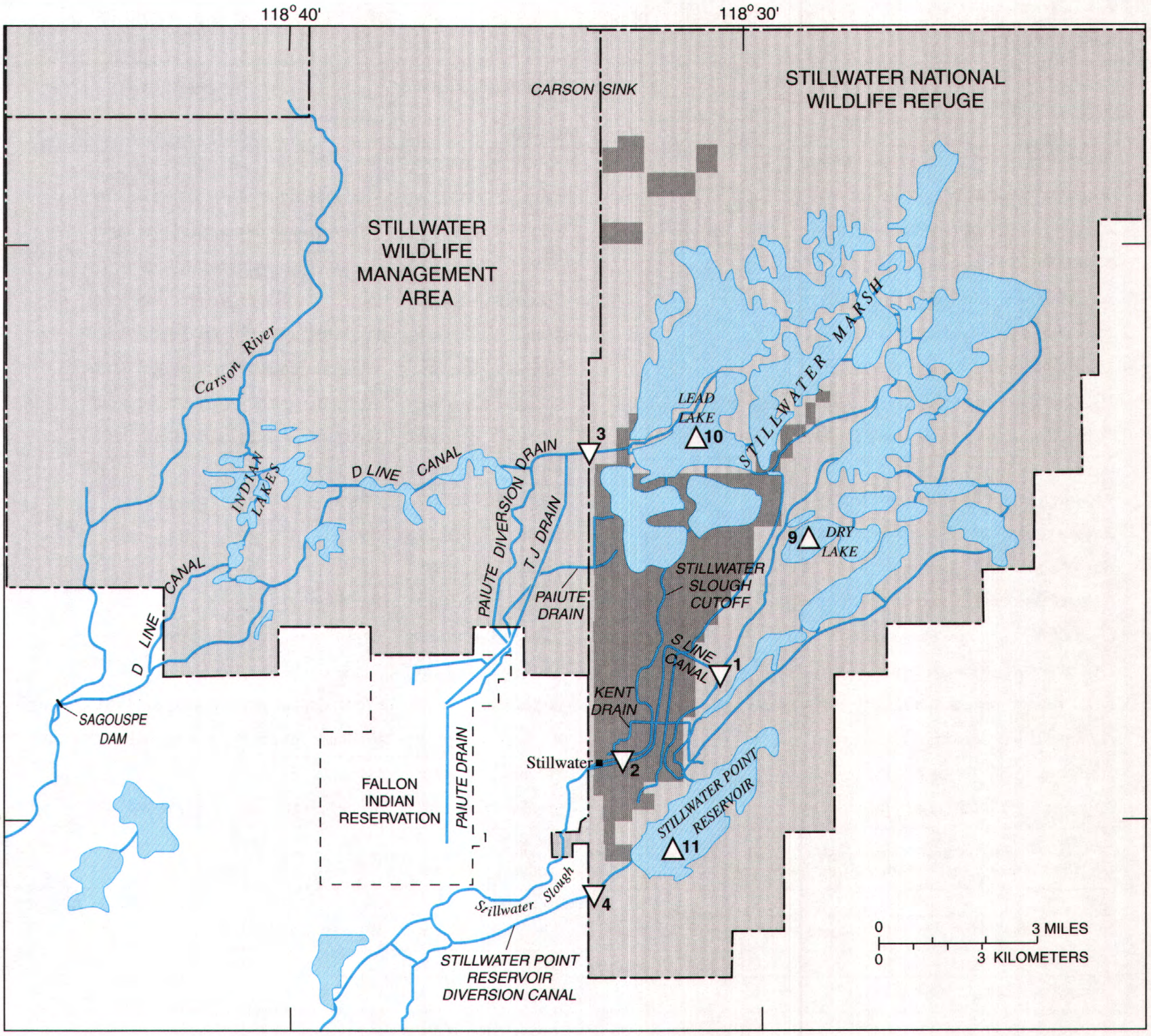
system (fig. 2). Elevated mercury concentrations in edible tissue prompted the State of Nevada to issue consumptive advisories for game fish in the lower Carson River Basin (Cooper and others, 1985) and one species of waterfowl (northern shoveler, *Anas clypeata*) in Carson Lake (Hallock, Burge, and Tuttle, 1993b).

Concern for human health and environmental quality prompted the U.S. Environmental Protection Agency to list the Carson River Mercury Site in 1990 on its National Priority List under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980. The site includes approximately 100 mi of the lower Carson River, including Stillwater NWR (U.S. Environmental Protection Agency, 1991, p. 1).

Agricultural Drainage

The NIWQP scientific activities were begun in 1986 in Lahontan Valley. Findings of the reconnaissance investigation were described by Hoffman and others (1990). Rowe and others (1991) presented physical, chemical, and biological data generated by subsequent NIWQP detailed studies during 1987–89. On the basis of these data, Lico (1992) interpreted physical and geochemical characteristics of the detailed study area, Hallock and Hallock (1993) interpreted biological aspects, and Hoffman (1994) summarized the detailed studies.

In 1990, the USFWS instituted a monitoring program in Stillwater NWR to assess implications of inorganic contaminants for fish, wildlife, and human health



Base from U.S. Geological Survey digital data, 1:100,000, 1970–85
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30', central meridian -119°00'

EXPLANATION

Open water

Wildlife Management Area and National Wildlife Refuge—Privately held lands (mostly the Canvasback Gun Club) shown in dark gray

Sample site—Number used in report

▽4 Drain water

△11 Wetland

Figure 2. Locations of drains entering Stillwater National Wildlife Refuge, other hydrologic features, and sampling sites (table 3). Extent of Stillwater National Wildlife Refuge as existing in 1997 (U.S. Fish and Wildlife Service, written commun., 1997).

and to assess changes in inorganic-contaminant concentrations in wetlands replenished by freshwater and agricultural drainage water (Tuttle and others, 1996). Dissolved solids, as measured by specific conductance, and 12 of 19 chemical elements monitored during the study exceeded levels of concern in 10 percent or more of the water, sediment, and(or) biological samples. Dissolved solids and aluminum, arsenic, boron, mercury, and zinc commonly exceeded concentrations associated with adverse biological effects. Chromium, copper, iron, lead, molybdenum, and selenium were found at levels of biological concern. Mercury, which exceeded recommended levels for human consumption in fish and waterfowl, was the only element that appeared to pose a direct threat to human health.

Lico and Pennington (1997) found that concentrations of dissolved solids and trace elements of concern were generally higher in the nonirrigation season in the Carson Division of the Newlands Project. However, because drainflows were higher, contaminant loads were greater during the irrigation season. The largest loads were delivered to Stillwater NWR. Arsenic, boron, and molybdenum concentrations in drain water commonly exceeded Nevada water-quality standards. Five identified areas near the perimeter of the Carson Division of the Newlands Project appeared to contribute proportionally greater loads of inorganic contaminants to drain water than did other areas investigated.

SAMPLE COLLECTION, MEASUREMENT, AND ANALYSIS

This monitoring effort involved independent sample collection, processing, and laboratory analysis by the USGS and USFWS. The particular techniques of sample collection, measurement, and analysis used by the two agencies are described in the next two sections: "Drains Entering Wetlands" presents USGS methods, and "Wetland Monitoring," USFWS methods.

Drains and Canals Entering Wetlands

Sampling Sites

The overall monitoring program consisted of collecting trace-element data on water, sediment, and biological samples from wetlands and related data on water from principal drains that enter the wetlands. The data-collection procedures used during the monitoring phase of NIWQP were essentially identical to those used during other NIWQP studies, from 1986 to the present. A principal drain is defined herein as a drain that represents a significant component of total flow to a wetlands and(or) was shown by previous work to transport high concentrations of potentially toxic constituents. Eight drain-water sampling sites were selected for their proximity to the wetlands without established backwater. These sites include three drains to Stillwater NWR, one irrigation-water delivery canal (S Line) that empties into Stillwater NWR, and four drains to Carson Lake. For this report, S Line Canal may be considered a drain (table 3; figs. 2 and 3).

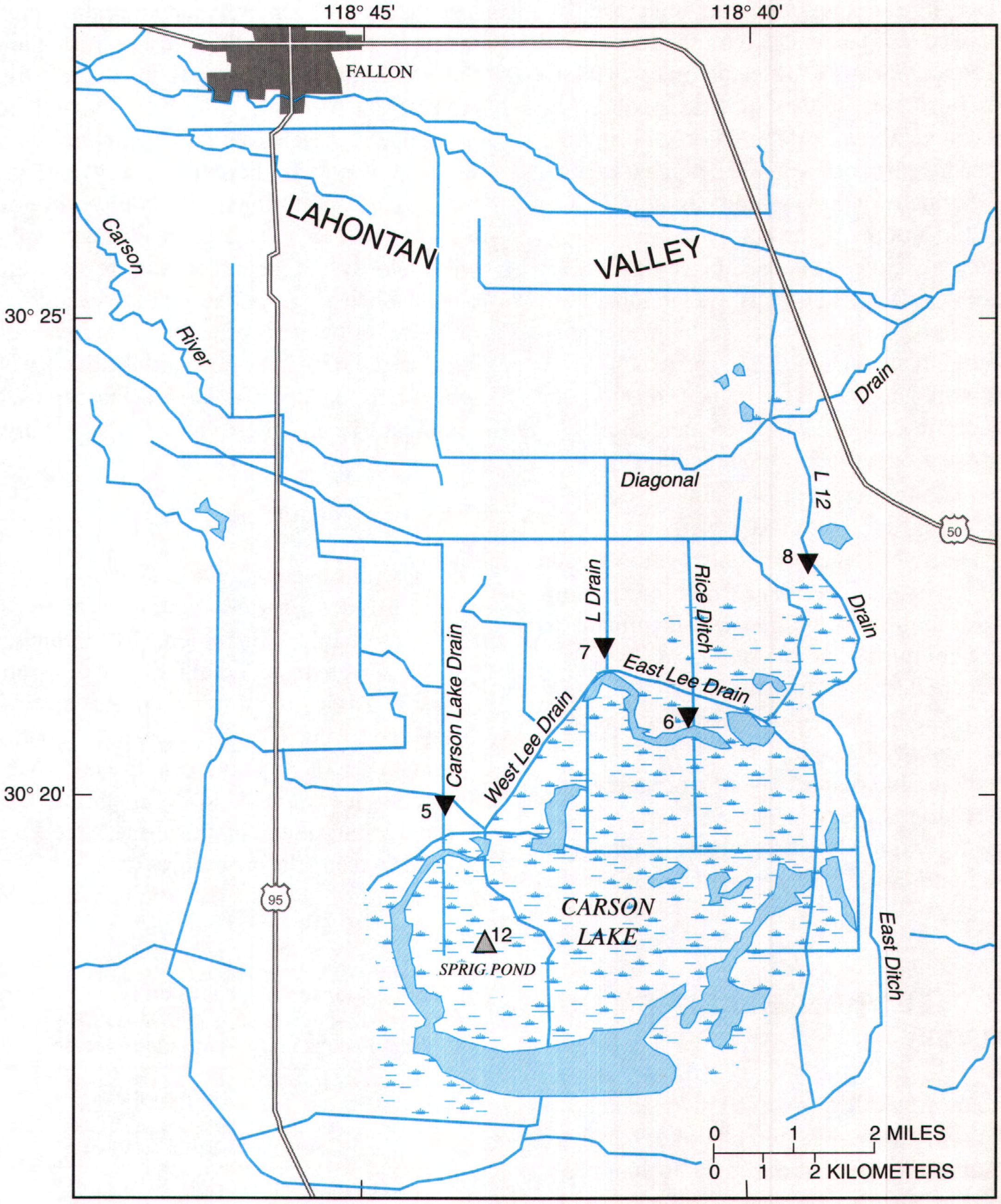
Table 3. Measurement sites on agricultural drains entering and in wetlands in Stillwater National Wildlife Refuge and Carson Lake, Nevada, 1994–96

Measurement site[1,2]	Agricultural drain or wetland
Stillwater National Wildlife Refuge[1]	
1	S Line Canal
2	Stillwater Slough
3	Paiute Diversion Drain below TJ Drain
4	Stillwater Point Reservoir Diversion Canal
9	Dry Lake
10	Lead Lake
11	Stillwater Point Reservoir
Carson Lake[2]	
5	Carson Lake Drain
6	Rice Ditch
7	L Drain
8	L 12 Drain
12	Sprig Pond

[1]See figure 2.
[2]See figure 3.

Drainflow Measurements

Drainflow quantity was determined by using the procedures described by Rantz and others (1982a). Electromechanical instruments to continuously record drainflow were installed at Paiute Diversion Drain below TJ Drain, Stillwater Point Reservoir Diversion Canal and S Line Canal. These instruments were checked periodically and recalibrated by onsite current-meter measurements. Computation of time-series drainflow measurements for these three sites was performed by using the procedures described by Rantz and others (1982b). For the five stations (table 3) without



Base from U.S. Geological Survey digital data, 1:100,000, 1970–85
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30', central meridian -119°00'

EXPLANATION

Open water

Wetland

Sampling site—Number used in report

8 ▼ Drain water

12 △ Wetland

Figure 3. Surface-water and bottom-sediment sampling sites (table 3) in and near Carson Lake. Diagonal Drain is informal local name that includes Lower Diagonal and Upper Diagonal Drains. Carson Lake Drain is also known locally as Cabin Drain.

continuously recording apparatus, drainflow was measured by using a current meter at the time of visit, usually monthly. Additional current-meter measurements of instantaneous drainflow to Carson Lake were made by the Bureau of Reclamation as part of another program. (Any onsite field measurements made by a hydrographer are called instantaneous herein).

Water-Quality Measurements, Water-Sample Collection, and Laboratory Analyses

Onsite determinations of specific conductance, temperature, barometric pressure, dissolved oxygen, pH, carbonate, bicarbonate, and total alkalinity, were measured according to the methods described by Wilde and Radtke (1998). Instruments for continuously recording specific conductance, a surrogate measure of dissolved-solids concentration, were used at the four drains entering Stillwater NWR and two drains entering Carson Lake (Carson Lake Drain and Rice Ditch). The instruments were maintained according to procedures described by Gordon and Katzenbach (1983). As with the drainflow monitors, these instruments were checked periodically and recalibrated onsite. Water-quality samples from the drains were collected and processed by the procedures described by Ward and Harr (1990) and Horowitz and others (1994). Arsenic, boron, lithium, and molybdenum were determined in water samples from all sites. The samples were filtered through a 0.45-micrometer-pore-size prerinsed filter (operationally defined as "dissolved") and then acidified to pH≤2 by adding concentrated nitric acid. Water samples for mercury determinations were collected at two sites, Stillwater Point Reservoir Diversion Canal and Stillwater Slough. Chemical analysis for mercury was done on whole-water samples that had been collected in acid-rinsed glass bottles and acidified immediately after collection by adding concentrated potassium dichromate/nitric acid. All drain-water samples were sent to the USGS National Water Quality Laboratory in Denver, Colo., for chemical analyses using the procedures described by Fishman and Friedman (1989) and Fishman (1993).

Statistical Analyses

Statistical data analysis generally was based on procedures described by Helsel and Hirsch (1992). Techniques to estimate missing specific conductance and boron concentrations included direct substitution, linear interpolation, and regression analysis, or a combination of the three depending on the length of missing record and other data. With the exception of L 12 Drain (table 3), measurements of specific conductance and dissolved-solids concentration were plotted for all sites to establish regression equations for each site. Because of the lack of measured dissolved-solids data for L 12 Drain during 1994, specific-conductance values were multiplied by a coefficient of 0.61, the mean of dissolved-solids coefficients (table 4), to obtain an equivalent dissolved-solids concentration for that year (Hem, 1985, p. 66–69). As with dissolved-solids concentration, a regression equation was developed for specific conductance and boron for each site, including L 12 Drain. Specific conductance was plotted as the independent variable, and dissolved-solids or boron concentration as the dependent variable. For each of the linear regressions, an equation was developed to estimate a dissolved-solids or boron concentration for a given specific-conductance measurement. The regression equations (table 4) were then used to compute the monthly mean dissolved-solids or boron concentrations from the monthly mean specific-conductance values, which were determined from the continuous specific-conductance record. Residuals from each regression were plotted versus the predicted values. Because neither curvature nor changing variance was observed, the simple-regression models appear to be good representations (Helsel and Hirsch, 1992, p. 221–263). Daily loads of dissolved solids and boron for Stillwater Slough and the four drains entering Carson Lake are the mathematical product of instantaneous flow, and instantaneous concentration. Load data were divided between the 5-month nonirrigation season and the 7-month irrigation season. Because the two seasons are unequal in length, daily loads also were calculated.

Seasonal load determinations for arsenic, lithium, and molybdenum were not attempted because of the known poor relation between concentrations of these trace elements and concentrations of dissolved solids in the study area (Lico and Pennington, 1997, p. 19–21).

Quality Control

Quality control of drainflow measurements consisted of current-meter spin tests, independent checks of arithmetic computations, and complete analysis of the station records for the measurement period. Quality control of drain-water samples in the field consisted of

Table 4. Linear-regression equations of dissolved-solids and boron concentrations in relation to specific conductance for drains entering Stillwater National Wildlife Refuge and Carson Lake, Nevada, 1986–96

[S, specific conductance per centimeter at 25 degrees Celsius. —, not calculated]

Agricultural drain	Dissolved solids (milligrams per liter)	Coefficient of determination, r^2	Number of samples	Dissolved boron (micrograms per liter)	Coefficient of determination, r^2	Number of samples
Stillwater National Wildlife Refuge						
S Line Canal	(0.579 S) + 15.1	99.7	10	(1.10 S) – 100	94.8	11
Stillwater Slough	(0.618 S) – 39.9	99.6	22	(1.00 S) + 97	99.4	21
Paiute Diversion Drain below TJ Drain	(0.687 S) – 295	99.3	18	(0.868 S) – 360	98.4	17
Stillwater Point Reservoir Diversion Canal	(0.624 S) – 35.1	99.6	20	(1.04 S) + 6.2	99.5	16
Carson Lake						
Carson Lake Drain	(0.611 S) – 4.9	99.0	22	(1.69 S) – 537	96.7	21
Rice Ditch	(0.598 S) + 8.6	99.1	17	(1.20 S) – 168	97.8	17
L Drain	(0.569 S) + 33	99.3	19	(1.10 S) – 103	98.8	19
L 12 Drain	([1])	—	—	(1.08 S) – 123	93.8	13

[1]See section titled "Drains Entering Wetlands of Carson Lake" in text.

equipment blanks, field blanks, and replicate samples (Horowitz and others, 1994). For statistical summaries, only one value from replicate samples was used to preclude biasing the data set. The results of the quality-control samples, published by the USGS in the annual water-data reports for water years 1994–96 (Clary and others, 1995; Bauer and others, 1996; Bostic and others, 1997), indicate that inadvertent contamination of the environmental samples either did not occur or was inconsequential considering the elevated ambient concentrations found in the study area. The published results also indicate that the replicate data show acceptable precision; the respective constituent concentrations were for the most part nearly identical. Quality-control practices of the USGS National Water Quality Laboratory were described by Pritt and Raese (1995).

Wetlands

Sampling Sites and Sampled Media

Sampling sites included Dry Lake (no. 9), Lead Lake (no. 10), and Stillwater Point Reservoir (no. 11) in Stillwater NWR and the Sprig Pond unit (no. 12) in Carson Lake (figs. 2 and 3). Data were collected from May through July each year. Within each study wetland, water-quality measurements and samples of sediment, detritus, vegetation, and invertebrates were collected for trace-element residue analysis from five randomly selected locations within a permanent study plot that measured 327 by 327 ft. Water samples were collected at three of these locations. Fish and bird samples were collected as near as possible to the study plot. Numbers of each sampled media collected during each year of the monitoring program are listed in table 5.

Water-Quality Measurements, Sample Collection, and Laboratory Analyses

Wetland water-quality measurements of specific conductance, pH, temperature, and dissolved oxygen were made onsite by using standard meters, probes, and electrodes. Temperature was measured by using a hand-held thermometer. Whole (unfiltered) water was hand dipped in the middle of the water column using 250-ml plastic bottles and acidified to pH$\leq$2.0. Sediment and detritus were collected by using a 2-in-diameter coring device and then placed in a precleaned 500-ml plastic container. Sediment samples included the top 2 in. of the core, whereas detritus samples included only the top 0.75 in. Each sediment and detritus sample consisted of a composite of five subsamples that were thoroughly mixed by using a stainless-steel knife. Pondweed (*Potamogeton* spp.) samples were collected by hand. Hemiptera samples were collected by using a kick net, placed in precleaned 500-ml plastic containers, and later sorted from unwanted debris in the laboratory. Fish were collected by using unbaited minnow traps and hoop nets. The fish were put in plastic bags and later processed. American coot (*Fulica americana*)

Table 5. Number of samples of water, sediment, detritus, and biota collected for trace-element concentrations in four wetlands in Lahontan Valley, Nevada, 1994–96

[—, no sample collected]

Wetland	Year	Number of Samples									
		Water	Bottom sediment	Detritus	Pondweed	Hemiptera	Fish	Coot egg	Avocet egg	Coot liver	Avocet liver
Stillwater National Wildlife Refuge											
Dry Lake:											
	1994	3	5	—	5	4	—	2	—	5	3
	1995	3	5	5	5	4	4	5	—	5	—
	1996	3	5	5	5	5	5	6	5	5	2
Lead Lake:											
	1994	3	5	—	5	5	—	5	2	—	5
	1995	3	5	5	5	2	1	5	—	5	—
	1996	3	5	5	5	5	5	7	3	5	3
Stillwater Point Reservoir:											
	1994	3	5	—	5	2	5	5	5	5	5
	1995	3	5	5	5	1	5	5	—	5	—
	1996	3	5	5	5	1	5	3	1	5	—
Carson Lake											
Sprig Pond:											
	1994	3	5	—	5	5	2	5	5	5	5
	1995	3	5	5	5	2	5	5	5	5	4
	1996	3	5	5	5	4	—	5	8	5	5

and american avocet (*Recurvirostra americana*) eggs were collected by hand and placed in a carton, stored on ice in the field, and later opened by using precleaned stainless-steel instruments in the laboratory. Embryos were inspected for gross abnormalities. Juvenile coots and avocets were collected by using a shotgun and steel shot and were placed in plastic bags. Livers from the birds were removed later in the laboratory. Preflighted juveniles were collected to study exposure to, and accumulation of, trace elements that occur in the study wetlands. All samples were stored on ice in the field. Sediment, detritus, and biological samples were placed in precleaned glass jars with Teflon-lined closures in the field or laboratory and subsequently were frozen.

All chemical analyses were done by the Environmental Trace Substances Research Center, Columbia, Mo., by methods described by U.S. Fish and Wildlife Service (1990, p. 3.9). Arsenic and selenium concentrations were determined by hydride-generation atomic-absorption spectroscopy. Mercury concentrations were determined by cold-vapor atomic-absorption spectroscopy. Concentrations of aluminum, barium, beryllium, boron, cadmium, chromium, copper, iron, lead, magnesium, manganese, molybdenum, nickel, strontium, vanadium, and zinc were determined by inductively coupled plasma-emission spectroscopy.

Quality Control

Interlaboratory quality-control techniques included the use of procedural blanks, duplicate samples, spiked samples, and reference materials. Quality control and laboratory performance at the Environmental Trace Substances Research Center were assessed and approved by the U.S. Fish and Wildlife Service (1990, p. 6.6); laboratory performance was within the prescribed precision range.

Toxicity Tests

During 1994–96, Microtox toxicity testing was used to assess toxicity of all water samples. Microtox testing provides a rapid assessment (5- and 15-minute procedures) of the relative toxicity of water samples by using a strain of photoluminescent marine bacteria, *Photobacterium phosphoreum*, as a test organism.

The Microtox instrument measures bacterial luminosity, which is assumed to be a measure of metabolic activity. A decrease in luminosity after exposure of the bacteria to a water sample is interpreted as a depression in metabolic activity and therefore provides an indicator of toxic response. Toxicity is expressed as the median concentration eliciting a 50-percent reduction in light output (EC_{50}); an EC_{50} of 100 percent or greater indicates that no effect on metabolic activity (and hence no toxicity) was observed in an undiluted sample. Procedures for Microtox assessment of water samples were described by Henry and Hickey (1991, p. 7). Wetland water samples used for Microtox testing were collected at the same time and locations as wetland water collected for trace-element analysis.

Remote Sensing of Wetland Habitats

Aerial photographs (1:12,000 scale), taken in August 1994, August 1995, and September 1996, were used to quantify wetland plant habitats and open water in Stillwater Marsh, including Canvasback Gun Club lands (fig. 2), and Carson Lake. The plants in wetland habitats include emergent vegetation, such as cattails (*Typha* spp.) and bulrush (*Scirpus* spp.), and wet-meadow vegetation, such as rushes (*Juncus* spp.) and saltgrass (*Distichlis* spp.). Color aerial photographs taken in 1994 provide poor definition of habitat types; infrared photographs taken in subsequent years better define the areas. Areal extent of wetland plant habitats and open water were determined by using a commercial computer software program to digitize both the natural color and infrared aerial photographs.

Aquatic Invertebrate Community

Benthic and nektonic invertebrates were collected at locations where the samples of sediment for chemical analysis were collected. Benthic invertebrates were collected by using a coring sampler. Each sample consisted of a composite of 10 sediment samples collected at a depth of 2 in. Samples were sieved through an 800-μm nylon mesh. Nektonic invertebrates were collected by using a kick net, which had an opening measuring 8 by 18 in. and an 800-μm mesh size. Nektonic invertebrates were collected by towing the kick net along ten 3-ft transects in the middle of the water column. Benthic and nektonic samples were stored in 500-ml plastic containers on ice in the field and transported to the laboratory, where they subsequently were frozen. The samples later were thawed for processing. Invertebrates were removed from debris, placed in 70-percent ethyl alcohol, and tentatively identified to family level. Taxonomic classification initially was based on Pennak (1989) and later was modified to conform to the federal standard data base, the Interagency Taxonomic Information System (accessible via URL <http://www.itis.usda.gov>). Taxa richness, heterogeneity, and evenness were calculated by methods described by Newman (1995, p. 293–300).

Fish-Community Structure and Condition

Passive fish-capture techniques (trapping) were used to collect fish because the electroshocking was ineffective in highly conductive water and the seining was hampered by the high densities of emergent and submergent vegetation. In all three years, 42-by-22-cm oval minnow traps with 3-cm openings were used. In each wetland each year, at least 15 traps were set to collect fish for a minimum of 24 hours. In 1996, 1-cm-mesh hoop nets also were used in each wetland; they were set for a minimum of 50 hours and checked at 24-hour intervals. Because of inconsistent methodologies, fish-capture data from 1994 were not included in the data analysis.

All captured fish were identified to species and counted. As many as 50 fish from each wetland were measured and weighed and examined for gross external aberrations. Fulton's condition factor was used to provide a relative measure of well-being of a selected size group of representative fish from each wetland (Anderson and Gutreuter, 1983, p. 294–295).

Modified Index of Biological Integrity (IBI) methodologies were used to assess the condition of the fish community in study wetlands. IBI methodologies were developed to provide a reproducible method for assessing conditions of stream fish (Miller and others, 1988; Plafkin and others, 1989). Because of obvious differences between stream and wetland fish communities, the use of IBI methodologies herein is intended solely for comparisons of fish-community condition among the four study wetlands and to provide a baseline for future comparisons. To calculate IBI scores, nine measures (metrics) related to fish-species composition, trophic status, and fish abundance and condition were adapted from Miller and others (1988, p. 14–15) and Plafkin and others (1989, p. 7.12–7.20): (1) number of native fish species, (2) number of benthic fish species, (3) proportion of tolerant individuals,

(4) proportion of omnivores, (5) proportion of insectivores, (6) proportion of top carnivores, (7) total fish abundance, (8) proportion of introduced fishes, and (9) proportion of fish with anomalies. Scoring ranges for the metrics generally are according to Plafkin and others (1989, p. 7.8). Scoring of the metric for analysis of total fish abundance was adapted from IBI methodologies developed for northern California (Miller and others, 1988, p. 15). Tolerance and trophic status of introduced fishes were obtained from Plafkin and others (1989, app. D). Tui chub was classified as tolerant of poor-quality water and omnivorous (Sigler and Sigler, 1987, p. 168). Because of capture methods used by USFWS biologists during 1994–96, fin erosion was not considered an anomaly.

Surveys of Bird Use of Wetlands

Data on bird use of wetlands were collected using point-control methodology (Bibby and others, 1992) along one 3,300-ft permanent transect established in each of the four wetlands. Each transect consisted of five points spaced linearly at 660-ft intervals. Surveys were initiated within 30 minutes after sunrise; 10 minutes was allocated for observation at each point. The transects were sampled monthly on or near the 15th of the month; only one transect was sampled during any sampling day. Sample sessions were July–September 1995 and May–September 1996. All bird species either seen or heard at each point were documented for year, wetland, month, and transect point.

Statistical Analyses

Trace-element concentrations for all sampled media were transformed to common logarithms to improve homogeneity of variance, and geometric means were calculated when a trace element was detected in at least 50 percent of the samples within a given wetland and year. A value equal to one-half the analytical reporting limit was assigned to samples for which a specific trace element was less than the analytical reporting limit.

Two-way analysis of variance (ANOVA) and Tukey's multiple-comparison tests were used to examine relations among wetlands and years of sampling for trace-element concentrations in unfiltered water, sediment, detritus (1995–96 only), vegetation, and coot eggs and livers. If the interaction terms were statistically significant, one-way ANOVA was performed to assess among-year differences within each wetland. Because of limited sample numbers in some wetlands and years, two-way ANOVA was not attempted for hemipterans, fish, and avocet eggs and livers. However, one-way ANOVA was used to assess among-wetlands differences and among-year differences within each wetland. Statistical tests were only performed for media and for years for which three or more samples were available. Two-way ANOVA and Tukey's multiple-comparison test also were used to examine relations among wetlands for invertebrate communities. Again, if interaction terms were significant, one-way ANOVA was performed for wetlands and for years.

Pearson's chi-square test (correlation coefficient) was used to examine relations between trace-element concentrations in unfiltered water, sediment, detritus, and aquatic vegetation and invertebrates. Because fish and bird species were not relegated to specific sampling points within each wetland, arithmetic means were used to examine relations among residue concentrations in these and other media.

RESULTS AND DISCUSSION OF MONITORING PROGRAM

The primary purpose of monitoring selected wetlands and agricultural drains entering the wetlands in Lahontan Valley during 1994–96 was to establish an adequate baseline to enable assessment of future trends in water quantity, water and habitat quality, and trace-element contamination. The abundant baseline information on water quantity and quality, trace-element concentrations in abiotic and biotic wetland components, toxicity of water, and abundance and distribution of wetland vegetation, invertebrate, fish, and bird life generated during the Lahontan Valley wetland monitoring provides insight to the current status of the valley's wetland system.

Water Supply

The principal water supply for irrigation in the Newlands Project area in Lahontan Valley is Lahontan Reservoir. Constructed in 1915 and filled in 1916, the reservoir has a maximum storage capacity of about 317,000 acre-ft with flashboards and an operational capacity of about 295,000 acre-ft without flashboards (Carol Grenier, Bureau of Reclamation, 1998, written commun.). Historically, the irrigation season in the area has been from March 15 through November 15. However, most releases from the reservoir—about 88 percent of total annual flow—have been from April 1 through October 31. For this report, the irrigation season is defined as the 7-month period from April through October.

A comparison of period-of-record monthly mean streamflow (1966–96) with calendar year 1994, 1995, and 1996 irrigation season is listed in table 6. These data show that releases from the reservoir during the 1994–96 irrigation seasons ranged from about 60 to 130 percent of the long-term average, thus representing a fairly wide range of flow conditions within which to interpret the environmental data collected during the 3-year monitoring program, during which the greatest irrigation-season flow was in 1995. During the 1994, 1995, and 1996 water years (October through September), total flow from the reservoir was about 230,000, 410,000, and 450,000 acre-ft, respectively, compared to the long-term (1967–96) average of about 370,000 acre-ft/yr. For the period 1975–87, on average, about 46 percent (range, 23 to 59 percent) of the water released annually from Lahontan Reservoir actually reached farm headgates owing to operational spills and conveyance loss (Maurer and others, 1994, p. 20). During the nonspill years 1988–92, after implementation of the 1988 Bureau of Reclamation Operating Criteria and Procedures, about 59 percent of released water reached farm headgates (Carol Grenier, Bureau of Reclamation, written commun., 1998). Of the water available for irrigation, about 35 percent reaching the headgates subsequently is discharged to downstream wetlands as irrigation return flow.

Table 6. Streamflows released from Lahontan Reservoir

[Streamflows were measured at U.S. Geological Survey gaging station about 1.1 mile downstream from Lahontan Dam, west of Fallon, Nev.]

Irrigation season[1] (April–October)	Monthly mean streamflow (cubic feet per second)	Monthly mean streamflow (acre-feet)
1966–1996	770	47,000
1994	470	28,000
1995	1,000	60,000
1996	860	52,000

[1]Historically, irrigation season in Lahontan Valley is March 15–November 15, but majority of releases from Lahontan Reservoir—about 88 percent of total annual flow—are during April 1–October 31. Irrigation season is defined herein as 7-month period April–October.

Drains Entering Wetlands of Stillwater National Wildlife Refuge

Of the principal drains to Stillwater NWR, the ones that were monitored are S Line Canal, Stillwater Slough, Paiute Diversion Drain (called Paiute Drain by the USGS (Clary and others, 1995; Bauer and others, 1996; Bostic and others, 1997), and Stillwater Point Reservoir Diversion Canal (fig. 2). For all sites, the maximum constituent concentrations almost always were in water samples collected prior to irrigation in the spring. None of these sites exactly match those reported by Rollins (1965), thus meaningful comparisons of historic dissolved-solids concentrations (1959–62) to those presented herein cannot be made. With the exception of mercury, statistical summaries of measurements made during each site visit are listed in table 7. (For discussion of mercury, see section "Concentrations and Loads of Total Mercury.")

S Line Canal

This site is along Hunter Road about 2 mi northeast of the community of Stillwater, Nev. (fig. 2), and was instrumented with continuous-flow and specific-conductance recorders. The USFWS used the site to study the effects of the influx of irrigation water (500 mg/L dissolved solids) on the ecology of Dry Lake during its inundation. Water-quality data from the S Line site also can be used as a reference with which to make comparisons with drain-water quality in the study area. Although annual median flows in S Line were virtually identical for the 3 years, a substantial decrease in concentration of dissolved solids and trace elements was recorded in 1995 and 1996 compared to 1994 (table 7). The higher concentrations in 1994 probably reflect the combined effects of evaporative concentration in Lahontan Reservoir (source water for irrigation in the Fallon area), which received little natural runoff during the 1993–94 water years, and reduced inflow to the reservoir, hence less streamflow available for dilution. For example, the median dissolved-solids concentration of 240 mg/L measured in the Carson River just downstream from Lahontan Dam for the sampling period March–October 1994 was about 74 percent greater than the concentrations for the same time period in 1995 and 1996, with medians of 137 mg/L and 138 mg/L, respectively. None of the recorded water-quality data for S Line exceeded existing beneficial-use criteria.

Table 7. Statistical summary of instantaneous drainflow and concentrations of dissolved solids and dissolved trace elements at seven drain sites where water enters wetlands of Stillwater National Wildlife Refuge and of Carson Lake, March–October, 1994–96

[*n*, number of measurements. —, no criterion or otherwise not applicable]

Agricultural drain	Calendar year	Summary statistics	Drainflow (cubic feet per second)	Dissolved solids[1] (milligrams per liter)	Arsenic[2] (micrograms per liter)	Boron[3] (micrograms per liter)	Lithium (micrograms per liter)	Molybdenum[4] (micrograms per liter)
Stillwater National Wildlife Refuge								
S Line Canal:								
	1994	Median	23	292	24	425	39	8.5
		Range	0.63–29	261–400	19–29	370–600	29–46	7–14
		Exceedances[5]	— (*n*=6)	0 (*n*=6)	0 (*n*=6)	0 (*n*=6)	— (*n*=6)	0 (*n*=6)
	1995	Median	22	174	12	180	20	6
		Range	6.6–32	168–238	10–15	170–330	20–40	6–6
		Exceedances[5]	— (*n*=6)	0 (*n*=6)	0 (*n*=5)	0 (*n*=5)	— (*n*=5)	0 (*n*=5)
	1996	Median	22	183	12	172	16	6
		Range	0.08–29	156–216	8–17	160–223	10–20	4.8–7.2
		Exceedances[5]	— (*n*=6)	0 (*n*=6)	0 (*n*=8)	0 (*n*=8)	— (*n*=8)	0 (*n*=8)
Stillwater Slough:								
	1994	Median	3.2	1,180	42	2,250	145	8.5
		Range	1.9–12	680–1,740	38–48	1,200–3,100	85–220	10–29
		Exceedances[5]	— (*n*=8)	0 (*n*=8)	0 (*n*=8)	8 (*n*=8)	— (*n*=8)	7 (*n*=8)
	1995	Median	12	872	35	1,500	100	18
		Range	1.4–16	658–5,520	30–53	1,100–8,000	80–270	16–58
		Exceedances[5]	— (*n*=9)	2 (*n*=9)	0 (*n*=9)	9 (*n*=9)	— (*n*=9)	4 (*n*=9)
	1996	Median	15	746	31	1,120	76	16
		Range	11–22	594–1,140	28–47	910–1,710	60–97	14–23
		Exceedances[5]	— (*n*=8)	0 (*n*=8)	0 (*n*=8)	8 (*n*=8)	— (*n*=8)	3 (*n*=8)
Paiute Diversion Drain below TJ Drain:								
	1994	Median	0.32	6,190	170	9,300	320	320
		Range	0.07–3.8	970–10,900	36–210	1,300–14,000	77–510	34–900
		Exceedances[5]	— (*n*=7)	5 (*n*=7)	—[6] (*n*=7)	7 (*n*=7)	— (*n*=7)	7 (*n*=7)
	1995	Median	7.7	1,320	29	1,500	100	41
		Range	0.12–16	818–13,700	22–180	1,000–17,000	70–510	21–540
		Exceedances[5]	— (*n*=7)	2 (*n*=7)	—[6] (*n*=7)	7 (*n*=7)	— (*n*=7)	7 (*n*=7)
	1996	Median	18	1,010	23	1,080	55	33
		Range	1.7–77	404–9,650	10–130	440–11,000	30–380	15–280
		Exceedances[5]	— (*n*=8)	2 (*n*=8)	0 (*n*=8)	5 (*n*=8)	— (*n*=8)	7 (*n*=8)
Stillwater Point Reservoir Diversion Canal:								
	1994	Median	13	633	64	1,450	58	31
		Range	1.7–32	476–1,950	43–130	840–3,300	49–80	24–69
		Exceedances[5]	— (*n*=12)	0 (*n*=12)	0 (*n*=12)	8 (*n*=8)	— (*n*=8)	11 (*n*=11)
	1995	Median	35	378	34	790	40	23
		Range	0.5–133	262–5,990	15–300	380–9,900	30–120	9–130
		Exceedances[5]	— (*n*=8)	2 (*n*=8)	—[6] (*n*=8)	4 (*n*=8)	— (*n*=8)	5 (*n*=8)
	1996	Median	38	494	40	740	38	20
		Range	13–157	164–1,240	11–71	190–2,000	20–60	5–47
		Exceedances[5]	— (*n*=8)	0 (*n*=8)	0 (*n*=8)	4 (*n*=8)	— (*n*=8)	4 (*n*=8)

Table 7. Statistical summary of instantaneous drainflow and concentrations of dissolved solids and dissolved trace elements at seven drain sites where water enters wetlands of Stillwater National Wildlife Refuge and of Carson Lake, March–October, 1994–96—Continued

Agricultural drain	Calendar year	Summary statistics	Drainflow (cubic feet per second)	Dissolved solids[1] (milligrams per liter)	Arsenic[2] (micrograms per liter)	Boron[3] (micrograms per liter)	Lithium (micrograms per liter)	Molybdenum[4] (micrograms per liter)
				Carson Lake				
Carson Lake Drain:								
	1994	Median	9.0	705	58	1,550	52	30
		Range	0.72–25	456–2,560	43–200	710–7,000	44–100	21–170
		Exceedances[5]	— (*n*=8)	0 (*n*=8)	—[6] (*n*=8)	7 (*n*=8)	— (*n*=8)	7 (*n*=7)
	1995	Median	14	519	41	970	50	25
		Range	2.1–26	430–892	33–120	700–1,800	40–70	15–46
		Exceedances[5]	— (*n*=8)	0 (*n*=8)	0 (*n*=7)	4 (*n*=8)	— (*n*=7)	6 (*n*=7)
	1996	Median	18	678	56	1,240	53	29
		Range	6–35	488–860	33–92	820–1,800	39–60	20–44
		Exceedances[5]	— (*n*=8)	0 (*n*=8)	0 (*n*=8)	8 (*n*=8)	— (*n*=8)	8 (*n*=8)
Rice Ditch:								
	1994	Median	0.62	478	36	730	54	14
		Range	0.06–9.1	299–654	21–55	420–1,100	38–66	8–22
		Exceedances[5]	— (*n*=8)	0 (*n*=8)	0 (*n*=8)	5 (*n*=8)	— (*n*=8)	3 (*n*=8)
	1995	Median	5	277	19	390	40	9
		Range	0.14–35	242–702	17–92	290–1,130	30–70	9–37
		Exceedances[5]	— (*n*=7)	0 (*n*=7)	0 (*n*=7)	2 (*n*=7)	— (*n*=7)	2 (*n*=7)
	1996	Median	1.3	284	20	409	25	11
		Range	0.02–14	190–400	12–30	190–660	20–40	7.1–23
		Exceedances[5]	— (*n*=8)	0 (*n*=8)	0 (*n*=8)	0 (*n*=8)	— (*n*=8)	1 (*n*=8)
L Drain:								
	1994	Median	5.6	503	44	800	53	18
		Range	2.1–22	348–671	27–78	470–1,100	42–66	10–25
		Exceedances[5]	— (*n*=8)	0 (*n*=8)	0 (*n*=8)	4 (*n*=8)	— (*n*=8)	4 (*n*=8)
	1995	Median	33	356	24	360	35	9
		Range	9.8–105	220–486	7–70	120–790	12–60	4–19
		Exceedances[5]	— (*n*=7)	0 (*n*=8)	0 (*n*=8)	1 (*n*=8)	— (*n*=8)	1 (*n*=8)
	1996	Median	28	314	26	437	28	14
		Range	15–61	186–466	12–34	210–712	13–40	6.6–17
		Exceedances[5]	— (*n*=8)	0 (*n*=8)	0 (*n*=8)	0 (*n*=8)	— (*n*=8)	0 (*n*=8)
L 12 Drain:								
	[7]1995	Median	9	181	11	345	26	6
		Range	4–29	124–315	7–31	120–490	12–40	4–13
		Exceedances[5]	— (*n*=7)	0 (*n*=7)	0 (*n*=6)	0 (*n*=6)	— (*n*=6)	0 (*n*=6)
	1996	Median	8.6	194	14	206	19	6.6
		Range	1.2–18	139–372	9–26	113–520	13–32	4.3–11
		Exceedances[5]	— (*n*=8)	0 (*n*=8)	0 (*n*=8)	0 (*n*=8)	— (*n*=8)	0 (*n*=8)

[1]Beneficial-use criteria for dissolved solids: Nevada standard for watering of livestock is 3,000 milligrams per liter (State of Nevada, 1997, art. 445A.119). Effect criterion for ducklings when no source of fresh water is available is 5,000 milligrams per liter (Mitcham and Wobeser, 1988, p. 45).

[2]Beneficial-use criterion for arsenic: Nevada chronic (96-hour) aquatic-life standard as As^{+3} is 180 micrograms per liter (State of Nevada, 1997, art. 445A.144).

[3]Beneficial-use criteria for boron: Nevada standard for watering of livestock is 5,000 micrograms per liter (State of Nevada, 1997, art. 445A.144). Nevada standard for irrigating sensitive crops is 750 micrograms per liter (State of Nevada, 1997, art. 445A.144).

[4]Beneficial-use criterion for molybdenum: Nevada aquatic-life standard is 19 micrograms per liter (State of Nevada, 1997, art. 445A.144).

[5]Number of exceedances (out of *n* measurements) of most stringent, respective beneficial-use criterion.

[6]Arsenic speciation was not done as part of monitoring program for this site and year.

[7]Site not established until 1995.

Stillwater Slough

This site is located where the slough flows beneath Stillwater Road, about 5 mi upstream from its discharge to the historic wetlands of the Canvasback Gun Club, a privately owned facility virtually surrounded by Stillwater NWR. This site was not considered optimal, but access to the former USGS gaging station (Stillwater Slough Cutoff), about 3 mi downstream, was denied by private landowners for much of the 1994–96 monitoring period. Although the alternate site was instrumented with a continuous specific-conductance recorder, it probably greatly underestimates the flow, hence the load of dissolved constituents, to receiving wetlands during the irrigation season. After access to the former gaging station eventually was allowed, hydrologic data collected at the two sites could be compared: For example, on August 13, 1996, instantaneous flow increased downstream from 15 to 32 ft^3/s, dissolved-solids concentration from 594 to 662 mg/L, and overall instantaneous dissolved-solids load from 24 to 57 ton/d. These increases probably were the result of a number of drain inputs between the two sites, Kent Drain in particular. As drainflow increased throughout the monitoring program, measured water-quality data showed corresponding decreases in concentration. During the 3-year monitoring period, the highest concentrations were recorded in 1995 (table 7). Beneficial-use criteria for boron and molybdenum were exceeded in individual samples for most of the recorded observations during 1994–96. The number of individual exceedences for molybdenum, however, decreased each successive year. The median molybdenum concentrations in 1995 and 1996 were less than the 19 µg/L beneficial-use criterion.

Paiute Diversion Drain Below TJ Drain

The Paiute Diversion Drain site is about 1,000 ft and 3,000 ft downstream from the respective confluences of TJ Drain and D Line Canal.[3] The combined flow enters Lead Lake. During 1994–96, the site was instrumented with continuous-flow and specific-conductance recorders. In 1994, the annual flow was entirely from TJ Drain, whereas in 1995 and 1996, water from this site may have included water from all three drains (table 7). With increased flow from Paiute Diversion Drain and(or) D Line Canal in succeeding years, the chemical quality of the water showed a decided improvement in terms of reduced concentrations. Maximum concentrations, however, remained relatively high in 1995 and 1996 and commonly corresponded with water samples collected immediately before the irrigation season. Of the constituents measured, boron and molybdenum concentrations remained elevated during the 3 years of monitoring; most samples exceeded beneficial-use criteria. Of the sites monitored in Stillwater NWR, Paiute Diversion Drain typically represented the poorest quality in terms of maximum concentrations of dissolved solids and trace elements.

[3]D Line Canal is defined herein as the distributary system originating at Sagouspe Dam diversion on the lower Carson River, interconnecting the several water bodies that comprise the Indian Lakes and terminating at the confluence of Paiute Diversion Drain near the northwest boundary of Stillwater NWR (figs. 1 and 2).

Stillwater Point Reservoir Diversion Canal

This site, known locally as Diagonal Drain, is about 1 mi upstream from Stillwater Point Reservoir, a principal water-storage facility for Stillwater NWR. During 1994–96, the site was instrumented with both continuous-flow and specific-conductance recorders. This site receives an unquantified mixture of treated municipal sewage, shallow ground-water seepage, irrigation return flow and, at times, irrigation water. Median instantaneous drainflow increased during each successive year; the largest increase, nearly 200 percent, was from 1994 to 1995 (table 7). Dissolved-solids concentration was relatively low (less than 650 mg/L) during all years. Of the four trace elements shown in table 7, boron and molybdenum exceeded beneficial-use criteria in a large percentage of water samples, whereas arsenic and lithium did not.

Drains Entering Wetlands of Carson Lake

Of the principal drains to Carson Lake, the ones that were monitored are Carson Lake Drain, Rice Ditch, L Drain, and L 12 Drain (fig. 3).

L 12 Drain was included in the program in 1995 when Holmes Drain was discontinued because of backwater conditions that made the data unreliable. Carson Lake Drain and Rice Ditch were instrumented only with continuous specific-conductance recorders.

Carson Lake Drain

This drain, also known locally as Cabin Drain, flows into the Sprig Pond unit of Carson Lake. Drainflow was measured periodically by field personnel of the Bureau of Reclamation and the USGS by using current meters. Median instantaneous drainflow increased 56 percent from 1994 to 1995 and 29 percent from 1995 to 1996 (table 7). Dissolved-solids concentrations decreased 26 percent from 1994 to 1995 yet increased 30 percent from 1995 to 1996. In spite of the overall increase in median flow during 1994–96, the median concentrations of dissolved solids and selected trace elements did not show a concomitant decrease; in 1996, they were nearly the same as those in 1994. A review of the 1994–96 continuous specific-conductance data indicates that the recorded daily concentrations of dissolved solids were highest (maximum about 2,400 mg/L) in February and March 1994, just prior to the irrigation season. An in-depth comparison of the continuous dissolved-solids data with the data shown in table 7 for the same time period reveals a discrepancy between the two records. The continuous-record data show a successive decline in average daily values from year to year as might be expected considering the apparent increase of drainflow evident in the periodic measurements. For example, median dissolved-solids concentrations for the continuous record were about 800 mg/L in 1994, 500 in 1995, and 300 in 1996. The continuous record probably is the more accurate of the two records. Infrequent measurements of dynamic environmental systems increase uncertainty or analytical error. Of the water-quality constituents measured, boron and molybdenum consistently exceeded the more restrictive beneficial-use criteria (table 7) for each during each of the 3 years of monitoring.

Rice Ditch

Rice Ditch, also known locally as Rice Drain, feeds mainly the north-central wetland units of Carson Lake and was instrumented with only a continuous specific-conductance recorder. Drainflow was measured periodically by the Bureau of Reclamation and the USGS. Median periodic drainflow for Rice Ditch increased substantially (about 700 percent) in 1995 compared to 1994 (table 7). For that same period, all monitored water-quality constituents showed a corresponding decrease in median concentration, presumably owing to dilution. The median flow in 1996 decreased nearly 300 percent from the 1995 sampling period, and, with the exception of lithium, concomittant slight increases in concentration of all monitored constituents were observed. Examination of the annual, continuous specific-conductance data for the 3-year monitoring period shows that the highest mean daily dissolved-solids concentrations (about 650 mg/L) typically did not occur during the irrigation season; the lowest mean concentrations (about 280 mg/L) occurred during the irrigation season. Of the individual constituents measured, boron and molybdenum exceeded beneficial-use criteria during the 3-year monitoring period. Boron met or exceeded the Nevada standard for irrigating sensitive crops in 62 percent of the samples in 1994, 29 percent in 1995, and none in 1996. Molybdenum exceeded the standard in 38 percent of the samples in 1994, 29 percent in 1995, and 12 percent in 1996.

L Drain

L Drain, at the north-central perimeter of Carson Lake, discharges to West Lee Drain and East Lee Drain for distribution to western and eastern parts of the lake. Median drainflow for L Drain increased substantially (nearly 500 percent) in 1995 compared to 1994, with a corresponding decrease in median concentration of all measured water-quality constituents (table 7). Median drainflow decreased about 15 percent from 1995 to 1996. In general, median arsenic, boron, and molybdenum concentrations decreased substantially in 1995 and 1996 compared to 1994. In terms of median dissolved-solids concentrations (about 500 mg/L or less), the water quality met applicable beneficial-use standards. Only boron and molybdenum occasionally exceeded beneficial-use criteria; exceedences (50 percent for each constituent) were greatest in water samples collected in 1994, a water-short year.

L 12 Drain

L 12 Drain connects to East Ditch (fig. 3) for distribution of drainflow along the east margin of Carson Lake. This station was added to the monitoring network in 1995 when Holmes Drain was discontinued owing to backwater effects. Drainflow, about 9 ft^3/s, varied little between the 1995 and 1996 irrigation seasons (table 7). Median concentrations of dissolved solids, arsenic, and molybdenum also showed relatively little change between the 2 years. Median concentrations of boron and lithium, however, were 40 and 27 percent less, respectively, in 1996 than in 1995. Median dissolved-solids concentrations for 1995 and 1996 were only about 20 and 30 percent greater, respectively, than that measured in irrigation water immediately downstream from Lahontan Reservoir during the same time period.

Loads of Dissolved Solids and Boron

Loads of dissolved solids and boron entering Stillwater NWR and Carson Lake were calculated 1994–96 (tables 8 and 9). Because of the lack of correlation of dissolved-solids concentration or drainflow with the three other measured trace elements—arsenic, lithium, and molybdenum—load estimates were not calculated for these constituents. Information on loading of persistent chemical constituents is important for terminal wetlands, where discharge is only by evapotranspiration, because of the tendency for dissolved-solids concentration to increase over time during seasons of minimal inflow. Load information also is important in making relative comparisons of loads among measured drain systems; the movement of large volumes of mineralized water can result in considerable contaminant transport even if the concentration of contaminants in solution is relatively low. Load data presented herein are divided between the 5-month nonirrigation season and the 7-month irrigation season. The loads for Stillwater Slough and the four drains entering Carson Lake are calculated solely from periodic instantaneous measurements and are given in terms of pounds or tons per day. (For a discussion of uncertainty in the determination of seasonal loads based solely on instantaneous measurements, see section "Evaluation of Load-Measurement Uncertainty Associated With Frequency of Data Collection in Agricultural Drains.") The loads calculated herein may not correspond to those reported earlier by Lico and Pennington (1997) because of differences in measurement location and calculation method.

Dissolved Solids

Stillwater National Wildlife Refuge

For the two sites in Stillwater NWR that were monitored annually, Paiute Diversion Drain below TJ Drain and Stillwater Point Reservoir Diversion Canal, the loads of dissolved solids were greatest during the irrigation season for each of the 3 years (table 8). The seasonal difference in loading rate undoubtedly is due to increased drainflow during the irrigation season. Other drain sites not similarly equipped to measure flows all year probably would reflect a similar seasonal trend (Lico, 1992; Lico and Pennington, 1997).

During 1995 and 1996, Paiute Diversion Drain delivered the greatest annual load of dissolved solids of the four principal drains entering Stillwater NWR. The annual load of dissolved solids delivered by this drain was about 2,700 tons in 1994, 20,000 in 1995, and 37,000 in 1996. During 1995 and 1996, the dissolved-solids load in Paiute Diversion Drain surpassed that delivered by Stillwater Point Reservoir Diversion Canal for the first time since 1986 (Lico, 1992, p. 18–20; Hoffman, 1994, p. 15–17). Of the four principal drains to Stillwater NWR, S Line delivered the least dissolved-solids load: about 1,100 tons in 1994, 1,900 in 1995, and 1,800 in 1996. These results are not unexpected because of the relatively low dissolved-solids concentrations in S Line compared to the other sites. Much of the water that passes the S Line site is good-quality water entering the Dry Lake (fig. 3) wetland, where USFWS biologists are evaluating the ecological effects of a wetland that receives limited, if any, agricultural return flow.

Carson Lake

Of the four monitored drains entering Carson Lake, Carson Lake Drain and L Drain delivered the greatest mean loads of dissolved solids to the Carson Lake wetlands (table 8). These two drains delivered a combined mean load of 53 tons/d (or 77 percent of the mean total daily load) in 1995 and 55 tons/d (or 87 percent) in 1996. The dissolved-solids loads delivered by Rice Ditch and by L 12 Drain were relatively low and ranged from about 4 to 13 percent of the mean total daily load delivered to Carson Lake by the four drains.

Boron

Stillwater National Wildlife Refuge

The overall trend of boron loads (table 9) generally parallels that for dissolved solids; this trend is consistent with the strong positive relation of boron with dissolved solids recognized by Hoffman and others (1990, p. 36) and by Lico and Pennington (1997, p. 6). As for dissolved-solids loads, the largest boron loads were delivered to Stillwater NWR during the irrigation season. Also, beginning in 1995, the boron loads passing Paiute Diversion Drain during the irrigation season exceeded those measured at Stillwater Point Reservoir Diversion Canal. The annual load of boron delivered by Paiute Diversion Drain below TJ Drain was about 7,000 lb in 1994, 51,000 in 1995, and 95,000 in 1996.

Table 8. Estimated seasonal loads of dissolved solids in drains entering Stillwater National Wildlife Refuge and Carson Lake, servicing agricultural areas near Fallon, Nev., 1994–96

[*n*, number of measurements. —, no data or not applicable]

Agricultural drain	Seasonal loads of dissolved solids (tons)											
	Nonirrigation season, November–March						Irrigation season, April–October					
	1994		1995		1996		1994		1995		1996	
	Total seasonal load	Mean daily load	Total seasonal load	Mean daily load	Total seasonal load	Mean daily load	Total seasonal load	Mean daily load (and range, for *n*)	Total seasonal load	Mean daily load (and range, for *n*)	Total seasonal load	Mean daily load (and range, for *n*)
Stillwater National Wildlife Refuge												
S Line Canal[1,2]	—	—	—	—	—	—	1,100	5.8	1,900	10	1,800	10
Stillwater Slough[3]	—	—	—	—	—	—	—	13 (7.2–24, *n*=7)	—	30 (19–64, *n*=8)	—	33 (25–42, *n*=7)
Paiute Diversion Drain below TJ Drain[1,4]	[5]1,000	8.6	920	6.1	9,400	63	1,700	8.1	19,000	89	28,000	132
Stillwater Point Reservoir Diversion Canal[1]	3,100	21	1,200	7.9	7,800	52	5,400	25	12,000	55	12,000	58
Carson Lake												
Carson Lake Drain[3,6]	—	—	—	—	—	—	—	22 (13–48, *n*=7)	—	20 (6.4–31, *n*=7)	—	34 (27–46, *n*=7)
Rice Ditch[3]	—	—	—	—	—	—	—	3 (0.09–7.4, *n*=7)	—	[7]8.7 (0.07–26, *n*=6)	—	4.2 (0.02–10, *n*=7)
L Drain[3]	—	—	—	—	—	—	—	10 (4.4–21, *n*=7)	—	[7]33 (16–62, *n*=6)	—	21 (8.8–45, *n*=7)
L 12 Drain[3]	—	—	—	—	—	—	—	—	—	[7,8]6.7 (2.5–16, *n*=7)	—	2.6 (0.40–4.2, *n*=7)

[1]Estimated from continuous recordings of drainflow and specific conductance using linear regression equations in table 4..

[2]No flow in canal during nonirrigation season, 1994–96.

[3]Means of instantaneous onsite measurements during irrigation season.

[4]Drainflow during 1994 represents TJ Drain flow; drainflow during 1995–96 represents combined flow from TJ Drain, D Line, and Paiute Diversion Drain.

[5]Data for November through February only; zero flow recorded for March.

[6]Known locally as Cabin Drain.

[7]Data collected in April 1995 not used in calculation because measurement preceded irrigation.

[8]Data collection did not begin until March 1995.

Table 9. Estimated seasonal loads of dissolved boron in drains entering Stillwater National Wildlife Refuge and Carson Lake, servicing agricultural areas near Fallon, Nev., 1994–96

[*n*, number of measurements. —, no data or not applicable]

Agricultural drain	Seasonal loads of boron (pounds)											
	Nonirrigation season, November–March						Irrigation season, April–October					
	1994		1995		1996		1994		1995		1996	
	Total seasonal load	Mean daily load	Total seasonal load	Mean daily load	Total seasonal load	Mean daily load	Total seasonal load	Mean daily load (and range, for *n*)	Total seasonal load	Mean daily load (and range, for *n*)	Total seasonal load	Mean daily load (and range, for *n*)
Stillwater National Wildlife Refuge												
S Line Canal[1,2]	—	—	—	—	—	—	3,000	17	4,600	25	1,800	10
Stillwater Slough[3]	—	—	—	—	—	—	—	55 (30–50, *n*=7)	—	105 (60–194, *n*=8)	—	98 (71–125, *n*=7)
Paiute Diversion Drain below TJ Drain[1,4]	[5]2,600	22	2,300	15	24,000	159	4,400	20	49,000	230	71,000	320
Stillwater Point Reservoir Diversion Canal[1]	11,000	72	4,100	27	28,000	180	20,000	92	44,000	200	44,000	210
Carson Lake												
Carson Lake Drain[3,6]	—	—	—	—	—	—	—	98 (50–283, *n*=7)	—	70 (29–110, *n*=7)	—	119 (58–155, *n*=7)
Rice Ditch[3]	—	—	—	—	—	—	—	8.4 (0.3–25, *n*=7)	—	[7]21 (0.1–66, *n*=6)	—	11 (0.07–27, *n*=7)
L Drain[3]	—	—	—	—	—	—	—	31 (15–55, *n*=7)	—	[7]80 (45–158, *n*=6)	—	65 (17–99, *n*=7)
L 12 Drain[3]	—	—	—	—	—	—	—	—	—	[7,8]20 (5–47, *n*=7)	—	10 (1.4–20, *n*=7)

[1]Estimated from continuous recordings of drainflow and specific conductance using linear regression equations in table 4.

[2]No flow in canal during nonirrigation season, 1994–96.

[3]Mean of instantaneous onsite measurements during irrigation season.

[4]Drainflow during 1994 represents TJ Drain flow; drainflow during 1995–96 represents combined flow from TJ Drain, D Line, and Paiute Diversion Drain.

[5]Data for November through February only; zero flow recorded for March.

[6]Known locally as Cabin Drain.

[7]Data collected in April 1995 not used in calculation because measurement preceded irrigation.

[8]Data collection did not begin until March 1995.

Stillwater Point Reservoir Diversion Canal delivered about 31,000 lb in 1994, 48,000 in 1995, and 72,000 in 1996. These two drains typically transport the majority of boron to Stillwater NWR. The estimated daily boron load passing the Stillwater Slough site during the irrigation season also is relatively large (fig. 2). This site is downstream from an area where water from thermal wells is used in and near the community of Stillwater, Nev. Leakage at land surface from some thermal wells is known to enter Stillwater Slough. The mean concentration of dissolved boron in deep thermal waters in the Stillwater, Nev., area is 16,000 µg/L (Morgan, 1982, p. 55).

Carson Lake

Similar to boron loads in agricultural drain water entering Stillwater NWR, the boron loads entering Carson Lake varied during the irrigation season from year to year in response to variations in drainflow. As in the case of dissolved-solids loads, the largest boron loads (greater than 70 percent) were delivered to Carson Lake by Carson Lake Drain and L Drain combined. During the irrigation season, Carson Lake Drain transported 98 lb/d in 1994, 70 in 1995, and 119 in 1996; and L Drain transported 31 lb/d in 1994, 80 in 1995, and 65 in 1996. Of the four monitored sites, Carson Lake Drain typically transported the greatest load of boron (table 9) in 1994 and 1996; in 1995, L Drain delivered the largest. Carson Lake Drain discharges to the Sprig Pond unit of Carson Lake. L Drain delivered a notably increased boron load in 1995 and 1996 compared to 1994. The increase, slightly greater than 100 percent, corresponded to an increase in median drainflow (table 9).

EVALUATION OF LOAD-MEASUREMENT UNCERTAINTY ASSOCIATED WITH FREQUENCY OF DATA COLLECTION IN AGRICULTURAL DRAINS

Each of two hydrologically dissimilar drainflow sites were equipped with a continuously recording gage for drainflow and for specific conductance (dissolved-solids concentration). This instrumentation allowed comparison of load calculations at 15-minute intervals with monthly samples at the two sites. Such a comparison can shed light on the amount of uncertainty or error that is associated with frequency of data collection for dissolved constituents in agricultural drains. Previous investigators (Dolan and others, 1981; Miertschin, 1986) made similar comparisons, but their examinations involved analysis of concentration of suspended particulate matter and mean daily flow of natural streams.

For the uncertainty analysis (table 10), the continuous record is considered the true record. The corresponding periodic record is comprised of instantaneous data collected about every 30 days. The percent differences between the continuous and instantaneous records (table 10) show that periodic measurements may substantially overestimate or underestimate the annual load of dissolved solids passing some sites and that these periodic estimates for Paiute Diversion Drain appeared to be less accurate than that for Stillwater Point Reservoir Diversion Canal. The principal reason for the underestimation and the lesser accuracy is the greater variability of daily drainflow at Paiute Diversion Drain, which can be extreme at times (Hoffman, 1994, p. 14), coupled with episodic flow events missed by the periodic instantaneous data.

The 1994–96 monitoring program was enhanced technically by the use of continuous-recording instruments on selected drains that exhibited highly variable flow rates. The degree of accuracy of the loading information for variable flow regimes is directly proportional to frequency of data collection for the time period of interest.

Concentrations and Loads of Total Mercury

Whole-water samples for total-mercury determinations were collected at Stillwater Slough and Stillwater Point Reservoir Diversion Canal during calendar years 1994–96. At the other sites, such samples were collected only during 1994. In December 1994, the data were evaluated for possible refinement of the overall monitoring program. With the exception of Stillwater Slough and Stillwater Point Reservoir Diversion Canal, most of the mercury data at the other sites were below the USGS minimum reporting level (0.1 µg/L). Therefore the decision was made to cease collecting total-mercury samples at the other sites. Because of the poor correlation of total mercury with drainflow or with other water-chemical data collected as part of the monitoring program, predictive regression equations for mercury concentration could not be developed. The results presented below (in the next two sections) are statistical summaries of mercury concentrations and loads for instantaneous samples.

Table 10. Comparison of continuous-recording and periodic onsite measurements of annual dissolved-solids loads in agricultural drains entering Stillwater National Wildlife Refuge, Nevada

[Annual load of dissolved solids: Values rounded to two significant figures]

Agricultural drain	Water year	Annual load of dissolved solids		
		A Continuous record[1] (tons)	*B* Instantaneous record[2] (tons)	*C* Difference between continuous and instantaneous records[3] (percent)
Paiute Diversion Drain below TJ Drain	[4]1994	2,700	5,400	100 (+)
	1995	20,000	7,500	62 (–)
	1996	37,000	21,000	43 (–)
Stillwater Point Reservoir Diversion Canal	1994	8,500	9,400	11 (+)
	1995	13,000	13,000	0
	1996	20,000	15,000	25 (–)

[1]Continuous recording of flow and specific conductance (as surrogate for dissolved-solids concentration). Annual load of dissolved solids calculated by summing products of tons per day by number of days per month. (Tons per day calculated by multiplying daily mean flow times daily mean dissolved-solids concentration times 0.0027.)

[2]Instantaneous measurement of flow and specific conductance (as surrogate for dissolved-solids concentration) on 15th day of each month. Annual load calculated by summing products of tons per day by number of days per month. (Tons per day calculated by multiplying instantaneous flow times instantaneous dissolved-solids estimate times 0.0027.)

[3]Calculated by formula $C = 100\,(B - A)\,/\,A$. Signs in parentheses indicate if instantaneous data overestimated (+) or underestimated (–) value.

[4]Zero flow recorded for March.

Stillwater Slough

The highest sampled concentrations of total mercury in drain water during the 1994–96 irrigation seasons, measured at the Stillwater Slough site, were relatively high compared to background sites sampled in a previous investigation (Hoffman and others, 1990). The median concentration of total mercury in Stillwater Slough during 1994–96 was 0.7 µg/L (n=21); values ranged from less than 0.1 to 3.5 µg/L. Of the 21 values, 3 were below the USGS minimum reporting level, 0.1 µg/L; 2 exceeded the 1-hour average (acute) Nevada standard for the protection of aquatic life, 2.0 µg/L; and 18 are known to have exceeded the 96-hour average (chronic) standard, 0.012 µg/L. (The chronic standard, however, is an order of magnitude lower than the minimum reporting level).

Stillwater Slough, a natural channel during the Comstock mining era in the 1800's probably delivered mercury-contaminated overflow from Carson Lake to the Stillwater wetlands (Hoffman, 1994, p. 8–11). This former flow-through system presumably allowed mercury bound to fluvial sediment to be deposited along the Stillwater Slough during the 1800's, when mercury was used in the milling of precious metals from the Comstock Lode. A sample of bottom sediment collected from the slough in 1987 contained 14 µg/g of mercury, dry weight (Hoffman and others, 1990, p. 113); another in 1988 contained 10 µg/g (Rowe and others, 1991, p. 163). Background concentrations in minimally contaminated bottom sediments typically are less than 1 µg/g, dry weight. Bottom sediments may be resuspended in the water column by a sufficient increase in water velocity and churning of sediments by the action of fish such as carp.

During the 1994–96 monitoring period, instantaneous total-mercury loads in Stillwater Slough ranged from less than 0.01 to 0.38 lb/d (median, 0.02 lb/d).

Stillwater Point Reservoir Diversion Canal

At this site during the 1994–96 irrigation seasons, the total-mercury concentration ranged from less than 0.1 to 0.8 µg/L; the median value was 0.4 µg/L (n=20). Of the 20 values, 2 were below the USGS minimum reporting level, 0.1 µg/L; at least 18 exceeded the chronic standard, 0.012 µg/L, and none exceeded the Nevada acute standard, 2.0 µg/L. Instantaneous total-mercury loads for the 3-year period ranged from less than 0.004 to 0.30 lb/d; the median value was 0.06 lb/d. The substantially greater median total-mercury load measured at Stillwater Point Reservoir Diversion

Canal (200-percent difference) relative to Stillwater Slough undoubtedly was due to the typically higher flow rates at the canal site. Regulations allow for 1- and 96-hour average-concentration limits to be exceeded only once every 3 years (U.S. Environmental Protection Agency, 1986).

PHYSICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS OF WATER, BOTTOM SEDIMENT, AND BIOTA IN WETLANDS

Field Measurements of Dissolved Oxygen, pH, and Specific Conductance

Dissolved Oxygen

Dissolved-oxygen (DO) concentrations, along with other water-quality properties, generally were measured in the late morning to early afternoon hours (typically during 10:00 a.m. to 3:00 p.m.). DO measurements at these times of day may be biased toward moderate to high values because oxygen typically is released by photosynthetic processes during this time period and because no nighttime measurements were made. In most surface water, DO concentration varies somewhat predictably over a 24-hour period in response to physical, chemical, and (primarily) biological factors. Minimum DO concentrations typically are observed at dawn after the period of darkness when oxygen uptake (respiration) by aquatic organisms exceeds DO production by aquatic plants. As the day proceeds, DO concentrations gradually increase to a maximum near midafternoon, when DO production greatly exceeds respiration, and then gradually decrease until dawn of the next day. DO concentrations exceeding 100-percent saturation are indicative of high primary productivity by aquatic plants. For example, high daytime productivity at Dry Lake in Stillwater NWR and in the Sprig Pond unit of Carson Lake (table 11) suggests that DO concentrations at these sites may be depressed during hours of darkness when oxygen uptake by respiratory processes exceeds oxygen production. Conversely, moderate to low concentrations during 10:00 a.m. to 3:00 p.m. in Lead Lake may indicate relatively lower productivity. The reason for the decline in DO concentrations in Stillwater Point Reservoir over the 3-year study is unknown. Low DO concentrations may adversely affect aquatic organisms, particularly fish (Herman and Meyer, 1990).

pH

The measured pH values indicate that the wetland waters are alkaline (table 11). The highest values were measured in Dry Lake, and the lowest in Stillwater Point Reservoir. The pH measured in Dry Lake during 1994–95 exceeded the upper permissible pH limit of 9.0 for most beneficial uses (table 1).

Specific Conductance

Mean annual specific conductance, an indirect measure of dissolved-solids concentration, in the study wetlands ranged from 575 μS/cm at 25°C in Stillwater Point Reservoir in 1995 to 14,000 μS/cm in Lead Lake in 1994 (table 11). The maximum value corresponded to lower water levels in Lead Lake during that year. Specific conductance was consistently lowest in Stillwater Point Reservoir, succeeded by Dry Lake.

Based on the regression equations listed in table 4, dissolved-solids concentrations exceeded the Nevada water-quality standard for watering of livestock at only one site; Lead Lake in 1994. Watering of livestock is a designated beneficial use of wetland water in Lahontan Valley. Presently Nevada does not have dissolved-solids standards for aquatic life or for propagation of wildlife. Because dissolved-solids tolerance of submergent and emergent plants and aquatic vertebrates and invertebrates varies widely, species composition shifts with changing concentrations (Stewart and Kantrud, 1971, p. 3). Elevated dissolved-solids concentrations may affect bird species as well. When relegated to water with a specific conductance greater than 20,000 μS/cm, ducklings died (Mitcham and Wobeser, 1988, p. 49). Ducklings relegated to water with a specific conductance in the range 7,500 to 20,000 μS/cm suffered sublethal effects on growth, feathering, and other physiological functions. Weight gain of ducklings reared on water with a specific conductance greater than 4,000 μS/cm was depressed. Mean specific conductance in Lead Lake in 1994 was 14,000 μS/cm.

Table 11. Field measurements of temperature, dissolved-oxygen concentration and saturation, pH, and specific conductance in four wetlands in Lahontan Valley, Nevada, June–July 1994–96

[—, not applicable]

Wetland	Year	Statistics	Water temperature (degrees Celsius)	Dissolved oxygen		pH (units)	Specific conductance (microsiemens per centimeter at 25°C)
				Concentration (milligrams per liter)	Saturation (percent)		
				Stillwater National Wildlife Refuge			
Dry Lake:							
	1994	Mean	25	15.5	217	9.6	593
		Range	25–26	13.4–16.8	186–238	9.5–9.8	580–610
	1995	Mean	28	12.9	189	9.1	1,610
		Range	—	—	—	—	—
	1996	Mean	29	9.8	147	7.5	1,080
		Range	29–30	9.5–10.3	142–157	—	900–1,210
Lead Lake:							
	1994	Mean	27	9.3	135	8.4	14,000
		Range	26–29	7.7–11.1	109–166	8.3–8.5	—
	1995	Mean	21	4.4	56	7.9	2,400
		Range	—	4.0–4.9	52–66	7.7–8.1	—
	1996	Mean	26	5.8	83	8.4	3,920
		Range	25–27	4.5–7.3	63–103	8.2–8.5	3,900–3,950
Stillwater Point Reservoir:							
	1994	Mean	25	11.6	162	8.3	1,060
		Range	24–28	7.7–14.8	105–202	8.0–8.6	1,010–1,080
	1995	Mean	23	6.1	81	7.6	575
		Range	22–23	5.8–6.4	78–84	7.5–7.7	550–600
	1996	Mean	17	3.0	35	7.5	787
		Range	15–18	1.7–4.5	21–51	7.4–7.5	750–810
				Carson Lake			
Sprig Pond:							
	1994	Mean	24	11.8	163	8.4	1,710
		Range	23–26	10.2–14.3	145–192	—	1,650–1,800
	1995	Mean	25	7.3	101	8.5	1,550
		Range	—	6.6–7.8	92–109	8.3–8.6	1,250–1800
	1996	Mean	30	10.9	163	8.7	1,120
		Range	27–32	7.4–16.8	107–264	8.5–9.0	1,050–1,200

Trace Elements

Concentrations In Sampled Media

Aluminum

Aluminum previously was identified as a concern in water and in avian diet (aquatic vegetation and invertebrates) during contaminants monitoring of wetlands in Stillwater NWR (Tuttle and others, 1996, p. 14–17). Aluminum concentrations commonly exceeded Federal water-quality criteria in unfiltered water samples collected from wetlands. In some cases, exceedences were by orders of magnitude. Comparisons of total and dissolved samples indicated that most aluminum was not in a dissolved phase (Hoffman and others, 1990, p. 99–100). Aluminum concentrations in a large percentage of food-chain organisms also exceeded levels associated with lethal and sublethal effects on waterfowl (Tuttle and others, 1996). Elevated aluminum in wetlands not receiving agricultural drainage suggests that aluminum may be naturally elevated in soils and wetlands in Lahontan Valley.

During 1994–96, aluminum was detected in all wetland water, sediment, detritus, pondweed, hemipteran, and fish samples; in 79 percent of the coot eggs and 91 percent of the avocet eggs; and in 31 percent of the juvenile-coot livers and 38 percent of the juvenile-avocet livers. Concentrations in most sampled media varied among study wetlands and years (table 12).

Aluminum concentrations in water and sediment did not correlate with pH or specific conductance. Concentrations in water did not correlate with concentrations in sediment, detritus, pondweed, or hemipterans. Aluminum concentrations in sediment correlated with concentrations in detritus ($p<0.001$, $r^2 = 0.322$), hemipterans ($p<0.001$, $r^2 = 0.383$), and pondweed ($p = 0 .037$, $r^2 = 0.073$), although r^2 was low for pondweed. Geometric-mean concentrations in unfiltered wetland water, sediment, and food-chain organisms did not correlate with mean concentrations in bird eggs.

During 1994–96, aluminum concentrations in all unfiltered wetland-water samples exceeded the Federal criterion, 87 µg/L (U.S. Environmental Protection Agency, 1998). High aluminum concentrations in water generally corresponded to observed water turbidity, which apparently increased during windy conditions. Toxicity of aluminum in water varies considerably with aluminum species and complexation (Sparling and Lowe, 1996, p. 2). Speciation of aluminum is affected by several environmental variables, particularly pH. In the pH range 6.0 to 8.0, aluminum has a low solubility and is considered to be biologically inactive. Aluminum solubility increases in more alkaline solutions (pH>8.0), but the biological implications are poorly understood.

The biological implications of aluminum in sediments also are uncertain. The correlation between aluminum in sediment and aquatic vegetation, however, suggests that sediment serves as a source of the aluminum in vegetation.

Bird species may be affected adversely by excessive aluminum in diet (Sparling, 1990). Aluminum concentrations in 28 percent of the vegetation samples and in 14 percent of the hemipteran samples exceeded a dietary concentration associated with reduced growth and behavioral effects in waterfowl, 5,000 µg/g, and concentrations in 12 percent of the vegetation samples exceeded a dietary concentration associated with reduced survival, 10,000 µg/g. Exceedences occurred in all wetlands except Dry Lake. Although aluminum in organisms that are typical of the avian food chain exceeded concentrations of concern, aluminum generally was not elevated in bird eggs and livers. Aluminum toxicosis in birds may be attributed to the formation of insoluble phosphates in the gastrointestinal tract and tissues and the subsequent interference with phosphate metabolism (Sparling, 1990; Sparling and Lowe, 1996). In such cases, aluminum in bird eggs and liver tissues may not be elevated. The correlation of aluminum concentration in sediment with concentration in pondweed and hemipterans suggests that sediment was the source of aluminum in organisms in the potential avian diet. Ingestion of plants or invertebrates by birds may result in potentially hazardous exposure to aluminum.

Table 12. Aluminum concentrations in unfiltered water, sediment, and biological samples collected from four wetlands in Lahontan Valley, Nevada, April–August 1994–96

[Geometric-mean (and range) data from U.S. Fish and Wildlife Service. Within each wetland for particular sample medium or type, geometric means having same appended letter (*a* or *b*) are not significantly different ($p<0.05$) across years; correspondingly, differing appended letters indicate significant difference between geometric means. —, no data available or not applicable. <, used with sample mean, indicates that value for more than half of samples was less than analytical detection limit; used with range, indicates that value for at least one sample was less than detection limit. In cases where analytical detection limit varied, maximum limit is given]

Wetland	Year	Total aluminum in water samples (micrograms per liter)	Aluminum in bottom-sediment samples (micrograms per gram)	Aluminum in biological samples (micrograms per gram)							
				Detritus	Pondweed	Hemiptera	Fish	Coot egg	Avocet egg	Coot liver	Avocet liver
Stillwater National Wildlife Refuge											
Dry Lake:											
	1994	373 *a*	19,722 *a*	—	1,492 *a,b*	486 *a*	—	8 *a*	—	[1]<5	[1]<5
		(280–450)	(17,540–20,310)	(—)	(907–2,611)	(195–1,214)	(—)	(8–9)	(—)	(—)	(—)
	1995	22,380 *b*	29,027 *b*	29,430 *a*	1,941 *b*	200 *a*	44 *a*	8 *a*	—	[1]<5	—
		(13,200–36,600)	(19,570–35,680)	(25,040–33,990)	(1,780–2,200)	(128–256)	(41–48)	(<5–11)	(—)	(<5–5)	(—)
	1996	3,070 *a*	31,992 *b*	30,736 *a*	892 *a*	388 *a*	299 *b*	53 *b*	[1]11	[1]<5	[1]<5
		(2,440–4,120)	(28,820–35,030)	(27,060–32,210)	(650–1,400)	(343–440)	(152–493)	(12–84)	(7–24)	(<5–5)	(<5–5)
Lead Lake:											
	1994	5,620 *a*	19,764 *a*	—	1,905 *a*	926 *b*	—	7 *a*	[1]13	—	[1]<5
		(2,900–8,720)	(13,830–25,680)	(—)	(1,230–2,710)	(403–1,316)	(—)	(6–9)	(6–19)	(—)	(—)
	1995	437 *b*	31,660 *b*	31,558 *b*	6,447 *b*	[1]1,624	[1]191	[1]<5	—	[1]<5	—
		(230–790)	(27,160–35,530)	(27,890–36,150)	(5,400–10,390)	(1,527–1,721)	(—)	(<5–15)	(—)	(<5–21)	(—)
	1996	1,590 *b*	25,939 *a,b*	24,999 *a*	805 *a*	131 *a*	[1]85	19 *b*	[1]12	[1]16	[1]<5
		(1,430–1,900)	(24,650–26,800)	(24,190–25,310)	(302–848)	(81–300)	(50–126)	(11–27)	(6–20)	(7–23)	(—)
Stillwater Point Reservoir:											
	1994	793 *a*	16,556 *a*	—	10,296 *b*	[1]9,004	160 *a*	6 *a*	[1]8	8 *a*	[1]13
		(390–1,380)	(11,620–20,360)	(—)	(4,530–17,600)	(7,710–10,300)	(101–244)	(5–7)	(5–9)	(<5–23)	(<5–40)
	1995	600 *a*	26,630 *b*	27,183 *a*	5,064 *a,b*	[1]422	104 *a*	[1]<5	—	[1]<5	—
		(265–1,230)	(24,000–29,380)	(23,540–30,390)	(3,310–6,200)	(—)	(47–150)	(<5–8)	(—)	(—)	(—)
	1996	293 *a*	25,343 *b*	24,509 *a*	1,600 *a*	[1]850	190 *a*	16 *b*	[1]7.3	11 *a*	—
		(95–630)	(20,430–27,080)	(13,440–28,450)	(459–1,700)	(—)	(88–549)	(9–26)	(—)	(<5–33)	(—)
Carson Lake											
Sprig Pond:											
	1994	7,800 *b*	22,510 *a*	—	14,839 *b*	4,787 *b*	[1]69	9 *a*	9 *a*	[1]<5	8 *a*
		(5,400–11,400)	(19,300–27,010)	(—)	(7,740–24,290)	(2,550–7,080)	(60–79)	(7–16)	(9–10)	(<5–9)	(<5–14)
	1995	457 *a*	34,590 *b*	31,481 *a*	1,166 *a*	[1]562	[1]116	[1]<5	[1]<5	[1]<5	[1]<5
		(270–610)	(32,510–36,290)	(28,040–35,540)	(477–2,200)	(558–566)	(37–382)	(<5–5)	(<5–6)	(—)	(—)
	1996	1,060 *a*	34,425 *b*	30,521 *a*	1,744 *a*	335 *a*	—	15 *b*	18 *b*	[1]<5	32 *a*
		(740–1,510)	(32,130–36,590)	(27,990–32,470)	(1,120–3,260)	(187–550)	(—)	(10–20)	(8–42)	(<5–72)	(<5–137)

[1]Analysis of variance was not attempted because of inadequate sample size or large number of samples having concentrations less than analytical detection limit.

Arsenic

Earlier NIWQP investigations in Lahontan Valley revealed that arsenic concentrations in water collected from agricultural drains and from wetlands that received irrigation drainage commonly exceeded standards for applicable beneficial uses and exceeded a concentration associated with toxicity to amphibians (Hoffman and others, 1990, p. 33). Concentrations were typically highest just prior to or during the early part of irrigation seasons. Arsenic concentrations in aquatic vegetation from several drain-water sites exceeded levels associated with effects on growth, development, and physiology in mallard (*Anas platyrhynchos*) ducklings. Fish collected from some sites contained concentrations associated with decreased growth and survival of bluegill (*Lepomis macrochirus*). Arsenic concentrations in invertebrates and bird livers from Stillwater WMA and Carson Lake were below levels of concern.

During 1994–96, arsenic was detected in all unfiltered water, sediment, detritus, and vegetation samples; in 78 percent of the hemipterans and 57 percent of the fish; in 19 percent of the coot eggs but in none of the avocet eggs; and in 62 percent of the coot livers and 13 percent of the avocet livers (table 13). Arsenic concentrations in unfiltered water positively correlated with specific conductance ($p<0.001$, $r^2 = 0.736$) but not with pH. Although r^2 values were low, arsenic concentrations in unfiltered water correlated with concentrations in sediment ($p = 0.036$, $r^2 = 0.123$) and in pondweed ($p = 0.019$, $r^2 = 0.153$). Concentrations in sediment were weakly correlated with concentrations in pondweed ($p = 0.011$, $r^2 = 0.106$). Concentrations in pondweed were correlated with concentrations in invertebrates ($p = 0.008$, $r^2 = 0.169$). Geometric-mean arsenic concentrations in invertebrates correlated with mean concentrations in fish ($p = 0.014$, $r^2 = 0.662$). Geometric-mean concentrations in water, sediment, or dietary organisms did not correlate with mean concentrations in bird eggs or livers.

Arsenic concentrations in unfiltered water samples collected from Sprig Pond, Lead Lake, and Stillwater Point Reservoir during 1994–96 consistently exceeded standards for applicable beneficial uses (table 1) and also exceeded concentrations associated with toxicity to amphibian embryos and larvae, 40 µg/L (U.S. Environmental Protection Agency, 1985a, p. 15), and toxicity to fish, 40 µg/L (Birge and others, 1979a, p. 523). Arsenic in sediments from all wetland units exceeded potentially toxic concentrations for sensitive benthic invertebrates, 6 µg/g, and arsenic concentrations in sediment from Lead Lake in 1995 exceeded a level associated with a broader range of toxicity, 33 µg/g (Persaud and others, 1993, p. 3).

Mean arsenic concentrations in pondweed and invertebrates were less than avian-diet effect levels, 30 µg/g (Camardese and others, 1990, p. 793). Also, concentrations in bird eggs and livers were below levels of concern (Stanley and others, 1994). Because concentrations in whole fish and bird livers were substantially lower than concentrations in potential food-chain organisms, arsenic in Lahontan Valley wetlands does not appear to magnify in food chains or concentrate in higher organisms.

Boron

Boron concentrations in water collected from agricultural drains and from wetlands receiving irrigation drainage in previous NIWQP investigations in Lahontan Valley commonly exceeded standards for applicable beneficial uses and were at a level associated with low-level fish toxicity (Hoffman and others, 1990, p. 34). Boron concentrations in water correlated with specific conductance, and concentrations tended to be higher before or in the early part of the irrigation season. Boron in a majority of aquatic-vegetation samples exceeded the avian-diet effect level. Concentrations in juvenile-bird livers collected in 1986 exceeded a level associated with reduced hatching success and juvenile survival. Boron concentrations in bird eggs and juvenile-bird livers collected in other years were generally lower but exceeded concentrations associated with reduced growth rate.

During 1994–96, boron was detected in all unfiltered wetland water, sediment, detritus, vegetation, and invertebrate samples; in 86 percent of the fish; in 53 percent of the coot eggs and 56 percent of the avocet eggs; and in 95 percent of the coot livers and 91 percent of the avocet livers (table 14). Boron concentrations in

Table 13. Arsenic concentrations in unfiltered water, sediment, and biological samples collected from four wetlands in Lahontan Valley, Nevada, April–August 1994–96

[Geometric-mean (and range) data from U.S. Fish and Wildlife Service. Within each wetland for particular sample medium or type, geometric means having same appended letter (*a* through *c*) are not significantly different (p<0.05) across years; correspondingly, differing appended letters indicate significant difference between geometric means. —, no data available or not applicable. <, used with sample mean, indicates that value for more than half of samples was less than analytical detection limit; used with range, indicates that value for at least one sample was less than detection limit. In cases where analytical detection limit varied, maximum limit is given]

Wetland	Year	Total arsenic in water samples (micrograms per liter)	Arsenic in bottom-sediment samples (micrograms per gram)	Arsenic in biological samples (micrograms per gram)							
				Detritus	Pondweed	Hemiptera	Fish	Coot egg	Avocet egg	Coot liver	Avocet liver
Stillwater National Wildlife Refuge											
Dry Lake:											
	1994	31 *a*	17.0 *a*	—	6.4 *a*	[1]1.0	—	[1]0.6	—	0.8 *a*	[1]<0.5
		(31–32)	(14–18)	(—)	(4.5–8.5)	(<1.0–1.4)	(—)	(<0.5–1.3)	(—)	(0.7–1.0)	(—)
	1995	7 *b*	14.0 *a*	13.5 *a*	3.2 *a*	[1]<0.5	1.0 *a*	[1]<0.5	—	[1]<0.5	—
		(29–58)	(10–18)	(11–16)	(1.2–9.8)	(<0.5–0.5)	(0.5–1.9)	(<0.5–0.5)	(—)	(—)	(—)
	1996	32 *a*	15.1 *a*	14.0 *a*	3.7 *a*	[1]<0.9	1.2 *b*	[1]<0.5	[1]<0.5	0.7 *a*	[1]0.4
		(25–36)	(13–18)	(12–19)	(1.4–6.2)	(<0.9–1.8)	(<0.8–2.5)	(<0.5–0.6)	(—)	(<0.5–1.9)	(<0.5–0.5)
Lead Lake:											
	1994	175 *b*	25.9 *b*	—	15.7 *a*	2.1 *b*	—	[1]<0.5	[1]<0.5	—	[1]<0.5
		(172–177)	(24–28)	(—)	(13.4–19.0)	(1.9–2.4)	(—)	(<0.5–0.7)	(—)	(—)	(—)
	1995	40 *a*	31.2 *c*	20.7 *a*	20.7 *b*	[1]4.8	[1]1.3	[1]<0.5	—	[1]<0.5	—
		(35–48)	(25–35)	(19–24)	(19.2–21.8)	(4.6–5.1)	(—)	(—)	(—)	(<5–1.2)	(—)
	1996	133 *b*	20.0 *a*	18.3 *a*	20.3 *b*	1.8 *a*	[1]0.9	[1]<0.5	[1]<0.5	[1]1.0	[1]<0.5
		(131–135)	(18–24)	(18–21)	(16.8–26.0)	(1.6–2.1)	(<0.9–1.5)	(<0.5–0.7)	(—)	(0.7–1.6)	(—)
Stillwater Point Reservoir:											
	1994	73 *c*	13.6 *a*	—	18.2 *b*	[1]9.0	[1]2.5	[1]<0.5	[1]<0.5	[1]<0.5	[1]<0.5
		(71–74)	(11–17)	(—)	(12.5–27.2)	(8.5–9.5)	(1.8–4.4)	(<0.5–0.9)	(—)	(<0.5–1.5)	(<0.5–1.5)
	1995	24 *a*	11.0 *a*	19.6 *b*	11.4 *a*	[1]<0.5	[1]<0.5	[1]<0.5	—	0.6 *a*	—
		(21–27)	(7–16)	(8–19)	(8.4–15.3)	(—)	(<0.5–1.3)	(—)	(—)	(<0.5–1.1)	(—)
	1996	43 *b*	16.3 *a*	12.6 *a*	11.9 *a,b*	[1]5.2	[1]<0.9	[1]0.4	[1]<0.5	0.6 *a*	—
		(43–43)	(11–19)	(10–28)	(9.3–15.4)	(—)	(<0.9–2.2)	(<0.5–0.6)	(—)	(<0.5–0.9)	(—)
Carson Lake											
Sprig Pond:											
	1994	81 *b*	17.6 *a*	—	16.4 *b*	9.2 *b*	[1]4.8	[1]<0.5	[1]<0.5	[1]0.5	[1]<0.5
		(75–86)	(15–20)	(—)	(14.1–17.7)	(6.6–18.1)	(4.0–5.6)	(—)	(—)	(<0.5–1.2)	(<0.5–0.5)
	1995	48 *a*	20.9 *b*	20.2 *a*	6.4 *a*	[1]0.5	[1]<0.5	[1]<0.5	[1]<0.5	0.4 *a*	[1]<0.5
		(43–50)	(19–23)	(20–21)	(4.3–12.8)	(<0.5–1.0)	(—)	(—)	(—)	(<0.5–0.8)	(—)
	1996	60 *a*	18.1 *a*	17.8 *a*	21.1 *b*	2.8 *a*	—	[1]<0.5	[1]<0.5	0.6 *a*	[1]<0.5
		(61–75)	(17–20)	(16–19)	(15.6–27.7)	(1.3–4.8)	(—)	(<0.5–0.5)	(—)	(<0.5–0.8)	(—)

[1]Analysis of variance was not attempted because of inadequate sample size or large number of samples having concentrations less than analytical detection limit.

Table 14. Boron concentrations in unfiltered water, sediment, and biological samples collected from four wetlands in Lahontan Valley, Nevada, April–August 1994–96

[Geometric-mean (and range) data from U.S. Fish and Wildlife Service. Within each wetland for particular sample medium or type, geometric means having same appended letter (*a* through *c*) are not significantly different ($p<0.05$) across years; correspondingly, differing appended letters indicate significant difference between geometric means. —, no data available or not applicable. <, used with sample mean, indicates that value for more than half of samples was less than analytical detection limit; used with range, indicates that value for at least one sample was less than detection limit. In cases where analytical detection limit varied, maximum limit is given]

Wetland	Year	Total boron in water samples (micrograms per liter)	Boron in bottom-sediment samples (micrograms per gram)	Boron in biological samples (micrograms per gram)							
				Detritus	Pondweed	Hemiptera	Fish	Coot egg	Avocet egg	Coot liver	Avocet liver
Stillwater National Wildlife Refuge											
Dry Lake:											
	1994	743 *a*	103.3 *a*	—	751 *b*	13.9 *a,b*	—	8.7 *a*	—	14.6 *b*	[1]4.5
		(740–750)	(88–119)	(—)	(689–977)	(10.4–22.5)	(—)	(7.4–10.3)	(—)	(13.3–16.2)	(3.0–6.0)
	1995	1,510 *a*	123.2 *a*	122.8 *a*	595 *a*	18.5 *b*	5.0 *a*	3.6 *a*	—	5.0 *a*	—
		(832–2,090)	(81–160)	(97–167)	(546–646)	(14.1–23.1)	(4.7–10.1)	(<2.0–8.2)	(—)	(3.6–21.6)	(—)
	1996	1,300 *a*	122.7 *a*	112.6 *a*	573 *a*	11.6 *a*	10.6 *b*	2.5 *a*	[1]<2.0	4.6 *a*	[1]<2.0
		(915–1,590)	(108–138)	(98–131)	(523–626)	(10.6–12.6)	(7.3–13.2)	(<2.0–5.2)	(<2.0–3.1)	(2.8–7.5)	(—)
Lead Lake:											
	1994	[1]10,770	66.9 *a*	—	283 *b*	73.9 *b*	—	6.8 *b*	[1]<0.5	—	[1]6.8
		(10,600–10,900)	(41–92)	(—)	(239–303)	(59.4–83.2)	(—)	(2.6–15.7)	(—)	(—)	(4.9–10.8)
	1995	1,600 *a*	89.5 *a,b*	87.8 *a*	74 *a*	[1]49.7	[1]10.6	[1]<2.0	—	6.4 *a*	—
		(1,390–1,930)	(82–100)	(80–102)	(65–88)	(46.7–52.9)	(—)	(—)	(—)	(3.2–9.3)	(—)
	1996	3,580 *b*	98.7 *b*	98.9 *a*	826 *c*	14.4 *a*	[1]8.1	3.3 *a*	[1]<2.0	8.0 *a*	[1]2.0
		(3,560–3,610)	(92–104)	(95–103)	(679–1,010)	(12.6–15.8)	(5.0–12.0)	(2.4–5.9)	(—)	(6.6–10.6)	(<2.0–3.4)
Stillwater Point Reservoir:											
	1994	1,210 *c*	55.8 *a*	—	87 *a*	[1]47.9	12.7 *b*	4.7 *a*	[1]1.4	5.7 *a*	[1]1.4
		(1,200–1,220)	(37–69)	(—)	(57–115)	(45.7–50.3)	(11.3–14.1)	(3.9–5.4)	(0.6–2.3)	(2.9–9.0)	(0.7–3.0)
	1995	598 *a*	74.2 *a,b*	82.2 *a*	225 *b*	[1]2.3	7.8 *a,b*	[1]<2.0	—	3.9 *a*	—
		(514–648)	(64–83)	(61–91)	(148–256)	(—)	(3.8–17.9)	(<2.0–8.5)	(—)	(3.2–9.3)	(—)
	1996	852 *b*	86.4 *b*	70.0 *a*	399 *c*	[1]23.5	3.3 *a*	2.4 *a*	[1]<2.0	2.7 *a*	—
		(812–875)	(65–96)	(37–108)	(301–497)	(—)	(<3.5–7.5)	(<2.0–3.1)	(—)	(2.2–3.3)	(—)
Carson Lake											
Sprig Pond:											
	1994	2,220 *b*	62.7 *a*	—	113 *a*	48.4 *b*	[1]15.5	0.8 *a*	1.2 *a*	6.9 *b*	3.4 *a*
		(2,180–2,250)	(47–85)	(—)	(71–237)	(41.9–51.8)	(14.9–16.1)	(<0.5–3.0)	(<0.5–4.1)	(5.3–10.1)	(3.0–3.6)
	1995	1,380 *a*	78.3 *a*	71.7 *a*	491 *b*	[1]18.0	[1]<2.0	2.8 *a,b*	[1]<2.0	2.3 *a*	3.1 *a*
		(1,190–1,510)	(76–81)	(63–77)	(178–649)	(12.8–25.8)	(<0.2–6.4)	(<2.0–7.9)	(—)	(<2.0–8.6)	(2.5–3.8)
	1996	1,180 *a*	84.4 *a*	79.9 *a*	731 *b*	10.0 *a*	—	4.7 *b*	5.3 *b*	4.0 *a,b*	4.7 *a*
		(1,050–1,400)	(80–89)	(76–84)	(537–998)	(8.7–12.9)	(—)	(<2.0–13.4)	(4.2–8.1)	(3.3–5.5)	(3.9–6.1)

[1]Analysis of variance was not attempted because of inadequate sample size or large number of samples having concentrations less than analytical detection limit.

unfiltered water significantly correlated with specific conductance ($p<0.001$, $r^2 = 0.985$) but not with pH. Boron concentrations in water correlated only with concentrations in hemipterans ($p<0.001$, $r^2 = 0.478$). Concentrations in sediment correlated with concentration in detritus ($p<0.001$, $r^2 = 0.545$), pondweed ($p<0.001$, $r^2 = 0.236$), and hemipterans ($p = 0.001$, $r = 0.268$). Geometric-mean concentrations of boron in water, sediment, and food-chain organisms did not correlate with mean concentrations in fish or in bird eggs and livers.

In general, during 1994–96, boron concentrations were lower in wetland water, higher in sediment, and substantially lower in bird samples than in the earlier NIWQP investigations (during the 1980's). During the same 3-year period, boron concentrations in wetland water consistently exceeded the irrigation-water-quality standard and exceeded concentrations associated with low-level toxicity (LC_{10}, lethal to 10 percent of test population) to aquatic vertebrates (Birge and others, 1979a, p. 523). As for aluminum, little information regarding the biological implications of boron in sediments is available. However, the correlation between concentrations of boron in sediment and boron in aquatic vegetation suggests that sediment serves as a source of the boron in vegetation.

Elevated boron in diet has been shown to adversely affect bird reproduction, growth, and survival (Smith and Anders, 1989). Boron concentrations in all pondweed samples and 35 percent of the aquatic-invertebrate samples exceeded a dietary concentration associated with reduced weight gain in mallard ducklings, 30 μg/g (Smith and Anders, 1989, p. 945). Concentrations in 58 percent of the pondweed samples exceed a 300-μg/g dietary concentration associated with reduced hatch weight and reduced weight gain. A dietary concentration associated with reduced hatching success or duckling survival, 1,000 μg/g, was exceeded in only one sample from the Lahontan Valley wetlands. A boron concentration associated with reduced weight gain in mallard ducklings, 3 μg/g (Smith and Anders, 1989, p. 948), was met or exceeded in 69 percent of coot eggs, 81 percent of juvenile livers, 29 percent of avocet eggs, and 72 percent of juvenile livers.

Although boron concentrations exceeded avian-diet effect levels in both pondweed and hemipteran samples, aquatic vegetation represented the greatest potential for exposure to boron for migratory birds. Boron could adversely affect their reproduction and survival. As may be expected, a herbivorous bird species (coot) had higher concentrations of boron in eggs and livers than an insectivorous species (avocet). Boron concentrations in pondweed correlated with concentrations in sediment and detritus. However, concentrations in these media did not correlate with concentrations in unfiltered water. The highest boron concentrations in sediment and pondweed were consistently found in Dry Lake, which has been managed using high-quality irrigation water since 1990. Since 1992, boron concentrations in sediment and pondweed from Dry Lake have increased (fig. 4).

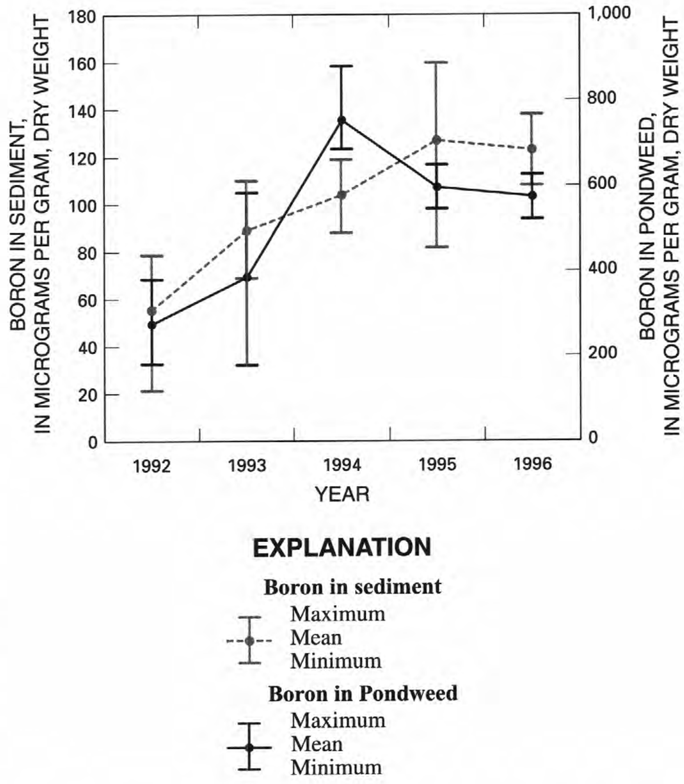


Figure 4. Mean boron concentrations and ranges in sediment and pondweed collected from Dry Lake in Stillwater National Wildlife Refuge, west-central Nevada, 1992–96.

Mercury

Previous investigators identified elevated mercury concentrations in water and sediment, in the avian diet (aquatic vegetation, aquatic invertebrates, and fish), and in bird eggs and livers (Hoffman and others, 1990; Hallock, Burge, and Tuttle, 1993a, b; Tuttle and others, 1996). In those investigations, dissolved mercury was detected in more than half of the wetland water samples collected in Lahontan Valley. Because the chronic aquatic-life standard and effect concentrations were less than the analytical detection limits provided by the laboratories, at least all measured concentrations exceeded levels of concern. Mercury in bottom sediments from drains and wetlands commonly exceeded concentrations associated with toxicity to freshwater and estuarine invertebrates. Mercury in avian food-chain organisms commonly exceeded concentrations associated with reduced reproduction and mallard-duckling behavioral effects. Concentrations in whole fish also exceeded these bird effect levels. Mercury in some bird eggs collected in Lahontan Valley exceeded concentrations associated with reduced hatch rate and juvenile survival. Concentrations in juvenile-bird livers commonly exceeded concentrations associated with reduced reproduction and histopathology. In addition, mercury exceeded recommended levels for human consumption in several fish and waterfowl samples and was therefore the only element that appeared to pose a direct threat to human health.

Mercury was detected in only four unfiltered wetland-water samples, but the detection limits reported by the USFWS laboratory were high, ranging from 0.5 to 1.5 µg/L. Detected concentrations ranged from 0.6 to 5.2 µg/L (table 15). Mercury, however, was measured in almost all sediment, detritus, invertebrate, fish, coot-egg, avocet-egg, coot-liver, and avocet-liver samples collected from all wetlands. Mercury was detected in all pondweed samples from Sprig Pond and Lead Lake, in 87 percent of the samples from Stillwater Point Reservoir, and in 33 percent of the samples from Dry Lake. Mercury concentrations in sediment significantly correlated with concentrations in detritus ($p<0.001$, $r^2=0.962$), pondweed ($p=0.027$, $r^2=0.401$), and invertebrates ($p = 0.008$, $r^2 = 0.172$). Geometric-mean concentrations of mercury in sediment and food-chain organisms did not correlate with mean concentrations in bird eggs or livers.

Mercury concentrations in sampled biological media generally were higher in 1994–96 than were found during the earlier NIWQP investigations (1980's), particularly in Stillwater NWR. The chronic aquatic-life standard for mercury, 0.012 µg/L, is substantially lower than the detection limits reported by the USFWS laboratory for mercury in water, 0.5 to 1.5 µg/L; therefore, at a minimum, the four wetland water samples collected during 1994–96 that had detectable concentrations of mercury exceeded the chronic aquatic-life standard. Similarly, all samples with detectable mercury concentrations exceeded an effect level for fish, 0.1 µg/L (Birge and others, 1979b, p. 635). Mercury concentrations in the Carson River correlate with suspended-solid concentrations in the water column, and suspended-solids concentrations are positively correlated with river flows exceeding 500 ft^3/s (Cooper and others, 1985; Bonzongo and others, 1996). With the exception of Sprig Pond, mercury concentrations were higher in livers of juvenile avocets than in those of juvenile coots. Elevated concentrations in coot eggs may be from increased consumption of insects by females during egg production to acquire sufficient protein (Fredrickson and Taylor, 1982).

Mercury in bottom sediment from all wetlands exceeded an estimate of the background mercury concentration in Lahontan Valley prior to mercury contamination less than 1 µg/g, dry weight. Mercury concentrations in most sediment samples exceeded effect concentrations for sensitive freshwater invertebrates, 0.2 µg/g (Persaud and others, 1993, p. 3) and estuarine and coastal marine invertebrates, 0.15 µg/g (Long and Morgan, 1991, p. 46). Concentrations in Lead Lake and Sprig Pond sediments exceeded a severe-effect level for aquatic sediments, 2.0 µg/g (Persaud and others, 1993).

At relatively low dietary concentrations, mercury can affect bird reproduction and survival. Mercury concentrations in all the fish and hemipteran samples and in 47 percent of the pondweed samples collected during 1994–96 met or exceeded an avian dietary concentration associated with reduced reproduction in successive generations of mallards, 0.5 µg/g (Heinz, 1979, p. 400). Concentrations in 30 percent of the invertebrate samples exceeded a dietary concentration associated with reduced reproduction in a single generation of black ducks and lesions in nerve tissue of hatchlings, 3.0 µg/g (Finley and Stendell, 1978, p. 61). A dietary concentration associated with histopathology in bird species, 1.1 µg/g (Nicholson and Osborn, 1984),

Table 15. Mercury concentrations in unfiltered water, sediment, and biological samples collected from four wetlands in Lahontan Valley, Nevada, April–August 1994–96

[Geometric-mean (and range) data from U.S. Fish and Wildlife Service. Within each wetland for particular sample medium or type, geometric means having same appended letter (*a* through *c*) are not significantly different ($p<0.05$) across years; correspondingly, differing appended letters indicate significant difference between geometric means. —, no data available or not applicable. <, used with sample mean, indicates that value for more than half of samples was less than analytical detection limit; used with range, indicates that value for at least one sample was less than detection limit. In cases where analytical detection limit varied, maximum limit is given]

Wetland	Year	Total mercury in water samples (micrograms per liter)	Mercury in bottom-sediment samples (micrograms per gram)	Mercury in biological samples (micrograms per gram)							
				Detritus	Pondweed	Hemiptera	Fish	Coot egg	Avocet egg	Coot liver	Avocet liver
Stillwater National Wildlife Refuge											
Dry Lake:											
	1994	[1]<1.1	0.2 *a*	—	[1]<0.2	3.0 *b*	—	3.4 *b*	—	18.6 *b*	[1]8.1
		(—)	(—)	(—)	(<0.2–0.2)	(2.8–3.2)	(—)	(1.6–7.6)	(—)	(4.6–53.1)	(2.5–20.2)
	1995	[1]<0.5	0.2 *a*	0.2 *a*	[1]0.1	1.3 *a*	1.4 *a*	0.8 *a*	—	3.8 *a*	—
		(—)	(0.1–0.3)	(0.1–0.3)	(<0.1–0.2)	(0.7–2.4)	(1.1–1.2)	(0.5–1.3)	(—)	(3.0–5.4)	(—)
	1996	[1]<1.5	0.2 *a*	0.2 *a*	[1]<0.2	2.3 *b*	1.4 *a*	1.0 *a*	[1]1.5	2.5 *a*	[1]9.2
		(—)	(<0.1–0.3)	(0.1–0.2)	(—)	(2.1–2.5)	(1.2–1.8)	(0.8–1.3)	(0.9–3.2)	(1.6–4.6)	(3.0–32.6)
Lead Lake:											
	1994	[1]2.7	12.3 *a*	—	1.3 *a*	6.2 *b*	—	22.1 *c*	[1]22.4	—	21.8 *b*
		(<1.1–5.2)	(10.9–14.6)	(—)	(1.1–1.7)	(5.4–7.0)	(—)	(18.4–26.5)	(21.8–23.1)	(—)	(15.1–45.6)
	1995	[1]<0.5	27.3 *b*	21.9 *b*	3.1 *b*	[1]3.4	[1]2.2	5.8 *b*	—	16.7 *b*	—
		(—)	(24.3–30.4)	(17.7–25.9)	(2.0–5.1)	(2.9–4.1)	(2.2–2.2)	(2.6–13.5)	(—)	(12.5–20.4)	(—)
	1996	[1]<1.5	10.1 *a*	9.5 *a*	0.3 *a*	2.1 *a*	[1]1.2	3.0 *a*	[1]2.7	4.5 *a*	6.5 *a*
		(—)	(7.5–11.2)	(7.0–11.7)	(0.2–0.3)	(1.7–2.7)	(0.7–1.6)	(2.5–4.1)	(2.1–4.6)	(1.7–11.0)	(6.1–7.0)
Stillwater Point Reservoir:											
	1994	[1]<1.1	1.5 *a*	—	0.9 *a*	[1]1.8	1.2 *a*	1.8 *a*	[1]5.2	4.4 *a*	[1]9.6
		(—)	(1.3–1.9)	(—)	(0.6–1.4)	(1.5–2.6)	(0.8–2.3)	(0.5–4.0)	(4.2–9.5)	(1.7–9.8)	(5.8–13.8)
	1995	[1]<0.5	1.4 *a*	1.6 *a*	0.3 *a*	[1]2.6	3.7 *b*	2.3 *a*	—	8.7 *a*	—
		(—)	(0.1–2.2)	(0.8–2.0)	(0.2–0.5)	(2.6–2.6)	(2.7–5.3)	(0.7–4.8)	(—)	(4.2–25.7)	(—)
	1996	[1]<1.5	1.7 *a*	0.5 *a*	0.1 *a*	[1]0.5	2.2 *a,b*	2.9 *a*	[1]2.1	10.3 *a*	—
		(—)	(1.0–2.1)	(0.1–2.1)	(<0.2–0.5)	(—)	(1.8–2.7)	(1.5–5.9)	(—)	(6.7–12.4)	(—)
Carson Lake											
Sprig Pond:											
	1994	[1]<1.1	5.4 *a*	—	3.4 *b*	2.2 *b*	[1]2.3	8.7 *b*	2.2 *a*	11.9 *a*	11.8 *a*
		(<1.1–1.7)	(4.5–6.0)	(—)	(2.3–5.3)	(1.7–2.4)	(2.0–2.7)	(5.6–13.2)	(1.3–2.8)	(5.6–15.8)	(9.6–14.7)
	1995	[1]<0.5	8.6 *b*	10.9 *b*	0.3 *a*	[1]10.8	[1]3.0	3.3 *a*	2.4 *a*	10.1 *a*	7.3 *a*
		(<0.5–0.6)	(5.0–11.0)	(9.7–12.0)	(0.1–0.7)	(10.7–10.8)	(2.2–4.5)	(2.2–7.4)	(1.5–3.2)	(4.2–32.2)	(6.5–9.9)
	1996	[1]<1.5	5.7 *a*	5.9 *a*	0.6 *a*	1.2 *a*	—	2.7 *a*	2.1 *a*	6.4 *a*	6.1 *a*
		(—)	(5.0–6.0)	(5.3–6.6)	(0.4–0.9)	(1.0–1.6)	(—)	(2.1–6.3)	(0.9–5.4)	(3.6–8.8)	(2.3–25.9)

[1]Analysis of variance was not attempted because of inadequate sample size or large number of samples having concentrations less than analytical detection limit.

was met or exceeded in 90 percent of the hemipterans, 89 percent of the fish, and 28 percent of the pondweed samples. Through a literature review, Zillioux and others (1993, p. 2260) estimated that the significant toxic-effects threshold concentration for most aquatic bird eggs was in the range 1.0 to 3.6 μg/g, wet weight. At such concentrations, behavioral effects became apparent, whereas at about 5 μg/g, wet weight, reduced hatching success and hatchling survival was evident. Overall, concentrations in 33 percent of the aquatic bird eggs examined during 1994–96 exceeded 1.0 μg/g, wet weight, and 5 percent exceeded 5.0 μg/g, wet weight. Zillioux and others (1993, p. 2260) also estimated a conservative liver-threshold concentration of 5 μg/g, wet weight, for major toxic effects in aquatic birds. During 1994–96, concentrations in 13 percent of the bird livers exceeded this threshold. Mercury concentrations in 82 percent of the bird livers exceeded 1.0 μg/g, wet weight, a concentration associated with behavioral effects.

Mercury contamination in Lead Lake is of particular concern. Mercury concentrations in all eggs collected from this wetland in 1994 exceeded a concentration associated with embryotoxicity. Mercury concentrations in samples of livers of juvenile avocets collected from Lead Lake during 1994 ranged from 3.8 to 11.4 μg/g, wet weight. Three samples exceeded concentrations associated with major toxic effects in waterfowl. The absence of juvenile coots in this wetland during that year may have resulted from embryotoxicity or poor hatchling survival associated with elevated mercury. Concentrations decreased in all media examined during 1994–96. Elevated mercury concentrations have been noted in fish and other biota in the first few years after inundation of newly constructed reservoirs (Bodaly and others, 1984). Increased methylation, mobility, and bioavailability of mercury resulting from the inundation of Lead Lake, which had been dry from 1989 to 1993, may have accounted for increased mercury concentrations in 1994 and 1995.

Selenium

Previous studies in Lahontan Valley identified selenium as a concern because of concentrations found in potential avian diet (invertebrates and fish) and in bird livers (Hoffman and others, 1990; Tuttle and others, 1996). Selenium concentrations in filtered water were commonly below the USGS reporting limit of 1.0 μg/L, and sample concentrations exceeding the reporting limit were less than concentrations associated with adverse effects on fish and wildlife. Also, concentrations in more than half the sediment samples were less than the USGS reporting limit of 0.1 μg/g dry weight, and the samples exceeding the reporting limit generally were consistent with selenium-normal environments. However, selenium commonly was elevated in food-chain organisms and in bird tissues. Concentrations in invertebrates collected from Stillwater Marsh and Carson Lake generally were less than concentrations associated with increased risk to fish and birds. Selenium residues in whole fish seldom exceeded concentrations of concern. Selenium in biological media tended to be higher in samples from Fernley WMA and from Massie and Mahala Sloughs (fig. 1) than in samples from other areas. Avian eggs contained residues below those associated with teratogenesis or embryonic mortality (Lemly, 1996). Concentrations in bird livers generally were below those associated with reproductive effects, and concentrations in waterfowl muscle and whole fish were below the Nevada criterion for human consumption.

During 1994–96, selenium concentrations in unfiltered wetland water were less than detection limits in all water samples. Selenium was detected in 65 percent of the sediment, 27 percent of the detritus, 7 percent of the vegetation, 70 percent of the invertebrate, and 81 percent of the fish samples; in all avocet eggs and all but one of the coot eggs; and in coot and avocet livers (table 16). Because selenium concentrations in the majority of water, detritus, and vegetation samples were less than the detection limits, statistical relations were not examined for these media. Selenium concentrations in sediment significantly correlated with concentrations in hemipterans ($p = 0.041$, $r^2 = 0.355$). Geometric-mean concentrations of selenium in sediment correlated with mean concentrations in coot livers ($p = 0.002$, $r^2 = 0.619$).

During 1994–96, selenium concentrations in bird livers were lower than those found in previous NIWQP investigations. Concentrations in other media in which selenium was detected and for which matched samples were available were not substantially different. Although selenium was not detected in unfiltered wetland water, the detection limits reported by the USFWS laboratory (5 to 6 μg/L), exceeded waterborne concentrations associated with long-term adverse effects in fish and wildlife populations, 2.0 μg/L (Lemly, 1996, p. 432). A selenium concentration of 1.0 μg/g in sediment

Table 16. Selenium concentrations in unfiltered water, sediment, and biological samples collected from four wetlands in Lahontan Valley, Nevada, April–August 1994–96

[Geometric-mean (and range) data from U.S. Fish and Wildlife Service. Within each wetland for particular sample medium or type, geometric means having same appended letter (*a* through *c*) are not significantly different (p<0.05) across years; correspondingly, differing appended letters indicate significant difference between geometric means. —, no data available or not applicable. <, used with sample mean, indicates that value for more than half of samples was less than analytical detection limit; used with range, indicates that value for at least one sample was less than detection limit. In cases where analytical detection limit varied, maximum limit is given]

Wetland	Year	Total selenium in water samples (micrograms per liter)	Selenium in bottom-sediment samples (micrograms per gram)	Selenium in biological samples (micrograms per gram)							
				Detritus	Pondweed	Hemiptera	Fish	Coot egg	Avocet egg	Coot liver	Avocet liver
Stillwater National Wildlife Refuge											
Dry Lake:											
	1994	[1]<6.0	[1]1.0	—	[1]<1.0	1.8 *a*	—	[1]0.7	—	7.3 *b*	[1]7.9
		(—)	(0.8–1.1)	(—)	(—)	(1.3–2.6)	(—)	(<0.5–1.8)	(—)	(4.5–9.9)	(5.8–9.4)
	1995	[1]<5.0	[1]<1.0	[1]<1.0	[1]<0.5	2.2 *b*	[1]<0.5	[1]1.5	—	2.2 *a*	—
		(—)	(—)	(—)	(—)	(2.2–2.3)	(—)	(1.4–1.7)	(—)	(1.6–3.5)	(—)
	1996	[1]<5.6	[1]<0.5	[1]<0.5	[1]<1.0	1.6 *a*	[1]1.1	[1]1.4	[1]3.0	2.2 *a*	[1]8.1
		(—)	(<0.5–0.7)	(—)	(—)	(1.5–1.9)	(<0.9–2.0)	(1.0–1.9)	(2.3–4.5)	(1.7–2.6)	(4.8–13.9)
Lead Lake:											
	1994	[1]<5.6	1.7 *b*	—	[1]<1.0	3.2 *b*	—	1.5 *a*	[1]3.0	—	6.8 *a*
		(—)	(1.5–2.0)	(—)	(—)	(3.0–3.8)	(—)	(1.3–1.7)	(2.9–3.0)	(—)	(2.1–11.3)
	1995	[1]<5.0	1.0 *a*	[1]<1.0	[1]<0.5	[1]2.1	[1]0.7	2.3 *b*	—	3.9 *a*	—
		(—)	(<1.0–1.3)	(<1.0–1.1)	(<0.5–0.7)	(—)	(—)	(1.7–3.4)	(—)	(3.3–4.5)	(—)
	1996	[1]<5.6	0.9 *a*	[1]0.6	[1]<1.0	1.8 *a*	[1]1.7	1.9 *a,b*	[1]2.6	4.4 *a*	9.7 *a*
		(—)	(0.6–1.1)	(<0.5–0.9)	(—)	(1.0–2.1)	(1.3–1.9)	(1.7–2.2)	(2.4–2.9)	(3.2–7.7)	(9.2–10.0)
Stillwater Point Reservoir:											
	1994	[1]<5.6	[1]0.8	—	[1]<1.0	[1]<1.0	1.6 *b*	1.4 *a*	[1]3.8	2.6 *a,b*	[1]8.4
		(—)	(0.6–1.0)	(—)	(<1.0–1.5)	(—)	(1.4–1.9)	(0.7–2.8)	(2.8–4.8)	(1.6–3.3)	(6.0–11.4)
	1995	[1]<5.0	[1]<1.0	[1]0.6	[1]<0.5	[1]1.4	2.1 *b*	1.9 *a*	—	2.1 *a*	—
		(—)	(—)	(<0.5–1.0)	(—)	(—)	(1.4–2.7)	(1.7–2.1)	(—)	(1.6–3.8)	(—)
	1996	[1]<5.6	[1]0.7	[1]<1.0	[1]<1.0	[1]<0.9	0.7 *a*	1.9 *a*	[1]5.0	3.7 *b*	—
		(—)	(0.6–0.9)	(—)	(—)	(—)	(<0.9–1.2)	(1.2–2.7)	(—)	(3.2–4.6)	(—)
Carson Lake											
Sprig Pond:											
	1994	[1]<6.0	[1]0.7	—	[1]<1.0	[1]<1.0	[1]1.6	1.9 *b*	2.1 *a*	4.5 *b*	6.1 *b*
		(—)	(0.5–1.3)	(—)	(<1.0–1.0)	(—)	(1.3–1.9)	(1.7–2.2)	(1.5–2.7)	(1.7–7.5)	(3.0–8.8)
	1995	[1]<5.0	[1]<1.0	[1]<1.0	[1]<0.5	[1]1.5	[1]0.9	1.4 *a*	1.6 *a*	2.1 *a*	3.2 *a*
		(—)	(—)	(—)	(—)	(—)	(0.6–1.1)	(1.2–1.6)	(1.1–2.4)	(1.6–2.6)	(2.9–3.4)
	1996	[1]<5.6	[1]0.5	[1]<0.5	[1]<1.0	[1]<0.8	—	1.3 *a*	1.5 *a*	2.5 *a*	4.3 *a,b*
		(—)	(<0.5–0.8)	(<0.5–0.7)	(—)	(—)	(—)	(0.9–1.8)	(1.2–1.9)	(2.0–2.9)	(3.3–6.4)

[1]Analysis of variance was not attempted because of inadequate sample size or large number of samples having concentrations less than analytical detection limit.

is the minimum concentration associated with effects on bird reproduction, and 4.0 µg/g is associated with severe effects (U.S. Department of the Interior, 1998, p. 153). Mean selenium concentrations in sediment from Dry Lake in 1994 and from Lead Lake in 1994 and 1995 exceeded 1.0 µg/g. No selenium concentrations in individual sediment samples exceeded 4.0 µg/g. With the exception of hemipteran samples collected from Lead Lake in 1994 (3.0 to 3.8 µg/g), selenium concentrations in organisms that are part of the avian diet were less than a selenium concentration of concern, 3.0 µg/g (Skorupa and others, U.S. Fish and Wildlife Service, written commun., 1996). Geometric-mean selenium concentrations in coot eggs, at less than 3.0 µg/g, were within the range of normal concentrations of selenium in aquatic bird eggs (Skorupa and Ohlendorf, 1991, p. 362). The geometric-mean concentration in avocet eggs collected from Stillwater Point Reservoir exceeded this concentration but was below the lower boundary of mean selenium concentrations in eggs associated with impaired egg hatchability among shorebirds, 8.0 µg/g. Also, concentrations in livers of juvenile avocets and coots were below concentrations associated with reproductive impairment (Heinz, 1996, p. 452).

Other Trace Elements

Lead

The Nevada water-quality standard for lead for protection of aquatic life is based on water hardness (Nevada Administrative Code 445.1339). For wetlands in Lahontan Valley, Hoffman and others (1990, p. 29) reported a median hardness of 440 mg/L as $CaCO_3$, which equates with a 96-hour average lead standard of 5.2 µg/L. During 1994–96, lead concentrations exceeded detection limits (6 to 11 µg/L) reported by the USFWS laboratory in 11 percent of the wetland water samples. All detected concentrations, ranging from 6 to 15 µg/L, exceeded the chronic aquatic-life standard (table 1). Although detected concentrations exceeded concentrations associated with low-level reproductive impairment in *Daphnia magna* (U.S. Environmental Protection Agency, 1985b), they were well below levels associated with lethal or sublethal effects on fish at elevated water hardness (Eisler, 1988, p. 61–64). Similarly, lead concentrations in sediment were below levels associated with toxicity to freshwater invertebrates, 31 µg/g (Persaud and others, 1993, p. 3) and estuarine and coastal marine invertebrates, 35 µg/g (Long and Morgan, 1991, p. 40).

Molybdenum

The Nevada water-quality standard for molybdenum for the protection of aquatic life is 19 µg/L. During 1994–96, 23 percent of the detected concentrations in wetland water samples, ranging from 10 to 80 µg/L, exceeded the Nevada aquatic-life standard. Low-level mortality (LC_1) of rainbow trout was found at a molybdenum concentration of 28 µg/L, and a higher level of mortality (LC_{50}) at concentrations exceeding 790 µg/L (Birge and others, 1979a, p. 523). Molybdenum concentrations during 1994–96 were well below levels associated with higher levels of mortality. Molybdenum also was below concentrations associated with aquatic-invertebrate mortality (Eisler, 1989, p. 28).

Zinc

Zinc was detected in 48 percent of the wetland water samples. The highest concentrations were in samples from Dry Lake. Zinc was not detected in samples from Stillwater Point Reservoir. Similar to lead toxicity, zinc toxicity to aquatic organisms correlates inversely with water hardness (U.S. Environmental Protection Agency, 1987). Standards for the protection of aquatic life are based on water hardness. Zinc concentrations observed during 1994–96 were below the chronic aquatic-life standard, 316 µg/L, calculated for the mean water hardness of Lahontan Valley wetlands (Hoffman and others, 1990, p. 29). Although zinc concentrations in pondweed (20–828 µg/g) and hemipterans (99–323 µg/g) were below dietary concentrations associated with reduced survival of mallards, 3,000 µg/g (Gasaway and Buss, 1972), concentrations in 23 percent of the pondweed and in 40 percent of the hemipteran samples exceeded a dietary concentration associated with immunosuppression in domestic chickens, 178 µg/g (Stahl and others, 1989).

Interactive Effects of Trace Elements

The combined effects of elevated contaminants measured in this study on fish, wildlife, and their habitat are largely uncertain. Although the combined effects of contaminants were not examined directly during this monitoring program, previous investigations demonstrated that water collected from selected agricultural drains and wetlands in Lahontan Valley was toxic to freshwater and saltwater fish larvae and invertebrates (Dwyer and others, 1992; Ingersoll and others, 1992; Finger and others, 1993; Lemly and others, 1993). Mortality occurred over a broad range of specific conductance. Although no single trace element exceeded toxic concentrations, Finger and others (1993, p. 37) noted that water samples that were toxic to fish and invertebrates contained elevated arsenic, boron, lithium, and molybdenum concentrations compared to background sites. During 1994–96, specific conductance and concentrations of arsenic, boron, and molybdenum in water samples collected from Dry Lake were below the ranges associated with toxicity as reported by Finger and others (1993, p. 26). Concentrations of lithium were not determined for these samples. Concentrations of arsenic, boron, and molybdenum in Sprig Pond and Stillwater Point Reservoir were near the lower end of the range associated with toxicity. For all 3 years, concentrations of these three constituents in Lead Lake exceeded levels associated with toxicity.

Assessment of toxicity using 5- and 15-minute Microtox procedures indicated that unfiltered water collected from Dry Lake in 1995 and Lead Lake in 1996 elicited a reduction in metabolic activity of *Photobacterium phosphoreum*. No other sample indicated toxicity (EC_{50} >100 percent for all 5- and 15-minute observations). In 1995, although Dry Lake water apparently indicated toxicity (EC_{50}=83 percent), the 95-percent confidence interval was wide (from 3 to greater than 100 percent) and metabolic response across the range of dilutions was inconsistent. Thus the observed response was likely due to error in the methodology rather than actual toxicity. Microtox testing indicated that water samples collected from Lead Lake in 1996 were toxic (EC_{50}=23 percent and 22 percent for 5- and 15-minute observations, respectively). In 1996, pH, specific conductance, and trace-element concentrations in Lead Lake generally were lower than concentrations found in 1994, when no metabolic depression was observed in the Microtox assays. This difference suggests that the observed toxicity to test organisms was not caused by these constituents.

The toxicity of individual trace elements to birds may be altered in the presence of other trace elements. Interactions between mercury and selenium have been documented extensively (U.S. Department of the Interior, 1998). Several investigators have noted antagonistic interactions: The toxicity of one or both elements is decreased in the presence of the other. However, other investigators found synergistic interactions—little toxic interaction or increased toxicity. Some of the discrepancy may stem from the various chemical forms of selenium and mercury examined in the individual studies. In a study administering environmentally relevant forms of mercury (as methylmercury chloride) and selenium (as selenomethionine) in diet, antagonistic interaction was evident when survival of adult mallards was examined, but synergistic interaction was evident when adverse reproductive effects (for example, reduced egg production, teratogenic effects, and reduced duckling survival) were considered (Heinz and Hoffman, 1998). Although the concentration of methylmercury chloride administered in that study (10 ug/g) was within the upper range of concentrations in potential avian-diet organisms found in this and other studies in Lahontan Valley (Rowe and others, 1991; Tuttle and others, 1996), concentrations of selenium in avian-diet organisms typically are well below the level associated with adverse effects by Heinz and Hoffman (1998).

Earlier investigators noted interactive effects from contaminants in agricultural drainage. Hoffman and others (1991) examined growth and biochemical effects in mallard ducklings maintained on diets containing boron and selenium separately and in combination. Adverse effects were more pronounced when these elements were administered concurrently and when diets contained reduced protein. Conversely, Stanley and others (1994) found that arsenic alleviated some adverse effects of selenium when both were administered to mallard ducklings in their diet. However, Fairbrother and others (1994) identified impaired immune system function in avocet chicks collected from areas with elevated concentrations of arsenic, boron, and(or) selenium.

Biological Implications of Contaminants of Concern

Previous investigations in Lahontan Valley identified concerns with dissolved-solids concentrations in water and the trace elements aluminum, arsenic, boron, chromium, mercury, selenium, and zinc in one or more biotic or abiotic media (Hoffman and others, 1990, p. 75; Tuttle and others, 1996, p. 57). Exposure pathways and potential biological effects of the various trace elements differ. Elevated trace-element concentrations may produce a variety of effects in wetland species and communities. Effects may stem from direct toxicity of water and sediment or from exposure of higher organisms to elevated trace-element concentrations through food chains. Concentrations of agricultural-drainage-related trace elements found in Lahontan Valley are within the range of concentrations associated with a variety of direct and indirect effects on fish and wildlife, including altered behavior (Kania and O'Hara, 1974; Heinz, 1979); biochemical and histological effects (Nicholson and Osborn, 1984), immunosuppression (Fairbrother and Fowles, 1990); decreased reproduction, malformation of embryos, and mortality (Heinz, 1996). Interactive effects of trace elements also may modify toxicity and organism response (Hoffman and others, 1991; Stanley and others, 1994). Trace-element effects at higher levels of biological organization are more difficult to quantify. However, agricultural development and associated drain water also have been linked to effects on biological communities, such as loss of habitat variability (Kerley and others, 1993, p. 20) and reduced species abundance and diversity (Dileanis and others, 1996, p. 63). These community-level effects may have been due to increased salinity, elevated trace-element concentrations, or both.

Wetland Communities

Measures of community structure, such as species diversity and species dominance, are commonly used indicators of stress in biological communities (Landis and Yu, 1995, p. 208). Water-quality properties can affect aquatic-invertebrate- and fish-community structure (Plafkin and others, 1989, p. 2.1). In general, decreased species diversity or dominance by one or few taxa are interpreted as effects of environmental stress. However, examples of increased species diversity or decreased species dominance resulting from contaminant exposure have been observed. Additionally, such indices disregard inherent dynamic and stochastic properties of an ecosystem, and it may be difficult to distinguish normal community dynamics from contaminant-induced effects. However, community-structure indices may be used effectively to assess community-structure similarity and change over time (Newman, 1995, p. 284). Therefore, aquatic-invertebrate and fish composition and other community characteristics were assessed to provide a reference for future changes in wetland-community structure.

Aquatic-Invertebrate Communities

Several indices are available to characterize invertebrate community structure (Newman, 1995, p. 284). Taxa richness, or the number of taxa in a given community, is the most basic measure of community structure. Taxa evenness, or the equitability of abundances among species in a community, measures community dominance by one or few taxa. Taxa-heterogeneity or species-diversity indices incorporate both taxa richness and evenness to provide a measure of community composition in relation to the diversity and abundance of taxa. Shannon's Index provides a measure of heterogeneity.

Invertebrate taxa collected in Lahontan Valley represent at least 6 classes, 15 orders, and 35 families. Insecta, encompassing 7 orders and 24 families, was the dominant class. In benthic samples, 17 taxa were identified (table 17). Chironomid larvae, identified in all lakes and all seasons, were generally the most abundant benthic organisms. Other common benthic organisms include ostracods, water boatmen (Corixidae), and physid (Physidae) and planorbid (Planorbidae) snails. In nektonic samples, 32 taxa were identified (table 18); however, 4 of the 32 taxa typically are not found in the water column and were thought to have been dislodged from aquatic plants during sample collection. Therefore these organisms were excluded from calculation of nektonic-community measures. Nektonic taxa dominance shifted between years and wetlands. *Daphnia*, mayflies (Baetidae), damselflies (Coenagriidae), water boatmen, and backswimmers (Notonectidae) were the most abundant nektonic invertebrates. The high population density of *Daphnia* spp. (5,000 to 25,000 individuals per sample) in 1995 skewed the measures of community structure. To enable a more meaningful comparison of community measures for other taxa among years, *Daphnia* spp. were excluded in the calculation of taxa heterogeneity and taxa evenness and in subsequent statistical comparisons.

The greatest mean density of benthic invertebrates was found in Lead Lake (table 19); this wetland also had the lowest taxa richness, evenness, and heterogeneity. Additionally, densities varied substantially between years. Although mean densities were lower, mean taxa richness, evenness, and heterogeneity in Sprig Pond were not significantly different from those in Lead Lake. In both wetlands, chironomids dominated the benthic-invertebrate community. Taxa richness, evenness, and heterogeneity were greatest in Stillwater Point Reservoir succeeded by Dry Lake (table 19). Although chironomids also were the dominant benthic invertebrates in these wetlands, other taxa were represented better.

Table 17. Benthic invertebrates in bottom-sediment samples from four wetlands in Lahontan Valley, Nevada, 1994–96

[Benthic invertebrates: Arranged by phylum. Values are estimated means ± standard deviations for unit area of bottom sediment; totals are for all phyla for given wetland in particular year. *n*, number of samples. —, taxon or taxa not observed]

Class or subclass	Order	Family	Benthic invertebrates in Stillwater National Wildlife Refuge (number per square meter ± standard deviation)									Benthic invertebrates in Carson Lake (number per square meter ± standard deviation)		
			Dry Lake			Lead Lake			Stillwater Point Reservoir			Sprig Pond unit		
			1994 (*n*=5)	1995 (*n*=2)	1996 (*n*=5)	1994 (*n*=4)	1995 (*n*=4)	1996 (*n*=5)	1994 (*n*=5)	1995 (*n*=2)	1996 (*n*=5)	1994 (*n*=3)	1995 (*n*=4)	1996 (*n*=3)
							Nemertea							
(unknown)	(unknown)	(unknown)	—	—	—	—	—	—	140±102	100±100	—	—	—	—
							Nematomorpha							
(unknown)	(unknown)	(unknown)	—	—	—	—	—	—	—	—	20±40	—	—	—
							Arthropoda							
Ostracoda	Podocopa	(unknown)	600±167	100±100	—	—	—	—	20±40	100±100	—	—	—	—
Arachnida	Trombidiformes	Hydrachnidae	—	—	20±40	—	—	—	—	—	160±320	—	—	—
Insecta	Ephemeroptera	Baetidae	—	—	40±50	—	—	—	—	—	140±230	—	—	—
	Odonata	Coenagrionidae	60±80	—	40±50	—	—	—	—	—	80±116	—	—	—
	Heteroptera	Corixidae	20±40	—	80±75	100±120	—	—	80±100	—	1,500±3,000	—	75±80	30±45
		Notonectidae	60±50	50±50	60±50	—	—	80±120	20±40	—	—	—	—	—
	Lepidoptera	Nepticulidae	—	—	—	—	—	—	—	—	—	—	—	30±45
	Coleoptera	Georyssidae	20±40	—	—	—	—	—	—	—	—	—	—	—
		Staphylinidae	—	—	—	—	—	—	—	—	—	—	—	30±50
	Diptera	Chironomidae	60±120	800±400	3,300±2,330	7,210±1,890	5,460±440	1,060±310	600±490	1,450±450	1,340±1,820	1,330±1,670	2,450±2,250	30±50
		Ephydridae	—	—	—	—	—	—	—	50±50	—	—	—	—
		Tabanidae	20±40	—	—	—	—	—	20±40	—	20±40	30±50	—	—
							Mollusca							
Gastropoda	Basommatophora	Lymnaeidae	—	—	—	—	—	20±40	—	—	—	—	—	200±140
		Physidae	80±70	—	120±70	1,750±2,240	550±950	260±260	400±200	800±0	880±490	130±190	150±190	1,300±1,500
		Planorbidae	20±40	—	—	—	—	20±40	—	50±50	1,800±2,830	—	—	430±330
Totals			940	950	3,660	9,060	6,010	1,440	1,280	2,550	5,940	1,490	2,680	2,050

Table 18. Nektonic invertebrates in samples from four wetlands in Lahontan Valley, Nevada, 1994–96

[Nektonic invertebrates: Arranged by phylum. Values are estimated means ±standard deviations for unit volume of water; totals are for all phyla for given wetland in particular year. *n*, number of samples. —, taxon or taxa not observed]

Class or subclass	Order	Family	Nektonic invertebrates in Stillwater National Wildlife Refuge (number per cubic meter ± standard deviation)									Nektonic invertebrates in Carson Lake (number per cubic meter ± standard deviation)		
			Dry Lake			Lead Lake			Stillwater Point Reservoir			Sprig Pond unit		
			1994 (*n*=5)	1995 (*n*=2)	1996 (*n*=5)	1994 (*n*=4)	1995 (*n*=1)	1996 (*n*=5)	1994 (*n*=5)	1995 (*n*=3)	1996 (*n*=5)	1994 (*n*=5)	1995 (*n*=3)	1996 (*n*=5)
Nemertea														
(unknown)	(unknown)	(unknown)	—	—	—	—	—	—	0.2±0.4	—	—	—	—	—
Arthropoda														
Ostracoda	Podocopa	(unknown)	0.4±0.5	1.6±1.6	—	—	—	—	0.4±0.5	—	—	—	—	—
Malacostraca	Amphipoda	(unknown)	—	0.5±0.5	0.2±0.5	—	—	—	—	0.4±0.5	—	—	—	—
Arachnida	Trombidiformes	Hydrachnidae	19.7±8.5	0.5±0.5	6.2±4.7	1.1±1.3	1.1±0	7.5±5.5	1.5±0.9	—	0.6±0.9	—	0.4±0.5	0.2±0.5
	Araneae	Pisauridae	—	—	—	—	—	—	0.2±0.4	0.4±0.5	—	—	—	—
		Araneidae	—	—	—	—	—	—	—	1.1±0.9	0.2±0.4	—	—	—
Insecta	Ephemeroptera	Baetidae	8.8±14.0	—	42.4±39.8	—	—	0.9±1.7	4.9±1.6	3.2±3.8	13.5±19.9	0.9±1.7	—	9.4±9.3
		Caenidae	—	—	0.2±0.4	—	—	—	—	—	—	—	—	1.7±2.5
	Odonata	Coenagriidae	22.3±13.3	8.0±0.5	16.1±17.6	—	—	11.6±22.6	5.4±4.2	7.9±3.1	2.4±2.5	0.2±0.4	0.4±0.5	41.3±31.7
		Gomphidae	—	—	—	—	—	—	—	—	—	—	—	0.2±0.4
		Libellulidae	1.1±2.1	—	—	—	—	—	—	0.4±0.5	—	—	—	—
	Heteroptera	Corixidae	14.4±22.9	14.5±11.2	155.3±11.2	249.5±78.8	3.2±0	19.7±8.9	88.5±41.6	20.3±7.2	203.1±319.1	31.3±12.8	39.3±8.1	6.2±8.0
		Gerridae	—	—	—	—	—	—	—	0.7±1.0	0.2±0.4	—	—	—
		Mesoveliidae	—	—	—	—	—	—	—	0.4±0.5	—	—	1.8±2.5	0.2±0.4
		Notonectidae	104.5±36.2	23.0±8.0	194.9±50.5	15.5±7.4	—	108.2±42.6	9.0±8.7	—	5.1±6.6	2.1±1.9	5.4±4.4	18.4±16.4
	Trichoptera	Phryganeidae	—	—	2.8±1.7	—	—	—	—	—	—	—	—	—
	Lepidoptera	Noctuidae	—	—	0.2±0.4	—	—	—	—	—	—	—	—	—
		Pyralidae	—	—	—	—	—	—	—	—	—	—	1.1±0.9	—
	Coleoptera	Gyrinidae	—	—	—	—	—	—	0.2±0.4	—	0.2±0.4	—	—	—
		Haliplidae	0.2±0.4	—	—	—	—	—	—	—	—	—	—	0.2±0.4
		Staphylinidae	0.4±0.9	—	—	—	—	—	0.9±1.0	—	—	—	—	—
	Diptera	Ceratopogonidae	—	—	—	—	—	—	—	1.4±2.0	—	—	—	0.2±0.4
		Chironomidae	0.9±1.3	8.6±1.1	1.1±0.7	1.9±1.2	3.2±0	0.2±0.4	3.0±1.8	46.4±41.4	16.3±21.5	0.9±1.0	14.6±11.1	0.4±0.9
		Culicidae	—	—	—	—	—	—	—	17.5±15.1	—	—	—	—
		Ephydridae	—	—	—	—	—	—	1.7±1.6	2.9±4.0	—	—	—	—
		Stratiomyidae	—	—	—	—	1.1±0	—	—	—	—	0.2±0.4	0.7±1.0	—
		Syrphidae	—	—	—	—	—	—	1.9±3.3	1.4±1.3	—	—	—	—
		Tabanidae	—	—	—	—	—	—	—	—	—	3.0±3.4	—	—
Totals			172.7	56.7	419.4	268.0	8.6	148.1	117.8	104.4	241.6	38.6	63.7	78.4

Although the mean density of nektonic invertebrates (excluding *Daphnia* spp.) was greatest in Dry Lake, it varied between years. Densities were more consistent in other wetlands. Taxa richness was greatest in Stillwater Point Reservoir, and taxa heterogeneity was greatest in Stillwater Point Reservoir and Dry Lake. Taxa richness and heterogeneity were lowest in Lead Lake. Apart from the temporary dominance of *Daphnia* spp. in 1995, hemiptera generally were the dominant taxa in all wetlands.

During 1994–96, concentrations of arsenic, boron, and molybdenum in unfiltered wetland water generally were below levels associated with adverse effects on aquatic invertebrates. However, concentrations of these constituents in unfiltered water from all but one wetland (Dry Lake) were similar to concentrations previously associated with toxicity to aquatic organisms in Lahontan Valley (Finger and others, 1993, p. 26). These three constituents generally correlate with measurements of specific conductance. Molybdenum in water correlated with reduced nektonic taxa richness ($p = 0.024$, $r^2 = 0.416$). Reduced nektonic taxa heterogeneity correlated with dissolved solids as specific conductance ($p = 0.003$, $r^2 = 0.591$), arsenic ($p<0.001$, $r^2 = 0.756$; fig. 5), and boron ($p = 0.001$, $r^2 = 0.658$) in water. Although above the chosen level of significance ($p \leq 0.05$), reduced nektonic taxa richness also appeared to correlate weakly with dissolved solids ($p = 0.060$, $r^2 = 0.311$) and with boron ($p = 0.075$, $r^2 = 0.284$). Measures of invertebrate-

Table 19. Population density and taxa richness, evenness, and heterogeneity for benthic and nektonic invertebrates collected from four wetlands in Lahontan Valley, Nevada, 1994–96

[Density: Estimates for benthic invertebrates are per unit area of bottom sediment, and for nektonic, per unit volume of water. Taxa richness, evenness, and heterogeneity are unitless ratios]

Wetland and year	Benthic invertebrates				Nektonic invertebrates			
	Density (number per square meter)	Taxa richness	Taxa evenness	Taxa heterogeneity	Density (number per cubic meter)	Taxa richness	Taxa evenness	Taxa heterogeneity
Stillwater National Wildlife Refuge								
Dry Lake:								
1994	940	9	0.35	1.35	173	12	0.19	1.27
1995	950	3	.18	.54	57	9	.31	1.47
1996	3,660	7	.09	.48	419	11	.16	1.20
Mean annual[1].......	1,850 *a*	6.3 *b*	.21 *b*	.79 *b*	216 *c*	10.7 *b*	.22 *a,b*	1.31 *c*
Lead Lake:								
1994	9,060	3	0.09	0.55	268	6	0.06	0.40
1995	6,010	2	.06	.31	9	5	.60	1.26
1996	1,440	7	.20	.88	148	9	.14	.89
Mean annual[1].......	5,503 *c*	4.0 *a*	.12 *a*	.58 *a*	190 *b,c*	6.7 *a*	.27 *b*	.85 *a*
Stillwater Point Reservoir:								
1994	1,280	7	0.32	1.32	118	16	0.17	1.07
1995	2,550	6	.28	1.09	104	17	.29	1.66
1996	5,940	10	.28	1.61	242	12	.20	1.22
Mean annual[1].......	3,310 *b*	7.7 *c*	.29 *c*	1.34 *c*	154 *b*	15 *c*	.22 *a,b*	1.32 *c*
Carson Lake								
Sprig Pond:								
1994	1,490	3	0.11	0.40	39	11	0.15	0.76
1995	2,680	3	.07	.34	64	10	.22	1.12
1996	2,050	7	.27	1.11	78	11	.22	1.32
Mean annual[1].......	2,073 *a*	4.3 *a*	.15 *a*	.62 *a*	60 *a*	10.7 *b*	.20 *a*	1.07 *b*

[1]Within each metric, mean-annual values having same appended letter (*a* through *c*) are not significantly different ($p<0.05$) across wetlands; correspondingly, differing appended letters indicate significant difference between mean-annual values.

[2]Taxa richness was based on all species identified in samples. However, taxa not normally expected in benthic samples (such as *Daphnia* spp.) or in nektonic samples (such as gastropods) were excluded from calculation of taxa evenness and heterogeneity. To assist in interpretation, *Daphnia* spp. were also excluded from calculation of these metrics in nektonic samples.

community structure did not correlate with aluminum in water. The infrequency of detection of lead, mercury, and selenium in wetland water precluded meaningful statistical interpretation. Other studies have implicated these constituents in water with adverse effects on aquatic organisms at concentrations where lower levels of detection were reported than during the 1994–96 monitoring program (see section "Concentrations in Sampled Media," under "Trace Elements"). Therefore, the potential for these elements in water to produce adverse effects on aquatic invertebrates and community structure in the Lahontan Valley wetlands remains uncertain.

Bottom sediments having elevated concentrations of trace elements also have been associated with adverse effects on aquatic invertebrates, including shifts in community structure (Moore and others, 1991; Suchanek and others, 1995). During 1994–96, arsenic and mercury concentrations in sediment exceeded concentrations associated with effects on benthic invertebrates. Arsenic concentrations in sediment correlated directly with reduced taxa evenness ($p = 0.034$, $r^2 = 0.376$) and inversely with abundance ($p = 0.034$, $r^2 = 0.376$) in benthic invertebrates (fig. 5). Although the selected level of significance was exceeded, arsenic concentrations in sediment also appeared to be correlated weakly with reduced benthic-invertebrate taxa richness ($p = 0.086$, $r^2 = 0.266$) and heterogeneity ($p = 0.099$, $r^2 = 0.248$). Arsenic concentrations in sediment also correlated with reduced nektonic-invertebrate taxa richness ($p<0.001$, $r^2 = 0.737$).

Mercury concentrations in bottom sediment correlated with reduced benthic-invertebrate taxa evenness ($p = 0.044$, $r^2 = 0.346$). Concentrations of mercury in sediment more weakly correlated with reduced benthic-invertebrate abundance ($p = 0.094$, $r^2 = 0.225$), taxa richness ($p = 0.052$, $r^2 = 0.326$), and taxa heterogeneity ($p = 0.090$, $r^2 = 0.260$; fig. 6). Concentrations of mercury in sediment also correlated with reduced nektonic-invertebrate taxa richness ($p = 0.006$, $r^2 = 0.553$). The correlation between mercury concentrations in sediment and reduced nektonic-invertebrate taxa evenness approached significance ($p = 0.053$, $r^2 = 0.325$). Elevated concentrations of mercury in bottom sediment have been shown to cause adverse effects on benthic-invertebrate community structure, including decreased benthic-community heterogeneity, such as was measured in Clear Lake, Calif., by Suchanek and others (1995), using Shannon's Index.

Selenium concentrations in bottom sediment correlated with reduced benthic-invertebrate abundance ($p = 0.037$, $r^2 = 0.366$) and nektonic-invertebrate heterogeneity ($p = 0.011$, $r^2 = 0.492$). However, these correlations were weakened because the concentration of selenium was below analytical detection limits in 35 percent of the samples.

Published information on biological-effect concentrations of aluminum and boron in bottom sediment is sparse. However, concentrations of these two elements in sediment did not correlate with measures of benthic- or nektonic-invertebrate community structure.

Vertebrate Communities

Fish Communities

Active fish-collection methods can be difficult to apply, so passive collection methods (traps) were used. Because passive sampling techniques may be selective for fish species and size (Hubert, 1983), fish captured during this investigation may not be entirely representative of species assemblage or population-size distribution within each wetland. For example, mosquitofish (*Gambusia affinis*), which tend to be small and slender, were observed in shallow backwater areas in all wetlands, but were rarely captured or retained in minnow traps. Therefore, it was deemed inappropriate to report capture success or size distributions for this species.

One native fish species—tui chub (*Gila bicolor*)—and four nonnative fish species—common carp (*Cyprinus carpio*), pumpkinseed (*Lepomis gibbosus*), fathead minnows (*Pimephales promelas*), and mosquitofish—were identified in the four study wetlands. Based on capture efficiencies, fish appeared to be most abundant in Lead Lake and Dry Lake, and species assemblages were very similar in the two wetlands (fig. 7). Overall, the smallest number of fish were captured in Sprig Pond despite more-intensive efforts with minnow traps, hoop nets, and gill nets set at several locations around the wetland.

Because of low fish-catch rates, little can be deduced from fish data. In general, fish appeared to be in good health, with no external or encysted parasites, external fungus or lesions, hemorrhaging, or tumors. Spinal deformations were noted in two fathead minnows from Lead Lake; however, these represented less than 1 percent of the samples. Fin erosion, seen on a number of fish from all wetlands, may have been due to the capture techniques (fish traps), which required holding and concentrating fish in the traps for 24 hours or more.

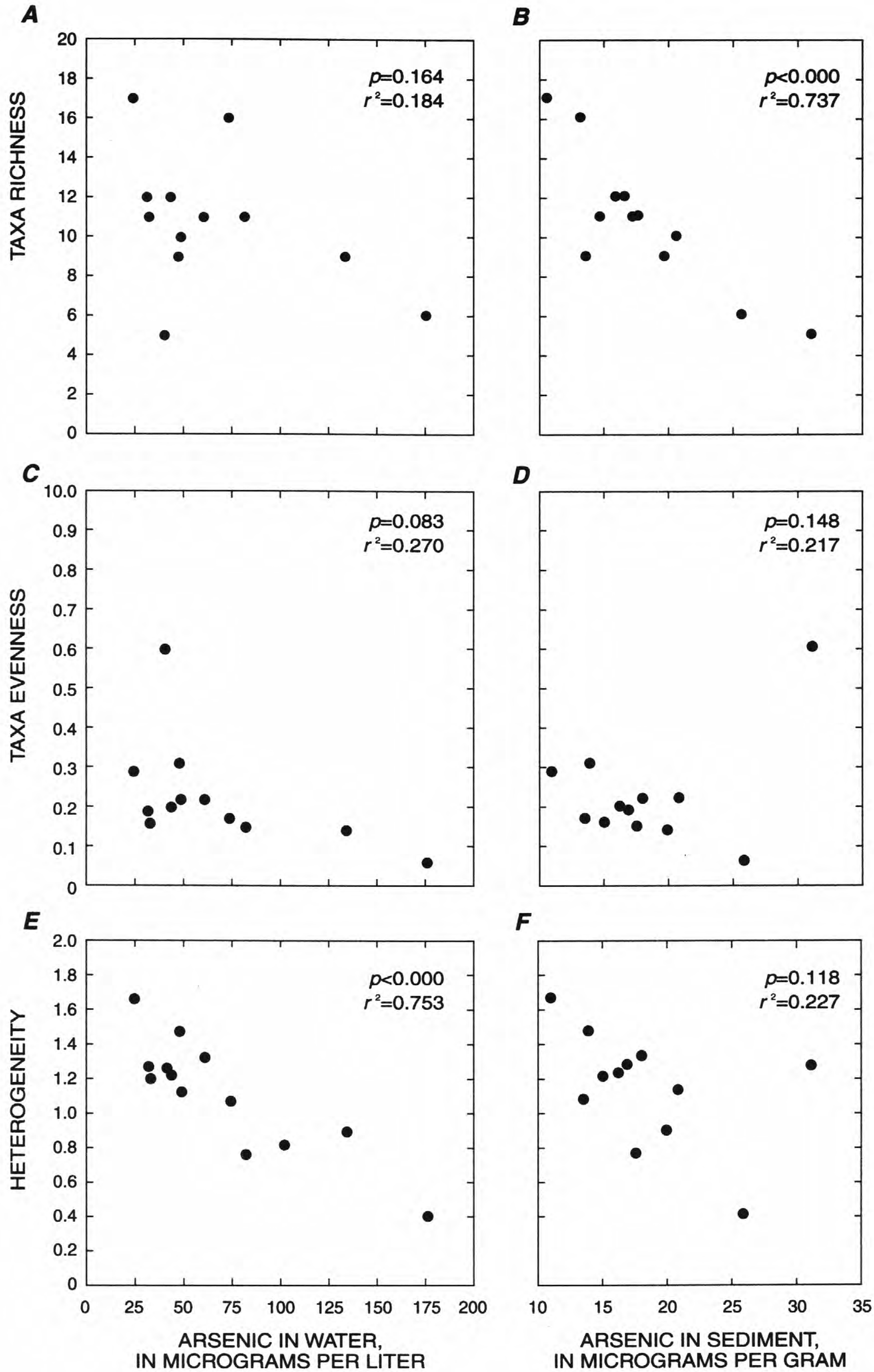


Figure 5. Relations between arsenic concentrations, in wetland water and in sediment, and nektonic-invertebrate community metrics (unitless ratios).

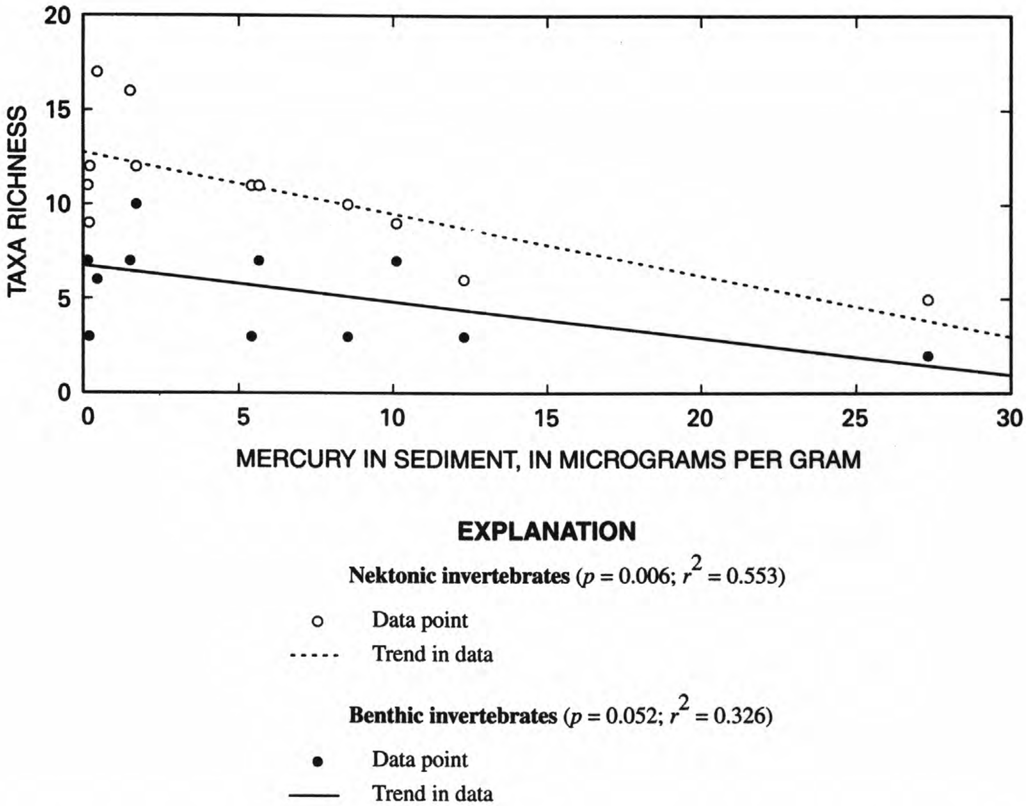


Figure 6. Relations between mercury concentrations in wetland sediment and benthic- and nektonic-invertebrate taxa richness (unitless ratios), showing regression lines or trends in data.

Environmental stress can affect growth rate and general condition of fish. Numerical condition factors, such as Fulton's condition factor, provide a measure of relative nutritional state or well-being of individual fish and populations (Anderson and Gutreuter, 1983, p. 294). Such factors also may be used to compare relative condition of populations and for monitoring environmental changes over time (Ney, 1993, p. 140). In general, the condition factor is smaller in individuals whose weight-to-length ratio is less than expected, possibly because of a poorer overall nutritional state. Because length-weight relationships are species dependent, interspecific comparisons may not be appropriate. Similarly, length-weight relationships may vary with fish age and season. Fish condition, as determined by Fulton's condition factor, was inconsistent among wetlands and species (table 20). For example, no statistical difference in Fulton's condition factor was found between tui chub from Dry Lake and those from Lead Lake. However, Fulton's condition factor was significantly greater for pumpkinseeds and significantly smaller for fathead minnows collected from Dry Lake when compared to those from Lead Lake.

Because of low fish catches regardless of wetland or year, statistical relations between contaminant concentrations and fish abundances and condition were not examined.

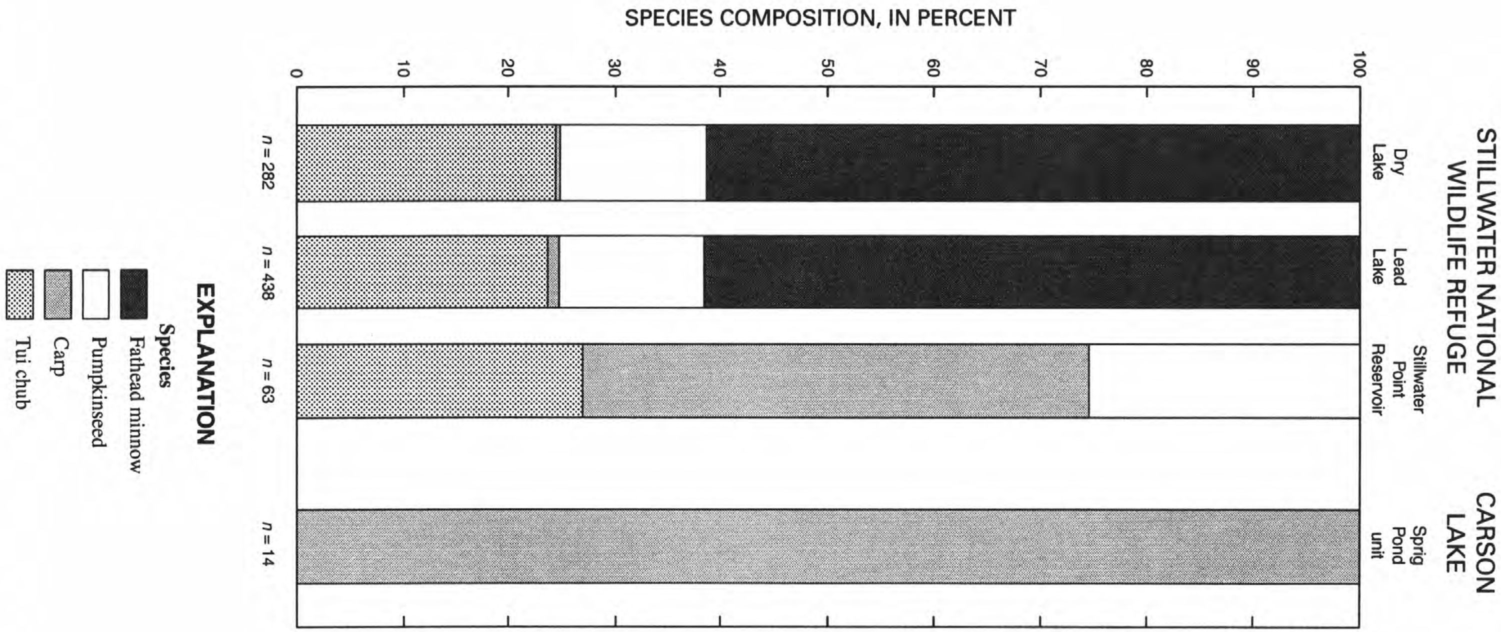


Figure 7. Fish species composition in four wetlands in Lahontan Valley, Nevada, 1995–96. *n*, number of fish (or sample size).

Table 20. Length, weight, and Fulton's condition factor for selected fish species, representing different size classes, collected from four wetlands in Lahontan Valley, Nevada, 1995–96

[—, no data]

Wetland	Fathead minnow			Pumpkinseed[1]			Carp[1]			Tui chub[1]		
	Mean length (inches)	Mean weight (ounces)	Mean Fulton's condition factor	Mean length (inches)	Mean weight (ounces)	Mean Fulton's condition factor	Mean length (inches)	Mean weight (ounces)	Mean Fulton's condition factor	Mean length (inches)	Mean weight (ounces)	Mean Fulton's condition factor
Stillwater National Wildlife Refuge												
Dry Lake	2.5±0.2	0.11±0.03	1.3±0.2 *a*	1.9±0.9	0.15±0.28	1.9±0.4 *b*	[2]2.6	[2]0.13	[2]1.3	2.2±0.3	0.07±0.02	1.2±0.2 *b*
Lead Lake	2.0±0.1	0.08±0.02	1.7±0.1 *b*	1.8±0.4	0.06±0.05	1.7±0.2 *a*	3.3±0.9	0.39±0.29	1.5±0.1 *a*	2.1±0.1	0.05±0.1	1.2±0.1 *b*
Stillwater Point Reservoir	—	—	—	1.9±0.3	0.07±0.03	1.7±0.2 *a*	2.9±0.4	0.27±0.11	1.9±0.5 *a*	1.9±0.1	0.04±0.01	0.9±0.1 *a*
Carson Lake												
Sprig Pond	—	—	—	—	—	—	3.0±0.4	0.34±0.13 *b*	2.0±0.2 *a*	—	—	—

[1]Mean Fulton's condition factors having same appended letter (*a* through *c*) are not significantly different ($p<0.05$); correspondingly, differing appended letters indicate significant difference between factors.

[2]Single fish sample.

The IBI, a community-condition index based on as many as 12 metrics related to fish-community taxonomic and trophic structure, abundance, and general health, was developed to assess the relative condition of stream fish communities (Plafkin and others, 1989). Although the IBI was not developed for palustrine fish communities, several of the metrics are applicable to the marsh habitat. Because IBI methodologies were designed to provide a reproducible fish-community indexing tool, these metrics may be useful in the future assessment of relative status and trends in Lahontan Valley wetland fish communities. Therefore, scoring listed in table 21 is provided only for comparison of fish-community condition in the four study wetlands and to provide a basis for future comparisons.

Community-condition scores were similar for Dry Lake, Lead Lake, and Stillwater Point Reservoir and were slightly lower for Sprig Pond (table 21). Scoring was affected strongly by depauperate fish communities, the dominance of tolerant species, and the indiscriminate dietary habits of the representative fishes. Fish communities in these wetlands possess many of the characteristics of a degraded fishery, including limited species diversity, predominance of tolerant species, skewed trophic structure, and lack of piscivorous fishes (Plafkin and others, 1989, p. 7–8). Although not reflected in the IBI score, age structure in all ponds was skewed toward younger individuals. The predominance of younger fish in Lead Lake is likely attributable to recent recolonization after desiccation (or near desiccation) in the early 1990's. It is uncertain if lack of larger individuals in other wetlands, which have received more reliable water supplies for longer periods, reflects recent recolonization, sampling bias, or poor survival among adults.

Bird Communities

During the eight sampling sessions combined, 79 bird species were observed (table 22). The highest numbers of birds were observed at Sprig Pond and the lowest at Dry Lake. However, differences in habitat types and visibility among transects are reflected in the numbers and species observed. Green-winged teal, cinnamon teal, mallard, yellow-headed blackbird, barn swallow, american white pelican, american coot, american avocet, black-crowned night heron, white-faced ibis, and marsh wren were generally the most abundant species in each wetland. No threatened or endangered birds (table 2) were observed during the surveys, and white-faced ibis and black tern were the only observed species of concern. White-faced ibis were seen in all study wetlands but were most common in Sprig Pond and Stillwater Point Reservoir. Few black terns were found in Sprig Pond and Lead Lake.

Table 21. Index of Biological Integrity metrics and scores as modified to assess fish assemblages in four wetlands in Lahontan Valley, Nevada, 1994–96

[Score: Ranking based on percentage similarity between calculated and reference-site values, used in bioassessments (Plafkin and others, 1989)]

Index of Biological Integrity metrics	Scoring criteria (percent)			Stillwater National Wildlife Refuge						Carson Lake	
				Dry Lake		Lead Lake		Stillwater Point Reservoir		Sprig Pond unit	
	For score of 5	For score of 3	For score of 1	Actual (count)	Score	Actual (count)	Score	Actual (count)	Score	Actual (count)	Score
Species richness and composition metrics:											
Native fish species	> 67	33–67	< 33	20	1	20	1	25	1	0	1
Benthic fish species	> 67	33–67	< 33	0	1	0	1	0	1	0	1
Tolerant individuals [1]	< 10	10–25	> 25	86	1	86	1	75	1	100	1
Trophic-composition metrics:											
Omnivores	< 10	10–25	> 25	86	1	86	1	75	1	100	1
Insectivores	> 45	20–45	< 20	14	1	14	1	25	3	0	1
Main carnivores	> 5	1–5	< 1	0	1	0	1	0	1	0	1
Fish abundance and condition metrics:											
All fish	Abundant	Common	Rare	Abundant	5	Abundant	5	Common	3	Rare	1
Introduced fishes [2]	< 33	33–67	> 67	76	1	76	1	73	1	100	1
Fish showing anomalies [3]	< 1	1–5	< 5	0	5	0	5	0	5	0	5
		Total scores..........................			17		17		17		13

[1] Does not include mosquitofish.

[2] Plafkin and others (1989).

[3] Does not include fin damage.

Table 22. Avian species along established transects in four wetlands in Lahontan Valley, Nevada, July–September 1995 and May–September 1996

[Avian species: Arranged by taxonomic order. *n*, number of observation periods. —, species not observed; <, less than; ?, separate species not identified]

Family	Avian species (and common name)	Sightings of avian species in Stillwater National Wildlife Refuge (mean number per period of observation ± standard deviation)						Sightings of avian species in Carson Lake (mean number per period of observation ± standard deviation)	
		Dry Lake		Lead Lake		Stillwater Point Reservoir		Sprig Pond unit	
		1995 (*n*=3)	1996 (*n*=5)	1995 (*n*=3)	1996 (*n*=5)	1995 (*n*=3)	1996 (*n*=5)	1995 (*n*=3)	1996 (*n*=5)
		Podicipediformes							
Podicipedidae	*Aechmophorus occidentalis* (western grebe)	—	17±6	213±30	91±18	38±30	38±24	34±9	31±47
	Podiceps nigricollis (eared grebe)	<1±<1	1±1	47±23	31±18	13±19	2±1	8±6	2±5
	Podilymbus podiceps (pied-billed grebe)	—	1±2	8±4	4±2	2±1	7±5	4±2	2±1
		Pelecaniformes							
Pelecanidae	*Pelecanus erythrorhynchos* (american white pelican)	20±13	16±12	53±54	456±250	9±8	103±83	58±45	165±111
Phalacrocoracidae	*Phalacrocorax auritus* (double-crested cormorant)	—	<1±<1	36±26	58±51	—	—	—	—
		Anseriformes							
Anatidae	? (duck species)	715±523	178±262	183±130	141±124	35±50	513±393	562±405	191±191
	Aix sponsa (wood duck)	—	<1±<1	—	—	<1±1	—	—	—
	Anas acuta (northern pintail)	41±30	27±37	8±3	5±3	11±9	6±9	33±23	4±6
	Anas americana (american wigeon)	25±35	15±30	3±4	5±9	—	2±2	<1±1	2±4
	Anas clypeata (northern shoveler)	4±4	2±2	1±1	18±14	<1±1	3±2	4±3	1±1
	Anas crecca (green-winged teal)	47±51	5±9	201±270	23±22	9±13	4±4	57±50	3±5
	Anas cyanoptera (cinnamon teal)	25±25	23±19	37±20	56±63	17±4	61±64	257±209	63±59
	Anas discors (blue-winged teal)	9±6	—	—	—	<1±1	<1±<1	3±4	<1±<1
	Anas platyrhynchos (mallard)	71±37	48±33	15±9	29±31	25±2	476±752	63±34	38±43
	Anas strepera (gadwall)	32±25	21±13	64±35	63±36	7±<1	31±22	21±22	13±13
	Aythya americana (redhead)	16±15	11±18	30±14	24±19	56±47	18±20	14±9	22±28
	Aythya collaris (ring-necked duck)	<1±<1	—	—	—	—	—	—	—
	Aythya valisineria (canvasback)	2±2	1±1	—	<1±1	—	1±1	—	—
	Branta canadensis (canada goose)	2±1	15±22	10±13	8±11	61±43	3±3	22±15	31±37
	Bucephala albeola (bufflehead)	—	—	—	<1±<1	—	<1±<1	—	—
	Oxyura jamaicensis (ruddy duck)	1±1	2±2	61±44	60±89	13±18	8±8	9±10	9±7

Table 22. Avian species along established transects in four wetlands in Lahontan Valley, Nevada, July–September 1995 and May–September 1996—Continued

Family	Avian species (and common name)	Sightings of avian species in Stillwater National Wildlife Refuge (mean number per period of observation ± standard deviation)						Sightings of avian species in Carson Lake (mean number per period of observation ± standard deviation)	
		Dry Lake		Lead Lake		Stillwater Point Reservoir		Sprig Pond unit	
		1995 (*n*=3)	1996 (*n*=5)	1995 (*n*=3)	1996 (*n*=5)	1995 (*n*=3)	1996 (*n*=5)	1995 (*n*=3)	1996 (*n*=5)
		Falconiformes							
Accipitridae	*Buteo jamaicensis* (red-tailed hawk)	—	—	—	—	—	<1±<1	—	—
	Circus cyaneus (northern harrier)	3±3	1±1	<1±1	<1±1	1±1	1±1	1±1	2±2
Falconidae	*Falco mexicanus* (prairie falcon)	—	—	—	<1±<1	—	—	—	—
	Falco sparverius (american kestrel)	—	—	—	—	<1±1	—	—	—
		Galliformes							
Phasianidae	*Callipepla californica* (california quail)	—	—	—	<1±1	—	—	—	—
		Ciconiiformes							
Ardeidae	*Ardea herodias* (great blue heron)	1±1	2±1	2±2	4±1	1±1	5±4	4±3	8±4
	Bubulcus ibis (cattle egret)	—	—	—	<1±1	6±5	4±4	—	<1±<1
	Casmerodius albus (great egret)	1±1	1±2	<1±1	3±2	4±1	3±3	13±6	20±15
	Egretta thula (snowy egret)	5±5	1±1	—	2±2	60±29	31±21	47±28	25±18
	Botaurus lentiginosus (american bittern)	1±2	1±3	—	—	1±1	1±2	—	2±3
	Nycticorax nycticorax (black-crowned night-heron)	5±3	12±11	6±2	10±3	25±6	26±17	43±9	45±30
Threskiornithidae	*Plegadis chihi* (white-faced ibis)	63±43	16±7	33±28	6±3	807±474	249±224	766±106	1567±1421
		Gruiformes							
Rallidae	*Fulica americana* (american coot)	151±148	135±160	451±374	1,025±727	883±560	722±716	665±298	263±184
	Porzana carolina (sora)	<1±<1	1±1	—	<1±<1	—	1±<1	2±1	5±9
	Rallus limicola (virginia rail)	1±<1	3±2	<1±1	—	—	1±2	1±1	—
		Charadriiformes							
Recurvirostridae	*Himantopus mexicanus* (black-necked stilt)	5±8	3±3	—	3±2	4±6	5±9	18±19	7±4
	Recurvirostra americana (american avocet)	4±4	12±15	2±2	5±3	24±12	14±22	49±51	1538±1485
Charadriidae	*Charadrius vociferus* (killdeer)	4±5	1±<1	1±1	1±1	2±2	6±5	6±7	—
Scolopacidae	? (sandpiper species)	—	—	<1±<1	—	—	—	—	—
	? (peep species)	—	2±4	—	15±30	4±4	31±57	—	15±23
	Actitis macularia (spotted sandpiper)	—	—	—	<1±<1	—	<1±1	<1±1	—
	Calidris alpina (dunlin)	—	—	—	<1±<1	—	—	—	—
	Calidris minutilla (least sandpiper)	—	—	—	<1±<1	—	7±12	—	—
	Limnodromus spp. (dowitcher species)	11±15	<1±<1	—	40±80	—	30±60	—	7±12

	Charadriiformes—Continued								
	Numenius americanus (long-billed curlew)	—	<1±<1	—	—	<1±1	1±1	1±1	<1±1
	Tringa melanoleuca (greater yellowlegs)	3±3	—	—	2±4	—	1±1	<1±1	—
	Tringa totanus (redshanks)	—	<1±<1	—	—	—	—	—	—
Phalaropodidae	*Phalaropus lobatus* (red-necked phalarope)	—	—	8±12	<1±<1	—	8±15	—	<1±1
	Phalaropus tricolor (wilson's phalarope)	4±5	<1±1	—	1±2	—	2±4	—	1±1
	Phalaropus spp. (phalarope species)	—	—	—	—	—	—	2±2	—
Laridae	? (gull species)	2±3	3±3	9±13	8±13	<1±1	2±2	400±295	5±7
	Chlidonias niger (black tern)	—	—	—	<1±1	—	—	<1±1	5±6
	Larus californicus (california gull)	2±2	3±5	46±56	5±3	5±5	3±3	6±5	4±3
	Larus delawarensis (ring-billed gull)	5±5	—	5±3	1±2	1±1	1±2	9±7	1±1
	Larus philadelphia (bonaparte's gull)	11±15	—	—	—	1±1	—	—	—
	Larus pipixcan (franklin's gull)	—	—	—	—	—	—	—	<1±1
	Sterna caspia (caspian tern)	3±4	<1±<1	6±5	3±3	<1±1	3±4	<1±1	—
	Sterna forsteri (forster's tern)	2±3	1±1	1±1	3±2	7±8	<1±<1	<1±1	19±16
	Columbiformes								
Columbidae	*Zenaida macroura* (mourning dove)	—	—	—	—	—	1±1	—	—
	Strigiformes								
Strigidae	*Asio flammeus* (short-eared owl)	—	—	—	—	1±1	—	—	—
	Caprimulgiformes								
Caprimulgidae	*Chordeiles minor* (common nighthawk)	3±4	1±2	—	—	—	2±3	1±2	<1±<1
	Piciformes								
Picidae	*Colaptes auratus* (northern flicker)	—	—	—	<1±<1	—	—	—	—
	Passeriformes								
Tyrannidae	*Tyrannus verticalis* (western kingbird)	—	—	—	—	—	—	—	<1±<1
Alaudidae	*Eremophila alpestris* (horned lark)	—	2±4	—	1±1	—	2±3	—	1±3
Hirundinidae	? (swallow species)	—	2±4	—	33±44	33±47	23±39	—	18±36
	Hirundo pyrrhonota (cliff swallow)	3±4	—	—	1±1	17±24	3±3	<1±1	1±3
	Hirundo rustica (barn swallow)	8±7	4±3	31±23	1±1	176±234	33±61	3±2	22±41
	Riparia riparia (bank swallow)	—	1±2	—	11±21	—	1±1	—	2±4
	Stelgidopteryx ruficollis (northern rough-winged swallow)	—	<1±1	—	<1±<1	2±2	<1±1	—	2±4
	Tachycineta bicolor (tree swallow)	—	<1±1	—	42±79	—	4±7	—	4±8
	Tachycineta thalassina (violet-green swallow)	1±2	—	—	—	1±1	—	—	—

Table 22. Avian species along established transects in four wetlands in Lahontan Valley, Nevada, July–September 1995 and May–September 1996—Continued

Family	Avian species (and common name)	Sightings of avian species in Stillwater National Wildlife Refuge (mean number per period of observation ± standard deviation)						Sightings of avian species in Carson Lake (mean number per period of observation ± standard deviation)	
		Dry Lake		Lead Lake		Stillwater Point Reservoir		Sprig Pond unit	
		1995 (*n*=3)	1996 (*n*=5)	1995 (*n*=3)	1996 (*n*=5)	1995 (*n*=3)	1996 (*n*=5)	1995 (*n*=3)	1996 (*n*=5)
		Passeriformes—Continued							
Corvidae	*Corvus corax* (common raven)	—	1±<1	—	3±3	1±1	<1±1	1±1	<1±<1
	Pica pica (black-billed magpie)	1±1	1±1	—	<1±<1	—	<1±<1	—	—
Troglodytidae	*Cistothorus palustris* (marsh wren)	45±8	33±9	19±10	19±4	21±18	17±11	15±6	29±12
Laniidae	*Lanius ludovicianus* (loggerhead shrike)	—	1±1	—	—	—	—	—	—
Sturnidae	*Sturnus vulgaris* (european starling)	—	—	—	8±16	—	—	—	—
Purulidae	*Geothlypis trichas* (common yellowthroat)	—	1±1	—	3±6	—	—	—	—
Icteridae	? (blackbird species)	—	—	—	—	—	<1±<1	17±24	—
	Agelaius phoeniceus (red-winged blackbird)	7±4	46±46	11±9	7±6	2±3	35±26	<1±1	5±4
	Euphagus cyanocephalus (brewer's blackbird)	—	1±1	<1±1	4±8	—	1±1	—	—
	Molothrus ater (brown-headed cowbird)	—	1±1	3±5	3±4	—	—	—	<1±1
	Sturnella neglecta (western meadowlark)	5±2	6±3	6±6	2±1	—	2±3	<1±1	<1±<1
	Xanthocephalus xanthocephalus (yellow-headed blackbird)	28±15	17±9	66±61	17±14	48±36	27±20	71±56	82±77
Fringillidae	*Amphispiza belli* (sage sparrow)	5±5	1±1	1±2	1±2	1±1	2±2	—	2±2
	Melospiza melodia (song sparrow)	6±4	12±5	8±6	7±3	1±1	2±3	—	<1±<1
	Zonotrichia leucophrys (white-crowned sparrow)	—	1±2	—	—	—	<1±<1	—	—
	Total number of individual birds (all taxa) observed....................................	1,410	717	1,690	2,374	2,436	2,590	3,291	4,287
	Total number of distinct species (all taxa) observed....................................	49	60	41	66	49	66	47	56

Wetland Habitat

Dramatic changes in areal extent of the wetlands were observed from 1994 to 1996 (table 23). The changes were attributed to above-normal precipitation and runoff during 1995 and 1996 after below-normal precipitation and runoff from the Sierra Nevada in the late 1980's and early 1990's during a regional drought. As a result of that drought, wetland acreage in Stillwater NWR and Carson Lake had dwindled to about 1,000 acres during 1992 (William Henry, U.S. Fish and Wildlife Service–Stillwater National Wildlife Refuge, written commun., 1997). Conversely, Carson River flows below Lahontan Reservoir were 111 percent of the period-of-record mean annual flow volume in 1995 and 122 percent of the average in 1996. These greater flow volumes resulted in an areal expansion of wetlands. The majority of the increase was in expansive shallow wetlands in areas lower on the hydrologic gradient. Water entered the southwestern part of Stillwater NWR primarily through two irrigation-water delivery conduits (D Line and S Line Canals) and four major agricultural drains (Stillwater Point Reservoir Diversion Canal, Stillwater Slough, Paiute Drain, and Paiute Diversion Drain). The initial wetlands included Stillwater Point Reservoir, lakes on Canvasback Gun Club lands, and Lead Lake. However, irrigation-quality water also has been discharged directly to Dry Lake since 1991. Water flowing from the initial wetlands flooded sequential wetlands down the hydrologic gradient toward Carson Sink to the northeast.

During 1994–96, gradual changes in wetland plant communities were observed in Stillwater NWR. Initial wetlands (higher on the hydrologic gradient) were typically deeper (3–6 ft) and more perennial in nature. Emergent vegetation, typically hardstem bulrush (*Schoenoplectus acutus*), was abundant in deeper water habitats (greater than 3 ft), whereas cattails (*Typha* spp.) were abundant in shallower habitats. Alkali bulrush (*Bolboschoenus maritimus*) with interspersed sedges and rushes was common around the ephemeral perimeter of the wetlands. Pondweed (*Potamogeton* spp.), primarily sago pondweed (*Potamogeton pectinatus*), was abundant in open-water habitats. Wetlands downgradient from the initial wetlands were typically shallower (less than 3 ft) and had narrow bands of cattails and alkali bulrush around the periphery. Cattails and hardstem bulrush were less common, and alkali bulrush became the dominant emergent plant with increased distance from the initial inflow. Similarly, pondweed was the dominant aquatic vegetation in open-water habitats in wetlands higher on the hydrologic gradient, but muskgrass (*Chara* spp.) and widgeongrass (*Ruppia maritima*) became more abundant in wetlands lower on the hydrologic gradient. Recently flooded wetlands farthest from the inflows typically were very shallow and nearly devoid of emergent and aquatic vegetation.

Table 23. Area of wetlands, Stillwater National Wildlife Refuge and Carson Lake, Nevada, August–September 1994–96

Wetland	Year	Area[1] (acres)		
		Open water	Emergent vegetation	Total
Stillwater National Wildlife Refuge				
Dry Lake:				
	1994	320	40	360
	1995	130	430	560
	1996	760	1,470	2,230
Lead Lake:				
	1994	260	270	530
	1995	530	460	990
	1996	930	1,950	2,880
Stillwater Point Reservoir:				
	1994	190	240	430
	1995	280	1,150	1,430
	1996	470	810	1,280
Stillwater Marsh area[2]:				
	1994	2,200	2,000	4,200
	1995	4,300	8,200	12,500
	1996	14,700	11,700	26,400
Carson Lake				
Sprig Pond:	1994	310	1,400	1,710
	1995	700	3,000	3,700
	1996	740	2,670	3,410
Carson Lake area[3]:				
	1994	1,270	4,130	5,400
	1995	1,880	7,100	8,980
	1996	2,670	7,050	9,720

[1]Rounded to nearest 10 acres.

[2]Includes Canvasback Gun Club lands (see fig. 2).

[3]Total wetlands area, including Sprig Pond (see fig. 3).

Of the three wetlands on Stillwater NWR assessed in the 1994–96 study, the most diverse of wetland plant communities were in the wetlands at Stillwater Point Reservoir. The dominant emergent-vegetation species were hardstem bulrush and southern cattail (*Typha domingensis*); alkali bulrush and inland saltgrass (*Distichlis spicata)* were around the wetland perimeter. Hardstem bulrush and southern cattail formed dense monotypic stands. Pondweed, primarily sago pondweed, was the dominant submergent-plant species. Aquatic vegetation was sparse in ephemeral areas around much of the wetland perimeter, although saltcedar (*Tamarix ramosissima*), a nonnative plant, was encroaching on ephemeral shores near the perimeter. Dry Lake consisted of a large, open water body fringed by cattails and alkali bulrush. Pondweed was again the dominant aquatic plant throughout the open-water areas. Salt grass was abundant in ephemeral areas around the perimeter. Also dominated by open water, Lead Lake had narrow bands of hardstem bulrush, alkali bulrush, and cattails fringing much of the lake. Emergent communities were more extensive in shallow areas toward the east side of the wetland. Saltcedar encroached on ephemeral areas along much of the shoreline and shallow areas within the wetland. Smotherweed (*Bassia hyssopifolia*), another nonnative plant, also was common around the perimeter. Submergent vegetation was uncommon throughout most of this wetland, although localized stands of longleaf pondweed (*Potamogeton nodosus*) were in the sampling area. Plant-community diversity also was relatively high in wetlands and open water of Carson Lake. Southern cattail and hardstem bulrush were the dominant emergent-plant species, and pondweed was abundant in open water in northern Sprig Pond. In the southern part of the wetland, alkali bulrush was the dominant emergent species around the perimeter, and muskgrass was abundant in the extensive open-water area.

Irrigation-Induced Effects on Ecosystem

Irrigation-induced effects on fish and wildlife and on their habitat in the Western United States are attributed largely to human modification of natural hydrologic characteristics and wetland processes and water supplies (Lemly and others, 1993, p. 2265). These modifications typically include the diversion of relatively fresh water prior to its entering wetlands, resulting in the desiccation of some wetlands and the alteration of natural hydrologic characteristics of others. In some cases, previously flow-through wetlands have become hydrologically isolated and serve as sinks in local topographic-low areas. Application of irrigation water to previously arid soils and the discharge of irrigation drainage to wetlands has also caused substantial changes in the biogeochemical cycling of many major and trace constituents (Lemly and others, 1993). Drainage from agricultural areas, including operational spills, surface runoff from fields, and subsurface drainage, may constitute a significant percentage of water entering wetlands. Agricultural drain water, particularly subsurface drainage, commonly contains elevated concentrations of dissolved solids, including a variety of major constituents and trace elements, which may have been mobilized from soils or local groundwater. Evaporative water loss may further concentrate these materials in wetlands. Hydrologically isolated wetlands in arid areas of the Western United States are particularly susceptible to persistent contaminant accumulation and concentration (Seiler, 1995). Because wetland communities are determined largely by hydrologic characteristics and water quality (Mitsch and Gosselink, 1986, p. 55 and p. 126), these alterations have effected changes in fish and wildlife populations and communities.

Hydrologic characteristics and wetlands processes and water supplies in Lahontan Valley have been modified substantially since the beginning of the Newlands Project in 1902 (Hoffman and others, 1990; Lico, 1992; Kerley and others, 1993; Hoffman, 1994). Among the more notable changes were the reduction of the amount of water entering and flowing through wetlands, shifts in timing and locations of inflow to wetlands, increased hydrologic isolation of wetlands, greater mobilization of dissolved solids and trace elements from agricultural soils, and degradation of the quality of water entering wetlands. Agricultural and nonagricultural water consumption, the discharge of drain water to wetlands, historic ore-milling activities, and wetland-management activities are major contributors to these modifications. Largely because of the lack of historical information, the incremental changes to the wetland ecosystem are difficult to discern. However, historic descriptions provide evidence that gross physical, chemical, and biological conditions in wetlands have changed substantially.

The diversity of wetland plant communities in Lahontan Valley has declined since the beginning of the Newlands Project. On the basis of early accounts, Donahue (1993) identified 27 historical wetland plant-community types in Lahontan Valley, and in the 1990's, Bundy and others (1996) identified 21 of them. In general, the dominant wetland plants currently found in Lahontan Valley are tolerant of saline conditions, whereas some of the historically described saline-intolerant communities are no longer found (Bundy and others, 1996).

No historical information on invertebrate communities was found. Currently, dominant invertebrate taxa in Lahontan Valley are tolerant of pollutants (Plafkin and others, 1989, app. C). Aquatic-invertebrate communities in Lahontan Valley wetlands, particularly in Lead Lake and Sprig Pond, exhibited some characteristics consistent with impaired stream systems, including absence of sensitive taxa, dominance of tolerant taxa, and low taxa richness. The 1994–96 monitoring data indicate that invertebrate community structure is, at least in part, affected by concentrations of dissolved solids, arsenic, boron, and(or) molybdenum in water and concentrations of arsenic and mercury in sediment.

Although at least 5 native and 15 introduced fishes have access to Lahontan Valley wetlands, only 1 native and 4 nonnative fish species were found in the wetlands. Fish communities in Lahontan Valley wetlands also exhibited characteristics consistent with impaired stream systems, including low species diversity, skewed trophic structure, and predominance of tolerant species (Plafkin and others, 1989). Concentrations of arsenic, boron, and molybdenum in water from some wetlands were similar to concentrations associated with toxicity to test organisms (Finger and others, 1993). In a limited number of water samples, arsenic, boron, lead, and mercury exceeded concentrations associated with low-level mortality or reproductive impairment in sensitive fish (Birge and others, 1979a and b).

Aquatic-bird occurrence, nesting, and reproduction have declined since the beginning of the Newlands Project (Kerley and others, 1993); the most noticeable decline has been since 1979 (U.S. Fish and Wildlife Service, 1996a). Declines have been attributed to wetland loss and degradation. Habitat degradation has contributed to decreased bird foraging and nesting habitat and has promoted increased predation through the concentration of predators in fewer or smaller wetland areas (Hallock, Janik, and Kerley, 1993, p. 63). Elevated concentrations of some trace elements may also affect avian reproduction and survival. Aluminum, boron, and mercury in avian food chains were found to exceed concentrations associated with sublethal effects, and 5 percent exceeded levels associated with embryotoxicity. Boron concentrations in a majority of the sampled eggs exceeded concentrations associated with sublethal effects. The actual effects of these elements on bird diversity and abundance in Lahontan Valley are uncertain.

SUMMARY AND CONCLUSIONS

The quantity and quality of wetlands in Lahontan Valley have declined since the advent of large-scale agriculture in the valley in the early 1900's. Recent investigations documented dissolved-solids and trace-element concentrations associated with adverse effects on fish and wildlife. Under the auspices of the Truckee–Carson–Pyramid Lake Water Settlement Agreement, the Department of the Interior implemented a program to acquire rights for water to restore and maintain a part of the historic wetlands in Lahontan Valley. Although inflow to wetlands will be restored in part, the effects of increased inflow on wetland contamination are uncertain. To establish a baseline for assessment of the benefits of water acquisition to wetland contamination, the U.S. Geological Survey and the U.S. Fish and Wildlife Service initiated a monitoring program in Lahontan Valley. Specific goals of the monitoring were to (1) develop a long-term hydrologic and biologic data base for the U.S. Department of the Interior Irrigation Drainage Program, (2) evaluate the effects of Federal activities on water quality, wetland quality, and biota in the area, and (3) identify progress toward the remediation of contaminant concerns in Lahontan Valley wetlands.

During 1994–96, monitoring data were collected from seven agricultural drains, one irrigation-water delivery canal, and four wetlands. Information generated also provided further insight into the probable current status of the Lahontan Valley wetland system, particularly concerning wetland water supply and wetland-habitat conditions.

Wetland Water Supply

- During 1994–96, releases from Lahontan Reservoir ranged from 60 to 130 percent of the long-term average. Because of operational spills and conveyance losses, only about 23 to 59 percent of the released irrigation water arrived at farm headgates, and about 35 percent of that water eventually entered wetlands as agricultural drainage.

- Maximum dissolved-solids concentrations generally were recorded before or very early in the irrigation season. Maximum dissolved-solids loads generally were observed during the irrigation season, coincident with increased flow.

- Of the monitored drains entering Stillwater National Wildlife Refuge, the highest dissolved-solids, boron, and molybdenum concentrations and the greatest number of exceedences of Nevada water-quality standards were found in water from the Paiute Diversion Drain. The lowest concentrations of these constituents were found in water from the S Line. No monitored constituents in S Line exceeded applicable standards.

- Of the monitored drains entering Carson Lake, the highest dissolved-solids, boron, and molybdenum concentrations and the greatest number of exceedences of Nevada water-quality standards were found in water from the Carson Lake Drain. Concentrations were generally lower in water from other drains.

- Concentrations of total mercury in drain water were generally below the analytical detection limit, 0.1 µg/L, in all conduits except Stillwater Slough and Stillwater Point Reservoir Diversion Canal. The highest concentrations of mercury in the water column were found in Stillwater Slough, whereas the highest mercury loads were found in Stillwater Point Reservoir Diversion Canal, which drains into Stillwater Point Reservoir.

Wetland-Habitat Conditions

- Aquatic-invertebrate and fish communities in Lahontan Valley wetlands exhibited some characteristics consistent with stream communities affected by pollutants or degraded water quality.

- Mercury represented the greatest threat to fish and wildlife in Lahontan Valley wetlands. Concentrations in all sampled media exceeded concentrations associated with adverse effects on wetland organisms. Concentrations in bottom sediment positively correlated with concentrations in food-chain organisms and negatively correlated with measures of aquatic-invertebrate community structure. Elevated concentrations of mercury in Lahontan Valley are attributed to historic ore-milling operations; however, drainage has redistributed mercury throughout Lahontan Valley. Because sediments act as both a sink for and a source of mercury in aquatic systems, the acquisition of water is unlikely to mitigate mercury contamination.

- Aluminum concentrations in food-chain organisms exceeded concentrations that are potentially toxic to birds. Concentrations in food chains positively correlated with concentrations in bottom sediment. Concentrations of aluminum in sediments likely reflect natural soil conditions; therefore, the increased inflow of higher quality water is unlikely to reduce biological concern regarding aluminum.

- Arsenic, boron, and molybdenum concentrations in unfiltered wetland water exceeded applicable standards and(or) biological-effect criteria. Concentrations of these elements were similar to concentrations previously associated with toxicity to aquatic organisms and negatively correlated with measures of aquatic-invertebrate community structure. Because dissolved solids (as specific conductance) positively correlated with concentrations of each of these elements, managing wetlands by using higher quality water (such as water having lower dissolved-solids concentration) might reduce the potential for toxicity associated with these elements in water and therefore benefit the aquatic ecosystem.

- Arsenic in bottom sediment in all sampled wetlands exceeded the concentration associated with toxicity to sensitive aquatic organisms and negatively correlated with measures of aquatic-invertebrate community structure. Because concentrations in unfiltered water positively correlated with bottom sediment, supplying wetlands with higher quality water may reduce the potential for toxicity.

- Boron concentrations in food-chain organisms, bird eggs, and juvenile-bird livers exceeded levels associated with sublethal effects on birds. Concentrations were generally higher in vegetation and in herbivorous birds. Concentrations in vegetation were positively correlated with bottom sediment. However, because concentrations in these media did not correlate with concentrations in unfiltered water, it is uncertain whether supplying wetlands with higher quality water would reduce boron concentrations in bottom sediment.

- Selenium was not detected in wetland water samples or in the bulk of the detritus and vegetation samples. Concentrations in biological media were not indicative of adverse effects to fish and wildlife, including impaired avian reproduction. Although previous National Irrigation Water Quality Program investigations identified potentially toxic selenium concentrations in biological samples, this element did not appear to represent a threat to fish and wildlife during the 1994–96 monitoring program. Because selenium concentrations in water were less than the analytical detection limit and because concentrations in other media correlated poorly with one another, little inference may be drawn for water- or wetland-management practices to minimize risks from selenium.

- Specific conductance, a surrogate measure of dissolved-solids concentration, appeared to be a useful variable to monitor the levels of salinity and potentially toxic trace elements in drains and wetlands of Lahontan Valley.

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