Field Screening of Water Quality, Bottom Sediment, and Biota Associated With Irrigation in and Near the Indian Lakes Area, Stillwater Wildlife Management Area, Churchill County, West-Central Nevada, 1995

By Peter L. Tuttle, U.S. Fish and Wildlife Service, and
Carl E. Thodal, U.S. Geological Survey

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre	4,047	square meter
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
foot squared per day (ft^2/d)	0.09290	meter squared per day
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
ton	0.9072	megagram

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).

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.

Water-quality units used in this report:

µg/g	microgram per gram	µS/cm	microsiemens per centimeter
µg/L	microgram per liter	mg/L	milligrams per liter
µm	micrometer	mL	milliliter

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ABSTRACT

A study began in 1995 to determine whether the quality of water or bottom sediment in the Indian Lakes area of the Stillwater Wildlife Management Area, Nevada, has caused or has potential to cause harmful effects on human health or on fish and wildlife, or may adversely affect the suitability of the water for other beneficial uses. The Indian Lakes area encompasses about 10,240 acres of upland desert shrub habitat with a series of man-made lakes and shallow marshes supported by irrigation water and several shallow seepage ponds and wet meadows supported by near-surface ground water. Agricultural activities appear to have contributed to a rise in local ground-water levels, which resulted in the creation of numerous ground-water supported seepage ponds. Dissolved solids and several water-quality constituents, including several potentially toxic trace elements, have become highly concentrated in some seepage ponds. Several of the ponds were highly productive, supporting high densities of aquatic vegetation and invertebrates. Invertebrate and vegetation community assemblages changed with increasing dissolved-solids concentrations. Several avian species, primarily shorebirds, frequented the ponds.

Samples of water from an irrigation-water delivery canal, a flow-through lake, eight seepage ponds, and two water-table wells; bottom sediment from eight seepage ponds; and biological tissue from nine seepage ponds were collected for chemical analyses. All pond-water samples analyzed contained concentrations of one or more constituents in excess of Nevada water-quality standards or existing or proposed Federal water-quality criteria for protection of aquatic life as well as public drinking water. Constituents that exceeded standards or criteria included pH, dissolved solids, chloride, arsenic, boron, fluoride, molybdenum, and uranium. Dissolved solids, arsenic, boron, fluoride, molybdenum, and uranium exceeded standards or proposed criteria by two or more orders of magnitude in some ponds.

Dissolved-solids and trace-element concentrations in seepage-pond water may present a hazard to some wildlife. Invertebrate samples from one or more ponds contained arsenic, boron, mercury, and selenium in excess of published avian dietary effect and concern concentrations. Arsenic, mercury, and selenium did not appear to be of concern in avian eggs. Boron exceeded 13 µg/g in one of four eggs examined. Mercury exceeded 1.3 µg/g (wet weight) in four of six samples and selenium exceeded 10 µg/g in five of six samples of avian livers. Dead resident wildlife, livestock bones, and evidence of avian mortality were found at some ponds. Causes of death were not determined.

Avian use of seepage ponds in 1995 was low compared to other wetlands in Lahontan Valley. However, avian use may increase during regional droughts. Avian nesting attempts at seepage ponds were documented, but avian recruitment was low. No single trace element, for which adequate data

were available, appeared responsible for low production or recruitment. Combined effects of elevated trace elements are uncertain.

Potential pathways of human exposure to trace elements in Indian Lakes include water-contact recreation, inhalation, or consumption of waterfowl or livestock using the ponds. However, the degree of human risk presented by Indian Lakes seepage ponds was not evaluated as part of this investigation.

INTRODUCTION

Background

During the last several years, concern has increased regarding the quality of irrigation drainage and its potentially harmful effects on human health, fish, and wildlife. Selenium concentrations exceeding water-quality criteria for the protection of aquatic life (U.S. Environmental Protection Agency, 1987a) have been detected in drainage from irrigated land in California and elsewhere. In 1983, incidents of mortality, congenital deformities, and reproductive failure in waterfowl were discovered by the U.S. Fish and Wildlife Service (USFWS) at Kesterson National Wildlife Refuge (NWR) in the San Joaquin Valley where irrigation drainage was impounded. In addition, toxic and potentially toxic trace elements and pesticide residues have been detected in other areas in western States that receive irrigation drainage (Feltz and others, 1991; Engberg and Sylvester, 1993).

Because of concerns expressed by the U.S. Congress, the Department of the Interior (DOI) started a program in October 1985 to identify the nature and extent of irrigation-induced water-quality problems that might exist in the Western States. The DOI developed a management strategy and formed an interbureau group known as the "Task Group on Irrigation Drainage," which prepared a comprehensive plan to review irrigation-drainage concerns for which the DOI might have responsibility.

The Task Group identified areas that warranted reconnaissance-level investigations related to three specific activities: (1) irrigation or drainage facilities constructed or managed by the DOI, (2) national wildlife refuges managed by the DOI, and (3) other migratory bird or endangered species management areas that receive water from DOI-funded projects. Through 1996, 26 reconnaissance investigations and 8 detailed studies were made. Nine field screening studies and four verification studies also were completed to obtain preliminary information on sites of potential concern. All investigations were directed toward determining whether irrigation drainage (1) has caused, or has the potential to cause, significant harmful effects on human health, fish, and wildlife; or (2) may adversely affect the suitability of water for other beneficial uses.

The Truckee-Carson-Pyramid Lake Water Rights Settlement Act of 1990 (Title II of Public Law 101-618) authorized the Secretary of the Interior to convey the Indian Lakes area of Stillwater Wildlife Management Area (WMA; fig. 1) to the State of Nevada or to Churchill County for fish and wildlife habitat and for human recreation. Much of Stillwater WMA, including the Indian Lakes area, is Bureau of Reclamation (BOR) withdrawn land. The State and County were reluctant to accept the property because of concern over documented mercury contamination in this area associated with the Carson River Mercury Site, which is on the U.S. Environmental Protection Agency National Priority List (Cooper and others, 1985; Sevon, 1988). To expedite the land transfer, the BOR investigated the extent and magnitude of mercury and other trace-element contamination in the Indian Lakes area. Water and soil samples collected from several sites within the Indian Lakes area, including several isolated, ground water-supported ponds (seepage ponds), were analyzed for mercury and several other trace elements. These analyses confirmed that mercury in some areas of Indian Lakes exceeded concern concentrations. Additionally, high concentrations of several trace elements were measured in seepage ponds. In some ponds, concentrations of arsenic, boron, beryllium, barium, cadmium, copper, chromium, iron, mercury, selenium, and zinc in water exceeded Nevada water-quality standards or fish and wildlife effect criteria. In some places, standards or criteria were exceeded by orders of magnitude.

Agricultural practices in Lahontan Valley have caused shallow ground-water levels to rise in several areas, including areas near Indian Lakes (Hoffman and others, 1990a; Seiler and Allander, 1993; Maurer and others, 1996). The National Irrigation Water Quality Program (NIWQP) Coordinators became concerned that a rise in shallow ground-water levels in the Indian Lakes area may have contributed to the creation of seepage ponds and to the concentration of dissolved solids due to evaporation. Further, contaminants in seepage ponds could represent a significant hazard to wildlife and human health. Therefore, the NIWQP Coordinators concluded that investigation of potential hazards associated with seepage ponds in the Indian Lakes area was warranted. The U.S. Geological Survey (USGS) and the USFWS agreed to complete additional investigations to assess these concerns.

Purpose and Scope

This report presents the findings of an investigation of seepage ponds in the Indian Lakes area in 1995. The objectives of the screening study were to (1) evaluate the areal extent and magnitude of trace-element contamination in water, sediment, and biota of isolated seepage ponds of the Indian Lakes area; (2) identify the sources of water in the isolated seepage ponds; and (3) assess the potential for significant harmful effects on wildlife, and possibly on human health and livestock. Data collected May-September 1995 included measurement of water-quality constituents; collection of water, sediment, invertebrates, shorebird eggs, and shorebird liver samples for analyses of trace-element concentrations. Avian-use surveys were used to address these concerns in the Indian Lakes area. Previously unpublished 1994 data for water samples collected and analyzed by the USGS and biological tissue samples collected and analyzed by the USFWS also are included.

Acknowledgments

The authors gratefully acknowledge John F. Miesner and Donald J. Franks of the U.S. Fish and Wildlife Service, Nevada State Office, for providing assistance in data collection; William G. Henry and Robert Flores of Stillwater National Wildlife Refuge for providing biological and public-use information on the Indian Lakes area; and Stanley N. Wiemeyer for providing valuable assistance and critical review during the preparation of the manuscript.

DESCRIPTION OF STUDY AREA

Location

The Indian Lakes area is in the southwestern part of Stillwater WMA, Churchill County, Nev. (fig. 1). Stillwater WMA is in the Carson Desert Hydrographic Area[1] (Rush, 1968) in the western Great Basin. The Carson Desert, also known as Lahontan Valley, is a broad alluvial basin encompassing approximately 2,000 mi^2 of nearly flat terrain. Altitudes of the valley floor range between 3,900 and 4,100 ft above sea level. Lahontan Valley is bounded by mountains ranging in altitude from 4,500 to 8,800 ft (Morrison, 1964). The Carson River, which originates in the Sierra Nevada, terminates in Lahontan Valley.

The Indian Lakes area is near the center of Lahontan Valley, with the Carson Sink, a playa, to the north and the Fallon agricultural area to the south (fig. 1). The Indian Lakes area encompasses approximately 10,240 acres, most of which is upland desert shrub habitat. The area contains a series of lakes and shallow marshes supported by irrigation water delivered through this area. Numerous shallow seepage ponds and wet meadows supported by near-surface ground water also are in the area.

History

Historically, the Carson River was the primary water source for Lahontan Valley. The river flowed unrestricted through a series of shallow lakes and marshes before discharging to the Carson Sink. On the basis of historical flow data for the Carson River, an average annual wetland size of 150,000 acres was estimated (Kerley and others, 1993). However, because of variable seasonal and annual river flow, wetland size probably ranged from practically zero to more than 200,000 acres. Prior to regulation, the Carson River channel in Lahontan Valley meandered and frequently shifted course (Hoffman, 1994). At least three historical river channels have been identified in the Indian Lakes area (Maurer and others, 1996, p. 15).

Historical conditions in the Indian Lakes area are largely unknown. Information available suggests that considerably less surface water existed in the Indian Lakes area prior to the turn of the century than at present. An 1868 Government Land Office map identified only two "alkali lakes" in the vicinity of Likes and Papoose Lakes (fig. 2). A slough, which extended from the northern end of the northernmost lake to the Carson

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[1]Formal hydrographic areas in Nevada were delineated systematically by the U.S. Geological Survey and Nevada Division of Water Resources in the late 1960's (Rush, 1968; Cardinalli and others, 1968) for scientific and administrative purposes. The official hydrographic-area names, numbers, and geographic boundaries continue to be used in Geological Survey scientific reports and Division of Water Resources administrative activities.

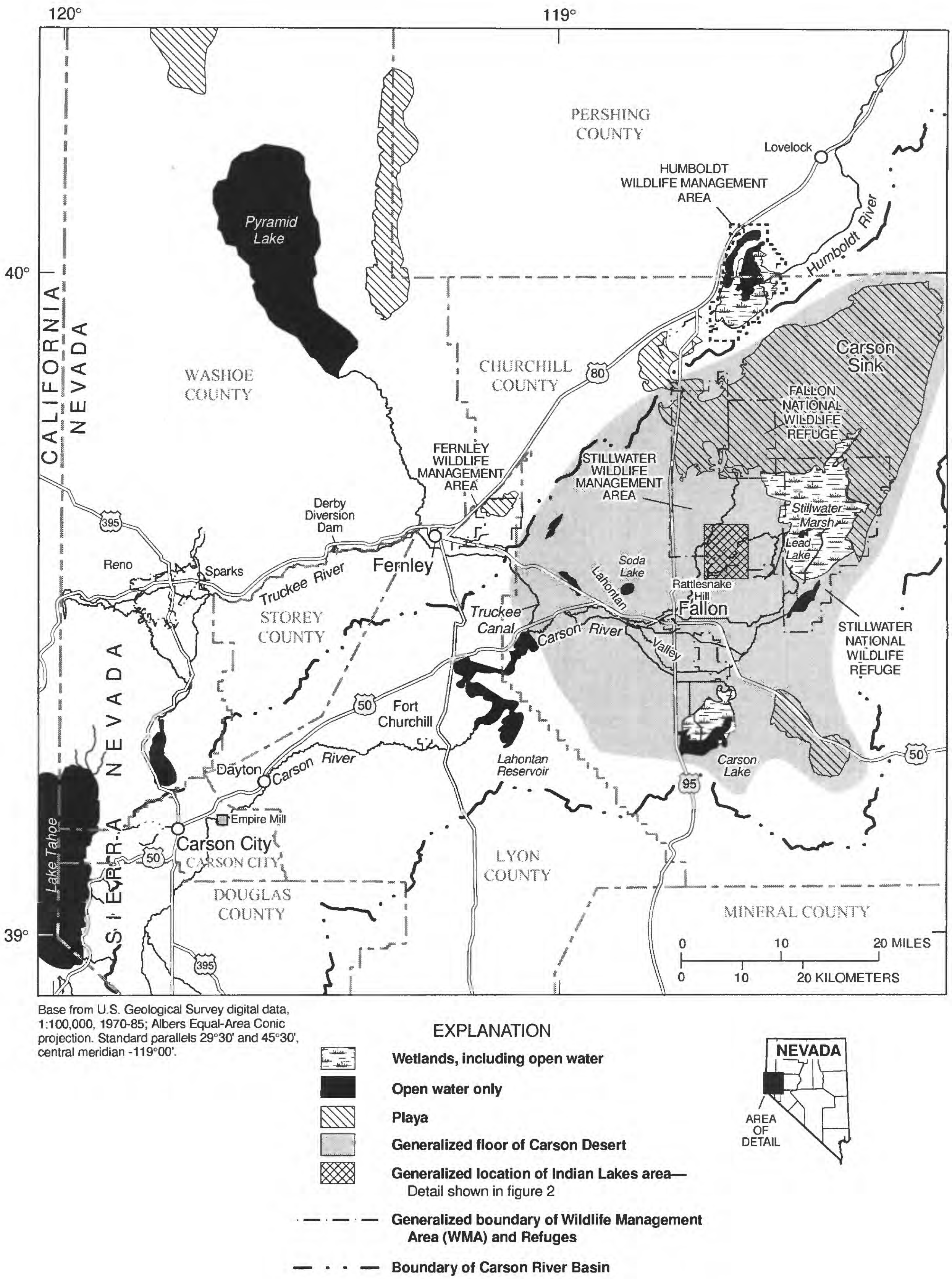
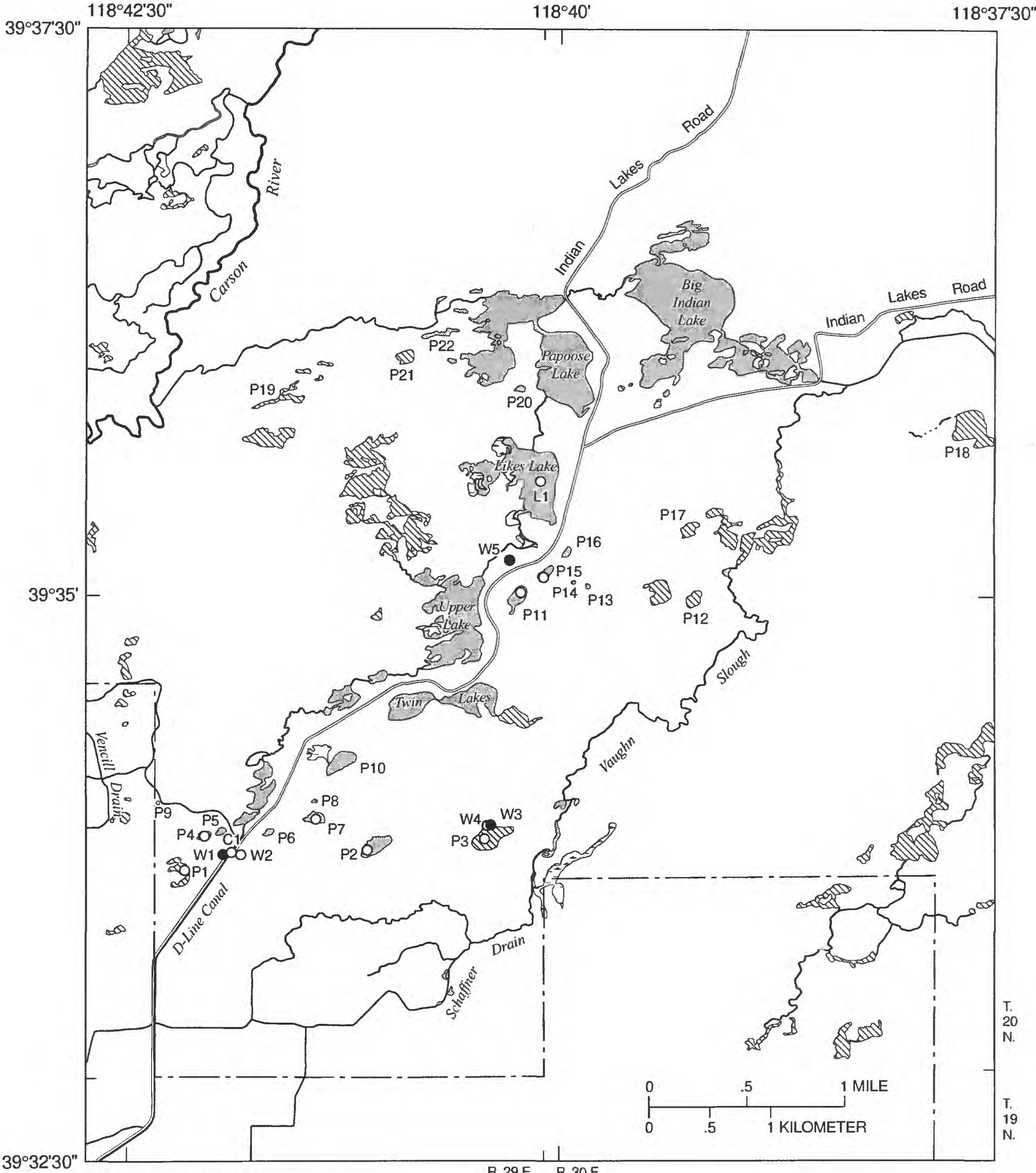


Figure 1. General physiographic features of Carson Desert and western Nevada.



Base from U.S. Geological Survey,
1:24,000 quadrangle: Indian Lakes, Nev., 1985

EXPLANATION

Open Water

Perennial

Ephemeral

Marsh

— - — **Boundary of Stillwater Wildlife Management Area**

C1 ○ **Sampling site**—Characters correspond to site numbers listed in table 2. C, canal; L, flow-through lake; P, seepage pond

W1 ● **Well or water-level site**—Characters correspond to site numbers listed in table 2.

Figure 2. Location of sampling sites in Indian Lakes area, Stillwater Wildlife Management Area, Nevada, 1995.

River also is depicted on the map. From the USGS Indian Lakes, Nev., 7.5-minute topographic quadrangle of 1985, the surface gradient drops slightly (less than 3 ft) from the Carson River to Papoose Lake. This slight decline suggests that water may have flowed from the Carson River to the Indian Lakes. The slough appears to be in the area of a historical Carson River channel (Maurer and others, 1996). Non-wetland (uplands) habitat in the area would probably have been similar to current upland habitats.

Historical information on human use of the Indian Lakes area is limited. The Indian Lakes area is within the historical range of the *Toedokado*, a group of northern Paiute Indians who occupied Carson Sink and Stillwater Marsh for more than 3,000 years (Fowler, 1992). Archaeological modeling predicted that approximately half of the Indian Lakes area was composed of habitat suitable for seasonal or permanent residence (Raven and Elston, 1989; U.S. Fish and Wildlife Service, 1995). However, little physical evidence of residences or long-term habitation has been documented in this area.

Irrigated agriculture in Lahontan Valley was begun after non-native-American settlement in 1855. Large-scale agricultural development followed the enactment of the Reclamation Act of 1902. The Newlands Project, created under this act, provided for the irrigation of federally withdrawn homestead lands near Fernley and Fallon. By 1905, the Truckee Canal was completed to import water from the Truckee River Basin and Lahontan Dam and Reservoir were completed in 1915 (fig. 1) to provide agricultural water storage for the Newlands Project.

Ground-water levels measured prior to expansion of irrigated agriculture indicated that a drainage system would be required for agriculture to be successful in the Carson Desert (Stabler, 1904, p. 49). Soil saturation and salinization in agricultural areas prompted the construction of an extensive system of agricultural drains in the 1920's. Most of these drains discharged to the lower Carson River or other wetlands (Maurer and others, 1996, p. 16). Regulation of the Carson River also modified natural flow volumes and patterns in Lahontan Valley. Following agricultural development, wetlands in Lahontan Valley were primarily supported by agricultural drain water and water released from Truckee Canal for power generation and from Lahontan Reservoir for operational spills and flood-water control.

Concern for loss and degradation of Lahontan Valley wetlands prompted wetland habitat protection measures in 1935, when the Truckee-Carson Irrigation District, the operator of the Newlands Project, proposed to establish a Wildlife Management Area. This proposal came to fruition in 1948 when a cooperative agreement between the USFWS (then the Bureau of Biological Survey), the Nevada Division of Wildlife (then the Nevada State Board of Fish and Wildlife Commissions), and the Truckee-Carson Irrigation District established the Stillwater WMA (Secretarial Notice Number 6449). This 50-year agreement designated approximately 224,000 acres of BOR land as the Stillwater WMA, of which 24,000 acres were administered by the USFWS as the Stillwater NWR. Stillwater WMA was managed as habitat for fish and wildlife, with the right of pasturage maintained by the Truckee-Carson Irrigation District. Under the Truckee-Carson-Pyramid Lake Water Rights Settlement Act of 1990, BOR transferred 77,520 acres of land to the USFWS to formally create the Stillwater NWR in 1991.

Climate

The climate of Lahontan Valley is that of a mid-latitude desert (Hoffman and others, 1990a). Temperatures range from an average daily minimum of 17°F in January to an average daily maximum of 93°F in July. Lahontan Valley is affected by the rain shadow of the Sierra Nevada, and annual average precipitation is about 5 in. (Dollarhide, 1975). The rate of evapotranspiration exceeds 50 in. annually (Morgan, 1982).

Geology and Soils

Geology of Lahontan Valley is described by Willden and Speed (1974) and Maurer and others (1996). In general, surficial deposits are characterized by unconsolidated, fine-grained lake and playa deposits of Pleistocene age, young fan gravels, and prograding delta deposits of Quaternary age. Surrounding mountains are composed of igneous, sedimentary, and metamorphic rock. The Fallon Formation underlies most of the developed lakes and seepage ponds in the Indian Lakes area. This formation consists of permeable sediments, including fine-grained shallow lake sand, eolian sand, and coarse-grained alluvium.

Soils in the Indian Lakes area are predominantly of the Tipperary-Appian association (Dollarhide, 1975). Three soil substrata—Tipperary-Appian clay complex, Appian clay complex, and Tipperary-Parran complex—are predominant in this association. Soils of these substrata are composed primarily of fine sands and clays and may be overlain with sand dunes. Soils of the Tipperary-Appian complex in the study area are typically well drained and have limited potential for crop production. A limited area of Ragtown Series soil is found in the vicinity of a historical slough that extended eastward from the Carson River to the vicinity of Papoose Lake. Soils in this area consist of loamy alluvium and are highly saline. The water table is seasonally near the land surface. Typically, soils forming under dry climatic conditions, such as those found in the Carson Desert, are poorly leached, and may contain high concentrations of soluble minerals, possibly including a variety of trace elements (Hoffman, 1994).

Hydrologic Setting

Historically, natural inflow from the Carson River, ground-water inflow, and (rarely) inflows from the Humboldt River maintained about 150,000 acres of wetlands in the Carson Desert (Kerley and others, 1993, p. 11). Most of the estimated historical wetland area was near Carson Lake, Stillwater Marsh, and the Carson Sink (fig. 1).

Agricultural activities in the Carson Desert have modified the hydrologic setting. Water imported for irrigation from the Truckee River through the Truckee Canal has increased the average annual flow of the lower Carson River by about 60 percent (Hoffman, 1994, p. 8). The water-distribution system that has been developed downstream from Lahontan Dam has 68.5 mi of main canals and 312 mi of laterals that deliver irrigation water to about 40,000 acres (Bureau of Reclamation, 1991). A simplified schematic diagram of the flow system (modified from Bauer and others, 1996, p. 188) is shown in figure 3.

The Indian Lakes area is in the floodplain of the lower Carson River. Between 1915 and the 1940's, the D-Line Canal was constructed through the Indian Lakes area to deliver irrigation water to agricultural areas to the north. Natural depressions were incorporated in the delivery system and, in the 1940's, sportsmen's groups constructed dikes and water-control structures to either enlarge (Likes and Papoose Lakes) or create (Upper Lake and Big Indian Lake) flow-through lakes for recreational use (Sumner and others, 1957). These developed lakes continue to be popular recreational resources.

The flow-duration curve in figure 4 shows the statistical probability that daily mean discharge in the Carson River below Lahontan Dam (USGS stream-gaging station 10312150) will equal or exceed the discharge indicated by the graph, based on data for water years 1967-95. During this field-screening study (May-June 1995), daily mean discharge equaled or exceeded values that have a probability between 0.001 and 0.03, indicating unusually high rates of streamflow during this study. Annual runoff in 1995 was 413,100 acre-ft, whereas the mean annual runoff for 1967-95 was 367,600 acre-ft/yr (Bauer and others, 1996, p. 235).

Water flowing to the Indian Lakes area is diverted from the Carson River at Sagouspe Dam into D-Line Canal for delivery of irrigation water to three farms having agricultural water rights for 490 acres. Irrigation water in excess of agricultural needs is delivered to wetlands in Stillwater NWR. The average annual volume of irrigation water delivered through D-Line Canal during 1975-93 was 12,500 acre-ft (U.S. Fish and Wildlife Service, 1995). Management of irrigation water in this area is by the Truckee-Carson Irrigation District as BOR contractors. Other than to provide irrigation water to the three farms, no water rights are dedicated to the Indian Lakes nor obligated to maintain them. No irrigated fields are in the immediate vicinity of the Indian Lakes area, but agricultural activities border the WMA to the south, west, and northwest. Two open ditches—Shaffner Drain, less than 1 mi south of the study area, and Vencill Drain, less than 1 mi west (fig. 2)—receive returnflow from nearby irrigated fields. Shaffner Drain discharges to Vaughn Slough, which discharges back to D-Line Canal downstream from Big Indian Lake. D-Line Canal discharges into Paiute Diversion Drain, which discharges available water into wetlands in the Carson Sink (fig. 3).

Ground-water resources of the Carson Desert are described by Glancy (1986) and Maurer and others (1996) as being found in unconsolidated sediments and in volcanic rocks beneath the floor of the valley. The basalt aquifer (volcanic rocks) is the principal source of domestic and industrial water for the City of Fallon and the nearby Naval Air Station. The rural population of the Carson Desert relies principally on the shallow (0 to 50 ft below land surface) sedimentary aquifer.

Hydraulic properties of the shallow aquifer are variable, with most of the ground-water flow moving through more transmissive sand and gravel deposits (Seiler and Allander, 1993, p. 7-8). Recharge is primarily by seepage from the Carson River and unlined irri-

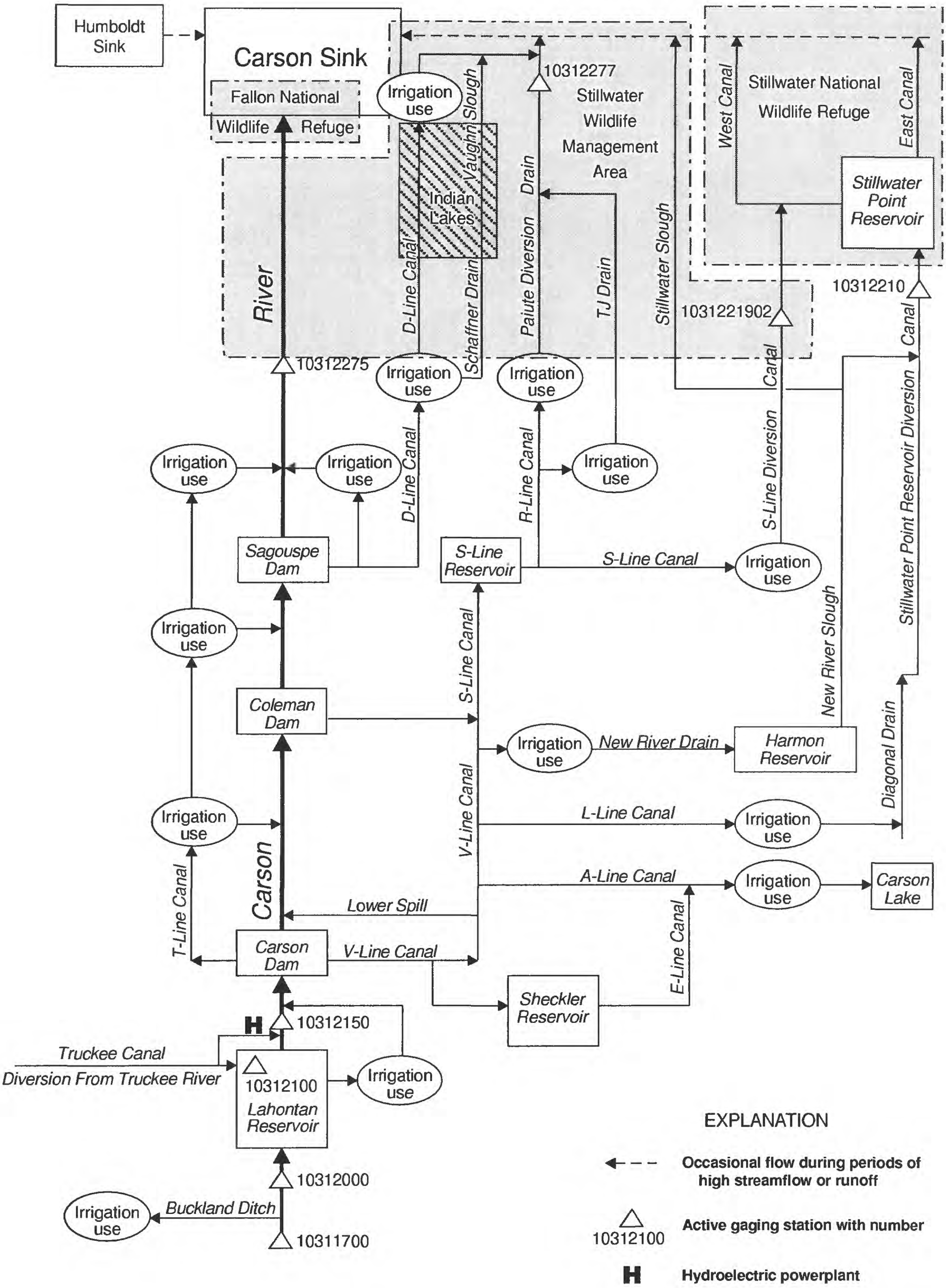


Figure 3. Schematic diagram of water distribution and drainage systems in Newlands Project, Churchill County, Nevada, 1995. Modified from Bauer and others (1996, p. 188)

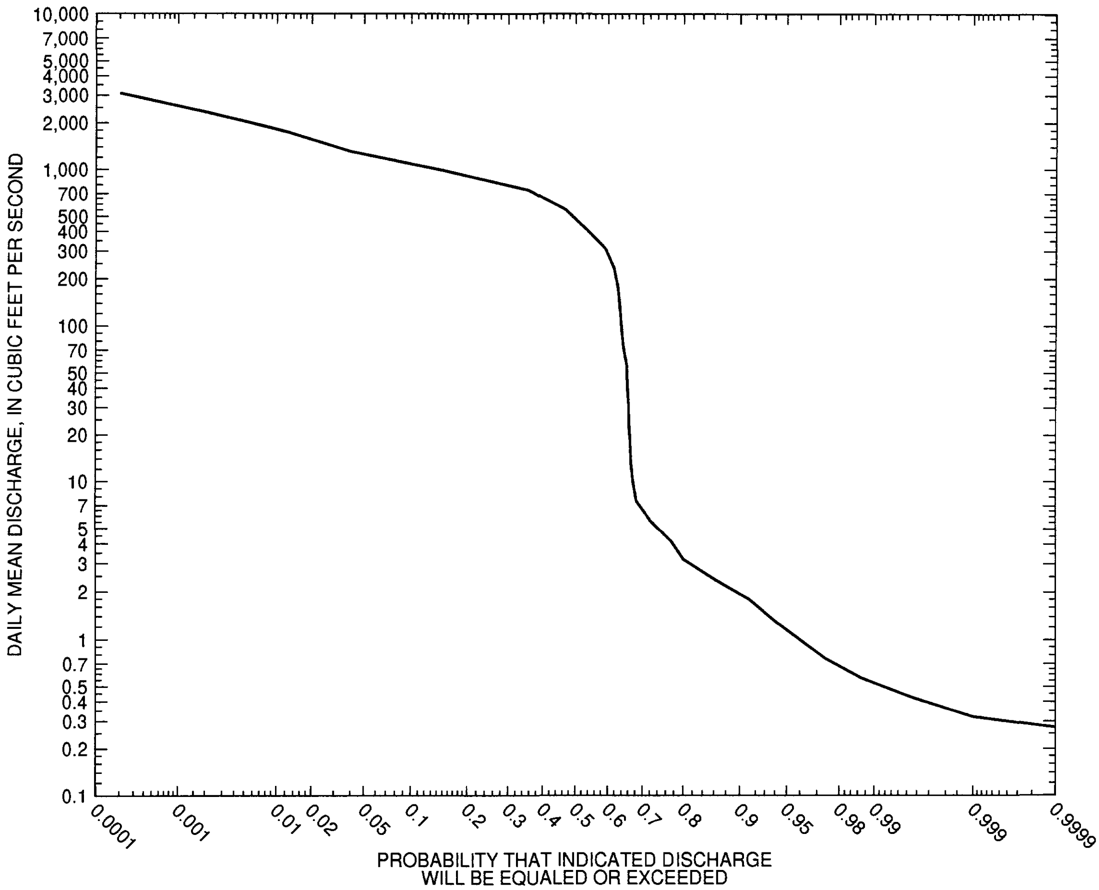


Figure 4. Flow-duration curve for Carson River below Lahontan Reservoir, near Fallon, Nevada, 1967-95.

gation canals and by percolation of irrigation water applied to fields (Seiler and Allander, 1993, p. 8). The complex network of predominantly unlined canals and laterals, and flood irrigation, have resulted in localized recharge of the shallow aquifer and caused shallow ground water to rise to near land surface in some areas. Between 1904 and 1992, water levels in wells northeast of Fallon have risen more than 15 ft due to recharge by irrigation water (Seiler and Allander, 1993, p. 10). The 60-ft rise in the water level of Soda Lake (fig. 1) from 1906 to 1930 is an extreme example of localized effects of irrigated agriculture on hydrology in the Carson Desert (Hoffman, 1994, p. 9). In contrast, wells in areas where open drains deeper than the water table have been constructed have had water-level declines of more than 5 ft (Seiler and Allander, 1993, p. 16). In the Indian Lakes area, several depressions in land surface have become seepage ponds, which are supported by shallow ground water.

The basalt aquifer is a highly transmissive (4,100-170,000 ft^2/d; Glancy, 1986, p. 18), asymmetrical, northeast-trending, mushroom-shaped mass that is almost completely enclosed by unconsolidated sediments, except where it is exposed at Rattlesnake Hill (Glancy, 1986, p. 13-14). The aquifer extends from about 1 mi southwest of Fallon northeast into the Indian Lakes area. Comparison of water levels measured in wells that tap the sedimentary aquifers with water levels in wells that tap the basalt aquifer indicate a downward vertical gradient from the surrounding sedimentary aquifers to the basalt aquifer southwest of the Indian Lakes area. The vertical gradient reverses near the WMA boundary, indicating discharge of water from the basalt aquifer to the sedimentary aquifers in the Indian Lakes area (Maurer and others, 1996, p. 46).

Altitudes of water levels measured in wells in the Carson Desert in 1992 indicate that ground water moves downgradient from an area of high hydraulic head (4,025 ft above sea level) 11 mi west of Fallon to areas of lower head (3,865 ft) 18 mi northeast of Fallon. These water levels indicate that ground-water flow divides west of Fallon: some of the flow moves toward Carson Lake (southeast) with a hydraulic gradient of about 6 ft/mi and some toward Carson Sink (northeast) with a gradient of about 9 ft/mi (Seiler and Allander, 1993, p. 17).

Biological Resources

Non-wetland habitat (uplands) in the Indian Lakes area are representative of the greasewood (*Sarcobatus baileyi*) and shadscale (*Atriplex confertifolia*) communities found in the Carson Desert. This community consists of low, widely spaced shrubs with sparse grasses and forbs. Dominant vegetation species include greasewood and shadscale, but spiny hopsage (*Grayia spinosa*) and rabbitbrush (*Chrysothamnus viscidflorus*) are common. Nevada oryctes (*Oryctes nevadensis*), a plant species of concern, has been identified in upland areas of Indian Lakes. This annual typically is found in deep, sandy soils. Terrestrial fauna common in the area include a variety of reptiles, small mammals, birds, and coyotes (*Canus latrans*).

Riparian communities are found along irrigation canals, agricultural drains, fringes of lakes receiving irrigation water, and some seepage ponds. Two introduced species, Russian olive (*Elaeagnus angustifolia*) and saltcedar (*Tamarix ramosissima*), dominate riparian vegetation, with native cottonwood (*Populus fremontii*) and willow (*Salix* sp.) found in some areas. Shorelines around developed lakes, wet meadows, and fringes of some seepage ponds are vegetated with grasses and rushes. Dominant species include saltgrass (*Distchlis stricta*), wire grass (*Juncus balticus*), and alkali bulrush (*Scirpus robustus*). Emergent vegetation, including wiregrass, alkali bulrush, cattails (*Typha* spp.), and hardstem bulrush (*Scirpus acutus*) are sparse around fringes of the developed lakes and some seepage ponds. Aquatic vegetation found in developed lakes and some seepage ponds include American pondweed (*Potamogeton nodosus*), sago pondweed (*P. pectinatus*), widgeon grass (*Ruppia* spp.), monkeyflower (*Mimulus* spp.), and coontail (*Ceratophyllum demersum*).

Developed lakes in the Indian Lakes area support at least 17 fish species, of which two—tui chub (*Gila bicolor*) and Tahoe sucker (*Catostomus tahoensis*)—are native to western Nevada. The Nevada Division of Wildlife manages a recreational fishery in the five larger flow-through lakes in the Indian Lakes area. Principal game species include three species of ictalurids (catfish), five perciforms (bass and perch), and trout. From 1986 to 1988, this fishery provided between 11,000 and 13,000 angler days, with 20,000-30,000 fish harvested annually (Sevon, 1988). Angler use and harvest have since declined primarily due to drought and reduced water deliveries. Historically, carp (*Cyprinus carpio*) and Sacramento blackfish (*Orthodon microlepidotus*) have been commercially harvested from Indian Lakes (U.S. Fish and Wildlife Service, 1995).

Aquatic fauna differ among seepage ponds. Fish are absent from most, if not all, of the seepage ponds despite earlier efforts to introduce fish to some ponds (Sumner and others, 1957). Invertebrate composition changes from communities dominated by several types of hemipterans (true water bugs) and dipterans (two-winged flies) to communities dominated by eubranchipods (brine shrimp; *Artemia* spp.). Earlier surveys reported that bullfrogs (*Rana catesbeiana*) and leopard frogs (*Rana pipiens*) were common in the Indian Lakes area (Sumner and others, 1957). However, recent surveys indicate that these species are uncommon in this area (U.S. Fish and Wildlife Service, 1995).

Lahontan Valley has been identified as an important area for avian species along the Pacific flyway and one of the most important wetlands in Nevada (Thompson and Merritt, 1988). Since the early 1970's, peak waterfowl counts in Lahontan Valley wetlands have ranged from 190,000 to more than 275,000 individuals (U.S. Fish and Wildlife Service, 1996). Shorebird counts have ranged from less than 10,000 to more than 250,000. Peak bird usage is typically during migration. The number of nesting birds is lower. Since the early 1970's, the number of nesting waterfowl pairs has ranged from 1,400 to more than 3,500, with the number of young produced annually estimated between less than 1,000 to almost 29,000. Counts of shorebird nesting and production are not available.

Two species protected under the Endangered Species Act, threatened bald eagle (*Haliaeetus leucocephalus*) and endangered American peregrine falcon (*Falco peregrinus anatum*), and one species proposed for listing, mountain plover (*Charadrius montanus*), have been reported in Lahontan Valley (table 1). Bald eagles winter in Nevada, with as many as 70 bald eagles reported in Lahontan Valley (Herron and others, 1985; U.S. Fish and Wildlife Service, 1996).

During winter months, bald eagles frequent the Indian Lakes area, where larger trees provide suitable roosts and fish in flow-through lakes provide food. Peregrine falcons have been sighted at Carson Lake and Stillwater NWR (Alcorn, 1988), typically from February to November (U.S. Fish and Wildlife Service, 1996). Peregrines are not known to nest in Lahontan Valley. Mountain plover have been reported infrequently in Lahontan Valley (U.S. Fish and Wildlife Service, 1996). This species is considered a migrant and sightings have not been reported in the Indian Lakes area.

Several avian species of concern (former category 2 candidates for listing as endangered or threatened) also have been sighted in Lahontan Valley (table 1). Three of these, western snowy plover (*Charadrius alexandrinus nivosus*), black tern (*Chilidonias niger*), and white-faced ibis (*Plegadis chihi*), have been reported at Indian Lakes. Western snowy plover occur over a broad range, but numbers have decreased across its range. Such declines have been noted in Lahontan Valley, with the population dropping from 760 in 1980 to 74 in 1991 (U.S. Fish and Wildlife Service, 1996).

In the Great Basin, snowy plovers forage and nest on poorly vegetated playa or lake fringes (Page and others, 1995). Snowy plovers generally forage in shallow (less than 1 in.) water or wet mud, with their diet consisting of aquatic and terrestrial insects. In the Great Basin,

Table 1. Endangered, threatened, and candidate species, and species of concern associated with wetlands in Lahontan Valley

[Primary habitat: ag, agricultural fields; non, non-wetland; rip, riparian; and wet, wetland]

Common name	Scientific name	Federal status [1]	Primary habitat
	Mammals		
Fringed myotis	*Myotis thysanodes*	concern	wet, non, ag
Long-eared myotis	*Myotis evotis*	concern	wet, non, ag
Long-legged myotis	*Myotis volans*	concern	wet, non, ag
Pacific Townsend big-eared bat	*Plecotus townsendii townsendii*	concern	wet, non, ag
Pale Townsend big-eared bat	*Plecotus townsendii pallescens*	concern	wet, non, ag
Pygmy rabbit	*Brachylagus idahoensis*	concern	rip
Small-footed myotis	*Myotis ciliolabrum*	concern	wet, non, ag
Spotted bat	*Euderma maculatum*	concern	wet, non, ag
Yuma myotis	*Myotis yumanensis*	concern	wet, non, ag
	Birds		
American peregrine falcon	*Falco peregrinus anatum*	endangered	wet, non, ag
Bald eagle	*Haliaeetus leucocephalus*	threatened	wet, rip, non, ag
Black tern	*Chlidonias niger*	concern	wet
Ferruginous hawk	*Buteo regalis*	concern	wet, rip, non, ag
Mountain plover	*Charadrius montanus*	candidate	non, ag
Northern goshawk	*Accipiter gentilis*	concern	non
Western burrowing owl	*Athene cunicularia hypugea*	concern	non
Western snowy plover	*Chardrius alexandrinus nivosus*	concern	wet
White-faced ibis	*Plegadis chihi*	concern	wet, ag
	Reptiles		
Northwestern pond turtle	*Clemmys marmorata marmorata*	concern	wet, rip
	Invertebrates		
Nevada viceroy	*Limenitus archippus lahontani*	concern	rip
	Plants		
Nevada oryctes	*Oryctes nevadensis*	concern	non

[1] Endangered, species so listed under Endangered Species Act of 1973, as amended; Threatened, species so listed under Endangered Species Act of 1973, as amended; Concern, existing information indicates that species listing may be warranted, but substantial biological information to support proposed rule is lacking.

snowy plovers have been reported to feed on brine shrimp (Page and others, 1995). A single snowy plover was observed on several occasions near pond sites P15 and P16 (fig. 2). Whether the same bird was observed on each occasion and whether the bird was nesting in the area are unknown.

Like snowy plovers, black terns occur over a broad range, but numbers have declined across the range (Dunn and Argo, 1995). Black terns nest in Lahontan Valley, but reports of nesting have been infrequent in recent years (Alcorn, 1988). Black terns have been sighted at the larger lakes in the Indian Lakes area. This species nests at shallow freshwater marshes with emergent vegetation. Their diet consists of insects and smaller fish.

Lahontan Valley supports one of the three largest populations of white-faced ibis in the western United States. Because white-faced ibis nest in dense emergent vegetation, this species probably does not nest in the study area. However, ibis are commonly observed foraging along lake fringes and in wet meadows of the Indian Lakes area. Ibis breeding colonies are found at Stillwater Point Reservoir in the Stillwater NWR and at Carson Lake.

PREVIOUS ENVIRONMENTAL-CONTAMINANT INVESTIGATIONS

Carson River Mercury Site

Between 1859 and the turn of the century, mercury amalgamation was used in the milling of gold and silver ore from the Comstock Mining District in the Virginia Range approximately 70 mi west of Stillwater NWR (Smith, 1943). As many as 186 mills, many of which were adjacent to the Carson River between Carson City and Dayton (fig. 1), were in operation during this period (Ansari, 1989). As much as 7,500 tons of elemental mercury may have been lost during milling operations (Bailey and Phoenix, 1944). Most was discarded in mill tailings or discharged to the Carson River in mill effluent.

Elevated mercury concentrations in water and sediment in the lower Carson River basin were identified in 1971-72 (Van Denburgh, 1973). In finding elevated mercury levels in fish collected between Empire and Lahontan Reservoir (fig. 1), Richins (1973) and Richins and Risser (1975) documented that mercury contamination extended to biological systems. Mercury concentrations in water, sediment, and fish in the lower Carson River were considerably higher than background levels (Cooper 1983; Cooper and Vigg, 1984; Cooper and others, 1985). For example, the mean concentration in carp muscle collected upstream from mercury-contaminated areas was 0.41 μg/g (wet weight; Cooper and others, 1985). Concentrations in fish muscle collected in the lower Carson River Basin ranged from 0.15 to 3.19 μg/g (wet weight), with 45 percent of the samples exceeding the 1.0-μg/g (wet weight) action level for human consumption of fish (U.S. Food and Drug Administration, 1984; U.S. Environmental Protection Agency, 1989).

Likes and Papoose Lakes in the Indian Lakes area were included in the study by Cooper and others (1985). Mercury concentrations in channel catfish (*Ictalurus punctatus*), white catfish (*Ictalurus catus*), white crappie (*Pomoxis annularis*), carp, and Sacramento blackfish ranged from 0.24 to 2.12 μg/g (wet weight). Thirty-eight percent of fish collected from Likes Lake and 75 percent of fish collected from Papoose Lake exceeded the action level for human consumption. The highest levels were found in carp. Sevon (1986) assessed mercury concentrations in seven fish species from Big Indian Lake. In addition to species examined by Cooper and others (1985), Sevon (1986) also included white bass (*Morone chrysops*) and rainbow trout (*Onchorynchus mykiss*). Mercury levels in this study ranged from 0.14 to 2.02 μg/g (wet weight). Fifty percent of these fish exceeded the action level for mercury in fish for human consumption. The highest concentration again was found in carp. As a result of these studies, the Nevada State Health Officer issued a consumption advisory in 1987 for fish collected from Lahontan Reservoir, the Carson River below Lahontan Dam, and all waters in Lahontan Valley.

Hallock and others (1993c) examined mercury in edible waterfowl tissues collected from Carson Lake and Stillwater WMA. Elevated mercury in one or more muscle tissue samples from three of five waterfowl species examined exceeded the 1.0-μg/g (wet weight) action level for human consumption. Significantly, mercury concentrations in muscle tissue of 90 percent of the northern shovelers (*Anas clypeata*) examined exceeded the action level for human consumption. As a result of these findings, the Nevada State Health Officer issued a consumption advisory in 1989 for northern shovelers taken from the Carson Lake area.

Concern for human health and environmental quality prompted the U.S. Environmental Protection Agency to list the Carson River Mercury Site on its National Priority List in 1990 under the Comprehensive Environmental Response, Compensation, and Liability Act. Among other areas, the site involves approximately 100 mi of the lower Carson River, including Stillwater NWR (U.S. Environmental Protection Agency, 1991a). Research and cleanup at this site are continuing as of 1997.

Activities of National Irrigation Water Quality Program

In 1986, the NIWQP Bureau Coordinators identified wetlands in and near Stillwater NWR (fig. 1) as being at risk of contamination by agricultural drain water from the Newlands Project, a DOI-sponsored irrigation project. A reconnaissance investigation of wetlands in and near Stillwater NWR was begun in 1986 to determine if agricultural drainage had caused, or had the potential to cause, adverse effects to human health or fish and wildlife, or to affect the suitability of water for beneficial uses (Hoffman and others, 1990b). The study determined that water in some areas that receive agricultural drainage contained concentrations of arsenic, boron, dissolved solids, sodium, and un-ionized ammonia in excess of baseline conditions or Federal and State criteria for the protection of aquatic life or the propagation of wildlife. Sediment from some affected wetlands contained elevated levels of arsenic, lithium, mercury, molybdenum, and zinc. Additionally, concentrations of arsenic, boron, copper, mercury, selenium, and zinc in biological tissues collected from some affected wetlands exceeded levels associated with adverse biological effects reported in other studies. The study concluded that arsenic, boron, mercury, and selenium were of primary concern to human health and fish and wildlife in and near Stillwater NWR.

Findings of the reconnaissance investigation prompted additional study of the potential effects of agricultural drainage in this area. Lico (1992) examined geochemical and physical processes controlling water quality in Lahontan Valley wetlands and found that ground and surface waters were generally of poor quality with several constituents exceeding regulatory standards or criteria. Processes controlling ground-water composition were dissolution of sedimentary minerals, evapotranspiration, and chemical precipitation. Trace-element concentrations were controlled by localized pH and redox conditions and interaction with sedimentary materials. Wetland sediment also was accumulating trace elements from the overlying water column.

Upstream water diversion and consumption have contributed to the decline of wetland acreage in Lahontan Valley by as much as 90 percent since the creation of the Newlands Project in 1902 (Kerley and others, 1993). Water diversions also modified historical flow patterns and other hydrologic characteristics, and flows through wetlands were reduced or eliminated. Water entering wetlands was largely supplied through agricultural drains, and consisted of a mixture of irrigation-delivery water, subsurface drainage, and surface runoff. This water typically contained concentrations of dissolved constituents, including several potentially toxic trace elements, that were higher than irrigation-delivery water alone. Although the load of dissolved constituents was not estimated to have substantially changed, these materials were being accumulated and concentrated in much smaller wetland areas than they had historically. When compared to historical accounts, species and habitat abundance and diversity in wetlands of Lahontan Valley have declined.

Surface and ground water collected on and near Stillwater WMA was toxic to invertebrates and fish larvae (Finger and others, 1993). Toxicity was not attributed to a single element, but appeared to be related to a mixture of dissolved constituents, including arsenic, boron, lithium, molybdenum, and dissolved solids. These findings were generally in agreement with earlier studies (Dwyer and others, 1990; Dwyer and others, 1992; Ingersoll and others, 1992).

Mercury and selenium were being accumulated in plants and plant detritus, and bio-magnified in invertebrates (Hallock and others, 1993b). These elements were transported to wetlands in organisms and particulate materials. Elevated levels of mercury in wetland components were attributed to historical mining practices while agricultural practices were suspected of contributing to elevated levels of selenium. Edible tissues (liver and muscle) of certain waterfowl species contained mercury in excess of the standard for human consumption (Hallock and others, 1993c). Selenium exceeded the standard for human consumption in some waterfowl livers.

Concentrations of boron, mercury, and selenium in avian eggs were generally below levels associated with adverse effects to embryonic development or egg hatchability (Hallock and others, 1993a). However, concentrations of these elements were elevated in juvenile livers, indicating that exposure to these contaminants took place in Lahontan Valley wetlands. In several samples, concentrations exceeded published levels associated with adverse effects to juvenile growth, development, or survival. Low avian production observed during this investigation was attributed to degraded habitat conditions, which contributed to increased predation and decreased food availability. Drought conditions during this investigation may have contributed to degraded habitat conditions.

During the NIWQP investigations, drift, detritus, and algae samples were collected from three lakes in the Indian Lakes area (Rowe and others, 1991; Hallock and Hallock, 1993). Concentrations of mercury in detrital material collected from Likes Lake (97.8 μg/g) and Big Indian Lake (52.6 μg/g) were the highest observed in the Newlands Project area (Rowe and others, 1991). The level in Papoose Lake (25.7 μg/g) was the fifth highest. Additionally, concentrations of aluminum (32,400 to 53,300 μg/g), copper (47.3 to 86.8 μg/g), lead (74.7 to 118 μg/g), and zinc (104 to 115 μg/g) in detrital matter from these lakes were among the highest found in the study area. Concentrations of copper, lead, mercury, and zinc approached or exceeded levels shown to adversely affect benthic organisms in freshwater (Persuad and others, 1993) and coastal marine and estuarine environments (Long and Morgan, 1991). Hoffman (1994) summarizes major findings from NIWQP activities in Lahontan Valley.

In May 1994, the USGS collected a water sample from each of three isolated seepage ponds in the Indian Lakes area (sites P6, P7, and P10, fig. 2) as part of NIWQP activities in west-central Nevada. The results are listed in table 2. USGS analytical results are maintained as paper copies at the District office in Carson City, Nev.

The data indicated elevated concentrations of potentially toxic constituents. However, alkaline water and high concentrations of constituents that are known to interfere with some analytical methods may have compromised the accuracy of some of these analyses. Analytical methods for determination of most cations (major and trace constituents) require that sufficient nitric acid be added to the sample at time of collection to maintain a pH that is less than 2 pH units. USGS field notes indicated that the volume of sample water required the addition of about 10 percent (by volume) concentrated nitric acid. Field notes also indicated that acidification caused the alkaline samples to effervesce, creating the potential for undesirable changes in composition.

SAMPLE COLLECTION, MEASUREMENT, AND ANALYSIS

Sampling Sites

Sampling sites for this field-screening study were selected to determine concentrations of constituents in water, bottom sediment, and selected biota in the Indian Lakes area. Study-team members visited 22 seepage ponds in May 8 and 12, 1995, to assess gross habitat conditions (occurrence of submergent and emergent vegetation and of aquatic invertebrates) and to make field measurements of physical characteristics (temperature, specific conductance, and pH). On the basis of this visit, eight ponds were selected for collection of samples of water and bottom sediment. Water samples also were collected from Likes Lake (a flow-through lake), D-Line Canal, and two of the five wells constructed for this study. Field measurements made at the time of sample collection included pH, specific conductance, water temperature, dissolved oxygen, and alkalinity. Biological samples were collected from nine seepage ponds. Sampling sites and types of analyses made are listed in table 3 and locations are shown in figure 2.

Sampling Methods

Water samples were collected in May-June 1995 by the USGS at 12 sites (table 3) for determination of major constituents and selected trace elements as listed in table 4. In addition, three sites (C1, W2, and P3; fig. 2) were sampled for determination of stable-isotope ratios (oxygen-18 relative to oxygen-16 and deuterium relative to hydrogen-1). Water samples from shallow ponds were grab-sampled using a clean polyethylene sample bottle pre-rinsed with native water. The water sample from Likes Lake (site L1) was composited from four samples collected to integrate the vertical water column. A DH81 standard (plastic) hand-held, depth-integrating sampler was used to sample D-Line Canal (site C1), following the equal-width-increment method described by Edwards and Glysson (1988, p. 61-65). Ground-water samples were collected from wells using a portable pump. A volume of well water equivalent to at least three times the volume

Table 2. Water hardness and concentrations of dissolved chemical constituents in water samples collected from selected seepage ponds, Indian Lakes area, Churchill County, Nevada, May 10, 1994

[Abbreviations and symbols: mg/L, milligrams per liter; °C, degrees Celsius; μg/L, micrograms per liter; <, less than; --, not determined]

Site No. (fig. 2)	Hardness (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Solids, dissolved, residue at 180°C (mg/L)	Nitrogen, nitrite plus nitrate, dissolved (mg/L)	Nitrogen, nitrite, dissolved (mg/L)	Nitrogen, ammonia, dissolved (mg/L)
P6	170	24	27	630	36	712	490	250	1.4	1,890	<0.05	<0.01	0.03
P7	11	1.8	1.5	34,000	260	52,100	22,000	4,600	320	100,100	<.05	.02	.06
P10	8	1.2	1.3	37,000	380	55,000	40,000	10,000	100	129,000	<.05	.02	.29

Site No. (fig. 2)	Phosphorus, ortho, dissolved (mg/L)	Arsenic, dissolved (μg/L)	Boron, dissolved (μg/L)	Cadmium, dissolved (μg/L)	Chromium, dissolved (μg/L)	Copper, dissolved (μg/L)	Lead, dissolved (μg/L)	Mercury, dissolved (μg/L)	Molybdenum, dissolved (μg/L)	Selenium, dissolved (μg/L)	Vanadium, dissolved (μg/L)	Zinc, dissolved (μg/L)
P6	<0.01	65	3,800	<1	1.2	<4	<1	<0.1	13	<1	10	30
P7	[1]50	38,000	320,000	<4	20	30	35	<.1	7,000	<25	890	<25
P10	[1]110	41,000	810,000	<10	12	7	25	<.1	12,000	<25	840	--

[1]Arsenic as arsenate (AsO_4^{-3}) will produce a similar color response as phosphate and may cause a positive interference with analysis.

Table 3. Sampling sites selected for collection of water, bottom sediment, and biota in Indian Lakes area, Churchill County, Nevada, 1995

[**Type of data and samples collected**: W, water; S, bottom sediment; B, biological tissue; F, field measurement of water temperature, specific conductance, and pH; WE, elevation of water surface. Symbol: --, no site identification or site not selected]

Site No. (fig. 2)	Site location	U.S. Geological Survey site identification [1]	Type of data and samples collected	Rationale for site selection [2]
		Irrigation canal		
C1	D-Line Canal at Indian Lakes Road	10312258	W, WE	Reference site
		Flow-through lake		
L1	Likes Lake	393530118400701	W	Reference site
		Seepage ponds		
P1	Township N20 Range E29 Section 26	393348118420801	F,W,S,B,WE	2nd quartile
P2	Township N20 Range E29 Section 25	393357118410501	F,W,S,WE	4th quartile
P3	Township N20 Range E29 Section 25	393358118402401	F,W,S,WE	Maximum
P4	Township N20 Range E29 Section 26	393357118420101	F,W,S,B,WE	3rd quartile
P5	Township N20 Range E29 Section 26	--	F,B	--
P6	Township N20 Range E29 Section 26	393358118414301	F,W,S,B,WE	1st quartile
P7	Township N20 Range E29 Section 26	393403118412401	F,W,S,B,WE	Median
P8	Township N20 Range E29 Section 26	--	F,B	--
P9	Township N20 Range E29 Section 26	--	F	--
P10	Township N20 Range E29 Section 26	--	F,B	--
P11	Township N20 Range E29 Section 24	393502118401201	F,W,S,B,WE	2nd quartile
P12	Township N20 Range E30 Section 19	--	F	--
P13	Township N20 Range E30 Section 19	--	F	--
P14	Township N20 Range E30 Section 19	--	F	--
P15	Township N20 Range E30 Section 19	393508118400401	F,W,S,B,WE	4th quartile
P16	Township N20 Range E30 Section 19	--	F	--
P17	Township N20 Range E30 Section 19	--	F	--
P18	Township N20 Range E30 Section 16	--	F	--
P19	Township N20 Range E29 Section 19	--	F	--
P20	Township N20 Range E29 Section 13	--	F	--
P21	Township N20 Range E29 Section 13	--	F	--
P22	Township N20 Range E29 Section 26	--	F	--
		Wells		
W1	Township N20 Range E29 Section 26	--	WE	--
W2	Township N20 Range E29 Section 26	393352118415101	W,WE	Near C1 recharge source
W3	Township N20 Range E29 Section 24	--	WE	--
W4	Township N20 Range E29 Section 25	393400118402301	W,WE	Near P3 discharge area
W5	Township N20 Range E29 Section 25	--	WE	--

[1] Sampling sites are assigned unique identification number on basis of geographic location. Eight-digit numbers are station numbers that follow "downstream order system": First two digits, or part number, refer to drainage basin. Following six digits are downstream-order number, which are assigned according to geographic location of site in drainage basin; larger number stations are downstream from smaller number stations. Sites not assigned unique identification number were not sampled for laboratory analyses.

The 15-digit numbers are based on grid system of latitude and longitude. First six digits denotes degrees, minutes, and seconds of latitude; next seven digits denote degrees, minutes, and seconds of longitude; last two digits (assigned sequentially) identify sites within 1-second grid. For example, site 393530118400701 is at 39°35'30" latitude and 118°40'07" longitude and is first site recorded in that 1-second grid.

[2] Two reference sites were selected for sampling; seepage ponds were ranked according to specific conductance measured during an April 1995 survey; two wells were selected for sampling.

Table 4. Minimum analytical reporting limits [1] for chemical constituents in water, bottom sediment, and biota

[µg/L, microgram per liter; µg/g, microgram per gram; mg/L, milligram per liter; --, analyte not determined in sampled media]

Constituent	Water (µg/L, except as indicated)	Bottom sediment (µg/g, dry weight, except as indicated)	Tissue (µg/g, dry weight)
Hardness	1 mg/L	--	--
Calcium	0.02 mg/L	[2]0.05	--
Magnesium	.01 mg/L	[2].005	10
Sodium	.20 mg/L	[2].005	--
Potassium	.10 mg/L	[2].05	--
Sulfur	--	[2].05	--
Sulfate	.10 mg/L	--	--
Chloride	.10 mg/L	--	--
Fluoride	.10 mg/L	--	--
Silica	.01 mg/L	--	--
Solids, dissolved, residue at 180°C	1 mg/L	--	--
Aluminum	1	[2].05	5
Antimony	1	.1	--
Arsenic	1	.1	.5
Barium	1	1.0	.5
Beryllium	1	1.0	.1
Bismuth	--	10	--
Boron	10	--	1.5
Cadmium	1	.1	.1
Cerium	--	4.0	--
Chromium	1	1.0	.5
Cobalt	1	1.0	--
Copper	1	1.0	.5
Europium	--	2.0	--
Gallium	--	4.0	--
Gold	--	8.0	--
Holmium	--	4.0	--
Iron	3	[2].05	10
Lanthanum	--	2.0	--
Lead	1	4.0	.5
Lithium	--	2.0	--
Manganese	1	4.0	4
Mercury	--	.02	.1
Molybdenum	1	2.0	.5
Neodymium	--	4.0	--
Nickel	1	2.0	.5
Niobium	--	4.0	--
Scandium	--	2.0	--
Selenium	1	.1	.5
Silver	1	.1	--
Strontium	--	2.0	1
Tantalum	--	40.0	--
Thorium	--	4.0	--
Tin	--	10.0	--
Titanium	--	[2].005	--
Uranium	1	.05	--
Vanadium	--	2.0	.5
Ytterbium	--	1.0	--
Yttrium	--	2.0	--
Zinc	1	4.0	20

[1] Listed analytical reporting limits are minimum concentration of substance that can be identified, measured, or reported with laboratory-determined level of confidence that analyte concentration is greater than zero. Analyses subject to interference from other substances or properties of sample will have higher analytical report limit.

[2] Analytical reporting limit expressed as percent.

calculated for water in the well bore was removed and frequent measurements of water temperature, pH, and specific conductance were made during well evacuation. Stable field measurements were assumed to indicate that water was being withdrawn directly from the aquifer, at which time, samples for laboratory analyses were collected. All water samples were collected and processed following procedures described by Ward and Harr (1990) and by Hardy and others (1989).

Field analyses of water temperature, specific conductance, pH, and alkalinity were made just prior to sample collection at all sites. Dissolved oxygen also was determined at all sites except P2 and W4. Procedures used for field analyses are described by Shelton (1994, p. 27-37). Quality assurance of field measurements and equipment was determined by calibration of meters with standards and buffers and through annual participation in the USGS National Field Quality Assurance program (Janzer, 1985).

High concentrations of dissolved solids interfere with chemical analyses of several metals and trace elements (Faires, 1993). Therefore, dilution of water samples in the field was required. Unfortunately, such dilutions compromised analytical reporting limits, which ranged from 1 to 12,000 µg/L in some instances. As a result, reporting limits exceeded water-quality standards and biological concern or effect concentrations for several constituents. For trace-element analysis by inductively coupled plasma-mass spectrometry, water samples that had specific conductance greater than 6,000 µS/cm were carefully diluted in the field with certified inorganic-free blank water. The high alkalinity of these samples would otherwise have required large volumes of nitric acid to maintain cationic metals in solution; in addition, the laboratory method requires dilution of samples with specific conductance greater than 6,000 µS/cm (Edward J. Zayhowski, U.S. Geological Survey, oral commun., 1995).

Bottom-sediment samples were collected from each of the eight ponds (table 3) within 400-ft^2 areas. At each site, five to seven equally spaced samples were collected from the top 2-4 in. of sediment using a teflon spatula and composited in a glass bowl. The composited sediment sample was thoroughly mixed using a teflon stirrer and then sieved in the field through a 63-µm plastic sieve. Native water from each site was used to facilitate the sieving process. Sieved samples were collected in cleansed plastic jars for trace-element analysis.

In 1994 and 1995, the USFWS collected 37 biological samples from nine seepage ponds for analysis of selected trace elements (tables 2 and 3). In 1994, four aquatic invertebrate and two American avocet (*Recurvirostra americana*) egg samples were collected from three ponds. In 1995, 17 aquatic invertebrate, 3 avocet egg, and 8 adult avocet liver samples were collected from nine ponds. Aquatic vegetation and avocet eggs were collected by hand (gloved). Aquatic invertebrates were collected with a kick net. Adult avocets were collected with a shotgun using steel shot. Aquatic vegetation and invertebrates were immediately placed in 60-mL acid-washed glass containers, stored on ice in the field, and frozen upon return to the laboratory. Eggs were placed in a carton, stored on ice in the field, and opened in the laboratory. Egg contents were placed in 60-mL acid-washed glass containers and then frozen. Embryos were not sufficiently developed to enable detection of developmental abnormalities. Adult avocets were stored on ice in the field and frozen upon return to the laboratory. Whole birds were later thawed to remove livers using acid-rinsed stainless steel instruments. Whole livers were placed in 60-mL acid-washed glass containers and then frozen. Quality-assurance methodologies used in field collections of biological samples are described by Rope and Breckenridge (1993).

Analytical Methods

Water samples were analyzed by the USGS National Water Quality Laboratory in Arvada, Colo., following procedures described by Fishman (1993) and by Faires (1993). Bottom-sediment samples were analyzed by the USGS Environmental Geochemistry Laboratory in Lakewood, Colo., following procedures described by Arbogast (1990). Stable-isotope analyses (oxygen-18 relative to oxygen-16 and deuterium relative to protium) were made by the USGS isotope fractionation project in Reston, Va. Quality-control procedures of the USGS National Water Quality Laboratory are described by Friedman and Erdmann (1982) and Jones (1987).

Biological samples were shipped frozen to the Research Triangle Institute, Research Triangle Park, N.C., for trace-element analysis. Tissue samples were prehomogenized using a food processor. A portion of the tissue sample was freeze dried for determination of moisture content. Arsenic and selenium concentrations were determined using graphite-furnace atomic absorption. Mercury concentrations were determined using cold-vapor atomic absorption. Other trace elements were determined using inductively coupled plasma spectroscopy. Laboratory analytical quality-assurance and quality-control procedures are given by Patuxent Analytical Control Facility (1990).

Avian-Use Surveys

To provide a general indication of bird use, the numbers and species of birds that visited seepage ponds were determined by observation of individual ponds between May 8 and July 21, 1995. Avian nesting season in this area generally is in May and June, with most juveniles fledging by late summer. Counts were made from fixed observation points for 15 to 30 minutes during each observation session. At least two of the counts at each of 10 ponds were within 2 hours of sunrise or sunset. The total number of individuals of each species noted during each observation period was recorded.

DISCUSSION OF RESULTS

Contaminant Criteria

Implications to fish and wildlife were assessed by comparison to State and Federal water-quality standards or criteria and to published reports of fish and wildlife concern and effect levels. Developed lakes in the Indian Lakes area are classified as class-C water (Nevada Administrative Code 445A.126). Beneficial uses of class-C water include municipal or domestic supply following treatment, irrigation, watering of livestock, aquatic life, propagation of wildlife, recreation involving contact and non-contact with water, and industrial uses. No beneficial uses for water in seepage ponds have been designated. Nevada standards or criteria for protection of aquatic life or other beneficial uses for selected trace elements in water are given in table 5. Selected concern and effect concentrations for invertebrates, fish, and wildlife in water, sediment, whole fish, avian diet, avian eggs, and avian livers used to evaluate ecological implications of trace elements associated with Indian Lakes seepage ponds are given in table 6. In table 6, and in the following discussions, concentrations of trace elements in sample matrices other than water are expressed on a dry-weight basis unless otherwise noted. Designation of a concern concentration was assigned to a value so noted in the literature or to a value associated with relatively minor effects (for example, LC_1 or decreased growth rate for a limited time period). Effect concentrations were assigned to values so noted in the literature or to values causing substantial effects (for example, LC_{50}, reduced survival or production, or teratogenesis). No discussion of contaminant concentrations is presented where information was not found for specific elements or matrices.

Physical and Biological Characteristics of Seepage Ponds

A total of 22 ponds near the D-Line Canal and developed lakes in the Indian Lakes area were surveyed (fig. 2). These ponds ranged in size from 0.1 to 16.4 acres (table 7). Numerous other salt-encrusted playas, wet meadows, and seeps less than 0.1 acre in size also were noted in the field surveys. Crystalline deposits were found on soil surfaces and vegetation around the fringes of most of the seepage ponds, seeps, and wet meadows. Crystalline deposits also were observed within the water in several of the more saline ponds. Water and crystalline deposits in several of the more saline ponds were red. This coloring is likely attributable to one or more species of bacteria common in saline lakes (Hammer, 1986). The occurrence and composition of aquatic invertebrates, aquatic vegetation, and emergent vegetation differed among ponds. Aquatic invertebrates and vegetation were absent from 9 of the 22 ponds surveyed. Most of these ponds were shallow and several were desiccated later in the summer. Submergent aquatic vegetation was noted in 5 ponds and emergent vegetation in 11 ponds. Saltgrass was found at varying densities along the fringes of all seepage ponds. Rooted, dead non-riparian vegetation (that is, greasewood, shadscale, and rabbitbrush) was found in several of the ponds, suggesting that water levels had risen in the recent past. Aquatic invertebrates were noted in 13 ponds. Changes in vegetation and invertebrate community composition are discussed in the section “Community Characteristics.”

Table 5. Water-quality standards and criteria applicable to designated waters in Nevada (Nevada Environmental Commission, 1991; Nevada Administrative Code (NAC) 445A.119 and 445A.144)

Constituent	Municipal or domestic supply	Aquatic life	Irrigation	Watering of livestock	Propagation of wildlife
pH	5.0-9.0	6.5-9.0	4.5-9.0	6.5-9.0	7.0-9.2
Dissolved solids (mg/L)	1,000	--	--	3,000	--
Chloride (mg/L)	400	--	--	1,500	1,500
Arsenic (μg/L)	50	[1,2] 180	100	200	--
Barium (μg/L)	2,000	--	--	--	--
Beryllium (μg/L)	0	--	100	--	--
Boron (μg/L)	--	--	750	5,000	--
Cadmium (μg/L)	5	(2,3)	10	50	--
Chromium (μg/L)	100	[2,3,4] 10	100	1,000	--
Copper (μg/L)	--	(2,3)	200	500	--
Fluoride (μg/L)	--	--	1,000	2,000	--
Iron (μg/L)	--	1,000	5,000	--	--
Lead (μg/L)	50	(2,3)	5,000	100	--
Manganese (μg/L)	--	--	200	--	--
Mercury (μg/L)	2	[5] 0.012	--	10	--
Molybdenum (μg/L)	--	19	--	--	--
Nickel (μg/L)	13.4	(2,3)	200	--	--
Selenium (μg/L)	50	[5] 5	20	50	--
Uranium (μg/L)	[6] 20	--	--	--	--
Zinc (μg/L)	--	(2,3)	2,000	25,000	--

[1] Arsenic criteria for aquatic life are specific for As^{+3}. The 96-hour average aquatic life criterion is given.
[2] Criterion applies to dissolved fraction only.
[3] Criteria for aquatic life are based on water hardness, which is expressed in milligrams per liter as $CaCO_3$. Formulas for 96-hour average criteria for specific elements are as follows:

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

[4] The 96-hour average aquatic-life criterion for chromium (VI) is given.
[5] The 96-hour average aquatic-life criterion is given.
[6] Proposed maximum contaminant level in drinking water (U.S. Environmental Protection Agency, 1991b).

Chemical Characteristics of Water, Sediment, and Biota

Water Quality

Twelve water samples were collected in May-June 1995 for laboratory analyses. Samples of all pond water analyzed contained concentrations of one or more constituents in excess of Nevada standards and criteria or existing or proposed Federal water-quality criteria. Constituents in exceedance included pH, dissolved solids, chloride, aluminum, arsenic, boron, fluoride, manganese, molybdenum, and uranium. Dissolved solids, arsenic, boron, fluoride, molybdenum, and uranium exceeded standards or proposed criteria by two or more orders of magnitude in some ponds.

Field measurements of physical characteristics and chemical constituents are listed in table 8. Water hardness and concentrations of dissolved major chemical constituents are listed in table 9 and concentrations of dissolved trace elements are listed in table 10.

Dissolved Solids

Field-measured specific conductance (an indirect measure of dissolved solids) in 22 isolated ponds at Indian Lakes ranged from 2,880 to 163,000 μS/cm in May 1995 (table 7). Fifteen of these measurements exceeded 20,000 μS/cm, an effect level determined for mallard ducklings (fig. 5; Mitcham and Wobeser, 1988). Dissolved solids, determined in water samples from eight seepage ponds, ranged from 1,510 to

Table 6. Selected effect and concern concentrations for trace elements. Concentrations other than for water are in dry weight unless otherwise noted

Constituent	Category	Water (micrograms per liter)	Concentration (micrograms per gram)				
			Sediment	Whole fish	Avian diet	Avian egg	Avian liver
Aluminum	Concern	[1] 87	--	--	--	--	--
	Effect	[2] 100	--	--	[3] 5,000	--	--
Arsenic	Concern	--	[4] 33	[5] 0.22	--	--	--
	Effect	[6] 40	[4] 85	[7] 2.1	[8] 30	--	[9] 4.5
Boron	Concern	[10] 200	--	--	[11] 30	[11] 13	[11] 17
	Effect	[12] 52,200	--	--	[11] 1,000	[11] 49	[11] 51
Cadmium	Concern	--	[4] 5	[5] 0.05	--	--	[13] 40
	Effect	[14] 1.0	[4] 9	--	[15] 200	--	--
Chromium	Concern	[16] 21.5	[4] 80	[17] 4.0	[18] 10	--	[15] 4.0
	Effect	[16] 190	[4] 145	[18] 50	[18] 50	--	--
Copper	Concern	[16] 3.4	[4] 70	[5] 0.9	--	--	--
	Effect	[16] 110	[4] 390	--	--	--	--
Iron	Concern	--	[19] 21,200	--	--	--	--
Lead	Concern	[20] 1.0	[4] 35	[5] 0.22	[21] 25	--	[22] 2
	Effect	[23] 3.5	[4] 110	--	[24] 125	--	[22] 8
Manganese	Concern	[16] 388	[19] 460	--	--	--	--
Mercury	Concern	--	[4] 0.15	[5] 0.17	--	--	--
	Effect	[25] 0.1	[4] 1.3	[26] 0.62	[27] 0.5	[27] 0.83	[27] 1.3
Molybdenum	Concern	[16] 28	--	--	[28] 200	--	--
	Effect	[16] 790	--	--	[28] 500	[29] 16	--
Nickel	Concern	--	[4] 30	--	--	--	--
	Effect	--	[4] 50	--	--	--	--
Selenium	Concern	[30] 1.5	[31] 1	[32] 4	[33] 3	[34] 4	[35] 10
	Effect	[30] 3.0	[31] 4	[32] 10	[33] 5	[34] 10	[35] 30
Vanadium	Concern	[16] 9.0	--	--	[36] 100	--	[36] 657
	Effect	[16] 170	--	--	--	--	--
Zinc	Concern	--	[4] 120	[6] 34.2	[37] 178	--	--
	Effect	[38] 32	[4] 270	--	[39] 3,000	--	[39] 401

[1] U.S. Environmental Protection Agency (1988); recommendation that aluminum in water should not exceed this level more than once every 3 years.

[2] Hall and others (1988); toxic to centrarchids at pH between 6.9 and 7.3.

[3] Sparling (1990); growth and survival of mallard (*Anas platyrhynchos*) and black ducks (*Anas rubripes*) were reduced at normal dietary concentrations of calcium and phosphorus.

[4] Long and Morgan (1991); concern concentration represents an Effect Range-Low (lower 10th percentile) and effect concentration represents an Effect Range-Median (median) of sediment-based bioassays.

[5] Schmitt and Brumbaugh (1990); 85th percentile of whole fish (wet weight) in the National Contaminant Monitoring Program.

[6] U.S. Environmental Protection Agency (1985a); mortality and malformation of fish and amphibian embryos and larvae. Wet weight basis.

[7] Gilderhus (1966); decreased growth and survival of juvenile bluegill (*Lepomis macrochirus*). Wet weight basis.

[8] Camardese and others (1990); growth, development, and physiology of mallard ducklings affected.

[9] Stanley and others (1994); reduced growth of mallard ducklings.

[10] Birge and Black (1977); LC_1 of embryo-larval toxicity tests to goldfish (*Carassius auratus*).

[11] Smith and Anders (1989); reduced weight gain of mallard ducklings through 21 days at 30 µg/g in diet; reduced body weight of hatchlings at 300 µg/g in diet (13 µg/g in eggs and 17 µg/g in juvenile liver); reduced hatching success, hatch weight, duckling survival, and duckling weight gain at 1,000 µg/g in diet (49 µg/g in egg and 51 µg/g in juvenile liver).

[12] Gersich (1984) 21-day LC_{50} for *Daphnia magna*.

[13] Furness (1996); threshold tissue concentration above which avian toxicity might be expected.

[14] Hughes (1973); LC_{50} for striped bass (*Morone saxatilis*).

[15] Cain and others (1983); mild to severe kidney lesions to mallard duckling. White and Finley (1978); slight to severe kidney lesions in adult mallards at a dietary concentration of 200 μg/g and slight to moderate gonad alteration at a dietary exposure of 20 μg/g.

[16] Birge and others (1979a) 28-day LC_1 (concern concentration) and LC_{50} (effect concentration) for embryo-larval toxicity tests to rainbow trout (*Salmo gairdneri*).

[17] Eisler (1986); a concentration of 4 μg/g suggests chromium contamination.

[18] S.D. Haseltine (U.S. Fish and Wildlife Service, written commun., 1985); survival of ducklings suppressed.

[19] Persaud and others (1993); lower effect level guideline (lower 5th percentile of sediment-based bioassays causing effect).

[20] U.S. Environmental Protection Agency (1985b); reproduction of Daphnia magna impaired 10 percent.

[21] Finley and others (1976); biochemical effects observed.

[22] Eisler (1988); concentration in avian liver exceeding 2 μg/g was elevated with 8 μg/g associated with lead poisoning.

[23] Wong and others (1981); LC_{50} for rainbow trout.

[24] Hoffman and others (1985a); reduced growth and abnormal development of American kestrels (*Falco sparverius*).

[25] Birge and others (1979b); rainbow trout LC_{50} in 28-day flow-through bioassay.

[26] Snarski and Olson (1982); reduced reproduction of fathead minnows (*Pimephales promelas*). Kania and O'Hara (1974); mean whole-body concentration as low as 0.7 μg/g wet weight was associated with diminished predator-avoidance behavior in mosquitofish (*Gambusia affinis*).

[27] Heinz (1979); diet (7 percent moisture) and liver tissue concentrations associated with reduced reproduction and duckling behavioral effects. Egg concentrations associated with reduced juvenile survival. Hen mallards, across generations had a mean of 1.3 μg/g (wet weight) in liver, whereas males had a mean of 4.4 μg/g. Nicholson and Osborn (1984); nephrotoxic lesions in European starlings (*Sturnus vulgaris*) fed a diet containing 1.1 μg/g mercury; liver contained 6.55 μg/g (dry weight).

[28] Eisler (1989); concern concentration included reduced growth; effect level included reproductive impairment.

[29] Friberg and others (1975); concentration was embryotoxic.

[30] Skorupa and others (1996); validated lowest observable effect in water for fish and wildlife by bioaccumulation was 1.5 to 3.0 μg/L. Lemly (1996); 2.0 μg/L on a total recoverable basis in 0.45-μm filtered samples, hazardous to health and long-term survival of fish and wildlife populations.

[31] Skorupa and others (1996); 1 μg/g in sediment was minimum concentration associated with effects on avian reproduction, whereas 3 μg/g in sediment was minimum concentration associated with effects on fish; EC_{100} of >4.0 μg/g in sediment for fish and birds in freshwater systems. See also Lemly and Smith (1987).

[32] Skorupa and others (1996); estimated true threshold for reproductive impairment of sensitive species. See also Lillebo and others (1988) and Lemly (1996).

[33] Lemly and Smith (1987) and Lemly (1996) identify a concern level for avian diet of 3 μg/g. Skorupa and Ohlendorf (1991) and Skorupa and others (1996) identified a critical dietary threshold of 5.0 μg/g.

[34] Skorupa and others (1996); susceptibility of captive mallard hatchlings to duck hepatitis virus was increased at 4 μg/g, whereas the lowest observed adverse effect level for mallards was 10 μg/g. Skorupa and Ohlendorf (1991) identify a critical embryotoxic and teratogenic threshold between 13 and 24 μg/g in avian eggs.

[35] Skorupa and others (1996); hepatic concentrations less than 10 μg/g indicative of safe selenium exposure; high risk of adverse biological effect at 30 μg/g in avian liver. Heinz (1996); reproductive impairment is possible when liver of egg laying females contain >3 μg/g (wet weight, or about 12 μg/g dry weight); important sublethal effects may occur when liver of young or adults contains greater than 10 μg/g (wet weight, or about 40 μg/g dry weight).

[36] White and Dieter (1978); altered lipid metabolism to adult mallards.

[37] Stahl and others (1989); immunosuppression in domestic chickens.

[38] U.S. Environmental Protection Agency (1987b), LC_{50} to aquatic invertebrates.

[39] Gasaway and Buss (1972); reduced mallard survival.

390,000 mg/L (fig. 6). Dissolved solids in all but one of these ponds exceeded the 3,000-mg/L Nevada water-quality criteria for the watering of livestock. Sodium was the dominant cation and, in general, sulfate was the dominant anion, although chloride, carbonate, and bicarbonate were codominant in some ponds (table 9). Like dissolved solids, chloride concentrations exceeded Nevada criteria for livestock watering and wildlife propagation in all but one of the ponds sampled.

pH

The pH of seepage-pond water ranged from 8.6 to 10.3 (table 7), with 13 of 22 ponds exceeding Nevada water-quality standards for municipal or domestic supply, or criteria for aquatic life, irrigation, watering of livestock, or propagation of wildlife (table 5). The pH of water sampled from D-Line Canal (site C1) was 8.0 and from Likes Lake (site L1) was 9.0. The pH of ground-water samples was 7.6 and 8.2 for sites W2 and W4, respectively. The characteristically alkaline pH of

Table 7. Field water-quality measurements and habitat characteristics of seepage ponds in Indian Lakes area, Stillwater Wildlife Management Area, Churchill County, Nevada, 1995

[Abbreviation: µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Site No. (fig. 2)	Size (acres)	Date	Specific conductance (µS/cm)	pH (standard units)	Vegetation		Aquatic invertebrates	
					Submergent	Emergent	Insect	Crustacea
P1	4.9	5/08/95	34,000	9.4	common	abundant	rare	abundant
P2	6.7	5/08/95	82,000	9.7	none	rare	rare	abundant
P3	10.8	5/08/95	163,000	9.0	none	none	none	none
P4	1.2	5/08/95	54,400	9.7	none	rare	rare	abundant
P5	1.0	5/08/95	16,800	9.2	abundant	abundant	abundant	rare
P6	0.8	5/08/95	2,880	8.9	abundant	abundant	abundant	rare
P7	2.8	5/08/95	41,300	10.3	none	rare	rare	abundant
P8	0.2	5/08/95	5,900	8.9	common	common	abundant	rare
P9	0.1	5/08/95	13,600	10.1	none	none	abundant	rare
P10	6.8	5/08/95	54,700	10.0	none	common	rare	abundant
P11	4.6	5/08/95	19,300	9.1	abundant	common	abundant	rare
P12	2.9	5/08/95	70,000	8.9	none	none	none	none
P13	0.2	5/08/95	32,000	9.2	none	none	none	none
P14	0.2	5/08/95	38,000	9.0	none	none	rare	abundant
P15	2.1	5/08/95	70,100	8.7	none	common	rare	abundant
P16	1.1	5/08/95	55,400	9.2	none	rare	rare	abundant
P17	3.0	5/08/95	54,000	8.9	none	none	none	none
P18	16.4	5/08/95	90,000	8.6	none	none	none	none
P19	5.4	5/12/95	11,600	9.1	none	none	none	none
P20	0.9	5/12/95	66,000	9.3	none	none	none	none
P21	3.3	5/12/95	7,250	8.8	none	none	none	none
P22	2.6	5/12/95	80,000	9.1	none	none	none	none

these samples is consistent with conditions common in lakes and wetlands in terminal areas of the Carson River Basin (Hoffman and others, 1990a) and in nearby river basins (Seiler and others, 1993; Thodal and Tuttle, 1996).

Trace Elements in Water, Sediment, and Biota

Concentrations of aluminum, arsenic, boron, molybdenum, and uranium in water from one or more of the seepage ponds (table 10) exceeded Nevada water-quality standards, criteria, or aquatic life-effect levels (tables 4 and 5). Concentrations of fluoride (table 9) also exceeded criteria for irrigation and watering of livestock (tables 4 and 5). However, the broad range of analytical reporting limits due to the necessary dilution of elevated dissolved solids in water samples for chemical analysis negated comprehensive evaluation of potential exceedances or effects of many trace elements in water. Reporting limits for some elements (beryllium, cadmium, chromium, copper, iron, lead, manganese, nickel, selenium, silver, and zinc) were higher than potentially toxic concentrations in some water samples. Nonetheless, fish or invertebrate species for which toxicity data were available were considered unlikely to be found in seepage pond water. Concentrations of these elements in biological samples were below levels of concern. Arsenic, iron, manganese, and mercury in bottom sediment (table 11) exceeded concentrations associated with toxicity to benthic organisms (table 6). Like water, benthic organisms that are susceptible to these trace elements are not likely to be found in seepage ponds. Arsenic, boron, mercury, and selenium in biological samples (table 12) exceeded concentrations associated with biological effects (table 6). Other trace elements in biological samples were below levels of concern. The occurrence of trace elements of concern is discussed in more detail in the following paragraphs.

Table 8. Field measurements of physical properties and chemical constituents for water samples from Indian Lakes area, Churchill County, Nevada, 1995

[Abbreviations: °C, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; --, no data available]

Site No. (fig. 2)	Date	Discharge, instantaneous (ft^3/s)	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percent saturation)
C1	6/30/95	5.8	220	8.0	19.0	9.8	121
L1	6/28/95	--	305	9.0	24.5	6.2	87
P1	6/28/95	--	59,800	9.4	30.0	7.4	142
P2	6/01/95	--	111,000	9.5	30.5	--	--
P3	6/01/95	--	173,000	8.4	27.5	0.4	14
P4	6/29/95	--	56,500	9.6	25.0	7.5	129
P6	5/31/95	--	2,850	8.5	22.5	9.2	124
P7	6/29/95	--	58,000	9.7	30.5	4.7	90
P11	6/02/95	--	19,600	8.9	21.0	4.8	67
P15	6/02/95	--	94,600	8.2	21.5	1.1	22
W2	6/30/95	--	751	7.6	16.0	5.8	68
W4	6/29/95	--	49,200	8.2	16.5	--	--

Aluminum

Aluminum detected in filtered water from Indian Lakes seepage ponds ranged from 30 to 290 µg/L (table 10). Nevada does not have water-quality criteria for aluminum, but the U.S. Environmental Protection Agency recommends that aluminum concentrations in water should not exceed 87 µg/L more than once every 3 years when the pH is between 6.5 and 9.0 (U.S. Environmental Protection Agency, 1988). Toxicity of aluminum differs considerably with chemical species and complexation. Speciation is affected by several environmental constituents, particularly pH. In general, aluminum becomes less toxic with increasing pH (Hall and others, 1988; Woodward and others, 1991; DeLonay and others, 1993; Farag and others, 1993). Under near-neutral to somewhat alkaline conditions (pH 6.0 to 8.0), aluminum has a low solubility and is virtually inactive biologically (Sparling and Lowe, 1996). Aluminum solubility increases in more alkaline solutions (pH greater than 8.0), but the biological implications are poorly understood.

Aluminum concentrations in aquatic invertebrates and vegetation were below the avian dietary effect level.

Arsenic

Arsenic appears to have micronutrient value to some organisms, but it can be toxic to plants and animals above threshold concentrations (Eisler, 1994). Toxicity and bioavailability of arsenic differ with chemical species (U.S. Environmental Protection Agency, 1985a). In general, inorganic arsenicals are more toxic than organic forms, and trivalent forms of arsenic are more toxic than pentavalent forms. Arsenic may accumulate in lower organisms, but does not concentrate in food chains. Concentrations in samples collected in this investigation indicate that arsenic is not accumulating in bird eggs and livers (fig. 7).

Arsenic concentrations in water samples from Indian Lakes seepage ponds were as high as 41,000 µg/L in 1994 (table 2); however, sample volume was increased by about 10 percent to acidify the samples as required before analysis. In 1995, the maximum observed arsenic concentration was 32,000 µg/L (table 10). Arsenic in seven of the eight seepage ponds from which water samples were collected exceeded Nevada standards for municipal or domestic supply (50 µg/L), irrigation (100 µg/L), and watering of livestock (200 µg/L, fig. 7). The Nevada criterion for the protection of aquatic life is based on trivalent arsenic (As^{+3}) with a chronic (96-hour) aquatic life criterion of

Table 9. Water hardness and concentrations of major dissolved chemical constituents in water samples from Indian Lakes area, Churchill County, Nevada, 1995

[Abbreviations and symbols: mg/L, milligrams per liter; °C, degrees Celsius; <, less than; --, not determined]

Site No. (fig. 2)	Date	Hardness (mg/L as CaCO3)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity (mg/L as $CaCO_3$)	Bicarbonate (mg/L as HCO_3)	Carbonate (mg/L as CO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, dissolved, residue at 180°C (mg/L)
C1	6/30/95	73	21	4.9	17	2.9	74	90	<1	25	8.6	<0.1	18	154
L1	6/28/95	83	21	7.3	32	4.5	84	73	14	44	15	.3	5.6	197
P1	6/28/95	380	12	85	24,000	310	10,600	5,030	3,900	29,000	7,500	9.8	[1]<0.5	69,200
P2	6/01/95	--	[1]<170	[1]<80	100,000	780	3,800	1,000	1,800	13,000	9,300	73	[1]<1.0	229,000
P3	6/01/95	--	[1]<250	250	150,000	2,600	6,000	4,930	1,180	64,000	62,000	.4	3.8	390,000
P4	6/29/95	140	18	23	23,000	540	25,500	9,000	10,900	15,000	6,100	64	[1]<1.0	63,200
P6	5/31/95	220	49	24	400	20	442	500	19	380	180	.9	12	1,510
P7	6/29/95	--	[1]<10	[1]<5	26,000	250	34,900	11,900	15,100	18,000	2,800	240	22	70,900
P11	6/02/95	85	7.5	16	580	190	720	586	144	7,700	2,000	1.1	<.1	16,300
P15	6/02/95	4,700	580	780	35,000	650	800	980	<1	58,000	19,000	1.1	1.1	120,000
W2	6/30/95	85	23	6.8	140	3.4	218	266	<1	100	44	.4	32	505
W4	6/29/95	650	46	130	16,000	220	2,200	2,700	<1	25,000	6,000	1.6	3.1	48,400

[1] Analytical reporting limit affected by sample dilution necessary to avoid interference from excessive dissolved solids.

Table 10. Concentrations of dissolved trace elements in water samples from Indian Lakes area, Churchill County, Nevada, 1995

[Abbreviation and symbol: µg/L, micrograms per liter; <, less than]

Site No. (fig. 2)	Date	Aluminum, dissolved (µg/L as Al)	Antimony, dissolved (µg/L as Sb)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Beryllium dissolved (µg/L as Be)	Boron, dissolved (µg/L as B)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Cobalt, dissolved, (µg/L as Co)	Copper, dissolved (µg/L as Cu)
C1	6/30/95	130	<1	10	31	<1	140	<1	<1	<1	2
L1	6/28/95	90	<1	18	33	<1	260	<1	<1	<1	3
P1	6/28/95	[1]<250	[1]<250	4,300	[1]<250	[1]<250	73,000	[1]<250	[1]<250	[1]<250	[1]<250
P2	6/01/95	[1]<4,000	[1]<4,000	32,000	[1]<4,000	[1]<4,000	470,000	[1]<4,000	[1]<4,000	[1]<4,000	[1]<4,000
P3	6/01/95	[1]<12,000	[1]<12,000	1,800	[1]<12,000	[1]<12,000	1,300,000	[1]<12,000	[1]<12,000	[1]<12,000	[1]<12,000
P4	6/29/95	290	[1]<2,500	22,000	[1]<2,500	[1]<2,500	190,000	[1]<2,500	[1]<2,500	[1]<2,500	[1]<2,500
P6	5/31/95	30	<1	44	78	78	2,400	<1	<1	<1	3
P7	6/29/95	[1]<2,500	[1]<2,500	29,000	[1]<2,500	[1]<2,500	170,000	[1]<2,500	[1]<2,500	[1]<2,500	[1]<2,500
P11	6/02/95	80	[1]<40	400	[1]<40	[1]<40	41,000	[1]<40	[1]<40	[1]<40	[1]<40
P15	6/02/95	[1]<700	[1]<700	320	[1]<700	[1]<700	290,000	[1]<700	[1]<700	[1]<700	[1]<700
W2	6/30/95	8	<1	2	19	<1	730	<1	<1	<1	1
W4	6/29/95	280	[1]<200	2,200	[1]<200	[1]<200	190,000	[1]<200	[1]<200	[1]<200	[1]<200

Site No. (fig. 2)	Date	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Lithium, dissolved (µg/L as Li)	Manganese, dissolved (µg/L as Mn)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Uranium, dissolved (µg/L as U)	Zinc, dissolved (µg/L as Zn)
C1	6/30/95	160	<1	20	13	4	4	<1	<1	2	<1
L1	6/28/95	99	<1	30	14	7	4	<1	<1	4	<1
P1	6/28/95	[1]<1,500	[1]<250	300	[1]<250	990	[1]<250	[1]<250	[1]<250	570	[1]<250
P2	6/01/95	[1]<20,000	[1]<4,000	[1]<800	[1]<4,000	42,000	[1]<4,000	[1]<4,000	[1]<4,000	19,000	[1]<4,000
P3	6/01/95	[1]<36,000	[1]<12,000	3,800	[1]<12,000	[1]<12,000	[1]<12,000	[1]<12,000	[1]<12,000	[1]<12,000	[1]<12,000
P4	6/29/95	[1]<1,500	[1]<2,500	200	[1]<2,500	2,000	[1]<2,500	[1]<2,500	[1]<2,500	1,200	[1]<2,500
P6	5/31/95	160	<1	110	3,000	16	9	<1	<1	4	7
P7	6/29/95	[1]<1,500	[1]<2,500	[1]<1,000	[1]<2,500	4,700	[1]<2,500	[1]<2,500	[1]<2,500	2,000	[1]<2,500
P11	6/02/95	[1]<120	[1]<40	1,100	100	350	[1]<40	[1]<40	[1]<40	97	[1]<40
P15	6/02/95	[1]<2,500	[1]<700	2,800	780	2,600	[1]<700	[1]<700	[1]<700	[1]<700	[1]<700
W2	6/30/95	13	<1	40	<1	17	4	<1	<1	13	<1
W4	6/29/95	[1]<750	[1]<200	500	310	9,500	[1]<200	[1]<200	[1]<200	3,200	[1]<200

[1] Analytical reporting limit affected by sample dilution necessary to avoid interference from excessive dissolved solids.

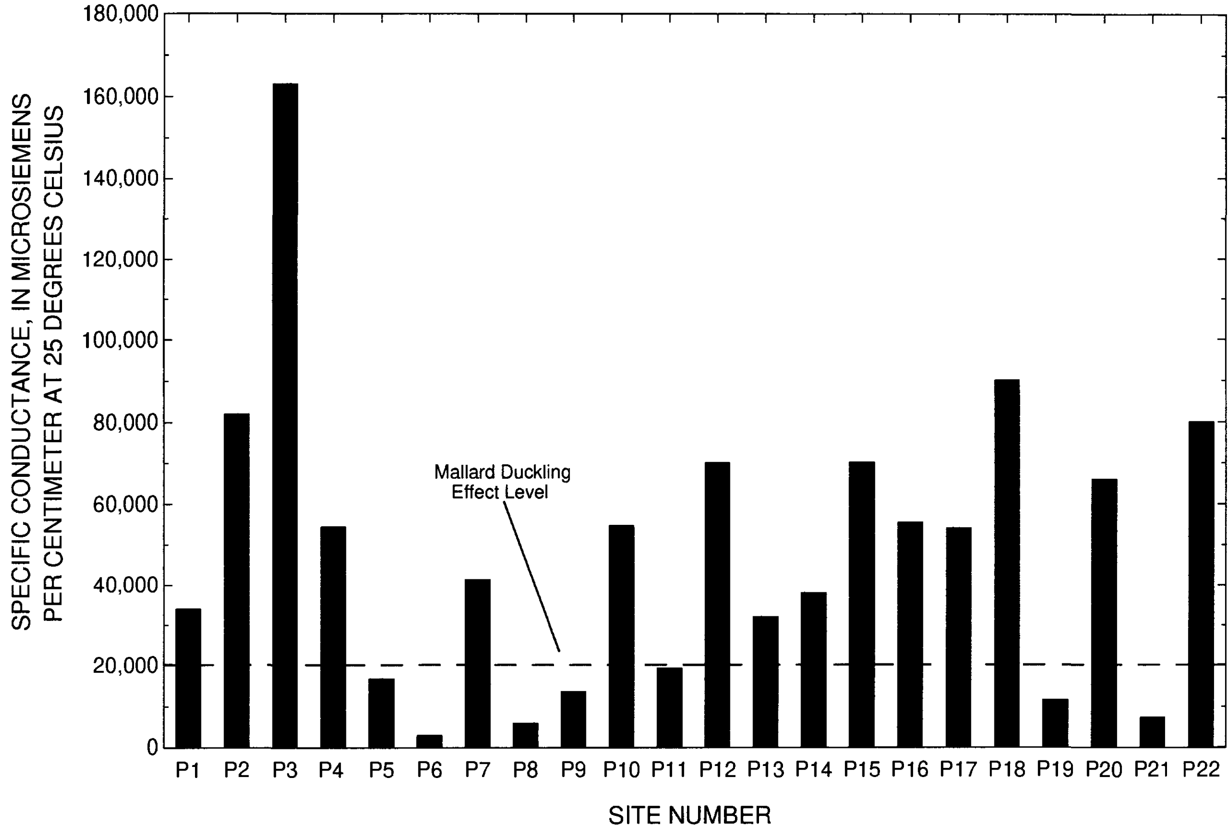


Figure 5. Specific conductance of water collected from seepage ponds in Indian Lakes area, Stillwater Wildlife Management Area, Nevada, May 8 and 12, 1995. Mallard duckling effect level from Mitcham and Wobeser (1988).

180 μg/L. This study determined total arsenic and did not differentiate between arsenic species. Eisler (1994) indicated that inorganic pentavalent arsenic (As^{+5}) was the most common form in water under conditions of high dissolved-oxygen concentration, high pH, high Eh, and reduced organic material. However, Lico (1992, p. 55) found that dissolved arsenic in sediment porewater from the Stillwater NWR wetland existed in a trivalent state because of reducing conditions that prevailed in these sediments.

Inorganic arsenic is acutely toxic to aquatic invertebrates at concentrations as low as 810 μg/L and to juvenile fish at concentrations as low as 490 μg/L (U.S. Environmental Protection Agency, 1985a). Other studies have found lower levels of mortality (LC_1) and malformation of fish and amphibian embryos and larvae at concentrations as low as 40 μg/L (U.S. Environmental Protection Agency, 1985a). In Indian Lakes seepage ponds, arsenic concentrations exceeded levels considered toxic to most aquatic vertebrate and invertebrate species (Eisler, 1994; J.P. Skorupa, U.S. Fish and Wildlife Service, written commun., 1996). However, crustaceans appear to be among the more tolerant aquatic species. Brine shrimp were found in seepage ponds in Indian Lakes with arsenic concentrations as high as 41,000 μg/L. Arsenic concentrations in sediment (table 11) collected from six of eight seepage ponds exceeded concentrations associated with toxicity to benthic freshwater organisms (Persaud and others, 1993) and benthic marine and estuarine organisms (Long and Morgan, 1991).

Dietary arsenic may cause mortality or produce sublethal effects to avian species. Arsenic may be fatal (11-day LC_{50}) to sensitive avian species (brown-headed cowbird, *Molothrus ater*) at dietary levels as low as 100 μg/g (Eisler, 1994). Waterfowl appear to be more tolerant, with mortality (LC_{50}) of mallards (*Anas platyrhynchos*) at dietary arsenic concentrations of 1,000 μg/g after 6 days and 500 μg/g after 32 days (National Academy of Sciences, 1977). Growth, development, and physiology of mallard ducklings may be affected at a dietary concentration of 30 μg/g arsenate

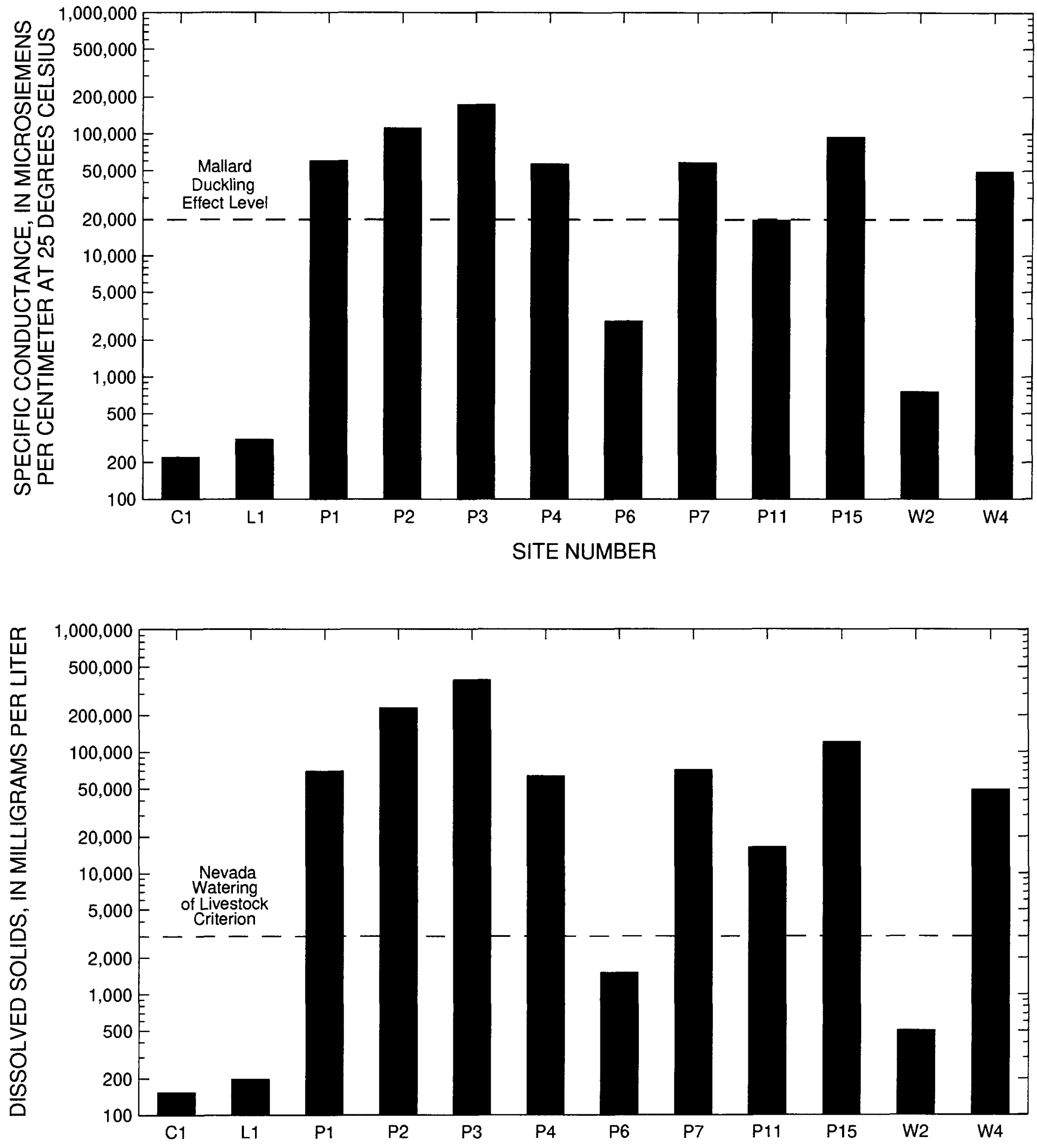


Figure 6. Specific conductance and dissolved solids in water collected from Indian Lakes area, Stillwater Wildlife Management Area, Nevada, May 31-June 30, 1995. Mallard duckling effect level from Mitcham and Wobeser (1988).

(Camardese and others, 1990), but effects are more severe at dietary concentrations between 100 and 400 µg/g (Camardese and others, 1990; Hoffman and others, 1992; Stanley and others, 1994). Camardese and others (1990) also documented biochemical effects in mallard ducklings maintained on diets containing 100 and 300 µg/g arsenic. Avian reproduction was affected at a dietary level of 400 µg/g (Stanley and others, 1994). Arsenic also has been associated with depressed immune-system function. Fairbrother and others (1994) found impaired growth and immune function in avocet chicks hatched from eggs collected

Table 11. Concentrations (dry weight) of trace elements and percent carbon in fine-grained (less than 63 micrometers) fraction of bottom-sediment samples from Indian Lakes area, Churchill County, Nevada, 1995

[Abbreviations and symbols: µm, micrometer; µg/g, microgram per gram; <, less than; >, greater than]

Site No. (fig. 2)	Date	Carbon, inorganic (percent)	Carbon, organic (percent)	Carbon, total (percent)	Aluminum, total (percent)	Antimony, total (µg/g)	Arsenic, total (µg/g)	Barium, total (µg/g)	Beryllium, total (µg/g)	Bismuth, total (µg/g)	Cadmium, total (µg/g)	Cerium, total (µg/g)	Chromium, total (µg/g)	Cobalt, total (µg/g)
P1	5/26/95	1.08	2.81	3.89	5.9	4	47	180	2	<10	0.2	53	28	14
P2	5/26/95	1.27	1.65	2.92	3.6	76	>400	99	1	<10	.3	37	20	9
P3	5/25/95	1.79	.77	2.56	4.5	6	96	190	1	<10	.1	36	19	10
P4	5/26/95	4.40	5.21	9.61	2.5	4	180	350	<1	<10	.2	22	17	6
P6	5/25/95	2.31	10.4	12.7	3.9	6	17	480	1	<10	.2	33	22	8
P7	5/26/95	1.69	3.11	4.80	5.4	9	120	240	1	<10	.3	45	31	14
P11	5/25/95	4.08	3.91	7.99	4.2	4	48	450	1	<10	.1	32	22	7
P15	5/25/95	2.68	2.78	5.46	.44	2	18	57	<1	<10	<.1	<4	3	1

Site No. (fig. 2)	Copper, total (µg/g)	Europium, total (µg/g)	Gallium, total (µg/g)	Gold, total (µg/g)	Holmium, total (µg/g)	Iron, total (µg/g)	Lanthanum, total (µg/g)	Lead, total (µg/g)	Lithium, total (µg/g)	Manganese, total (µg/g)	Mercury, total (µg/g)	Molybdenum, total (µg/g)	Neodymium, total (µg/g)	Nickel, total (µg/g)
P1	28	<2	11	<8	<4	32,000	27	23	100	710	0.06	2	22	19
P2	23	<2	7	<8	<4	23,000	19	12	80	660	.1	430	16	24
P3	17	<2	6	<8	<4	22,000	20	6	50	780	.05	140	14	12
P4	12	<2	5	<8	<4	17,000	13	12	70	1,600	.04	32	4	12
P6	27	<2	7	<8	<4	26,000	17	27	40	2,200	.05	17	11	12
P7	48	<2	13	<8	<4	33,000	26	17	100	920	.19	11	21	28
P11	15	<2	7	<8	<4	20,000	17	19	50	2,100	.07	27	7	10
P15	3	<2	<4	<8	<4	2,300	<2	11	20	520	<.02	100	<4	3

Site No. (fig. 2)	Niobium, total (µg/g)	Scandium, total (µg/g)	Selenium, total (µg/g)	Silver, total (µg/g)	Strontium, total (µg/g)	Tantalum, total (µg/g)	Thorium, total (µg/g)	Titanium, total (percent)	Tin, total (µg/g)	Uranium, total (µg/g)	Vanadium, total (µg/g)	Ytterbium, total (µg/g)	Yttrium, total (µg/g)	Zinc, total (µg/g)
P1	8	9	0.4	0.2	760	<40	8	0.32	<10	5.3	110	1	13	90
P2	12	6	.4	.1	780	<40	<10	.21	<10	37	190	<1	9	59
P3	6	6	.2	<.1	2,000	<40	220	.24	<10	170	86	<1	9	62
P4	<4	4	.6	<.1	1,400	<40	11	.16	<10	10	70	<1	6	59
P6	4	5	.4	.3	800	<40	11	.23	<10	4.2	72	<1	9	73
P7	18	9	.6	.2	610	<40	17	.31	<10	11	320	1	12	87
P11	<4	5	.2	.4	1,400	<40	<8	.25	<10	24	62	<1	9	66
P15	<4	<2	.1	<.1	2,300	<40	<14	.02	<10	59	9	<1	<2	55

Table 12. Concentrations of trace elements and percent moisture in biological samples collected from seepage ponds, Indian Lakes area, Churchill County, Nevada, 1994-95

[All values except percent moisture in micrograms per gram, dry weight. Symbols: <, less than; --, not determined.]

Site No. (fig. 2)	Species	Sample matrix	Date	Percent moisture	Aluminum	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Copper
					Aquatic vegetation							
P1	pondweed	whole	7/21/95	91.6	16.6	27.0	217	<.2	264	<.2	<1.0	5.5
P3	pondweed	whole	7/21/95	89.6	136	36.6	11.8	<.2	795	<.2	1.2	6.3
P15	pondweed	whole	7/21/95	92.4	57.0	13.6	80.6	<.2	345	<.2	<1.0	4.7
					Aquatic invertebrates							
P1	brine shrimp	whole	6/22/95	86.9	64.1	38.2	1.5	<.2	1,050	.5	<.9	3.5
P4	brine shrimp	whole	7/21/95	90.3	190	134	5.2	<.2	862	.3	<1.0	5.7
P4	brine shrimp	whole	9/18/95	90.0	374	181	10.9	<.2	1,130	<.2	<1.0	5.9
P5	odonata	whole	7/21/95	84.4	18.4	2.4	1.9	<.1	71.1	<.1	<.5	10.4
P5	corixids	whole	7/21/95	80.7	13.3	2.8	3.6	<.2	31.5	<.2	<1.0	15.8
P5	corixids	whole	9/18/95	83.7	200	29.8	13.3	<.2	98.0	<.2	<1.0	9.1
P6	notonectids	whole	5/10/94	--	45.0	2.2	2.5	<.8	82.2	<.8	1.0	39.4
P6	corixids	whole	5/10/94	89.9	42.6	.7	5.6	<.1	36.0	.2	<.5	18.7
P6	notonectids	whole	7/21/95	85.7	25.3	2.1	51.6	<.2	24.4	.4	<1.0	10.6
P6	corixids	whole	7/21/95	78.4	12.9	1.4	67.9	<.2	8.0	.5	<.9	9.3
P7	brine shrimp	whole	5/10/94	--	1,970	268	24.1	<.7	1,900	<.7	1.6	10.2
P7	brine shrimp	whole	6/22/95	90.9	2,940	117	17.5	<.2	599	1.6	2.4	14.8
P7	brine shrimp	whole	6/22/95	90.2	2,850	118	18.8	<.2	552	1.5	2.4	15.2
P7	brine shrimp	whole	6/22/95	90.5	2,640	102	18.4	<.2	536	1.8	2.0	15.6
P8	corixids	whole	6/22/95	83.3	137	107	4.4	<.1	589	.5	<.5	25.7
P10	brine shrimp	whole	5/10/94	--	4,960	166	45.8	<.7	3,330	<.7	2.5	18.5
P10	brine shrimp	whole	6/22/95	87.9	3,480	153	29.5	<.2	1,510	.4	3.1	15.5
P10	brine shrimp	whole	6/22/95	90.3	1,500	203	9.9	<.2	2,680	<.2	1.3	8.2
P10	brine shrimp	whole	7/21/95	79.3	3,690	261	4.5	<.2	3,200	<.2	<1.0	5.8
P11	notonectids	whole	7/21/95	82.7	18.4	3.8	1.1	<.2	144	.6	<1.0	19.8
P15	brine shrimp	whole	6/22/95	91.1	727	40.6	9.8	<.2	435	.4	<1.0	7.7

Table 12. Concentrations of trace elements and percent moisture in biological samples collected from seepage ponds, Indian Lakes area, Churchill County, Nevada, 1994-95—Continued

Site No. (fig. 2)	Species	Sample matrix	Date	Percent moisture	Aluminum	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Copper
					Avian eggs							
P1	avocet	egg	5/08/95	74.6	11.4	<0.5	2.0	<0.1	3.2	<0.1	<0.5	2.4
P7	avocet	egg	5/10/94	--	4.3	.8	.7	<.4	27.0	<.4	<.4	3.9
P10	avocet	egg	5/10/94	--	3.6	.8	1.0	<.4	8.8	<.4	21.3	18.0
P15	avocet	egg	6/02/95	63.9	11.5	<.5	2.6	<.1	2.6	<.1	<.5	2.2
P15	avocet	egg	6/02/95	23.1	13.3	<.5	8.1	<.1	<2.0	<.1	<.5	1.5
					Avian liver							
P7	avocet	liver	6/22/95	71.4	12.2	1.2	.7	<.1	9.2	5.4	<.5	25.6
P7	avocet	liver	6/22/95	71.9	5.0	.8	<.5	<.1	8.7	4.8	<.5	23.7
P7	avocet	liver	6/22/95	71.5	6.7	1.1	.5	<.1	8.7	4.7	<.5	19.4
P7	avocet	liver	6/22/95	70.4	5.0	1.2	1.1	<.1	10.9	3.2	<.5	16.0
P7	avocet	liver	6/22/95	69.4	10.4	.8	1.6	<.1	11.4	6.0	<.5	18.0
P7	avocet	liver	6/22/95	71.6	5.0	1.9	1.0	<.1	10.0	1.0	<.5	13.5

Table 12. Concentrations of trace elements and percent moisture in biological samples collected from seepage ponds, Indian Lakes area, Churchill County, Nevada, 1994-95—Continued

Site No. (fig. 2)	Date	Iron	Lead	Magnesium	Manganese	Mercury	Molybdenum	Nickel	Selenium	Strontium	Vanadium	Zinc
						Aquatic vegetation						
P1	7/21/95	340	2.8	5,250	9,920	<0.2	<1.0	<1.0	<1.0	352.4	1.6	23.0
P3	7/21/95	318	<2.0	4,340	1,660	<.2	4.8	<1.0	<1.0	72.3	1.6	168
P15	7/21/95	330	<2.0	4,750	3,270	<.2	1.7	1.4	<1.0	133.9	1.0	83.0
						Aquatic invertebrates						
P1	6/22/95	377	<1.8	3,810	55.6	1.13	6.7	<.9	3.1	90.9	<.9	27.2
P4	7/21/95	777	<1.9	1,600	33.9	.39	8.8	2.3	2.0	40.5	1.2	32.4
P4	9/18/95	951	<2.0	2,300	46.0	.39	13.3	2.1	3.1	66.9	1.9	35.8
P5	7/21/95	108	<.5	1,210	54.2	.47	<2.0	.7	1.0	10.4	<.5	84.9
P5	7/21/95	91	<2.0	742	57.0	2.88	<1.0	<1.0	<1.0	18.0	<1.0	78.4
P5	9/18/95	521	<2.0	1,420	168	1.61	<1.0	<1.0	<1.0	62.3	<1.0	56.9
P6	5/10/94	143	<1.7	1,420	67.1	<.41	1.0	<.8	<.8	15.9	<.8	134
P6	5/10/94	144	<.5	1,300	90.2	.15	<2.0	<.5	.6	21.5	<.5	125
P6	7/21/95	280	<1.9	2,270	599	.47	<1.0	<1.0	1.3	183	<1.0	132
P6	7/21/95	331	<1.9	1,070	216	.79	<.9	<.9	<.9	128	<.9	132
P7	5/10/94	1,460	40.1	1,820	69.3	<.38	38.6	3.4	<.7	168	17.5	29.9
P7	6/22/95	4,020	<2.0	3,510	129	.53	15.8	7.0	2.5	51.0	36.9	52.2
P7	6/22/95	3,920	2.1	3,370	130	.49	12.8	6.6	1.5	72.2	35.0	50.1
P7	6/22/95	3,570	<2.0	3,180	121	.50	14.2	7	2.2	73.3	31.8	54.7
P8	6/22/95	210	.6	877	19.3	1.50	16.6	1.4	1.4	13.5	2.8	128
P10	5/10/94	3,330	<1.5	2,520	88.8	<.36	42.2	2.4	<.7	53.3	53.3	37.7
P10	6/22/95	5,780	<1.9	2,760	223	<.19	19.8	5.6	2.5	39.3	28.7	47.5
P10	6/22/95	2,230	<1.9	1,540	72.7	<.19	35.1	2.5	1.0	25.8	19.8	30.1
P10	7/21/95	699	<1.9	616	34.5	<.19	45.0	<1.0	3.8	17.3	11.5	20.8
P11	7/21/95	141	<1.9	1,560	50.4	2.30	4.6	<1.0	2.9	30.8	<1.0	220
P15	6/22/95	1,420	<2.0	3,600	56.4	.51	5.6	2.2	1.2	80.2	3.2	35.1

Table 12. Concentrations of trace elements and percent moisture in biological samples collected from seepage ponds, Indian Lakes area, Churchill County, Nevada, 1994-95—Continued

Site No. (fig. 2)	Date	Iron	Lead	Magnesium	Manganese	Mercury	Molybdenum	Nickel	Selenium	Strontium	Vanadium	Zinc
						Avian eggs						
P1	5/08/95	90	<1.0	353	1.8	1.33	2.6	<0.5	2.5	19.8	<0.5	29.0
P7	5/10/94	87	<.9	357	<4.3	2.27	1.3	<.4	2.5	14.4	14.4	40.1
P10	5/10/94	231	<.7	587	5.5	.72	1.0	9.2	.9	34.5	<.4	40.4
P15	6/02/95	107	2.0	375	2.1	1.25	1.1	<.5	2.8	19.5	<.5	40.4
P15	6/02/95	131	2.2	343	2.4	.58	<.5	<.5	2.0	29.7	<.5	53.6
						Avian liver						
P7	5/10/94	1,300	<1.0	802	16.2	24.0	2.5	<.5	13.2	1.1	<.5	126
P7	5/10/94	790	<1.0	659	11.6	.91	.9	<.5	5.6	.8	<.5	103
P7	6/22/95	1,510	<1.0	828	16.7	17.0	2.7	<.5	12.6	.8	<.5	115.5
P7	6/22/95	1,650	<1.0	804	14.1	10.0	3.1	<.5	15.7	2.4	<.5	88.6
P7	6/22/95	538	<1.0	810	17.2	31.0	2.5	<.5	10.8	1.2	.6	101
P7	6/22/95	1,580	<1.0	791	11.0	4.09	2.1	<.5	11.0	1.3	<.5	70.9

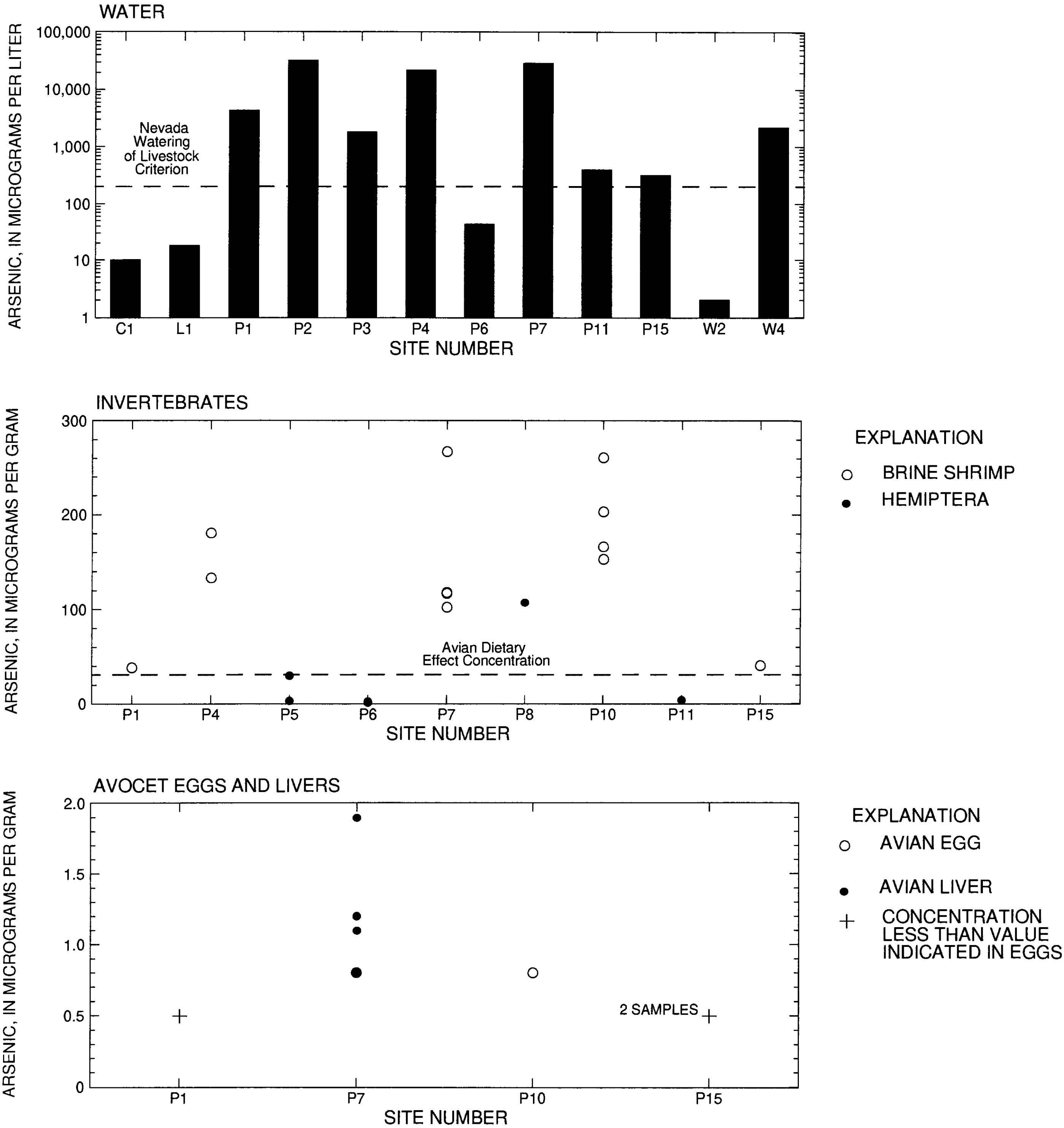


Figure 7. Arsenic concentrations in water, invertebrates, and avocet eggs and livers collected from seepage ponds in Indian Lakes area, Stillwater Wildlife Management Area, Nevada, 1994-95. Avian dietary effect concentration from Camardese and others (1990).

from wetlands containing elevated levels of arsenic, boron, and selenium. The highest incidence of adverse effects was in chicks from an area with very high levels of arsenic and moderate concentrations of selenium, leading the researchers to surmise that arsenic plays a more significant role in contributing to adverse effects than boron or selenium. Inorganic arsenicals also have been associated with increased risk of several cancers in humans; however; little evidence exists that arsenic causes cancer in other animals (Eisler, 1994).

Arsenic concentrations in potential avian dietary items (invertebrates, table 12) collected from four of nine seepage ponds at Indian Lakes exceeded a potentially toxic threshold for sensitive species (100 μg/g), but were below levels associated with mallard mortality. Similarly, arsenic in invertebrates collected from six of nine ponds exceeded concentrations associated with adverse sublethal effects to avian species.

Arsenic has been associated with embryonic mortality and teratogenic effects in avian species (Eisler, 1994). However, Stanley and others (1994) did not find reduced hatching or teratogenic effects in eggs from mallards maintained on diets containing up to 400 μg/g sodium arsenate. The mean arsenic concentration in eggs associated with the maximum dietary concentration was 3.6 μg/g. All eggs collected from seepage ponds at Indian Lakes were below this concentration.

Camardese and others (1990) found mean arsenic concentrations of 0.3 and 1.3 μg/g in livers of mallard ducklings maintained on diets containing 100 and 300 μg/g sodium arsenate, respectively. As indicated above, growth, development, and physiology were affected at these dietary concentrations. The mean arsenic concentration in livers of adult avocets collected from Indian Lakes, 1.3 μg/g, was consistent with the higher dietary arsenic concentration.

Boron

Boron concentrations in water samples from Indian Lakes seepage ponds ranged from 2,400 to 1,300,000 μg/L (table 10). In all sampled ponds, concentrations exceeded the Nevada water-quality criterion for irrigation (750 μg/L) and in seven of eight ponds, concentrations exceeded the criterion for watering of livestock (5,000 μg/L; fig. 8). Nevada eliminated the boron criterion for protection of aquatic life in 1995. Boron in water may be toxic to aquatic organisms. Invertebrate (*Daphnia magna*) mortality (21-day LC_{50}) has been found from 52,200 to 53,200 μg/L boron as boric acid, with a maximum allowable toxicant concentration (MATC) between 6,000 and 13,000 μg/L (Lewis and Valentine, 1981; Gersich, 1984). The MATC's were determined by sublethal effects to growth and production. Boron concentrations in water exceeded the MATC in seven of eight seepage ponds sampled in this study. Six of the ponds exceeded potentially toxic levels.

Hatching success of eggs from mallards maintained on a diet supplemented with 1,000 μg/g boron was reduced by almost 50 percent (Smith and Anders, 1989). Productivity (number of ducklings through 21 days) of females maintained on a diet containing 1,000 μg/g boron was reduced. Body weights of hatchlings of adults maintained on diets supplemented with 300 and 1,000 μg/g boron were lower also. Weight gain of ducklings maintained on diets supplemented with 30, 300, and 1,000 μg/g boron were depressed through 21 days. Delayed growth rate and biochemical effects were found in female mallards maintained on diets containing 100 and 400 μg/g (Hoffman and others, 1990b). In this study, boron concentrations in invertebrates from the nine ponds exceeded the 30 μg/g dietary concern concentration, exceeded 100 μg/g in seven ponds, and exceeded 1,000 μg/g in four ponds.

Adverse effects of boron were increased in the presence of selenium in diet (Hoffman and others, 1991). These effects became more pronounced when dietary protein was reduced. At a restricted dietary protein level (7 percent), increased mortality was found in mallard ducklings maintained on a diet supplemented with 15 μg/g selenium and 1,000 μg/g boron. Selenium concentrations did not approach 15 μg/g in this study. Boron in one avocet egg exceeded concentrations associated with reduced hatch weight of mallard ducklings (Smith and Anders, 1989). Boron concentrations in other avocet eggs and livers did not exceed biologically significant levels.

Fluoride

Fluoride concentrations in water samples from Indian Lake seepage ponds ranged from 0.4 to 240 mg/L (table 9). Concentrations exceeded the Nevada irrigation criterion in seven ponds and the livestock watering standard in four ponds (fig. 9). Fluoride concentrations were not determined in sediment or biological samples.

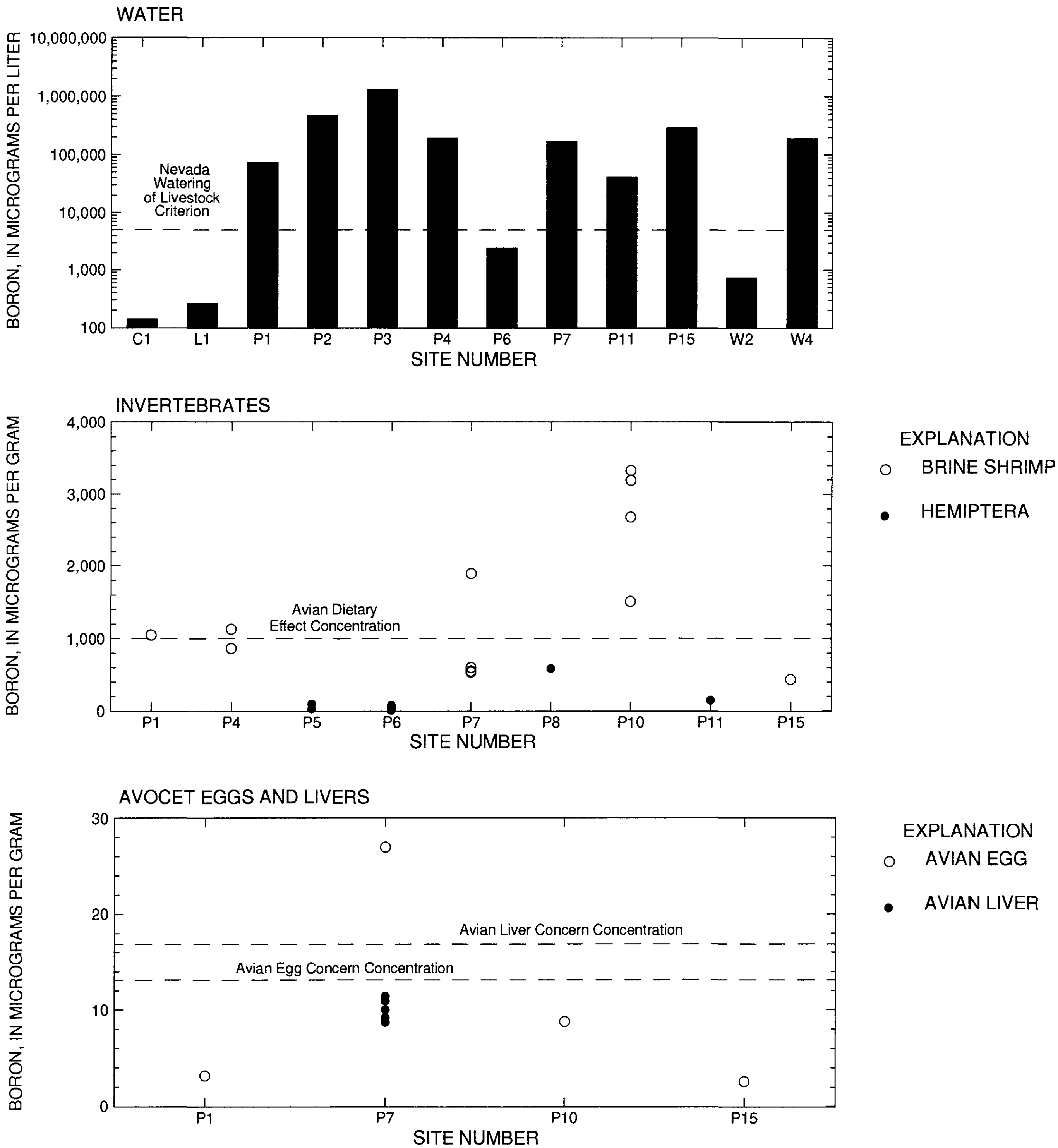


Figure 8. Boron concentrations in water, invertebrates, and avocet eggs and livers collected from seepage ponds in Indian Lakes area, Stillwater Wildlife Management Area, Nevada, 1994-95. Avian dietary effect concentration and avian liver and egg concern concentrations from Smith and Anders (1989).

Chronic exposure to fluoride has been associated with developmental abnormalities in mammals and reproductive and developmental effects in avian species (Cooke and others, 1996; Fleming, 1996). Egg size was reduced in eastern screech owls (*Otus asio*) maintained on diets containing 40 and 200 µg/g fluoride (Hoffman and others, 1985b). Bone development in the higher dietary group was affected also. Hatching success of eggs from birds maintained on a diet containing 200 µg/g fluoride was reduced (Pattee and others, 1988). Fluoride concentrations were not determined in biological samples collected from Indian Lakes seepage ponds. However, fluoride may accumulate in invertebrates, birds, and mammals in excess of environ-mental concentrations (Cooke and others, 1996). If so, fluoride levels in avian tissues and dietary items at Indian Lakes seepage ponds may be sufficient to elicit adverse biological responses.

Mercury

Mercury concentrations were less than the 0.1-µg/L analytical reporting limit in water of three ponds sampled in 1994 (table 2). Mercury was not analyzed for in water samples in 1995. The mercury concentration in a sediment sample collected from one seepage pond (table 11, site P7, 0.19 µg/g) exceeded a concentration associated with toxicity to benthic freshwater organisms (Persaud and others, 1993) and benthic marine and estuarine organisms (Long and Morgan, 1991).

Concentrations of mercury in invertebrate samples and in avian egg and liver samples are shown in figure 10. Mercury in diet can affect avian reproduction and survival, with organic forms of mercury being more toxic (Eisler, 1987). Reproduction of successive generations of mallards was reduced at dietary concentrations as low as 0.5 µg/g methyl mercury (Heinz, 1979). Corresponding mean mercury concentration in eggs and livers ranged from 0.79 to 0.86 µg/g and 0.89 to 1.62 µg/g (wet weight), respectively. Adult American black ducks (*Anas rubripes*) fed 3.0 µg/g (dry weight) for two breeding seasons showed no adverse effects, but clutch size, egg hatchability, and juvenile survival were reduced (Finley and Stendell, 1978). Corresponding mean concentrations in eggs and juvenile livers were 3.86 µg/g and 10.23 µg/g (wet weight), respectively. Dietary exposure to 1.1 µg/g total mercury has been associated with nephrotoxic lesions in kidneys of juvenile European starlings (*Sturnus vulgaris*; Nicholson and Osborn, 1984). Mortality of adult

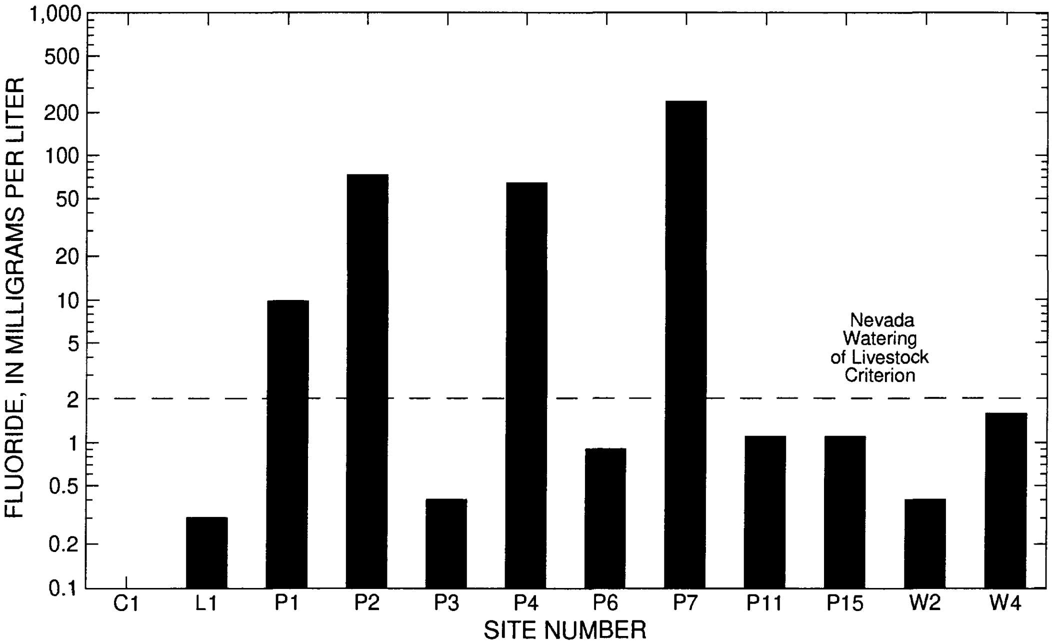


Figure 9. Fluoride concentrations in water collected from Indian Lakes area, Stillwater Wildlife Management Area, Nevada, 1995.

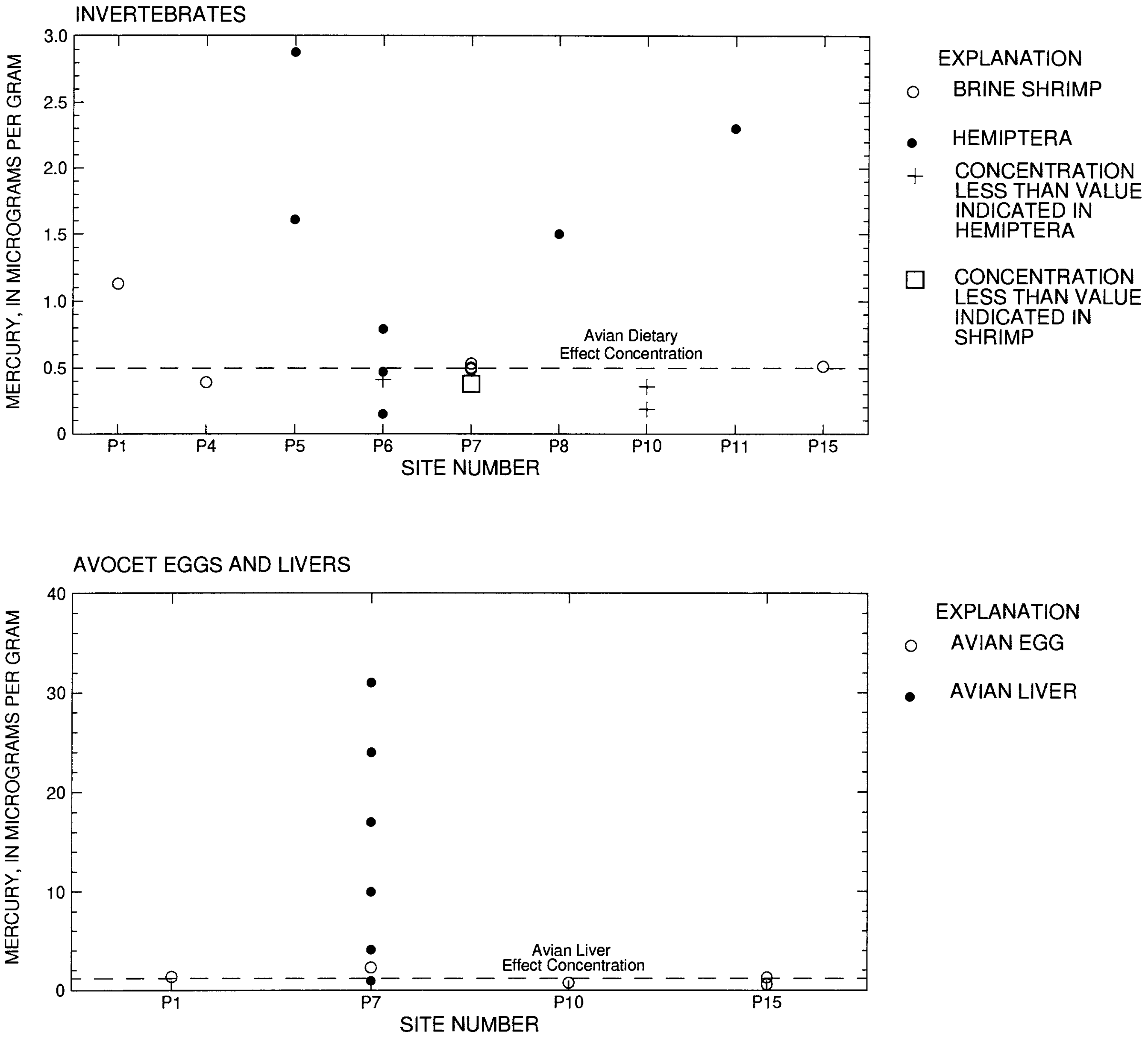


Figure 10. Mercury concentrations in invertebrates and avocet eggs and livers collected from seepage ponds in Indian Lakes area, Stillwater Wildlife Management Area, Nevada, 1994-95. Avian dietary and liver effect concentrations from Heinz (1979).

ring-necked pheasants (*Phasianus colchicus*) occurred at dietary concentrations of 12.5 µg/g (Spann and others, 1972).

Concentrations in invertebrates collected from Indian Lakes seepage ponds ranged from less than reporting limits (0.19 to 0.41 µg/g) to 2.88 µg/g (table 12). Mercury in invertebrates from seven of nine seepage ponds exceeded the 0.5 µg/g dietary effect concentration (Heinz, 1979). Concentrations in invertebrate samples from four ponds met or exceeded the dietary concentration associated with histopathological effects. Concentrations in invertebrates from one pond approached a level that may be potentially toxic to waterfowl offspring. Concentrations in avocet eggs were below levels associated with decreased production. Concentrations in adult avocet livers, ranging from 0.26 to 9.5 µg/g, wet weight (0.91 to 31.0 µg/g, dry weight), were below concentrations associated with decreased survival of juvenile waterfowl. However, concentrations in six of eight livers exceeded levels associated with decreased production.

Toxic interactions between mercury and selenium have been well documented (Cuvin-Aralar and Furness, 1991). Several studies have indicated that the toxicity of one or both toxicants are decreased in the presence of the other (antagonistic interaction). However, other studies have indicated little toxic interaction or increased toxicity (synergistic interaction; Skorupa and others, 1996). Some of the discrepancy may stem from the different chemical forms of selenium and mercury examined in the individual studies. In a study examining the interactive effects of environmentally relevant chemical forms (methylmercury chloride and selenomethionine) administered through diet, antagonistic interaction was found when survival of adult mallards was examined (selenium provided some protection against mercury toxicity). However, synergistic interaction was found when reproductive effects (egg production, teratogenic effects, and duckling survival) were considered (G.H. Heinz and D.J. Hoffman, Patuxent Environmental Science Center, written commun., 1996). The concentrations of methylmercury chloride and selenomethionine in diet administered in this study (10 mg/g each) were greater than concentrations found in potential avian dietary organisms collected from Indian Lakes seepage ponds. Interactive effects of these trace elements at Indian Lakes are uncertain.

Molybdenum

Molybdenum concentrations in water samples from Indian Lakes seepage ponds ranged from 16 to 42,000 μg/L (table 10). Concentrations in six of the eight sampled seepage ponds exceeded the Nevada molybdenum criterion for the protection of aquatic life (19 μg/L) and an aquatic-life concern concentration (28 μg/L). However, molybdenum concentrations in invertebrates and aquatic vegetation (table 12) were below avian dietary concern and effect levels (Eisler, 1989). No criteria for protection of aquatic life were found for molybdenum in bottom sediments.

Selenium

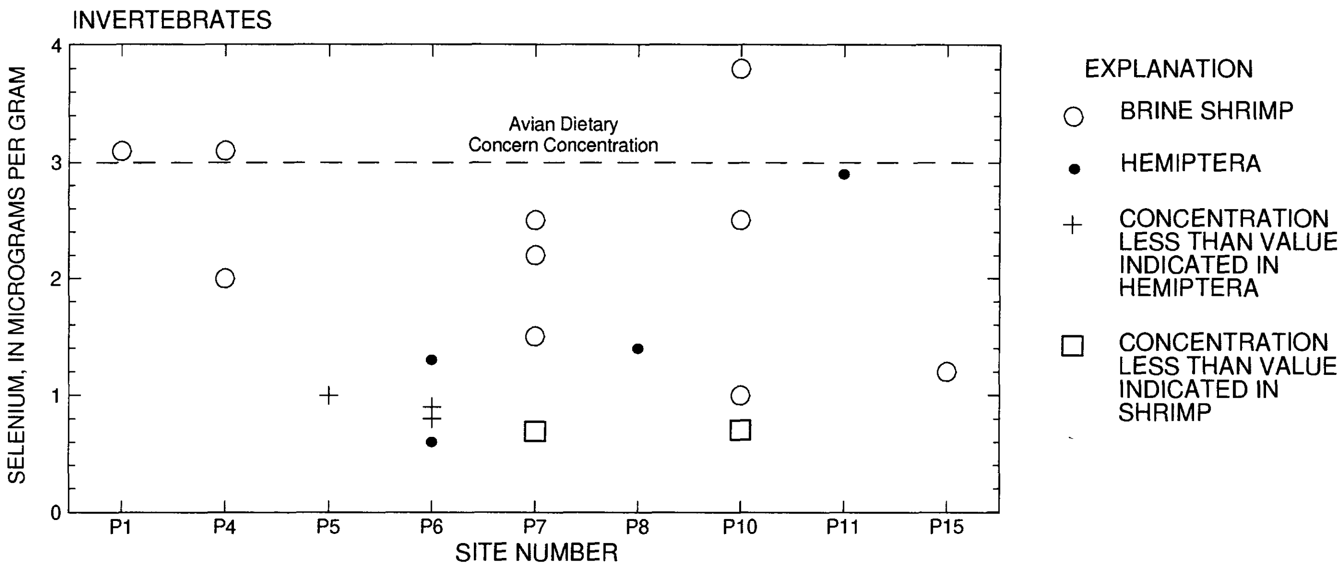
Selenium was not detected in water samples at the analytical reporting limits attainable (table 10), and concentrations in bottom-sediment samples (table 11) all were less than a published level of concern (1 μg/g; Skorupa and others, 1996). Selenium was detected in other sample matrices, indicating that selenium was present in at least some seepage ponds (fig. 11). Three invertebrate samples exceeded an avian dietary-concern concentration of 3.0 μg/g (Lemly, 1996), but no invertebrate samples exceeded a critical dietary threshold of 5.0 μg/g (Skorupa and others, 1996). Selenium concentrations in avocet eggs from Indian Lakes were below embryotoxic and teratogenic thresholds and concentrations associated with increased susceptibility of mallard hatchlings to a duck hepatitis virus (Skorupa and Ohlendorf, 1991; Skorupa and others, 1996). The mean selenium concentrations in avian livers (12.6 μg/g) exceeded a level at which the possibility of reproductive impairment and sublethal effects increase (Heinz, 1996). However, hepatic selenium concentrations provide a limited basis for interpreting risk to avian species (Skorupa and others, 1996).

Uranium

Dissolved uranium concentrations in water samples from Indian Lake seepage ponds ranged from 4.0 to 19,000 μg/L (table 10) and concentrations in bottom sediment ranged from 4.2 to 170 μg/g (table 11). Radiological analyses of water were not done and uranium concentrations were not determined in biological tissues. Implications of elevated uranium are uncertain. Uranium is considered highly toxic, from both chemical and radiological standpoints (Weast and Astle, 1981); the proposed maximum contaminant level (MCL) for uranium in drinking water is 20 μg/L (U.S. Environmental Protection Agency, 1991b). However, uranium toxicity to avian species may be relatively low. Haseltine and Sileo (1983) found no mortality, no histopathological effects, and no difference in weight in American black ducks maintained for 6 weeks on diets containing up to 1,600 μg/g uranium.

Avian Use of Indian Lakes Seepage Ponds

From May through July 1995, representatives of 12 families of birds were observed in close association with seepage ponds at Indian Lakes (table 13). Dominant families included Recurvirostridae (avocets and stilts), Scolopacidae (sandpipers and allies), and Anatidae (ducks). Recurvirostridae, primarily American avocets, was the most common family. These high counts were attributed to a group of about 20 avocets observed on several occasions in May and June.



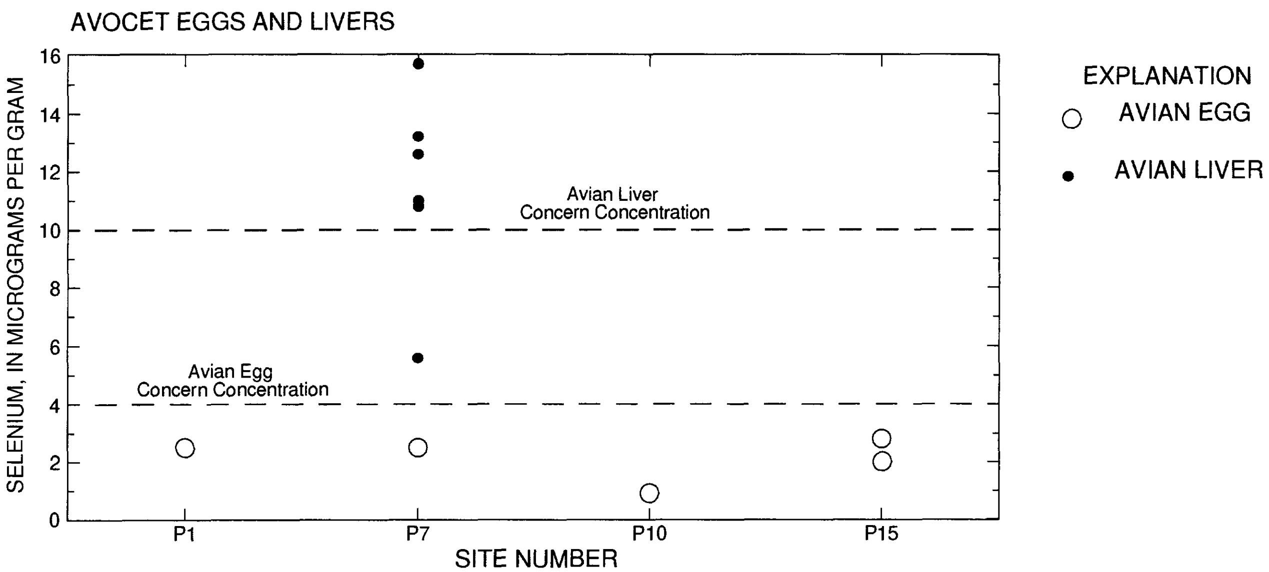


Figure 11. Selenium concentrations in invertebrates and avocet eggs and livers collected from seepage ponds in Indian Lakes area, Stillwater Wildlife Management Area, Nevada, 1994-95. Avian dietary concern concentration from Lemly and Smith (1987); avian liver and egg concern concentrations from Skorupa and others (1996).

Bird use appeared to be highest in May and June, with a maximum daily count of 62 birds in a survey of eight ponds. Counts for most species declined in July, with a maximum daily count of 16 birds in a survey of eight ponds. Certain ponds appeared more attractive to birds than others. The heaviest use was found at site P7, followed by lighter usage at sites P1, P8, and P10. Ducks were most often observed on less saline ponds (sites P5, P6, P7, P8, and P11). Avocets were most commonly observed on more saline ponds that supported brine shrimp and brine flies (*Ephedra* spp.; sites P1, P2, P7, and P10). In 1995, migratory bird use of Indian Lakes seepage ponds was low in comparison with other wetlands in Lahontan Valley (U.S. Fish and Wildlife Service, 1996).

Bird use, nesting attempts, and production in Lahontan Valley wetlands appear to be positively correlated with wetland acreage, with the lowest use and

Table 13. Avian-use surveys of seepage ponds in Indian Lakes area, Stillwater Wildlife Management Area, Churchill County, Nevada, 1995

[Numbers represent cumulative birds counted during all observation periods. Symbol: --, none sighted]

Family	Site number (figure 2)																						Total
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	
Number of observation periods	10	5	4	6	6	6	10	5	1	10	5	1	1	1	5	4	1	1	1	3	1	1	88
Anatidae (ducks)	2	--	--	--	4	11	4	16	--	--	3	--	--	--	--	--	--	--	--	--	--	--	40
Ardidae (herons)	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	1
Threskiornithidae (ibis)	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
Recurvirostridae (avocets, stilts)	34	12	--	9	--	--	135	4	--	21	--	--	--	--	6	1	--	--	--	--	--	--	222
Charadriidae (plovers, killdeer)	2	--	--	--	--	--	2	--	--	1	3	--	--	--	5	--	--	--	--	--	--	--	13
Scolopacidae (sandpipers and allies)	6	--	--	--	--	--	34	5	--	--	2	--	--	--	--	--	--	--	--	--	--	--	47
Phalaropodidae (phalaropes)	--	--	--	--	--	1	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3
Laridae (gulls)	--	--	--	--	--	--	3	--	--	19		--	--	--	--	--	--	--	--	--	--	--	22
Alaudidae (larks)	8	--	--	--	--	--	3	--	--	6	--	--	--	--	--	--	--	--	--	--	--	--	17
Hirundinidae (swallows)	--	--	--	2	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4
Corvidae (magpie)	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	2
Icteridae (blackbirds)	--	--	--	--	8	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	11
Total	52	12	0	11	14	15	184	25	0	48	10	0	0	0	11	1	0	0	0	0	0	0	383
Average	5.2	2.4	0	1.8	2.3	2.5	18.4	5.0	0	4.8	2	0	0	0	2.2	0.2	0	0	0	0	0	0	4.4

production typically occurring in drought situations (U.S. Fish and Wildlife Service, 1996). However, the opposite may be true for Indian Lakes seepage ponds. Counts at Indian Lakes seepage ponds were low in 1995 even though above-average precipitation in the region contributed to expanded wetland acreage and favorable habitat conditions in other Lahontan Valley wetlands. The number of birds using and attempting to nest at Indian Lakes seepage ponds appeared to be substantially higher in 1994 when wetland acreage was less and wetland habitat conditions were more degraded following an extended drought in the late 1980's and early 1990's.

In May and June 1995, evidence of avian nesting was found at five seepage ponds, although actual production was low. Two waterfowl nests were found at site P2; however, both nests had been preyed upon. In view of the tolerance limit of juvenile waterfowl to dissolved solids and the distance to the closest freshwater (approximately 0.6 mi), hatchlings probably would not have survived. A single hen with a brood (six chicks) was observed on site P6. The measured dissolved-solids concentration in this pond (1,510 mg/L) was below levels associated with sublethal effects and decreased duckling survival. Evidence of shorebird nesting, including empty and predated nests, was found at sites P1, P7, and P15. Occupied nests were found at sites P1 and P15; however, no avocet hatchlings were noted during continued monitoring of these ponds, suggesting that these nestings were not successful. In May 1994, several occupied avocet nests were located at sites P7 and P10. In that year, other ponds were not surveyed, nor was reproductive success monitored.

Distribution of Selected Chemical Constituents Among Sampling Sites

The distribution of chemical constituents among sites sampled in the Indian Lakes area depends on several factors. In water, solutes are transported with the inflowing source water, and additional solutes are introduced by dissolution of minerals in contact with the water and by atmospheric deposition. Solute concentrations also are affected by removal of water by evapotranspiration, which tends to increase concentrations of dissolved solutes. Under certain thermodynamic conditions, some solutes may be removed from solution by mineral precipitation (Lico, 1992, p. 55). Concentrations of constituents in bottom sediment primarily are from the mineral composition of the rocks from which the sediment was derived. Bottom sediment also can act as a source or sink for constituents, depending on conditions such as pH and Eh of the sediment and the water that may surround it.

Concentrations of constituents in biota may be derived by simple diffusion from the aquatic habitat into biological matrices. Ingestion of water permits absorption of solutes, and many solutes are assimilated or utilized in metabolic processes. Depending on characteristics of the organism, environment, and constituent, certain solutes may "bioaccumulate"—that is, accumulate in an organism to concentrations that are an order of magnitude or more above those in food or water consumed by the organism. "Biomagnification" is the accumulation of progressively higher concentrations by successive trophic levels of a food chain, and requires that the constituent of concern will bioaccumulate in representatives of the food chain.

Source water for the Indian Lakes area primarily is a mixture of water from Carson and Truckee Rivers, by way of the D-Line Canal, and also is the dominant source of recharge to the basalt and sedimentary aquifers that discharge to the Indian Lakes area (Lico and Seiler, 1994, p. 23; Maurer and others, 1996, p. 46). Concentrations of major constituents and dissolved solids measured in the water sample from site C1 (D-Line Canal; table 9) are within ranges determined for Carson River below Lahontan Reservoir by Lico and Seiler (1994, p. 25). All concentrations are less than the median concentrations of Lico and Seiler, probably due to the rate of discharge from Lahontan Reservoir at the time C1 was sampled. Concentrations of most trace elements at site C1 (table 10) are similar to concentrations reported for samples collected in water year 1995 from the Carson River near Fort Churchill (fig. 1; USGS site 10312000; Bauer and others, 1996, p. 230). Concentrations of aluminum (130 μg/L) and arsenic (10 μg/L) at site C1 are exceptions.

Concentrations of several major constituents in samples from the flow-through lake (site L1; table 9) generally are higher than site C1, possibly due to evaporation. The concentration of silica is one exception, probably due to biological assimilation by diatoms. Concentrations of trace elements in samples from the two sites are similar, with arsenic and boron possible examples of conservative evaporative concentration. Comparison of concentrations of sodium and chloride also suggest evaporation between sites C1 and L1.

An undetermined number of hydrologically isolated seepage ponds are present throughout the Indian Lakes area. These ponds are not connected to other surface water and exist because they are depressions in the land surface that intercept the shallow ground-water table. Four borings were completed in the Indian Lakes area in 1904 (Stabler, 1904) and measured water levels ranged from 7 ft below land surface in one boring near present day Big Indian Lake (section 18 of Township 20 North, Range 30 East) to 19 ft in a boring completed between sites P2, P3, and P10 (section 25 of Township 20 North, Range 29 East). Depth to water in wells constructed for this study (sites W1-W5; table 14) ranged from 2.3 ft below land surface at site W1, near D-Line Canal, to 5.1 ft at site W5, between D-Line Canal and P11.

Lines of levels were run between measuring points established at each well (sites W1-W5), at D-Line Canal (site C1), and at selected seepage ponds (sites P1-P4, P6, P7, P11, and P15) to determine the direction and gradient of ground-water flow. Water levels are reported as relative to the water-surface altitude at site P3 and are listed in table 14. The direction of flow and hydraulic gradient were determined from data on the relative geographic positions, distances between, and water-level altitudes (total heads) for three sites located in a triangular arrangement (Heath, 1984, p. 11). Using water-level altitudes for well sites W2, W4, and W5 and then for seepage pond sites P1, P3, and P15, this method indicates that ground water moves from D-Line Canal toward the southeast with gradients of 0.003 ft/ft and 0.002 ft/ft, respectively. Using well site W1 and seepage pond sites P1 and P4, the direction of ground-water flow is away from D-Line canal toward the northwest with a gradient of 0.007 ft/ft. The two opposite directions, both away from D-Line Canal indicate a recharge mound beneath the canal. The steeper gradient (0.007 ft/ft) toward the northwest was calculated from three altitudes closer to the canal, and the gradient flattens at distance from the canal.

Well sites W3 and W4 are adjacent to seepage pond site P3 and site W4 was completed 5 ft deeper (12.45 ft below land surface) than W3 (7.45 ft). Depth-to-water measurements for both wells indicate that the water table is about 0.9 ft above the water surface of site P3 (0.89 and 0.87, respectively; table 14). This indicates a gradient of ground water toward this seepage pond. A slight upward vertical gradient (0.004 ft/ft) between ground water at 12.45 ft and ground water at 7.45 ft below land surface also was measured between these two wells.

Table 14. Water levels and stable-isotope composition of water samples from selected sites, Indian Lakes area, Churchill County, Nevada, 1995

[Symbol: --, not applicable or not determined]

Site No. (fig. 2)	Date	Water levels relative to water-surface altitude at site P3 (feet)	Delta deuterium (permil)	Delta oxygen-18 (permil)
C1	6/30/95	17.76	-101.0	-13.36
P1	6/29/95	13.94	--	--
P2	6/29/95	2.42	--	--
P3	6/29/95	0	-44.4	-0.85
P4	6/29/95	13.65	--	--
P6	6/29/95	13.24	--	--
P7	6/29/95	6.16	--	--
P11	6/29/95	4.14	--	--
P15	6/29/95	1.86	--	--
W1	6/30/95	17.27	--	--
W2	6/28/95	17.23	-89.3	-10.62
W3	6/28/95	.87	--	--
W4	6/28/95	.89	--	--
W5	6/28/95	7.92	--	--

Samples from sites W2 and W4 represent the quality of shallow ground water in the Indian Lakes area. Concentrations of most major constituents in samples from these sites bracket median concentrations reported for 15-110 analyses of samples of shallow ground water reported by Lico and Seiler (1994, p. 85-86). Concentrations in samples from site W2 are generally lower than those from site W4 because leakage of relatively dilute water from D-Line Canal has recharged the shallow ground-water flow system near the canal. Calcium is an exception to this general trend, and the concentration from site W4 twice the concentration from site W2, but both are less than the median concentration reported by Lico and Seiler (1994). Lico (1992, p. 47) explained how a similar loss of calcium was due to evaporative concentration of ground water from Stillwater WMA by documenting that calcite has precipitated from solution and accumulated in the sediment in which the wells were completed. Thermodynamic calculations (Lico, 1992, table 10) indicate oversaturation of the aqueous phase with respect to calcite in samples of shallow ground water from the Carson Desert, supporting precipitation of calcite as the mechanism for the decreased calcium concentration.

Concentrations of aluminum, arsenic, boron, lithium, manganese, molybdenum, and uranium all increased in samples from site W2 compared to W4 (table 10). The sample from site W2 has concentrations that represent dilution of shallow ground water with irrigation-quality water while concentrations for site W4 equaled or exceeded maximum concentrations of arsenic, boron, and uranium in samples of shallow ground water reported for the Carson Desert (Lico and Seiler, 1994, p. 85-86).

Concentrations of major and trace-element constituents in samples from seepage ponds generally are higher (tables 8 and 9) than concentrations reported for shallow ground water sampled from the Carson Desert (Lico and Seiler, 1994, p. 85-86) and concentrations measured in samples from sites W2 and W4 (tables 8 and 9). This is due primarily to evaporative concentration.

Changes in concentrations of major constituents relative to chloride are shown in figure 12. The curves in figure 12 connect the ratio of major-constituent concentrations to chloride concentrations for sites C1, L1 (source water), W2, W4 (shallow ground water), and P3 (seepage pond). Similar ratios for samples from other sites sampled in Indian Lakes area are plotted as individual points. Graphing constituent concentrations as ratios relative to chloride is used to mask changes caused by evaporative concentration (and it assumes that no chloride is added by dissolution of aquifer or lakebed material). Decreases in calcium and inorganic carbon shown in figure 12 suggest that calcite is precipitating from solution (Lico, 1992, p. 55) and the similar decrease in magnesium may indicate that magnesium calcite ($MgCO_3$) also is precipitating (Drever, 1988, p. 66).

The relation between stable isotopes of water (hydrogen and oxygen) is shown in figure 13. The stable isotopes evaluated were oxygen-18 relative to oxygen-16 ($^{18}O/^{16}O$) and deuterium (hydrogen-2) relative to hydrogen-1 ($D/^{1}H$). Each ratio is determined for a water sample and then related mathematically to the comparable ratio for an international reference standard known as Vienna-Standard Mean Ocean Water (V-SMOW). By convention, the computed results are expressed as delta oxygen-18 ($\delta^{18}O$) and delta deuterium (δD); the units of measure are parts per thousand (abbreviated as "permil" or $^{o}/_{oo}$). A negative delta value indicates that the sample water is isotopically lighter than the standard; that is, the sample has a smaller proportion of oxygen-18 or deuterium, relative to oxygen-16 or hydrogen-1, than the standard. Because "'isotopic fractionation" results from physical, chemical, or biological processes, the delta value of the stable isotopes of water will change. For example, during the physical process of evaporation, $\delta^{18}O$ increases (becomes heavier) because ^{16}O is lighter and leaves water at a greater rate than the heavier ^{18}O. The terms isotopically heavier and isotopically lighter are relative and are used for comparing the composition of water samples (Fritz and Fontes, 1980, p. 4-5).

Three water samples were collected from selected sites in the Indian Lakes area for stable-isotope determinations. The sample from site C1 represents source water (D-Line Canal), site W2 represents a mixture of shallow ground water and source water, and site P3 represents a seepage pond. Figure 13 shows the isotopic composition of these three samples in relation to similar analyses made for selected samples of ground water from the Carson Desert. The figure also shows that the trend line between sites C1 and P3 has a slope that parallels the evaporation trend line reported by Lico and Seiler (1994, p. 17) and that the mixture of irrigation water and shallow ground water represented by site W2 could evaporate to have an isotopic composition similar to water from site P3.

Figure 14 is similar to figure 12 except ratios of concentrations of trace elements relative to concentrations of chloride are shown to evaluate the distribution of trace elements in water samples. Figure 14 indicates that boron probably is affected only by evapotranspiration, while the scatter exhibited by arsenic and uranium suggests other processes are affecting measured concentrations. Lico (1992, p. 55) presents evidence of arsenic being incorporated in ferric (oxy)hydroxide (FeOOH) coatings on surfaces of lake sediment collected from Lead Lake, Stillwater WMA.

Concentrations of trace elements in samples of bottom sediment from seepage ponds in the Indian Lakes area (table 11) are generally comparable to concentrations reported for samples collected from the Stillwater WMA (Hoffman and others, 1990a, p. 112; Lico, 1992, p. 34). Concentrations of arsenic in six of eight bottom-sediment samples from the Indian Lakes area are higher than the median value (21 μg/g) of 22 drain-bottom samples (Lico, 1992, p. 34), and one

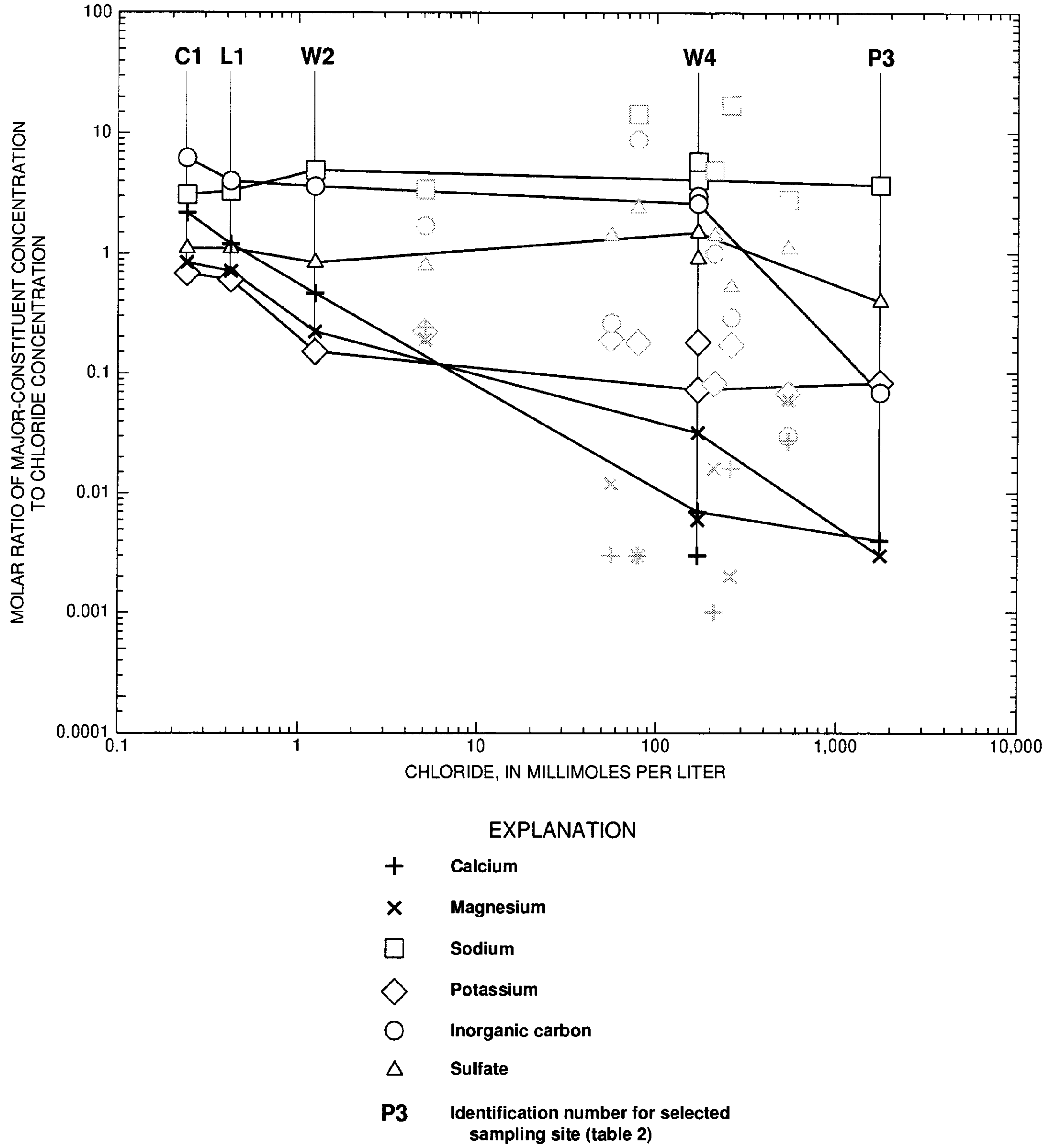


Figure 12. Relation between concentrations of chloride and of major constituents for water samples in Indian Lakes area, Stillwater Wildlife Management Area, Nevada, 1995. Diagonal lines connect constituent concentrations for selected sampling sites. Other sampling sites (table 2) are not labeled.

sample from site P2 exceeded the maximum reporting level of the laboratory (400 μg/g). Concentrations measured in samples from the Indian Lakes area exceeded maximum concentrations reported by Lico (1992, p. 34) for manganese, molybdenum, uranium, and vanadium, but concentrations of chromium, copper, mercury, and selenium typically were lower than median values.

Available data indicate that water in the Indian Lakes area originates from irrigation water, both from the delivery canal (D-line Canal) and from the groundwater flow systems that are recharged from irrigation practices in the Carson Desert. Concentrative effects of evapotranspiration have increased concentrations of arsenic, boron, molybdenum, and uranium to potentially toxic concentrations in seepage ponds. Deviation

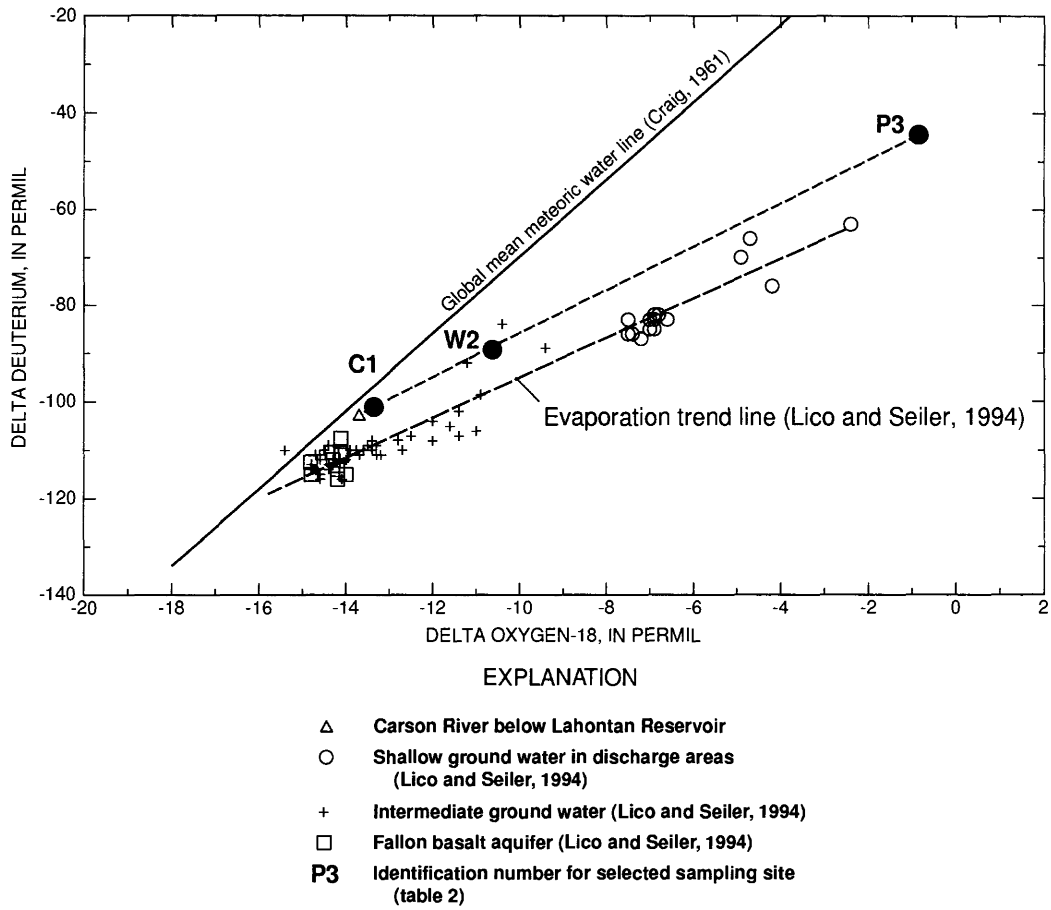


Figure 13. Relation between stable-isotope composition of hydrogen (deuterium) and oxygen in water collected from Indian Lakes area, 1995, from Carson River, and from selected wells in Carson Desert, Churchill County, Nevada (Lico and Seiler, 1994, p. 17).

of concentrations from those predicted for conservative solutes may be explained by mineral precipitation and ion exchange with ferric (oxy)hydroxide coatings on surfaces of lake-bottom sediment.

WETLAND COMMUNITY CHARACTERISTICS

Among ponds that support aquatic or riparian organisms, community composition differed. Dissolved solids appeared to be the dominant factor affecting communities. Salinity in water may have a major influence on composition of plant, invertebrate, and vertebrate communities (Rawson and Moore, 1944; Stewart and Kantrud, 1972; Hammer, 1986). In general, species composition declines with increasing salinity. Such declines in species composition were noted in seepage ponds at Indian Lakes. Submergent aquatic vegetation was abundant in most ponds with specific conductance less than 20,000 µS/cm, but was absent from most ponds with higher specific conductance (table 7). In contrast, cattails and hardstem bulrush were found in only two ponds with specific conductance less than 15,000 µS/cm. Alkali bulrush persisted in all but the most saline pond. Saltgrass was found along the fringes of seepage ponds over the range of observed specific conductance. Saltgrass was often encrusted with salt deposits.

Similar shifts in species composition were noted in invertebrate communities. In less saline ponds (less than 20,000 µS/cm), back swimmers (*Notonectidae*), water boatmen (*Corixidae*), gnats and midges (*Chironomidae*), mosquitoes (*Culicidae*), dragonflies (*Odonata*), and water beetles (*Hydrophilidae, Dyticidae*, and *Belostomatidae*) were common. In more saline ponds (greater than 30,000 µS/cm), brine shrimp

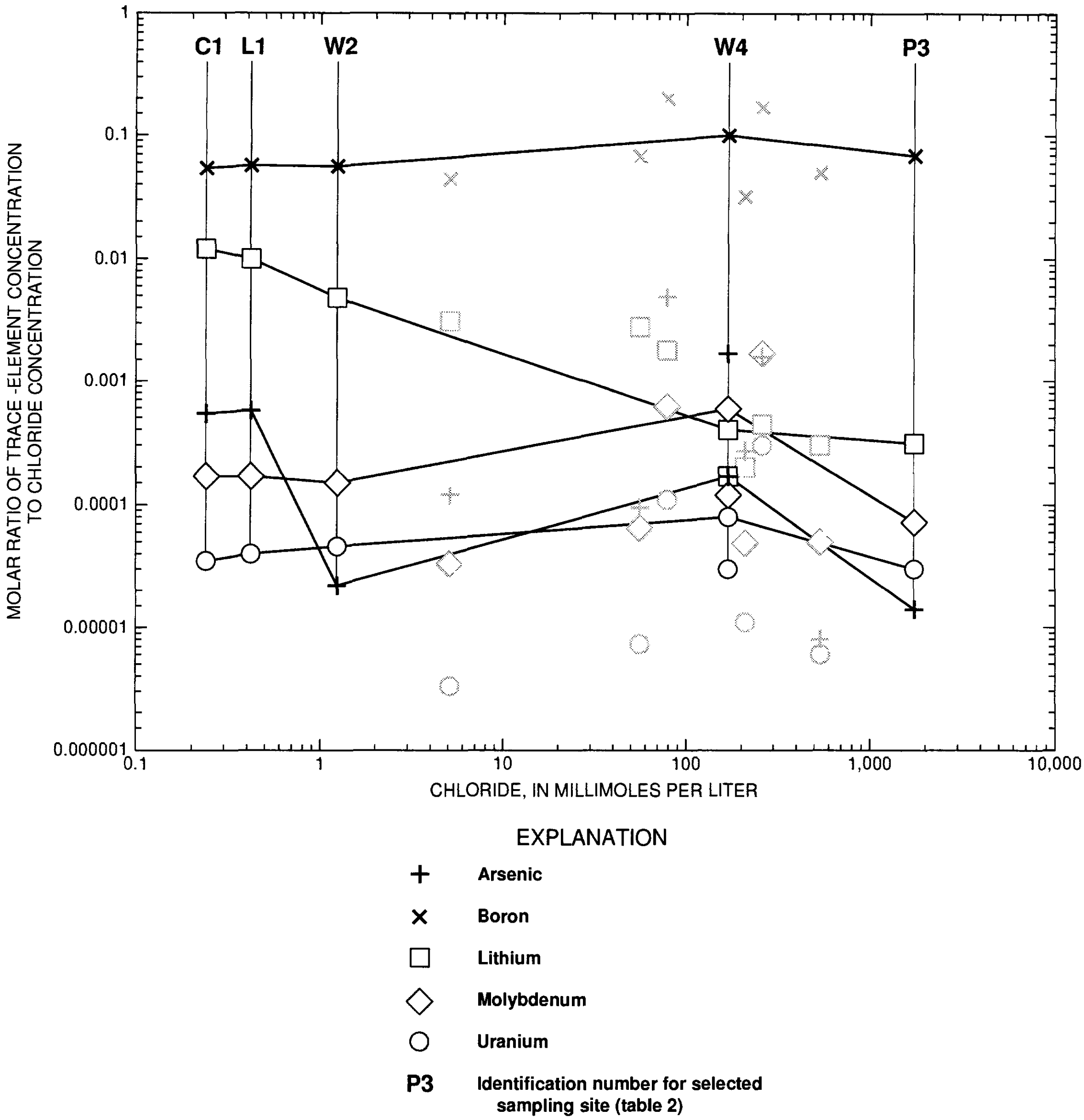


Figure 14. Relation between concentrations of chloride and of trace-element constituents for water samples in Indian Lakes area, Stillwater Wildlife Management Area, Nevada, 1995. Diagonal lines connect constituent concentrations for selected sampling sites. Other sampling sites (table 2) are not labeled.

were the dominant aquatic invertebrate and dense collections of brine flies were observed at times around the margins of some ponds. Water boatmen were infrequently found in some of the more saline ponds. Brine shrimp and brine flies were not observed in the most saline pond (site P3). These species can tolerate salinities ranging up to the saturation point of sodium chloride (Wirth 1971; Pennak, 1989).

WILDLIFE MORTALITY AND TOXICITY CONCERNS

Concentrations of dissolved solids and several trace elements in water of most Indian Lakes seepage ponds exceeded Nevada water-quality criteria and concentrations associated with adverse effects to a wide variety of aquatic organisms (table 15). However, ben-

Table 15. Summary of inorganic constituents of concern in water, sediment, and biological samples collected from seepage ponds in Indian Lakes area, Churchill County, Nevada, 1995

[Abbreviations and symbol: Y, concentration in one or more samples exceeded water-quality standard, proposed criterion, or biological concern or effect concentration; N, concentrations was below level of concern; U, data not available; --, standard, criterion, or biological-effect information not available]

Constituent	Exceedance of water-quality criterion (table 4)	Effects to wildlife (table 5)				
		Water	Bottom sediment	Avian diet	Avian eggs	Avian livers
pH	Y	--	--	--	--	--
Dissolved solids	Y	--	--	--	--	--
Chloride	Y	--	--	--	--	--
Aluminum	N	Y	--	N	--	--
Arsenic	Y	Y	Y	Y	N	N
Boron	Y	Y	--	Y	Y	N
Cadmium	N	N	N	N	--	N
Chromium	N	N	N	N	--	N
Copper	N [1]	N [1]	N	--	--	--
Fluoride	Y	--	--	U	--	--
Iron	N	--	Y	--	--	--
Lead	N [1]	N [1]	N	N	N	N
Manganese	Y	--	Y	--	--	--
Mercury	N	N	Y	Y	N	Y
Molybdenum	Y	Y	--	N	N	--
Nickel	N	N	N	--	--	--
Selenium	N	N [1]	N	Y	N	Y
Uranium	Y	--	--	U	--	--
Vanadium	U	U [1]	--	N	--	N
Zinc	N [1]	N [1]	N	N	--	N

[1] Water samples analyzed in 1994 exceeded criterion.

eficial uses have not been designated to Indian Lakes pond water and it is unlikely that fish or other sensitive aquatic organisms will be introduced or become established in the seepage ponds. Previous attempts to introduce warm-water fish to some seepage ponds have failed (Sumner and others, 1957). Therefore, effects to migratory birds and resident wildlife may be more appropriate measures of potential ecological concern. Several of the constituents found at elevated concentrations in Indian Lakes seepage ponds have the potential to adversely affect migratory birds and resident wildlife. However, effects to these species are dependent on exposure to seepage-pond water or constituents therein. Certain factors may mitigate exposure, and actual threats to wildlife are difficult to discern. Potential effects to avian and resident wildlife may be associated with dissolved solids in general, or with specific trace elements.

Tolerance limits of aquatic and emergent plants and aquatic vertebrates and invertebrates to dissolved solids vary widely, thus producing shifts in species composition (Stewart and Kantrud, 1972; Hammer, 1986). In general, species composition declines with increasing salinity. Elevated dissolved-solids concentrations may affect avian species. Ducklings died when relegated to water with a specific conductance greater than 20,000 μS/cm (Swanson and others, 1984; Mitcham and Wobeser, 1988). Ducklings relegated to water with a specific conductance from 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 specific conductance greater than 4,000 μS/cm was depressed.

Dissolved solids in Indian Lakes seepage ponds may affect waterfowl production. Of 22 seepage ponds surveyed, dissolved solids in all but one (P6) exceeded concentrations associated with reduced survival and sublethal effects in ducklings if freshwater is not readily available (Swanson and others, 1984; Mitcham and Wobeser, 1988). The only waterfowl brood noted in 1995 was on the pond with the lowest dissolved-solids concentration. The potential for dissolved solids to affect survival and recruitment of other avian species nesting around ponds is uncertain.

Avian mortality associated with salts becoming crystallized on feathers may be a concern at some of the more saline seepage ponds at Indian Lakes. Highly saline water in evaporation ponds in the Tulare Basin, Calif., has been associated with calcium carbonate deposits on the rectrices of ruddy ducks (*Oxyura jamaicensis*) that caused erosion of feather structure (Euliss and others, 1989). Feather encrustation and erosion may compromise the ability to feed and fly. Alkalinity concentrations, expressed as calcium carbonate, were higher in Indian Lakes seepage pond water (442-34,900 mg/L, table 9) than in Tulare Basin evaporation ponds (287-451 mg/L, Schroeder and others, 1988, p. 81). Additionally, USFWS personnel in New Mexico have documented considerable mortality of birds that utilize hypersaline playa lakes (Mark Wilson, U.S. Fish and Wildlife Service, oral commun., 1996). Mortality was associated with salt becoming encrusted on feathers, which compromised the water-repellant properties of the feathers and the bird's ability to fly. In controlled studies, sodium poisoning was determined to be the eventual cause of death (Linda Glaser, National Wildlife Health Center, oral commun., 1996). Ingestion of sodium may result from drinking limited amounts of water and excessive preening. Under non-controlled conditions, predation, resulting from the inability to fly, and hypothermia, resulting from loss of insulating capacity and water repellant properties of the feathers, may be responsible for many of the deaths. Such occurrences seem to be more prevalent during periods of cold weather when hypersaline lakes remain unfrozen and are attractive to passing waterfowl. Freshwater bodies in the vicinity freeze and are not attractive.

To investigate the potentially adverse effects of high salinity and salt encrustation, six of the more saline ponds were visited in November 1996. Waterfowl flushed from one pond did not appear impaired. No dead or impaired birds were found during this trip, although one "feather spot" was found on an island in site P3. This spot, a collection of numerous feathers in a small area, was evidence that an unidentifiable bird had died at the site. However, no carcass was found and physical condition or cause of death could not be determined. Abundant evidence of coyotes was found in and around the pond, suggesting that dead wildlife may be quickly scavenged. Also during this visit, two dead desert horned lizards *(Phrynosoma platyrhinos*) and one dead Great Basin collared lizard (*Crotaphytus insularis bicintores*) were found at site P3. Additionally, remains of cattle (bones) were found in or near several seepage ponds.

Elevated concentrations of trace elements may represent a threat to migratory birds. Because of high salinities of most seepage ponds and the occurrence of freshwater in the vicinity, most seepage ponds are probably not used as primary drinking-water sources for most wildlife. In the absence of water ingestion, inhalation and ingestion as a result of preening and diet would represent pathways of wildlife exposure. Only the latter was considered in this investigation, although investigations of avian mortality due to salt encrustation in New Mexico suggest that preening may be a significant route of toxicant exposure to some avian species. Several of the seepage ponds were highly productive and supported high densities of aquatic invertebrates. In 1995, limited numbers of shorebirds and waterfowl were observed feeding heavily in and around saline ponds. Assessment of avocet stomach contents documented that semiaquatic insects and brine shrimp were consumed. Invertebrates collected from these ponds contained concentrations of arsenic, boron, mercury, and selenium in excess of wildlife dietary concentrations (table 6) associated with adverse responses in controlled studies. Fluoride concentrations in biological samples were not determined; however, because of elevated concentrations in water and the propensity of fluoride to accumulate in tissues, this element also may be a concern in wildlife diets.

Avian (avocet) eggs were collected from three ponds to assess trace-element concentrations and embryo condition. Because of the high incidence of egg predation at Indian Lakes seepage ponds, eggs were taken when an opportunity arose. Unfortunately, all eggs collected were in early developmental phases, and evaluation of late-stage embryos for teratogenic effects was not possible. Of three eggs found in 1995, two were cracked with one partially desiccated. A blastodisc or embryo was not found in the third egg, suggesting that the egg was infertile. Concentrations of trace elements did not exceed levels associated with embryonic mortality or teratogenesis. Boron concentrations in one egg exceeded a level associated with decreased hatchling weight (Smith and Anders, 1989). Reasons for eggshell cracking and possible infertility are uncertain. High dietary fluoride has been associated with reduced egg-shell thickness and breakage strength (Fleming, 1996). However, fluoride in biological tissues and egg-shell thickness or strength were not assessed in this study.

Livers of avocets collected from seepage ponds at Indian Lakes contained elevated concentrations of mercury and selenium. Selenium levels, which exceeded concentrations at which the possibility of reproductive or sublethal effects increased (Heinz, 1996), appeared to be consistent with concentrations in livers of shorebirds collected from other wetlands in Lahontan Valley (Hoffman and others, 1990a). Mercury concentrations in Indian Lakes avocet livers, which exceeded concentrations associated with decreased production (Heinz, 1979), were generally higher than concentrations in shorebird livers collected in other Lahontan Valley wetlands. Whether avocets in the Indian Lakes area also foraged at lakes in the system that are known to be contaminated with mercury is uncertain, however.

Avian nesting was documented at five seepage ponds in 1995. However, recruitment was low. Nest failures may have been related to a number of causes. Several active nests were scavenged by coyotes or gulls (*Larus* spp.). High predation rates may, at least partly, account for low recruitment. If waterfowl were successful at hatching eggs, juvenile survival at most ponds would have been questionable because of elevated dissolved solids. Dietary exposure to trace elements is another possible cause for low recruitment. Combined effects of trace elements on embryo mortality or adult health and egg production also may account for reproductive failure. Possible effects of elevated dietary fluoride on egg-shell strength remain uncertain.

Bald eagles represent the only species protected under the Endangered Species Act that frequents the Indian Lakes area. Bald eagles are primarily piscivorous, but carrion and injured wildlife also are important to bald eagles wintering in Nevada (Herron and others, 1985). Mercury concentrations in fish in flow-through lakes exceed the avian dietary effect concentration (table 6) and a 0.1-µg/g predator protection concentration (Cooper and others, 1985; Sevon, 1988). In the absence of fish in seepage ponds, bald eagle exposure to contaminants in seepage ponds would be limited to contaminants in dead or injured wildlife or livestock associated with seepage ponds. The actual threat to bald eagles associated with the consumption of dead or injured wildlife or livestock associated with seepage ponds is considered to be minimal.

HUMAN HEALTH CONCERNS

Indian Lakes is a popular recreational area in Lahontan Valley, with visitor use approaching 12,000 people per year (U.S. Fish and Wildlife Service, 1995). Recreational activities generally include hunting, fishing, swimming, and other pursuits involving water contact. Agricultural uses of the Indian Lakes is limited to grazing of domestic livestock, primarily cattle. Trace elements in Indian Lakes seepage ponds may present a hazard to humans. Like wildlife, exposure and uptake of trace elements is required to cause adverse effects. Pathways of human exposure may include ingestion of water or contaminated foods, dermal contact, or inhalation.

Concentrations of one or more constituents in water of all the Indian Lakes seepage ponds sampled exceeded Nevada water-quality standards or criteria (table 5) for one or more beneficial uses; therefore, water in most Indian Lakes seepage ponds is unsuitable for most human uses. Fish do not inhabit these ponds, thereby eliminating fish consumption as a pathway of human exposure to trace elements. Seepage ponds frequently are used for hunting during waterfowl season. This study did not assess trace-element residues in ducks. Consumption of livestock grazed in the Indian Lakes area may represent another pathway for human exposure. Cattle were frequently observed in or around seepage ponds, and evidence of grazing on vegetation around the periphery of several seepage ponds and emergent vegetation in less saline ponds was apparent. Whether cattle consumed or accumulated potentially hazardous concentrations of trace elements is uncertain. Similarly, human exposure to potentially hazardous contaminants in seepage ponds through dermal contact, inhalation, or consumption was not considered in this investigation.

SUMMARY

In 1995, a study began in the Indian Lakes Area of the Stillwater WMA to determine whether nearby DOI activities associated with irrigation have caused or have the potential to cause harmful effects on human health or on fish and wildlife, or may adversely affect the suitability of water from seepage ponds for other beneficial uses. The Indian Lakes area encompasses about 10,240 acres of upland desert shrub habitat with a series of manmade lakes and shallow marshes supported by irrigation-supply water and several shallow seepage ponds and wet meadows supported by near-surface ground water. Samples of water from seepage ponds (8 samples), an irrigation-water delivery canal (1 sample), a flow-through lake (1 sample), and water-table wells (2 samples); bottom sediment from seepage ponds (8 samples); and biological tissue from seepage ponds (37 samples) were collected for chemical analyses and to evaluate the suitability of water in the ponds for human, livestock, or wildlife exposure. Assessments of habitat, avian use, occurrence of dead or impaired wildlife, and trace elements in sediment and biota were used to identify potential wildlife hazards. Assessments of ground-water quality and flow direction were used to evaluate possible water sources for Indian Lakes seepage ponds.

Agricultural activities appear to have contributed to a rise in local ground-water levels, which may have resulted in the creation of numerous ground-water-supported seepage ponds. Dissolved solids and several water-quality constituents, including potentially toxic trace elements, have become highly concentrated in some of the Indian Lakes seepage ponds. Samples of all pond water analyzed contained concentrations of one or more constituents in excess of Nevada standards and criteria or existing or proposed Federal water-quality criteria. Constituents in exceedence included pH, dissolved solids, chloride, aluminum, arsenic, boron, fluoride, manganese, molybdenum, and uranium. Dissolved solids, arsenic, boron, fluoride, molybdenum, and uranium exceeded standards or proposed criteria by two or more orders of magnitude in some ponds. Several of these constituents exceeded concentrations associated with adverse effects to fish and aquatic invertebrates. However, fish or susceptible aquatic life were considered unlikely to become established in the isolated ponds. Concentrations of arsenic, iron, manganese, and mercury in bottom-sediment samples collected from one or more ponds exceeded concentrations associated with toxicity to benthic organisms.

Several of the ponds were highly productive and supported high densities of aquatic invertebrates. Invertebrate and vegetation community assemblages shifted with dissolved-solids concentrations. Aquatic insects and vascular aquatic vegetation were restricted to ponds with lower dissolved-solids concentrations. High densities of brine shrimp were found in most of the more saline seepage ponds. Several avian species, primarily shorebirds, fed on invertebrates from the ponds. Invertebrate samples from one or more ponds contained arsenic, boron, and mercury in excess of dietary concentrations associated with adverse effects to avian species in controlled studies. A few invertebrate samples exceeded a dietary concern concentration for selenium.

Despite elevated dietary concentrations, arsenic, mercury, and selenium did not appear to be of concern in avian (avocet) eggs. Boron exceeded a concern concentration in one of four eggs examined. In avian livers, mercury exceeded a published effect concentration and selenium exceeded normal hepatic concentrations for birds. Implications of highly elevated concentrations of fluoride and uranium in water to fish or wildlife are uncertain.

High dissolved-solids concentrations in water may represent a risk to hatchlings of waterfowl nesting around seepage ponds. Mineral encrustation and sodium toxicity in avian species may be a concern at some of the more saline seepage ponds at Indian Lakes. Although no encrusted birds were found during surveys of the ponds, evidence of a dead bird was found at one pond; the cause of death could not be determined. Dead resident wildlife and livestock bones also were found during pond surveys. However, high rates of predation may have prevented an accurate assessment of actual wildlife mortality at Indian Lakes seepage ponds.

In 1995, avian use at seepage ponds was low compared to other wetlands in Lahontan Valley. However, the use may increase during regional droughts and corresponding reductions in availability of higher quality habitats in other local wetlands. Avian nesting attempts at seepage ponds were documented but nesting success, as evidenced by the occurrence of avian juveniles, was low. No single trace element, for which adequate data were available, appeared responsible for low production or recruitment. Combined effects of elevated trace elements or effects of elements for which data are lacking are uncertain. High rates of nest predation and hatchling mortality also may have accounted for lack of avian recruitment.

The Indian Lakes area is a popular recreational area in Lahontan Valley. Recreational uses include water-based recreation and hunting. Agricultural use of the area is limited to livestock grazing. Potential pathways of human exposure to trace elements in Indian Lakes include water-contact recreation, inhalation, or consumption of waterfowl or livestock using the ponds. However, the degree of human risk presented by Indian Lakes seepage ponds was not considered as part of this investigation.

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