Field Screening of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage In the Yuma Valley, Arizona, 1995

By SAEID TADAYON[1], KIRKE A. KING[2], BRENDA J. ANDREWS[2], and WILLIAM P. ROBERTS[1]

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

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 97—4236

U.S. GEOLOGICAL SURVEY
U.S. FISH AND WILDLIFE SERVICE
BUREAU OF RECLAMATION
BUREAU OF INDIAN AFFAIRS

Tucson, Arizona
1997

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

U.S. GEOLOGICAL SURVEY
Mark Schaefer, Acting Director

For additional information write to:

District Chief
U.S. Geological Survey
Water Resources Division
520 N. Park Avenue, Suite 221
Tucson, AZ 85719–5035

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Box 25286
Federal Center
Denver, CO 80225–0286

CONTENTS

	Page
Abstract	1
Introduction	2
Purpose and scope	3
Previous investigations	3
Description of the study area	3
Sample collection and analysis	5
Surface-water samples	5
Bottom-sediment samples	6
Biota samples	6
Discussion of results	9
Water quality	9
Bottom sediment	13
Biota	15
Summary	19
Selected references	20
Basic data	25

FIGURES

1.	Map showing data-collection sites, Yuma Valley, Arizona, 1995	4
2.	Trilinear diagram showing composition of surface-water samples, Yuma Valley, Arizona, March and June 1995	13

TABLES

1.	Sampling sites where surface water, bottom sediment, and biota were collected, Yuma Valley, Arizona, 1995	6
2.	Types of field measurements and laboratory analyses for samples collected at sampling sites, Yuma Valley, Arizona, 1995	7
3.	Chemical and physical determinations of surface-water, bottom-sediment, and biota samples, Yuma Valley, Arizona, 1995	8
4.	Statistical summary of selected properties and inorganic constituents in surface-water samples, Yuma Valley, Arizona, March and June 1995	10
5.	Drinking-water regulations and aquatic-life criteria for selected constituents	11
6.	Concentrations of trace elements in bottom-sediment samples, Yuma Valley, Arizona, and in soils of the western conterminous United States	14
7.	Analytical results for field blanks, Yuma Valley, Arizona, March and June 1995	27
8.	Analytical results for surface-water samples, Yuma Valley, Arizona, March and June 1995	28
9.	Analytical results for bottom-sediment samples, Yuma Valley, Arizona, June 1995	33
10.	Residues of organochlorine compounds in fish and birds, Yuma Valley, Arizona 1995	37
11.	Statistical summary of residues of p,p'-dichlorodiphenyldichloroethlyene in common carp, Yuma Valley, Arizona, 1995	37
12.	Concentrations of trace elements in cattails, freshwater clams, and birds, Yuma Valley, Arizona, 1995	38
13.	Concentrations of trace elements in fish, Yuma Valley, Arizona, 1995	39

TABLES—Continued Page

14. Statistical summary of trace elements in common carp, Yuma Valley, Arizona, 1995 40
15. Comparison of concentrations of trace elements in samples of fish, Yuma Valley, Arizona, 1995, to the 85th percentile of the National Contaminant Biomonitoring Program..... 41
16. Selenium concentrations in whole carp from various locations in Arizona 42

CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
acre	0.4047	hectare
acre-foot (acre-ft)	0.001233	cubic hectometer

Temperature can be converted to degrees Celsius (°C) or degrees Fahrenheit (°F) by using the following equations:

$$°C = (°F - 32)/1.8$$
$$°F = 1.8(°C) + 32$$

Dry weight for biological analyses can be converted to wet weight using the following equation:

Wet weight = 1-percent moisture x dry weight

ABBREVIATED UNITS FOR WATER QUALITY, BOTTOM SEDIMENT, AND BIOTA

Chemical concentration in water is reported in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the mass (milligrams) per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is given in microsiemens per centimeter (μS/cm) at 25°C. Chemical concentrations in sediment and biota are reported in micrograms per gram (μg/g), which is equal to parts per million (ppm); micrograms per kilogram (μg/kg), which is equal to parts per billion (ppb), or in percent, which is equal to parts per hundred.

Field Screening of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Yuma Valley, Arizona, 1995

By Saeid Tadayon[1], Kirke A. King[2], Brenda J. Andrews[2], *and* William P. Roberts[1]

Abstract

Because of concerns expressed by the U.S. Congress and the environmental community, the Department of the Interior began a program in late 1985 to identify the nature and extent of water-quality problems induced by irrigation that might exist in the western States. Surface water, bottom sediment, and biota were collected from March through September 1995 along the lower Colorado River and in agricultural drains at nine sites in the Yuma Valley, Arizona, and analyzed for selected inorganic and organic constituents. Analyses of water, bottom sediment, and biota were completed to determine if irrigation return flow has caused, or has the potential to cause, harmful effects on human health, fish, and wildlife in the study area.

Concentrations of dissolved solids in surface-water samples collected in March generally did not vary substantially from surface-water samples collected in June. Concentrations of dissolved solids ranged from 712 to 3,000 milligrams per liter and exceeded the U.S. Environmental Protection Agency secondary maximum contaminant level of 500 milligrams per liter for drinking water. Concentrations of chloride in 9 of 18 water samples and concentrations of sulfate in 16 of 18 water samples exceeded the U.S. Environmental Protection Agency secondary maximum contaminant level of 250 milligrams per liter for drinking water. Calcium and sodium were the dominant cations, and chloride and sulfate were the dominant anions.

The maximum selenium concentration of 8 micrograms per liter exceeded the U.S. Environmental Protection Agency aquatic-life chronic criterion of 5 micrograms per liter. Concentrations of lead in 7 of 18 water samples and concentrations of mercury in 4 of 18 water samples exceeded the aquatic-life chronic criteria of 3.2 and 0.012 micrograms per liter, respectively. Concentrations of antimony, beryllium, cadmium, and silver in the water samples were below analytical reporting limits.

Arsenic was detected in 3 of 9 bottom-sediment samples, and concentrations ranged from 11 to 16 micrograms per gram. Concentrations of aluminum, beryllium, boron, copper, lead, and zinc were highest in samples from Main Drain at southerly international boundary near San Luis, Arizona. Selenium was detected in all bottom-sediment samples, and concentrations ranged from 0.1 to 0.7 micrograms per gram. Concentrations of cadmium, europium, holmium, mercury, molybdenum, silver, tantalum, tin, and uranium were below analytical reporting limits in the bottom-sediment samples. Concentrations of trace elements in bottom-sediment samples were

[1]U.S. Geological Survey, 520 N. Park Avenue, Suite 221, Tucson, AZ 85719-5035.
[2]U.S. Fish and Wildlife Service, 2321 West Royal Palm Road, Suite 103, Phoenix, AZ 85021-4951.

within the ranges found in a study of soils of the western United States and did not indicate a significant accumulation of these constituents. p,p'-Dichlorodiphenyldichloroethylene (commonly referred to as p,p'-DDE) was detected in one bottom-sediment sample at a concentration of 1.4 micrograms per gram. No other organochlorine compounds were detected in the bottom-sediment samples.

DDE was present in all fish and bird samples. Almost one-half of the fish samples contained DDE residues that were two times higher than the mean calculated for a national study in 1984–85. Twenty-three percent of the fish contained more than three times the national mean. Fish from downstream parts of the Main Drain had the highest concentrations of DDE. Although concentrations of DDE in fish and in bird carcasses and eggs were above background levels, residues generally were below thresholds associated with chronic poisoning and reproductive problems in fish and wildlife.

Concentrations of 18 trace elements were detected in cattail (*Typha sp.*) roots, freshwater clam (*Corbicula fluminea*), fish, and bird samples. Selenium in most fish and in livers of red-winged (*Agelaius phoeniceus*) and yellow-headed (*Xanthocephalus xanthocephalus*) blackbirds was above background concentrations but below toxic concentrations. In contrast, selenium was present in a killdeer (*Charadrius vociferus*) liver sample at potentially toxic concentrations. Arsenic, cadmium, mercury, and selenium did not occur with the frequency or at concentrations that would cause concern for fish and wildlife populations except for the selenium in killdeer. Aluminum, chromium, copper, and nickel contamination was especially high at the Main Drain at the international boundary near San Luis. Common carp (*Cyprinus carpio*) from this site contained the highest mean concentrations of aluminum and chromium ever recorded in Arizona.

INTRODUCTION

During the past decade, there has been increasing concern about the quality of irrigation drainage— surface and subsurface water that drains irrigated land—and its potential effects on human health, fish, and wildlife. Elevated concentrations of selenium have been detected in subsurface drainage water from irrigated land in the western part of the San Joaquin Valley in California. In 1983, incidences of mortality, congenital defects, and reproductive failures in waterfowl were reported by the U.S. Fish and Wildlife Service (USFWS) at the Kesterson National Wildlife Refuge in the western part of the San Joaquin Valley where irrigation drainage was impounded. In addition, potentially toxic trace elements and pesticide residues have been detected in other areas in the western States that receive irrigation drainage.

Because of concerns expressed by the U.S. Congress and environmental organizations, the U.S. Department of the Interior (DOI) began a program in late 1985 to identify the nature and extent of water-quality problems induced by irrigation drainage that might exist in the western States. In October 1985, an interbureau group known as the "Task Group on Irrigation Drainage" was formed within the DOI. The Task Group prepared a comprehensive plan for reviewing irrigation-drainage concerns for which the DOI may have responsibility. Subsequently, 26 areas in 13 States that warranted reconnaissance-level studies were identified. The study areas relate to three areas of DOI responsibility: (1) irrigation or drainage facilities constructed or managed by the DOI; (2) national wildlife refuges managed by the DOI that receive irrigation drainage; and (3) other migratory-bird or endangered-species management areas that receive water from DOI-funded projects. Each reconnaissance investigation was done by interbureau field teams of scientists representing different disciplines from the U.S. Geological Survey (USGS), USFWS, Bureau of Reclamation, and Bureau of Indian Affairs.

As part of the DOI irrigation-drainage program, surface water, bottom sediment, and biota were collected and analyzed in 1986–87 to determine concentrations of trace elements and organochlorine compounds in the lower Colorado River Valley (Radtke and others, 1988). Trace elements and organochlorine compounds were detected in some of the samples.

In March 1995, the USGS, in cooperation with the USFWS, began a second investigation along the lower Colorado River and in agricultural drains at nine sites in the Yuma Valley, Arizona (fig. 1). Surface-water and bottom-sediment samples were collected by the USGS, and biota samples were collected by the USFWS. Surface water, bottom sediment, and biota were analyzed for selected inorganic and organic constituents to determine if the irrigation return flow has caused or has the potential to cause harmful effects to human health, fish, and wildlife in the study area.

Purpose and Scope

Samples of surface water, bottom sediment, and biota (cattails, freshwater clams, fish, and birds) were collected and analyzed for selected inorganic and organic constituents. Surface-water samples were collected in March and again in June 1995, bottom-sediment samples were collected in June, and biota samples were collected between March and September of 1995. Analytical results from these samples were compared with established Federal and State standards to interpret the magnitude and spatial variation of the concentrations of these constituents. The purpose of this report is to present the results of the field screening in the Yuma Valley, Arizona. Data are in table 4, figure 2, and in tables 7–16 in the "Basic Data" section at the end of the report.

Previous Investigations

Several hydrologic and environmental investigations were conducted within the watersheds of the lower Colorado River and Gila River. In a nationwide sampling program completed by the USFWS in 1984 for contaminants in fish, the National Contaminant Biomonitoring Program (NCBP) reported that 5 of the 10 highest arithmetic mean selenium concentrations occurred in fish from the lower Colorado River (Schmitt and Brumbaugh, 1990).

In a USGS reconnaissance investigation of water, sediment, and biota in the lower Colorado River Valley, selenium concentrations in some samples exceeded guidelines for protection of fish and wildlife resources (Radtke and others, 1988). With the exception of cadmium, the dissolved trace elements, radionuclides, and organochlorine-compound data from the lower Colorado River did not exceed State of Arizona maximum allowable limits for protected uses of surface water. Selenium concentrations in bottom sediment ranged from about one to five times the 95-percent baseline for western soils. In addition, dichlorodiphenyldichloroethane (DDD), dichlorodiphenyldichloroethylene (DDE), dichlorodiphenyltrichloroethane (DDT), and polychlorinated biphenyls (PCB's) were detected in bottom sediment in the study area. DDE was detected in all bottom-sediment samples and ranged from 0.1 to 7.5 µg/kg dry weight. Mean concentrations of selenium and zinc in carp-tissue samples at all sites exceeded the NCBP 85th percentile for fish.

In a study by the USFWS, Baker and others (1992) stated that toxaphene, DDE, dieldrin, and chlordane concentrations in sediment and fish samples collected from 1976 to 1989 remained stable at levels below those known to adversely affect fish and wildlife. Concentrations of several trace elements that include aluminum, arsenic, barium, beryllium, boron, chromium, copper, iron, manganese, vanadium, and zinc, however, appeared to be increasing in plant tissues and (or) sediments. Selenium in irrigation drainage was at levels that can be bioaccumulated in the food chain.

DESCRIPTION OF THE STUDY AREA

The study area includes the lower Colorado River and agricultural drains near Yuma, Arizona (fig. 1). The study area includes about 150,000 acres of irrigable land. Although the Yuma Valley is one of the most arid parts of the United States, irrigation has made possible an almost

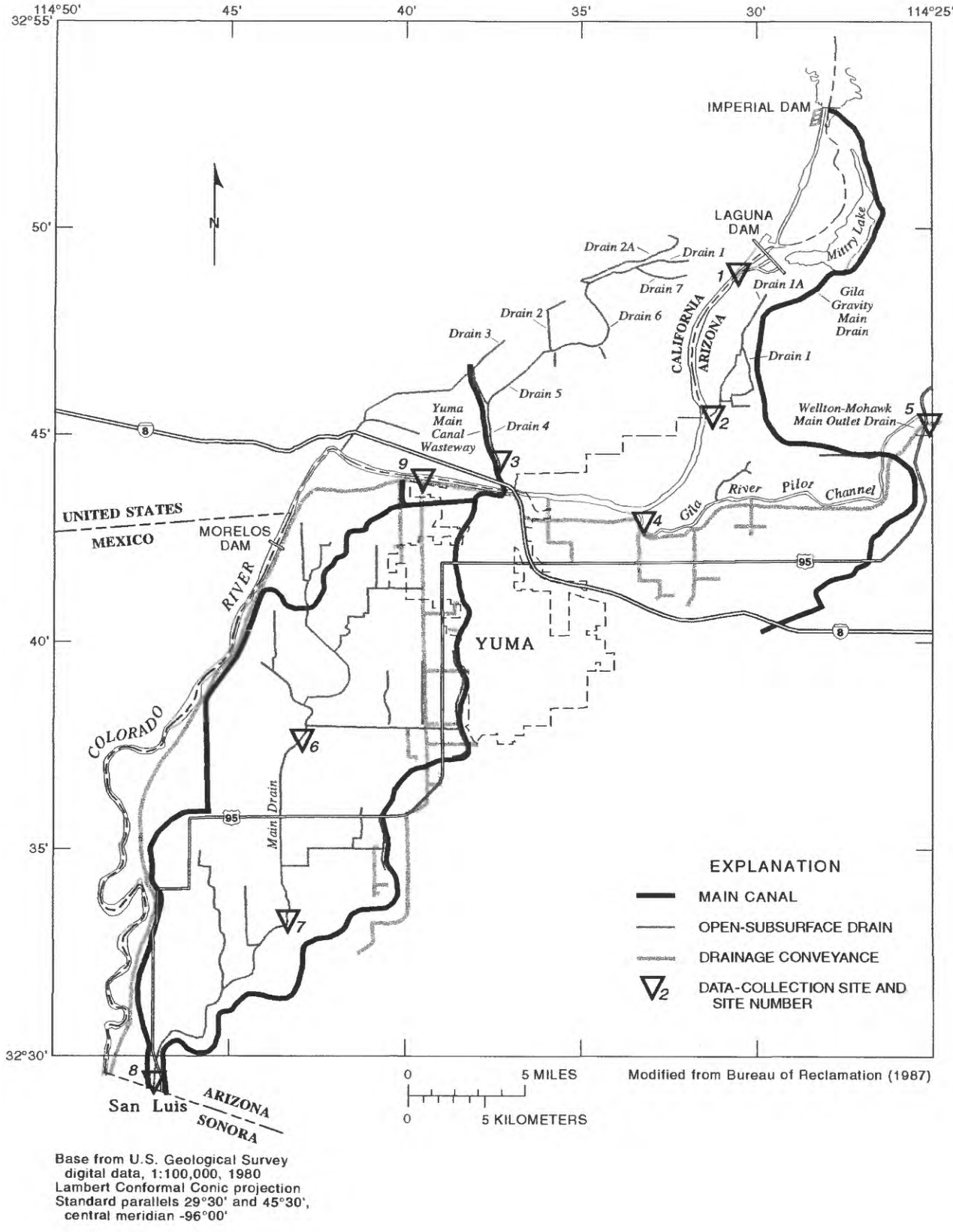

Figure 1. Data-collection sites, Yuma Valley, Arizona, 1995.

continuous growing season. The average consumptive use of water by crops in the Yuma Valley is about 4 acre-ft/acre. Agricultural activities have added chemicals to the entire study area and changed ground-water flow patterns, surface-water distributions, and the saturated thickness of the aquifer. Major crops include cotton, alfalfa, wheat, vegetables (lettuce, cauliflower, and broccoli), and citrus.

The Colorado River is the major source of irrigation and ground-water recharge in the Yuma Valley. Much of the ground water is derived from irrigation that is discharged by surface drains or by drainage wells. In addition to being important resources to millions of people in Arizona, California, and northern Mexico, the Colorado River and its tributary, the Gila River, also provide an important wetland habitat for migratory birds and are frequented by several endangered species—the bald eagle (*Haliaeetus leucocephalus*), brown pelican (*Pelecanus occidentalis*), peregrine falcon (*Falco peregrinus*), and Yuma Clapper rail (*Rallus longirostris yumanensis*). Two Federal wildlife facilities (Imperial and Cibola National Wildlife Refuges) and one State wildlife management area (Mittry) are in the study area.

The Yuma Valley has a warm, arid climate that is characterized by hot summers and mild winters. In the summer, high temperatures that combine with moist air from the Gulf of Mexico may result in occasional high-intensity thunderstorms. Winter storms are characterized by gentle rain, which results in little or no runoff. During 1986–95, the annual precipitation in Yuma ranged from 0.83 to 5.13 in., and the temperature ranged from a monthly mean of 11.9°C in January to 36.2°C in August (U.S. Department of Commerce, 1986–95). Mean annual precipitation in Yuma is between 4 and 5 in.

The study area is in the Sonoran Desert, a region of barren, low, and generally northwestward-trending mountain ranges separated by extensive desert basins. The geologic materials range from hard, dense crystalline rocks, such as gneiss, schist, and granite, to unconsolidated alluvium and windblown sand (Olmsted and others, 1973). The unconsolidated sediment was deposited during the late Tertiary and Quaternary periods and from mid-Pliocene to Holocene (Barmore, 1980). Soils in the Yuma Valley generally are alkaline and consist of fine sandy loam to silty clay loam.

Surface-water, bottom-sediment, and biota samples were collected along the lower Colorado River and also from agricultural drains at nine sites in the Yuma area (table 1). The study area extends from about 1.4 mi downstream from Laguna Dam to the international boundary between the United States and Mexico (fig. 1).

SAMPLE COLLECTION AND ANALYSIS

Surface-Water Samples

Surface-water samples were collected in March and June 1995 from nine sites along the lower Colorado River and from agricultural drains in the Yuma Valley (tables 1 and 2; fig. 1). Water samples were collected and processed according to methods described by Ward and Harr (1990). On-site measurements of pH, alkalinity, specific conductance, dissolved-oxygen concentration, air temperature, and water temperature were made at the time of the sampling. Water samples were analyzed for concentrations of major ions, nitrite plus nitrate, and trace elements (table 3). Water samples collected for measurement of dissolved inorganic constituents were filtered through a 45-micrometer membrane filter. Samples collected for analyses of hardness were not filtered. Nitric acid was added to the samples collected for the determination of most major ions and trace elements; potassium dichromate was added to samples collected for mercury analysis. The samples were analyzed by the USGS National Water-Quality Laboratory in Arvada, Colorado. Inorganic constituents were analyzed using procedures described by Fishman and Friedman (1989).

Duplicates and field blanks were collected to ensure the precision and accuracy of the surface-water samples. Duplicates were collected at sites 2 and 6 in March and June of 1995, respectively. Field blanks were collected in March and June 1995. Duplicates and field blanks were analyzed for the same constituents and were subjected to the same process of sample collection, field processing, preservation, and laboratory handling as the environmental samples. Field blanks were collected by pouring deionized water

Table 1. Sampling sites where surface water, bottom sediment, and biota were collected, Yuma Valley, Arizona, 1995

Site number	Station number	Station name	Remarks
1	09429600	Colorado River below Laguna Dam	Site 1 is about 1.4 miles downstream from Laguna Dam at the USGS streamflow-gaging station. Site serves as an upstream reference that has not been influenced by agriculture in the Yuma Valley.
2	09529000	North Gila Drain No. 1, near Yuma	Site 2 is northeast of Yuma. Drain 1 and its tributary, Drain 1A, drain intensively cultivated land in Arizona.
3	09530000	Reservation Main Drain No. 4 at Yuma	Site 3 includes feeder drains 1, 2, 2A, 3, 5, 6, and 7 that flow into Drain 4 before emptying into the Colorado River just north of Yuma. These waterways drain agricultural lands in California.
4	09520700	Gila River near mouth, near Yuma	Site 4 receives considerable return flow from project drains south of Gila River that has not been influenced by agriculture.
5	09529300	Wellton–Mohawk Main Outlet Drain near Yuma	Site 5 is a drain at the eastern project boundary and also is a reference site.
6	323732114425701	Main Drain	Site 6 is just downstream from the East Drain and represents drainage from extensive agricultural land south of the City of Yuma.
7	323310114433001	Main Drain	Site 7 is just downstream from the Southeast Drain and represents drainage from the south-central part of the study area.
8	09534000	Main Drain at southerly international boundary, near San Luis	Site 8, Main Drain at the international boundary, near San Luis, collects most of the drain water from the study area. Many feeder drains are in the intensively cultivated farmland southwest of Yuma. This drain flows into Mexico at the town of San Luis.
9	09521100	Colorado River below Yuma Main Canal Wasteway, at Yuma	Site 9 is 5.3 miles downstream from Gila River, and 6.4 miles upstream from the international boundary.

into the sample bottle and by putting deionized water through the churn splitter. To prepare a field blank for analysis of dissolved-inorganic constituents, the deionized water was passed through a 45-micrometer membrane filter.

Bottom-Sediment Samples

Bottom-sediment samples were collected at nine sites for trace elements and at four sites for organochlorine compounds (tables 2 and 3). Sediment samples were collected using a scoop sampler when the water was shallow and a clam sampler when the water was deep. Samples from each site were collected in several sections across the channel, composited, and mixed into a single representative sample. A 500-micrometer mesh nylon sieve was used to sieve sediment samples for trace elements, and a 2.0-millimeter steel sieve was used for organochlorine analyses. At the laboratory, samples collected for trace-element analyses were air dried and then crushed and sieved through a 230-mesh (63-micrometer) screen. The fine materials that passed through the screen were retained and analyzed. Samples were analyzed for organochlorine compounds by the USGS National Water-Quality Laboratory in Arvada, Colorado; however, analyses for trace elements were done by the USGS Environmental Geochemistry Laboratory in Lakewood, Colorado. Bottom sediment was analyzed using procedures described by Wershaw and others (1987) and Severson and others (1987).

Biota Samples

Samples were collected between March and September 1995 (table 1). Three cattail (*Typha sp.*) plants were collected at each location except site 5

Table 2. Types of field measurements and laboratory analyses for samples collected at sampling sites, Yuma Valley, Arizona, 1995

Analyses performed	Sites where samples were collected (see fig. 1)
Field measurements of surface-water samples	
pH, alkalinity, specific conductance, dissolved oxygen, temperature, major ions, nitrite plus nitrate, and trace elements	1–9
Laboratory analyses of bottom-sediment samples	
Trace elements	1–9
Organochlorine compounds	1, 5, 8, and 9
Laboratory analyses of biota samples	
Trace elements (cattail[1])	1–4 and 6–9
Trace elements (clam[2])	1, 2, 5, 6, 8, and 9
Trace elements and organochlorine compounds (fish[3])	1–6, 8, and 9
Trace elements and organochlorine compounds (avian[4])	2, 4, and 6

[1]Composite sample of roots from three plants per site.
[2]Composite of 12–50 individuals per site.
[3]Common carp were collected from sites 1–6, 8, and 9. Five striped mullet were collected each from sites 3 and 4 and composited into a single sample per site. Channel catfish and flathead catfish were collected from sites 6 and 9, respectively.
[4]Yellow-headed blackbird carcasses and egg samples were collected from site 2, red-winged blackbird carcasses from site 6, and killdeer from site 4.

where the banks were too steep to support cattails. The roots were gently washed in drain or river water where collected to remove excess sediment. The roots were cut from the stem and combined into a single composite sample from each area. Each sample was then weighed, wrapped in aluminum foil, and placed on wet ice until it could be transferred to a commercial freezer.

Clams (*Corbicula fluminea*) were collected by sweeping bottom sediment by hand. Individuals were counted, then opened, and the contents removed. Excess water was blotted from the tissue, and the tissues were pooled on tared aluminum foil sheets and weighed. Fish were collected using a gill net, hook and line, or a .22-caliber rifle or pistol. Whole fish were individually weighed and measured. Carp (*Cyprinus carpio*) and catfish (*Ictalurus punctatus, Pimethales promelas*) samples were individually wrapped in aluminum foil. Striped mullet (*Mugil cephalus*) were collected from two sites. Five mullet from each site were weighed, measured, and composited into a single sample by site. Birds were collected by shotgun using steel shot. Whole bodies were weighed and plucked, and the bill, feet, wingtips, and gastrointestinal tract were removed and discarded. Bird livers were pooled into a single sample per site and analyzed for metals. Carcasses were composited by species at each site and analyzed for organochlorine compounds. Clams, fish, and bird carcass and liver samples were wrapped in aluminum foil and placed on wet ice until transferred to a commercial freezer. Contents of a single clutch of four eggs of the yellow-headed blackbird (*Xanthocephalus xanthocephlus*) were composited in an acid-rinsed jar and frozen for organochlorine analysis.

Samples were analyzed for selected organochlorine compounds at Hazelton Environmental Services, Inc., Madison, Wisconsin (table 2). For each analysis, the sample was homogenized, and a portion was mixed with anhydrous sodium sulfate and extracted with hexane in a Soxhlet apparatus for 7 hours. Lipids were removed by Florisil column chromatography (Cromartie and others, 1975). Sep-pak Florisil cartridges were used to remove the lipids (Clark and others, 1983). The organochlorine compounds were separated into four fractions on a SilicAR column to ensure the separation of dieldrin or endrin into an individual fraction (Kaiser and others, 1980). The individual fractions were analyzed with a gas-liquid chromatograph equipped with an electron-capture detector and a 1.5/1.95 percent SP-2250/SP-2401 column. Residues in 10 percent of the samples were confirmed by gas chromatography/mass spectrometry. The lower limit of quantification varied with sample mass but was usually 0.01 µg/g for all organochlorine compounds and 0.05 µg/g for PCB's. Results of organochlorine analyses are expressed in micrograms per gram, wet weight, unless otherwise specified.

Bird livers, fish, clams, and cattail roots also were analyzed for aluminum, arsenic, barium, beryllium, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, strontium, vanadium, and zinc. Arsenic and selenium concentrations were determined by graphite-furnace atomic-absorption

Table 3. Chemical and physical determinations of surface-water, bottom-sediment, and biota samples, Yuma Valley, Arizona, 1995

[µS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; °C, degrees Celsius; µg/L, micrograms per liter; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; o,p'-DDD, o,p'-dichlorodiphenyldichloroethane; p,p'-DDD, p,p'-dichlorodiphenyldichloroethane; o,p'-DDE, o,p'-dichlorodiphenyldichloroethylene; p,p'-DDE, p,p'-dichlorodiphenylchloroethylene; o,p'-DDT, o,p'-dichlorodiphenyltrichloroethane; p,p'-DDT, p,p'-dichlorodiphenyltrichloroethane]

Surface water	Bottom sediment		Biota
Field determinations	**Trace elements**	**Organochlorine compounds (µg/kg)**	**Trace elements (µg/g)**
Specific conductance (µS/cm)	Aluminum (%)	Aldrin	Aluminium
Alkalinity (mg/L)	Arsenic (µg/g)	Benzene, hexachlor	Arsenic
pH (units)	Barium (µg/g)	Alpha benzene hexachloride (alpha-BHC)	Barium
Dissolved oxygen (mg/L)	Beryllium (µg/g)	Beta benzene hexachloride (beta-BHC)	Beryllium
Temperature (°C)	Bismuth (µg/g)	cis-Chlordane	Boron
Major ions (mg/L)	Boron (µg/g)	trans-Chlordane	Cadmium
Bromide	Cadmium (%)	Chloroneb	Chromium
Chloride	Calcium (%)	Dacthal (DCPA)	Copper
Fluoride	Cerium (µg/g)	o,p'-DDD	Iron
Magnesium	Chromium (µg/g)	p,p'-DDD	Lead
Potassium	Cobalt (µg/g)	o,p'-DDE	Magnesium
Silica	Copper (µg/g)	p,p'-DDE	Manganese
Sodium	Europium (µg/g)	o,p'-DDT	Mercury
Sulfate	Gallium (µg/g)	p,p'-DDT	Molybdenum
Nutrients (mg/L)	Gold (µg/g)	Dieldrin	Nickel
Nitrite plus nitrate	Holmium (µg/g)	Endrin	Selenium
Trace elements (µg/L)	Iron (µg/g)	Endosulfan	Strontium
Aluminum	Lanthanum (µg/g)	Heptachlor	Thallium
Antimony	Lead (µg/g)	Heptachlor epoxide	Vanadium
Arsenic	Lithium (µg/g)	Isodrin	Zinc
Barium	Magnesium (%)	Lindane	**Organochlorine compounds (µg/g)**
Beryllium	Mercury (µg/g)	o,p'-Methoxychlor	Aldrin
Boron	Molybdenum (µg/g)	p,p'-Methoxychlor	Alpha benzene hexachloride (alpha-BHC)
Cadmium	Neodymium (µg/g)	Mirex	Beta benzene hexachloride (beta-BHC)
Chromium	Nickel (µg/g)	cis-Nonachlor	Delta benzene hexachloride (delta-BHC)
Cobalt	Niobium (µg/g)	trans-Nonachlor	Gamma benzine hexachloride (gamma-BHC)
Copper	Phosphorus (%)	Oxychlordane	cis-Chlordane
Iron	Potassium (%)	Pentachloronisole	trans-Chlordane
Lead	Scandium (µg/g)	cis-Permethrin	o,p'-DDD
Manganese	Selenium (µg/g)	trans-Permethrin	p,p'-DDD
Mercury	Silver (µg/g)	Polychlorinated biphenyls (PCB's)	o,p'-DDE
Molybdenum	Sodium (%)	Toxaphene	p,p'-DDE
Nickel	Strontium (µg/g)		o,p'-DDT
Selenium	Tantalum (µg/g)		p,p'-DDT
Silver	Thorium (µg/g)		Dieldrin
Uranium	Tin (µg/g)		Endrin
Vanadium	Titanium (µg/g)		Heptachlor epoxide
Zinc	Uranium (µg/g)		Hexachlorobenzene (HCB)
	Vanadium (µg/g)		Mirex
	Yttrium (µg/g)		cis-Nonachlor
	Ytterbium (µg/g)		trans-Nonachlor
	Zinc (µg/g)		Oxychlordane
			Polychlorinated biphenyls (PCB's)
			Toxaphene

spectrophotometry (U.S. Environmental Protection Agency, 1984). Mercury concentrations were quantified by cold-vapor atomic absorption (U.S. Environmental Protection Agency, 1984). All other elements were analyzed by inductively coupled plasma atomic-emission spectroscopy (Dahlquist and Knoll, 1978; U.S. Environmental Protection Agency, 1987). Blanks, duplicates, and spiked samples were used to maintain quality assurance and quality control (QA/QC) in the laboratory. QA/QC was monitored by Patuxent Analytical Control Facility (PACF). Analytical methods and reports met or exceeded PACF QA/QC standards. Concentrations of trace elements in cattails, clams, and birds are reported in micrograms per gram, dry weight. Concentrations of trace elements in fish are expressed both in micrograms per gram wet weight and dry weight to facilitate data comparison with published studies. Percent moisture is listed in table 10 (see "Basic Data" section at the back of this report) for readers who wish to convert dry-weight values to wet-weight equivalents. See also the "Conversion Factors" section at the beginning of the report.

Because of the limited sample size—one sample per site—contaminant residues in cattail, clam, mullet, and avian samples were not statistically analyzed. Geometric mean DDE and metalloid concentrations in carp collected from eight sites were statistically compared using analysis of variance (ANOVA) to better define differences in contaminant levels in carp. Organochlorine-compound and trace-element concentrations were transformed to logarithms for statistical comparisons; geometric means are presented in table 11 (see "Basic Data" section at the back of this report). The Bonferroni multiple-comparison method (Neter and Wasserman, 1974) was used to test for mean separation when ANOVA showed significant differences.

Organochlorine residues in fish from the Yuma Valley were compared with those reported by the NCBP for fish collected in 1984–85 from 112 stations nationwide (Schmitt and others, 1990). DDE was detected in fish tissue at 98 percent of the national sampling sites; thus the NCBP study provides a benchmark with which to compare organochlorine-compound contamination in fish from the Colorado River and irrigation drain water from the Yuma Valley in context with the rest of the country. Similarly, trace-element concentrations in fish from the Yuma Valley were compared with the NCBP data compiled for fish collected from 109 stations in 1984–85 (Schmitt and Brumbaugh, 1990). For trace elements, Schmitt and Brumbaugh (1990) calculated the 85th percentile for each element. In this study, concentrations of a trace element were considered elevated when they exceeded the 85th percentile of the nationwide geometric mean. The 85th percentile was not based on toxicity hazards to fish, but provides a frame of reference to identify trace elements of potential concern.

Comparisons of data from this study with data from the NCBP should be made with caution as, by definition, the NCBP data are national in scope. Regional bias is not taken into account. Also, NCBP data are based on chemical analysis of an aggregate of fish species that may not be representative of species sampled in this study. Nevertheless, the NCBP data provide a useful frame of reference with which to compare the data in this study.

DISCUSSION OF RESULTS

Water Quality

A summary of selected chemical and physical data was prepared for surface-water samples from the Yuma Valley (table 4). Results of the analyses of all surface-water samples are shown in table 8 (see "Basic Data" section at the back of this report). Some surface-water data were compared with the U.S. Environmental Protection Agency (USEPA) drinking-water regulations (U.S. Environmental Protection Agency, 1994a, b), aquatic-life criteria (U.S. Environmental Protection Agency, 1986), and State of Arizona surface-water quality standards (State of Arizona, 1992); the results are presented in table 5.

Properties.—pH ranged from 7.7 to 8.2, and the median value was 8.0 for 18 samples. Values of pH generally were similar in samples collected in March and June and were within the secondary maximum contaminant level (SMCL) range of 6.5 to 8.5 and chronic criteria range of 6.5 to 9 set by the USEPA for drinking water and aquatic life,

Table 4. Statistical summary of selected properties and inorganic constituents in surface-water samples, Yuma Valley, Arizona, March and June 1995

[µS/cm, microsiemens per centimeter at 25°Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; ND, not detected; <, less than]

Constituent	Number of analyses	Minimum	Maximum	Median
Specific conductance (µS/cm)	18	1,200	4,500	1,910
pH (units)	18	7.7	8.2	7.95
Water temperature (°C)	17	18	29.5	24.5
Hardness as $CaCO_3$ (mg/L)	18	240	760	525
Alkalinity as $CaCO_3$ (mg/L)	18	152	358	236
Dissolved solids at 180°C (mg/L)	18	712	3,000	1,460
Bromide (mg/L)	18	.09	.63	.22
Calcium, dissolved (mg/L)	18	60	180	135
Magnesium, dissolved (mg/L)	18	21	75	46
Sodium, dissolved (mg/L)	18	120	700	265
Sodium adsorption ratio	18	3	11	4.5
Potassium, dissolved (mg/L)	18	5	7.6	5.25
Bicarbonate as HCO_3 (mg/L)	16	185	437	284
Sulfate, dissolved (mg/L)	18	130	890	485
Chloride, dissolved (mg/L)	18	120	790	265
Fluoride, dissolved (mg/L)	18	.5	1.9	.6
Silica, dissolved (mg/L)	18	11	23	20.5
Nitrogen, nitrite plus nitrate, dissolved, as N (mg/L)	18	.05	2.80	1.35
Aluminum, dissolved (µg/L)	18	<1	6	3
Antimony, dissolved (µg/L)	18	ND	ND	ND
Arsenic, dissolved (µg/L)	18	<1	12	2
Barium, dissolved (µg/L)	18	26	130	61.5
Beryllium, dissolved (µg/L)	18	ND	ND	ND
Boron, dissolved (µg/L)	18	180	1,300	335
Cadmium, dissolved (µg/L)	18	ND	ND	ND
Chromium, dissolved (µg/L)	18	<1	6	3
Cobalt, dissolved (µg/L)	18	ND	ND	ND
Copper, dissolved (µg/L)	18	2	11	5
Iron, dissolved (µg/L)	18	<3	12	<9
Lead, dissolved (µg/L)	18	<1	15	<2
Manganese, dissolved (µg/L)	18	5	410	62.5
Mercury, dissolved (µg/L)	18	<.1	1.8	<.1
Molybdenum, dissolved (µg/L)	18	4	38	11
Nickel, dissolved (µg/L)	18	4	13	8
Selenium, dissolved (µg/L)	18	<1	8	<1
Silver, dissolved (µg/L)	18	ND	ND	ND
Uranium, dissolved (µg/L)	18	3	18	5
Vanadium, dissolved (µg/L)	18	3	54	8
Zinc, dissolved (µg/L)	18	3	10	6

Table 5. Drinking-water regulations and aquatic-life criteria for selected constituents

[MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; DWS, domestic water source; AgI, agricultural irrigation; AgL, agricultural livestock watering; mg/L, milligrams per liter; µg/L, micrograms per liter; ---, no established level; D, dissolved]

	Drinking-water regulations		Aquatic-life criteria[1]		State of Arizona surface-water quality standards[2]		
Constituent	MCL[3]	SMCL[4]	Chronic	Acute	Domestic water source (DWS)[5]	Agricultural irrigation (AgI)[5]	Agricultural livestock watering (AgL)[5]
pH (units)	---	6.5–8.5	6.5–9	---	5.0–9.0	4.5–9.0	6.5–9.0
Chloride (mg/L)	---	250	---	---	---	---	---
Fluoride (mg/L)	4	---	---	---	4	---	---
Sulfate (mg/L)	---	250	---	---	---	---	---
Total dissolved solids (mg/L)	---	500	---	---	---	---	---
Nitrate (as N; mg/L)	10	---	---	---	10	---	---
Nitrite (as N; mg/L)	1	---	---	---	1	---	---
Arsenic (µg/L)	50	---	---	---	50	2,000	200
Barium (µg/L)	2,000	---	---	---	1,000D	---	---
Cadmium (µg/L)	5	---	[6]1.1	[6]3.9	5	50	50
Chromium (µg/L)	100	---	[6]210	[6]1,700	100	1,000	1,000
Copper (µg/L)	---	([7])	[6]12	[6]18	1,000D	5,000	500
Iron (µg/L)	---	300	1,000	---	---	---	---
Lead (µg/L)	([7])	---	3.2	82	50	10,000	100
Manganese (µg/L)	---	50	---	---	---	10,000	---
Mercury (µg/L)	2	---	.012	2.4	2.1	---	10
Selenium (µg/L)	50	---	5	20	50	20	50
Silver (µg/L)	100	---	[6].12	[6]4.1	---	---	---
Zinc (µg/L)	---	5,000	[6]110	[6]120	5,000	10,000	25,000

[1]U.S. Environmental Protection Agency (1986).

[2]Canals in the Yuma area above the water-treatment plant in Yuma have been designated for domestic water source, agricultural-irrigation, and agricultural livestock-watering uses. Canals in the Yuma area below the water-treatment plant have been designated for agricultural-irrigation, and agricultural livestock-watering uses.

[3]U.S. Environmental Protection Agency (1994a).

[4]U.S. Environmental Protection Agency (1994b).

[5]State of Arizona (1992).

[6]Hardness-dependent criteria (100 milligrams per liter as $CaCO_3$ used).

[7]Treatment techniques are specified for drinking-water distribution systems if concentrations are above action levels of 15 micrograms per liter for lead and 1,300 micrograms per liter for copper.

respectively (U.S. Environmental Protection Agency, 1986, 1994b). Specific conductance ranged from 1,200 µS/cm at site 1 to 4,500 µS/cm at site 5, and the median value was 1,910 µS/cm for 18 samples. Hardness values ranged from 240 to 760 mg/L as $CaCO_3$, and the median value was 525 mg/L as $CaCO_3$, which indicates that the water in the study area is very hard. Alkalinity ranged from 152 mg/L $CaCO_3$ at site 1 to 358 mg/L as $CaCO_3$ at site 5. The median value of alkalinity for the 18 samples was 236 mg/L. Concentrations of dissolved oxygen ranged from 6.5 mg/L at site 2 to 14.8 mg/L at site 5, and the median value was 8.8 mg/L. Concentrations of dissolved solids ranged from 712 mg/L at site 9 in June to 3,000 mg/L at site 5 in March, and the median value for 18 samples was 1,460 mg/L. Concentrations of dissolved solids in samples collected in March generally were similar to concentrations in samples collected in June; however, the concentration of dissolved solids in the sample collected from site 4 in March was about three times the concentration in the sample collected in June. The higher concentration of dissolved solids in the sample collected in March probably was due to storm runoff in the Gila River at the time of sampling. Concentrations of dissolved solids in all water samples were above the SMCL of 500 mg/L for drinking water.

Major Ions.—The highest concentrations of calcium (180 mg/L), magnesium (75 mg/L), sodium (700 mg/L), and potassium (7.6 mg/L) were in water samples collected at site 5. With the exception of site 4, concentrations of calcium, magnesium, sodium, and potassium generally were similar for samples collected in March and June. Concentrations of calcium, magnesium, sodium, and potassium in samples collected at site 4 were higher in March than in June. Sodium-adsorption ratios, which are the proportion of sodium ions to calcium and magnesium ions expressed in milliequivalents per liter, ranged from 3 to 11, and the median value for 18 samples was 4.5.

Bicarbonate concentrations ranged from 185 mg/L at site 1 to 437 mg/L at site 5. Concentrations of dissolved chloride (790 mg/L), fluoride (1.9 mg/L), and sulfate (890 mg/L) were highest in samples collected at site 5. With the exception of site 4, concentrations of chloride, sulfate, and fluoride generally were similar in samples collected in March and June. Concentrations of chloride in 9 of 18 samples and sulfate in 16 of 18 samples exceeded the USEPA SMCL's of 250 mg/L. Calcium and sodium were the dominant cations, and chloride and sulfate were the dominant anions (fig. 2).

Nutrients.—Nitrogen compounds in surface water originate from natural and anthropogenic sources. Natural sources of nitrogen are soil and biological material; anthropogenic sources include fertilizers, sewage, and animal wastes (Hem, 1989; Moore, 1991). Dissolved nitrite plus nitrate as nitrogen (N) ranged from 0.05 mg/L at site 9 to 2.8 mg/L at site 5, and the median value for 18 samples was 1.35 mg/L. Concentrations of dissolved nitrite plus nitrate were higher in six of nine samples collected in March than in samples from the same sites collected in June.

Trace Elements.—The highest concentrations of dissolved arsenic (12 µg/L), barium (130 µg/L), chromium (6 µg/L), copper (11 µg/L), iron (12 µg/L), and zinc (10 µg/L) were below the USEPA MCL's and SMCL's for drinking water, below the chronic and acute aquatic-life criteria, and below surface-water quality standards of the State of Arizona. Dissolved lead was detected in 7 of 18 water samples, and concentrations ranged from 1 to 15 µg/L. Lead concentrations exceeded the chronic aquatic-life criterion of 3.2 µg/L at sites 5, 8, and 9. Dissolved mercury was detected in 5 of 18 samples, and concentrations ranged from 0.2 to 1.8 µg/L. Concentrations of mercury in all five samples exceeded the chronic aquatic-life criterion of 0.012 µg/L. Dissolved selenium was detected in 11 of 18 samples, and concentrations ranged from 1 to 8 µg/L. One sample collected at site 4 exceeded the chronic aquatic-life criterion of 5 µg/L. The data indicate that, in general, concentrations of dissolved trace elements from sites 6, 7, and 8 from the Main Drain did not increase with increasing distance downstream. Concentrations of dissolved lead, mercury, and selenium did not exceed the USEPA MCL's or SMCL's for drinking water or acute aquatic-life criteria in any of the water samples collected in the study area. The maximum concentrations of vanadium (54 µg/L) and zinc (13 µg/L) were in samples collected from sites 2 and 5, respectively. Antimony, beryllium,

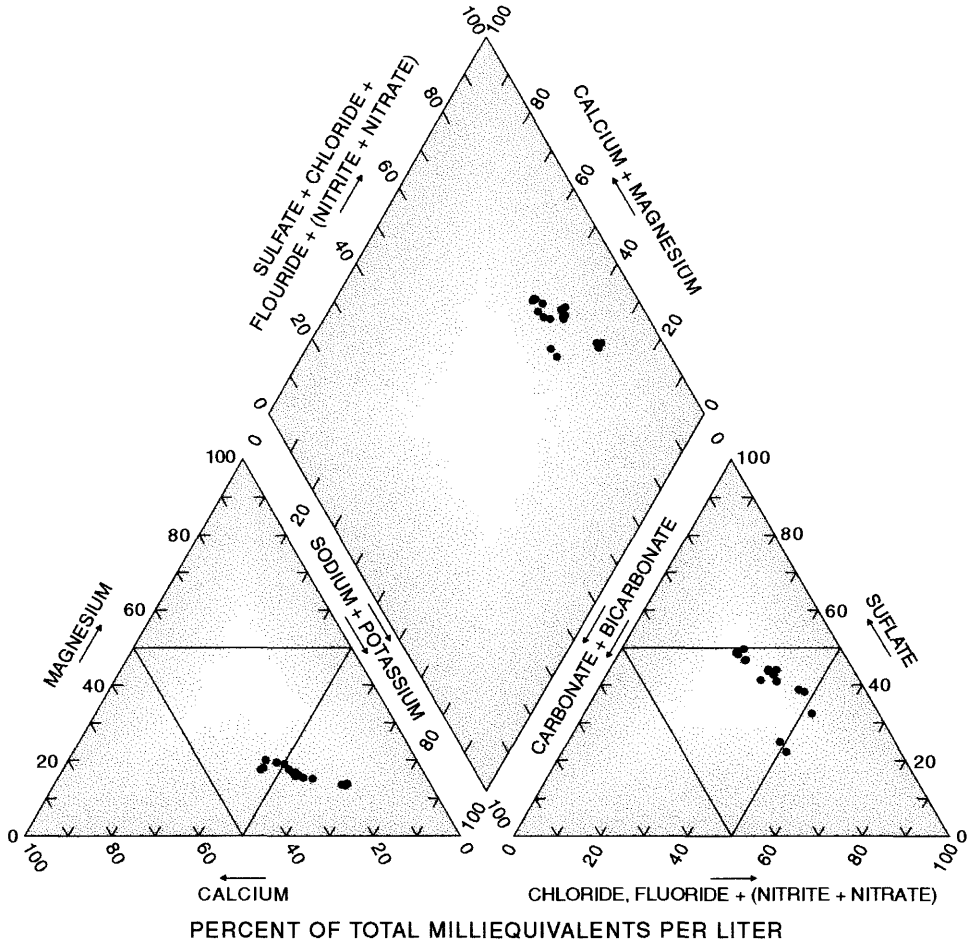

Figure 2. Composition of surface-water samples, Yuma Valley, Arizona, March and June 1995.

cadmium, and silver were not detected in any of the water samples. On the basis of analyses of two field blanks (table 7, see "Basic Data" section at the back of this report), sample collection and analytical procedures were free of contamination. The duplicate and environmental samples from sites 2 and 6 showed little or no difference in constituent concentrations (table 8, see "Basic Data" section at the back of this report).

Bottom Sediment

Results of the analyses of bottom-sediment samples for selected trace elements and organochlorine compounds are presented in table 9 (see "Basic Data" section at the back of this report). Because of the absence of trace-element criteria for bottom sediment, analytical results from the sampling sites are compared with geochemical concentrations in soils of the western United States compiled by the USGS (table 2 from Shacklette and Boerngen, 1984). Table 6 has been modified from Shacklette and Boerngen to include only the constituent concentrations that were part of the chemical analyses.

Trace Elements.—Arsenic was detected at sites 4, 5, and 9, and concentrations ranged from 11 to 16 µg/g. The highest concentrations of total recoverable aluminum (6.4 µg/g), beryllium (2 µg/g), boron (1.3 µg/g), copper (23 µg/g), lead (30 µg/g), and zinc (87 µg/g) were detected in samples from site 9. Selenium was detected at all sampling sites, and concentrations ranged from 0.1 to 0.7 µg/g. In 1986, bottom-sediment samples were collected at 11 sites along the lower Colorado

Table 6. Concentrations of trace elements in bottom-sediment samples, Yuma Valley, Arizona, and in soils of the western conterminous United States

[Minimum and maximum are reported in micrograms per gram (µg/g) or percent by weight (%); <, less than; >, greater than; ND, not detected. Modified from Shacklette and Boerngen (1984)]

Constituent	Bottom-sediment samples, Yuma Valley		Soils of the western conterminous United States		Constituent	Bottom-sediment samples, Yuma Valley		Soils of the western conterminous United States	
	Minimum	Maximum	Minimum	Maximum		Minimum	Maximum	Minimum	Maximum
Aluminum (%)	2.2	6.4	0.5	>10	Molybdenum (µg/g)	ND	ND	<3	7
Arsenic (µg/g)	<10	16	<.10	97	Neodymium (µg/g)	10	36	<70	300
Barium (µg/g)	400	590	70	5,000	Nickel (µg/g)	3	33	<5	700
Beryllium (µg/g)	<1	2	<1	15	Niobium (µg/g)	<4	13	<10	100
Boron (µg/g)	.3	1.3	<20	300	Phosphorus (µg/g)	.02	.12	40	4,500
Calcium (%)	1.6	5.2	.06	32	Potassium (%)	1.1	2.1	.19	6.3
Cerium (µg/g)	27	82	<150	300	Scandium (µg/g)	<2	14	<5	50
Chromium (µg/g)	9	170	3	2,000	Selenium (µg/g)	.1	.7	<.1	4.3
Cobalt (µg/g)	2	27	<3	50	Sodium (%)	.55	1.7	.05	10
Copper (µg/g)	2	23	2	300	Strontium (µg/g)	120	380	10	3,000
Gallium (µg/g)	4	14	<5	70	Thorium (µg/g)	<4	12	2.4	31
Iron (%)	.74	5.9	.1	>10	Tin (µg/g)	ND	ND	<.1	7.4
Lanthanum (µg/g)	15	42	<30	200	Titanium (%)	.08	1.3	.05	2
Lead (µg/g)	9	30	<10	700	Uranium (µg/g)	ND	ND	.68	7.9
Lithium (µg/g)	7	38	5	130	Vanadium (µg/g)	17	210	7	500
Magnesium (%)	.29	1.4	.03	>10	Yttrium (µg/g)	7	30	<10	150
Manganese (µg/g)	260	2,600	30	5,000	Ytterbium (µg/g)	<1	3	<1	20
Mercury (µg/g)	ND	ND	<.01	4.6	Zinc (µg/g)	23	87	10	2,100

River from Davis Dam to Imperial Dam. Concentrations of selenium from these 11 sites ranged from less than 0.1 to 7.1 µg/g (Radtke and others, 1988). In this study, concentrations of trace elements in bottom-sediment samples generally were similar at the nine sites in the study area. Cadmium, europium, holmium, mercury, molybdenum, silver, tantalum, tin, and uranium were not detected in any of the bottom-sediment samples. Concentrations of trace elements in bottom-sediment samples in the study area were within the ranges found in soils of the western United States (table 9, see "Basic Data" section at the back of this report).

Organochlorine Compounds.—The only organochlorine compound detected in the bottom-sediment samples was p,p'-DDE (1.4 µg/g) at site 9. The minimum reporting level for p,p'-DDE was 1.0 µg/g. Maximum concentrations of chlordane, DDD, DDE, DDT, and PCB's in samples collected from 11 sites along the lower Colorado River from Davis Dam to Imperial Dam in 1986 were 1.0, 2.4, 7.5, 0.8, and 4 µg/kg, respectively (Radtke and others, 1988).

Biota

Organochlorine Compounds in Fish.—Residues of DDE were detected in all 22 fish samples and individual levels ranged from 0.05 to 1.20 µg/g wet weight (table 10, see "Basic Data" section at the back of this report). Ten fish samples (carp and catfish) contained DDE at two times the national geometric mean (0.19 µg/g wet weight) reported for the sampling period in 1984–85 by the NCBP (Schmitt and others, 1990). Five samples contained more than three times the national mean for DDE. DDE residues were highest in carp from agricultural drain water at sites 2, 4, 6, 8, and 9 (ANOVA, $p = 0.0002$) and lowest at site 1 (table 11, see "Basic Data" section at the back of this report). PCB's were detected at low concentrations (less than or equal to 0.13 µg/g wet weight) in four fish samples (table 10, see "Basic Data" section at the back of this report). Dieldrin and chlordane residues were found only in carp from sites 6 and 8, which were the areas where DDE was highest. Hexachlorobenzine (HCB) was not detected in fish samples.

DDE residues in fish collected from the Yuma Valley in 1995 were higher than DDE residues in fish collected from the same general area a decade earlier. The geometric mean residue for DDE in fish collected from the Yuma Valley during this study was 0.25 µg/g wet weight (range = 0.05–1.20 µg/g).

Although not statistically significant, carp from the downstream parts of the Main Drain (sites 6 and 8) generally had the highest residues of DDE. Only one fish sample contained concentrations of DDE that exceeded the criterion for DDE and metabolites of 1.0 µg/g established for protection of wildlife (National Academy of Sciences and National Academy of Engineering, 1973).

Organochlorine Compounds in Birds.—DDE was recovered in all bird-carcass and egg samples (table 10, see "Basic Data" section at the back of this report). Concentrations in carcasses ranged from 0.75 µg/g in the yellow-headed blackbird sample to 5.90 µg/g in the killdeer sample. A single clutch of yellow-headed blackbird eggs contained 0.17 µg/g DDE. PCB's (0.06 µg/g) and chlorodane (0.01 µg/g) were detected only in the killdeer-carcass sample. Dieldrin also was detected at a low concentration (0.02 µg/g) in the red-winged blackbird (*Agelaius phoeneceus*) and killdeer-carcass samples; dieldrin was not found in the yellow-headed blackbird carcasses or eggs. HCB was detected at low concentrations (0.01–0.05 µg/g) in all bird carcasses.

The lowest DDE residue in bird eggs associated with reproductive failure is about 3 µg/g wet weight (Blus, 1984); therefore, DDE in yellow-headed blackbird eggs from the Yuma Valley was far below the critical threshold. Overall organochlorine compounds were below concentrations associated with chronic poisoning and reproductive problems in birds (Stickel, 1973; Cromartie and others, 1975; Blus, 1982, 1984).

Trace Elements in Cattails.—Concentrations of 18 metals were detected in cattail roots (table 12, see "Basic Data" section at the back of this report). Nine USEPA priority pollutants (arsenic, beryllium, cadmium, chromium, copper, lead, nickel, selenium, and zinc) were found in cattail tissues. Arsenic was present in all cattail samples, and concentrations ranged from 2.24 to 21.47 µg/g dry weight. The highest arsenic concentrations recorded in cattails were from sites 1 and 9 on the Colorado River. Beryllium was found at low concentrations in six of eight samples, and cadmium was detected in only one cattail sample. Chromium and nickel concentrations differed greatly among the sites; the highest levels generally were present in cattails collected from agricultural drains rather than the Colorado River. Copper was fairly consistent among sites varying less than one order of magnitude from lowest to highest concentration. Lead was detected in five of eight samples, and selenium was detected in seven of eight samples. The highest levels of lead and selenium were detected in cattails from agricultural drain site 2. Concentrations of zinc ranged from 29 to 46 µg/g and were fairly uniform among areas.

Trace Elements in Clams.—Concentrations of arsenic in clams were less variable than in cattail roots. Arsenic in clams was highest in those from irrigation drainage canals (table 12, see "Basic Data" section at the back of this report); however, arsenic in cattail roots was highest from the Colorado River. Beryllium and lead were not detected in clams. Cadmium was detected in all clam samples. The clam sample from site 9 contained the highest cadmium concentration (1.59 µg/g dry weight). Chromium and copper levels varied only slightly among collection sites.

The highest concentrations of chromium and copper were detected in samples from sites on the Colorado River rather than agricultural drains. Concentrations of nickel ranged from 1.41 to 15.02 µg/g; the highest levels were detected in clams from sites 5 and 6. Selenium in clams ranged from 3.83 µg/g at site 6 to 8.70 µg/g at site 5. Concentrations of zinc generally were consistent and ranged from 68 to 94 µg/g from site to site. Mean concentrations of zinc (ANOVA, $p = 0.0001$) were significantly higher in clams (84 µg/g) than in cattail roots (34 µg/g).

Trace Elements in Fish.—Concentrations of all trace elements detected in fish are presented in table 13 (see "Basic Data" section at the back of this report). Although aluminum is not a USEPA priority pollutant, the especially high concentrations found in carp from site 8 warrants special mention. Unfortunately, there are no NCBP aluminum data for comparison. Aluminum in carp from site 8 (tables 13 and 14, see "Basic Data" section at the back of this report) varied from 681 to 1,118 µg/g, dry weight (wet weight, range = 154–255 µg/g; mean = 205 µg/g). The mean level of aluminum in carp from site 8 was 5.5 times greater than the site with the next highest mean. By comparison, aluminum concentrations in carp from several Arizona lakes and rivers including Lake Pleasant, Alamo Lake, San Carlos Reservoir, and the Verde River ranged from 2.6 to 60.6 µg/g wet weight (King and others, 1991). The maximum aluminum level in carp from the effluent-dominated lower Gila River was 172 µg/g wet weight (King and others, 1997). Comparing the carp data from site 8 with data from these and three other Arizona studies (Radtke and others, 1988; King and others, 1993; and Baker and King, 1994) indicates that carp collected at site 8 had the highest mean concentrations of aluminum ever recorded in Arizona. These levels indicate a probable point source of aluminum contamination near site 8.

NCBP data are available for seven elements—arsenic, cadmium, copper, lead, mercury, selenium, and zinc reported in wet weight (Schmitt and Brumbaugh, 1990). Arsenic was recovered in all our fish samples. Wet weight concentrations ranged from 0.06 to 1.70 µg/g (table 15, see "Basic Data" section at the back of this report). The NCBP 85th percentile for arsenic was 0.27 µg/g (Schmitt and Brumbaugh, 1990). Elevated arsenic levels (greater than or equal to the NCBP 85th percentile) occurred most frequently (100 percent, 5/5) in carp from site 1 (table 15, see "Basic Data" section at the back of this report). Arsenic also exceeded the NCBP 85th percentile in one or more samples from each of the other sites except sites 2 and 9. A one-way ANOVA ($p = 0.1497$), however, indicated that there were no differences among sites.

Arsenic acts as a cumulative poison (Jenkins, 1981) and is listed by the USEPA as one of 129 priority pollutants (Keith and Telliard, 1979). Data from this study confirm observations reported by Jenkins (1981) that the potential bioaccumulation or bioconcentration of arsenic was moderate for fish and birds and high to very high for mollusks and higher plants. Chronic arsenic poisoning is seldom encountered in any species except man (Eisler, 1988). Background arsenic concentrations in biota usually are less than 1 µg/g wet weight (Eisler, 1988). Only the composite mullet sample collected at the confluence of the Gila and Colorado Rivers exceeded this concentration. Although 39 percent of the fish samples exceeded the NCBP 85th percentile, only one sample was above the normal background concentration of 1 µg/g; therefore, there appears to be little potential for arsenic-related problems in fish in the Yuma Valley.

Striped mullet was the only fish species that accumulated measurable concentrations of beryllium (table 13, see "Basic Data" section at the back of this report). This fact may reflect the propensity of beryllium to accumulate in plants and not animals (table 12, see "Basic Data" section at the back of this report) and the mullet's primarily herbivorous food habits (Minckley, 1979).

Cadmium was detected at 0.21 and 0.22 µg/g dry weight in two carp samples from site 9 (table 13, see "Basic Data" section at the back of this report). The NCBP 85th percentile for cadmium in fish is 0.05 µg/g (Schmitt and Brumbaugh, 1990); therefore, where cadmium was detected (only in carp from site 9), it was above NCBP concentrations. This finding and the fact that cadmium was recovered only in clams from site 9 suggests that there may be a source for cadmium input into the Colorado River upstream from site 9.

Cadmium, like arsenic, acts as a cumulative poison (Jenkins, 1981) and is listed by the USEPA as a priority pollutant (Keith and Telliard, 1979). Cadmium is toxic to a variety of fish and wildlife

and causes behavioral, developmental, and physiological problems in aquatic life at sublethal concentrations (Rompala and others, 1984). Cadmium tends to bioaccumulate in fish (Rompala and others, 1984), clams (Schmitt and others, 1987), and cattail roots (Sullivan, 1991) especially in species living in close proximity to sediments contaminated by cadmium. The potential for bioaccumulation or bioconcentration of cadmium was highest in clams and bird tissues (100 percent), and lowest in cattails and fish. None of the fish samples in this study contained whole-body concentrations of cadmium above the threshold of 0.5 µg/g considered harmful to fish (Walsh and others, 1977).

The organs and tissues of fish and wildlife that contain greater than 4.0 µg/g total chromium dry weight should be viewed as presumptive evidence of chromium contamination (Eisler, 1986). Only one of three carp samples from site 8 and both mullet samples (sites 3 and 4) exceeded the concentration reported for the NCBP (table 13, see "Basic Data" section at the back of this report).

Copper was detected in all fish samples, and concentrations ranged from 1.88 to 40.62 µg/g dry weight (table 13, see "Basic Data" section at the back of this report). Copper exceeded the NCBP 85th percentile in one-half or more of the samples from sites 2, 3, 4, 8, and 9 (table 15, see "Basic Data" section at the back of this report). Although not statistically significant, carp from site 8 contained the highest concentrations of copper (table 14, see "Basic Data" section at the back of this report).

None of the fish samples contained detectable concentrations of lead (table 13, see "Basic Data" section at the back of this report). Although lead was detected in all sediment samples and in five of eight cattail samples, it was not detected in clam, fish, or bird tissues.

Mercury was detected in only 5 of 31 fish samples, and concentrations were below the NCBP 85th percentile (table 15, see "Basic Data" section at the back of this report). Mercury is of special concern because it can bioconcentrate in organisms and biomagnify through the aquatic food chain. The highest concentration of mercury (0.10 µg/g wet weight) was detected in a single channel catfish from site 9. This concentration, however, was well below the 1.0 µg/g wet weight generally accepted as the maximum concentration in biota from unpolluted environments (Eisler, 1987). Overall, mercury did not occur with the frequency or at concentrations that would cause concern for fish populations in the Yuma Valley.

Nickel was detected in all samples (table 13, see "Basic Data" section at the back of this report). No national baseline data exist for nickel to compare the fish samples from the Yuma Valley. Mean concentrations were greatest in carp from sites 4 and 8 (ANOVA, $p = 0.0002$; table 14, see "Basic Data" section at the back of this report).

Selenium was detected in all samples, and concentrations ranged from 0.51 to 2.04 µg/g wet weight (table 15, see "Basic Data" section at the back of this report). Selenium exceeded the NCBP 85th percentile in all carp from sites 1, 2, 4, 5, and 8. Mean concentrations of selenium in carp collected from the Colorado River and concentrations of selenium in carp from irrigation drain-water canals were similar. The exception is that mean concentrations of selenium in carp from site 6 were significantly lower than those in carp from sites 1 and 2 (ANOVA, $p = 0.0033$; table 14, see "Basic Data" section at the back of this report). Mean concentrations of selenium in carp from the Yuma Valley generally were lower than those in carp collected from the upstream parts of the Colorado River between Laguna Dam and Lake Mead (table 16, see "Basic Data" section at the back of this report).

Selenium is an essential trace element in animal diets, but it is toxic at concentrations only slightly above required dietary levels. Although selenium in most fish was above the NCBP 85th percentile background level, selenium generally was below toxic concentrations that could affect fish and wildlife. The highest concentration of selenium (2.04 µg/g wet weight) in fish whole-body samples was well below the 6.9–7.2 µg/g wet weight threshold associated with selenium-induced reproductive failure of bluegills at Hyco Reservoir in North Carolina, which is contaminated with selenium (Gillespie and Baumann, 1986). In a comprehensive summary of threshold levels of selenium, Lemly and Smith (1987) reported that selenium-induced reproductive failure in fish was associated with whole-body selenium concentrations of 12 µg/g dry weight. The highest concentration of selenium in fish in this study was

7.79 µg/g dry weight; therefore, a limited potential exists for selenium toxicity to fish populations in the Colorado River near Yuma and in irrigation drainage canals in the Yuma Valley.

Zinc was found in all fish samples, and concentrations varied from 41 to 296 µg/g dry weight (table 13, see "Basic Data" section at the back of this report). Zinc tends to bioaccumulate more readily in carp than in most fish species (Lowe and others, 1985; Schmitt and Brumbaugh, 1990; and King and others, 1993); therefore, comparing zinc in carp with the national background concentration composed of many species of fish would not be a valid comparison. There were no among-area differences in zinc concentrations (ANOVA, $p = 0.0791$; table 16, see "Basic Data" section at the back of this report).

At site 8, concentrations of four trace metals in carp were especially high. Carp from site 8 contained exceptionally high levels of aluminum; mean concentrations were the highest ever recorded in Arizona. Carp from site 8 also contained elevated concentrations of chromium, copper, and nickel. Mean concentrations of chromium also were higher in carp from site 8 than in carp from other lakes and streams in Arizona (King and others, 1991, 1993; and Lusk, 1993). Only carp from one or two collection sites on the lower Gila River, which is effluent dominated, contained higher mean concentrations of copper and nickel than did carp from site 8.

Trace Elements in Birds.—Arsenic was considerably lower in bird tissues and eggs (0.19–0.50 µg/g dry weight) than in cattail roots (2.24–21.47 µg/g) and clams (7.41–11.53 µg/g; table 12, see "Basic Data" section at the back of this report). Nickel concentrations were considerably lower in bird tissues and eggs than in cattail roots and clams. Beryllium and lead were not detected in bird tissues and eggs. Cadmium was not recovered in either egg sample but was present in all three liver samples. Copper was present in all bird samples; the highest concentrations were in tissues and the lowest concentrations were in eggs. Mercury was not detected in blackbird samples but was present in low concentrations in the killdeer-liver sample (0.56 µg/g dry weight) and in an egg of a common moorhen (*Gallinula chloropus*; 0.17 µg/g). Selenium ranged from 3.50 to 4.33 µg/g in eggs and from 4.06 to 13.57 µg/g in bird livers. Zinc concentrations were similar among bird tissues.

Cadmium, mercury, and selenium are the elements most likely to bioconcentrate and cause reproductive problems in birds (Eisler, 1985, 1987; Ohlendorf and others, 1986, 1988). Cadmium was not detected in either egg sample (table 12, see "Basic Data" section at the back of this report). The concentration of cadmium in liver tissues of birds considered to represent normal background concentrations is less than 3 µg/g dry weight (Ohlendorf, 1993). Cadmium was recovered in all three bird-liver samples, but residues were low—less than or equal to 1.80 µg/g dry weight. On the basis of the limited data, cadmium is not considered a contaminant of concern for birds nesting in the Yuma Valley.

Mercury was detected in one of three liver samples (0.56 µg/g dry weight) and in one of two egg samples (0.17 µg/g). Background concentrations of mercury in bird livers are from less than 1 to 10 µg/g dry weight, and concentrations greater than 6 µg/g may be toxic to some species (Ohlendorf, 1993). The concentration of mercury in the killdeer-liver sample (0.56 µg/g dry weight) was well below the toxic level. Background concentrations of mercury in eggs of wild birds usually are less than 1.0 µg/g dry weight (Ohlendorf, 1993). Mercury concentrations in eggs greater than 1.5 µg/g may be toxic; therefore, the 0.17 µg/g of mercury detected in the common moorhen egg was well within the background range. Mercury concentrations found in bird-carcass and egg samples from the Yuma Valley were well within the normal or background range.

The primary element of concern was selenium. Selenium usually averages less than 10 µg/g, dry weight in livers of birds from normal environments (Schroeder and others, 1988; Ohlendorf, 1993). Selenium concentrations in livers of red-winged and yellow-headed blackbirds collected in this study were well within the range of selenium levels found in normal environments; however, the 13.57 µg/g dry weight of selenium detected in the killdeer liver was within the 10 to 30 µg/g range that may be considered toxic (Ohlendorf, 1993).

Normal or background concentrations of selenium in eggs varies from 1 to 3 µg/g dry weight, and concentrations greater than 8 µg/g are considered toxic (Ohlendorf and others, 1993).

Concentrations of selenium in the eggs of the yellow-headed blackbird (3.50 µg/g) and common moorhen (4.33 µg/g) were above background levels but below toxic concentrations.

SUMMARY

Because of concerns expressed by the U.S. Congress and environmental organizations, the DOI began a program in late 1985 to identify the nature and extent of water-quality problems potentially induced by irrigation drainage in the western States. Surface water, bottom sediment, and biota were sampled in 1986–87 in the lower Colorado River Valley to determine concentrations of trace elements and organochlorine compounds as part of the DOI irrigation drainage program (Radtke and others, 1988). Trace elements and organochlorine compounds were detected in some of the samples collected in the study area.

In March 1995, the USGS and the USFWS began a second study along the lower Colorado River and agricultural drains at nine sites in the Yuma Valley, Arizona. Surface-water samples were collected by the USGS in March and June 1995, and bottom-sediment samples were collected in June 1995. Biota (fish, birds, freshwater clams, and cattails) samples were collected by the USFWS between March and September of 1995. Surface water, bottom sediment, and biota were analyzed for selected inorganic and organic constituents to determine if irrigation drain water has caused or has the potential to cause harmful effects on human health, fish, and wildlife in the study area. Analytical results were evaluated to describe the magnitude and spatial variation of concentrations of these constituents.

Specific conductance, alkalinity, hardness, and dissolved solids were greatest in water samples collected from site 5. Concentrations of dissolved solids ranged from 712 to 3,000 mg/L, which exceeded the SMCL of 500 mg/L for drinking water. The highest concentrations of calcium (180 mg/L), magnesium (75 mg/L), sodium (700 mg/L), and potassium (7.6 mg/L) were detected in water samples collected at site 5.

The highest concentrations of bicarbonate (437 mg/L), chloride (790 mg/L), fluoride (1.9 mg/L), and sulfate (890 mg/L) also were found in water samples collected at site 5. Concentrations of chloride in 9 of 18 samples and sulfate in 16 of 18 samples exceeded the USEPA SMCL's of 250 mg/L for drinking water. Calcium and sodium were the dominant cations, and chloride and sulfate were the dominant anions. Dissolved nitrite plus nitrate concentrations ranged from 0.05 mg/L to 2.8 mg/L.

The highest concentrations of dissolved arsenic (12 µg/L), barium (130 µg/L), chromium (6 µg/L), copper (11 µg/L), and iron (12 µg/L) were below the MCL's and SMCL's of the USEPA, acute and chronic aquatic-life criteria, and surface-water quality standards of the State of Arizona. Concentrations of lead ranged from less than 1 to 15 µg/L and exceeded the chronic aquatic-life criterion of 3.3 µg/L in three samples. Mercury was detected in 4 of 18 samples, and concentrations ranged from 0.2 to 1.8 µg/L, which exceeded the chronic aquatic-life criterion of 0.012 µg/L. Selenium was detected in 10 of 18 water samples and ranged from less than 1 to 8 µg/L. Concentrations of selenium exceeded the chronic aquatic-life criterion of 5 µg/L in only one sample. Data indicate that, in general, concentrations of dissolved trace elements in the Main Drain did not increase with increasing distance downstream.

Arsenic was detected in 3 of 9 bottom-sediment samples, and concentrations ranged from less than 10 to 16 µg/g. The highest concentrations of total recoverable aluminum (6.4 µg/g), beryllium (2 µg/g), boron (1.3 µg/g), copper (23 µg/g), lead (30 µg/g), and zinc (87 µg/g) were detected in samples from site 8. Selenium was detected in all bottom-sediment samples and ranged from 0.1 to 0.7 µg/g. Cadmium, europium, holmium, mercury, molybdenum, silver, tantalum, tin, and uranium were not detected in any of the samples. Trace-element concentrations in bottom-sediment samples from the study area were within the ranges found in soil of the western United States and do not indicate a significant accumulation. p,p'-DDE was detected only at site 8 (1.4 µg/kg).

DDE was detected in all fish and bird samples. Almost half the fish contained DDE at levels two times higher than the national mean of the NCBP in 1984–85; 23 percent of the fish contained more than three times the national mean. Fish from downstream parts of the Yuma Main Drain had the

highest concentrations of DDE. Although DDE in fish, bird carcasses, and eggs was above levels reported by the NCBP, concentrations generally were below thresholds associated with chronic poisoning and reproductive problems in fish and wildlife.

Concentrations of 18 metals were detected in samples of cattail roots, freshwater clams, fish, and birds. Selenium in most fish and in livers of red-winged and yellow-headed blackbirds was below toxic concentrations. In contrast, selenium was detected in the killdeer-liver sample at potentially toxic levels. Arsenic, cadmium, mercury, and selenium did not occur with the frequency or at concentrations that would cause concern for fish and wildlife populations, except for the selenium in killdeer. Aluminum, chromium, copper, and nickel concentrations were especially high at site 8. Common carp from site 8 contained the highest mean concentration of aluminum and chromium ever recorded in Arizona.

SELECTED REFERENCES

Andrews, B.J., King, K.A., and Baker, D.L., 1997, Environmental contaminants in fish and wildlife of Havasu National Wildlife Refuge: Phoenix, Arizona, U.S. Fish and Wildlife Service Contaminant Report, Arizona Ecological Services Field Office, 65 p.

Baker, D.L., and King, K.A., 1994, Environmental contaminant investigation of water quality, sediment and biota of the upper Gila River basin, Arizona: Phoenix, Arizona, U.S. Fish and Wildlife Service Contaminant Report, Arizona Ecological Services Field Office, 26 p.

Barmore, R.L., 1980, Soil survey of Yuma-Wellton area, parts of Yuma County, Arizona, and Imperial County, California: U.S. Department of Agriculture, Soil Conservation Service, 99 p.

Blus, L.J., 1982, Further interpretation of the relation of organochlorine residues in brown pelican eggs to reproductive success: Environmental Pollution, v. 28, no. 1, p. 15–33.

___1984, DDE in birds' eggs—Comparison of two methods for estimating critical levels: Wilson Bulletin, v. 96, no. 2, p. 268–276.

Bureau of Reclamation, 1987, Ground-water study, Yuma area, Arizona-California: Bureau of Reclamation Annual Report, Drainage Facilities Map 423–303–1567, revised from 1984.

Clark, D.R., JR., Clawson, R.L., and Stafford, C.J., 1983, Gray bats killed by dieldrin at two Missouri caves—Aquatic microinvertebrates found dead: Bulletin Environmental Contamination Toxicology, v. 30, no. 2, p. 214–218.

Cromartie, E., Reichel, W.L., Locke, L.N., Belisle, A.A., Kaiser, T.E., Lamont, T.G., Mulhern, B.M., Prouty, R.M., and Swineford, D.M., 1975, Residues of organochlorine pesticides and polychlorinated biphenyls and autopsy data for bald eagles, 1971–72: Pesticides Monitoring Journal, v. 9, no. 1, p. 11–14.

Dahlquist, R.L., and Knoll, J.W., 1978, Inductively coupled plasma-atomic emission spectrometry—Analysis of biological materials and soils for major trace- and ultra-trace elements: Applied Spectroscopy, v. 32, no. 1, p. 1–29.

Eisler, Ronald, 1985, Cadmium hazards to fish, wildlife, and invertebrates—A synoptic review: Laurel, Maryland, U.S. Fish and Wildlife Service, Biological Report 85(1.2), 46 p.

___ 1986, Chromium hazards to fish, wildlife, and invertebrates—A synoptic review: Laurel, Maryland, U.S. Fish and Wildlife Service, Biological Report 85(1.6), 60 p.

___ 1987, Mercury hazards to fish, wildlife, and invertebrates—A synoptic review: Laurel, Maryland, U.S. Fish and Wildlife Service, Biological Report 85(1.10), 90 p.

___ 1988, Arsenic hazards to fish, wildlife, and invertebrates—A synoptic review: Laurel, Maryland, U.S. Fish and Wildlife Service, Biological Report 85(1.12), 92 p.

Fishman, M.J., and Friedman, L.C., eds., 1989, Methods for determination of inorganic substances in water and fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Gillespie, R.B., and Baumann, P.C., 1986, Effects of high tissue concentrations of selenium on reproduction by bluegills: Transactions of the American Fisheries Society, v. 115, p. 208–213.

Hem, J.D., 1989, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Jenkins, D.W., 1981, Biological monitoring of toxic trace elements: U.S. Environmental Protection Agency Report 600/S3–80–090, p. 1–9.

Kaiser, T.E., Reichel, W.L., Locke, L.N., Cromartie, E., Krynitsky, A.J., Lamont, T.G., Mulhern, B.M.,

Prouty, R.M., Stafford, C.J., and Swineford, D.M., 1980, Organochlorine pesticide, PCB PBB residues and necropsy data for bald eagles from 29 States—1975–77: Pesticides Monitoring Journal, v. 13, no. 4, p. 145–149.

Keith, L.H., and Telliard, W.A., 1979, Priority pollutants—I, A perspective view: Environmental Science and Toxicology, v. 13, no. 4, p. 416–423.

King, K.A., Andrews, B.J., and Martinez, C.M., 1997, Contaminants in fish and wildlife of the lower Gila River, Arizona: Phoenix, Arizona, U.S. Fish and Wildlife Service Contaminant Report, Arizona Ecological Services Field Office, 69 p.

King, K.A., Baker, D.L., Kepner, W.G., and Krausmann, J.D., 1991, Contaminants in prey of bald eagles nesting in Arizona: Phoenix, Arizona, U.S. Fish and Wildlife Service Contaminant Report, Arizona Ecological Services Field Office, 16 p.

King, K.A., Baker, D.L., Kepner, W.G., and Martinez, C.T., 1993, Trace elements in sediments and fish from National Wildlife Refuges on the Colorado River, Arizona: Phoenix, Arizona, U.S. Fish and Wildlife Service Contaminant Report, Arizona Ecological Services Field Office, 24 p.

Lemly, A.D., and Smith, G.J., 1987, Aquatic cycling of selenium—Implications for fish and wildlife: Washington, D.C., U.S. Fish and Wildlife Service Leaflet 12, 10 p.

Lowe, T.P., May, T.W., Brumbaugh, W.G., and Kane, D.A., 1985, National contaminant biomonitoring program—Concentrations of seven elements in freshwater fish, 1978–81: Archives Environmental Contamination and Toxicology, v. 14, no. 3, p. 363–388.

Lusk, J.D., 1993, Selenium in aquatic habitats at Imperial National Wildlife Refuge: Tucson, University of Arizona, Cooperative Fish and Wildlife Research Unit, master's thesis, 151 p.

Marron, Hal, Phinney, Dennis, and Musgrove, Judy, 1989, Artificial recharge and well rehabilitation for management of ground-water nitrates in Peoria, Arizona, *in* Fourth Symposium on Artificial Recharge of Ground Water in Arizona: Phoenix, Arizona, Salt River Project, Proceedings, May 23–24, 1989, p. 105–111.

Minckley, W.L., 1979, Aquatic habitats and fishes of the Lower Colorado River, Southwestern United States: Boulder City, Nevada, Bureau of Reclamation, Final Report, Contract No. 14–06–300–2529, 478 p.

Moore, J.W., 1991, Inorganic contaminants of surface water—Research and Monitoring Priorities: New York, Springer–Verlag, 334 p.

National Academy of Sciences, National Academy of Engineering, 1973, Section III—Freshwater aquatic life and wildlife, water quality criteria: Washington, D.C., U.S. Environmental Protection Agency, Ecological Research Series EPA–R3–73–033, p. 106–213.

Neter, John, and Wasserman, William, 1974, Applied linear models: Homewood, Illinois, Richard D. Irwin, Inc., 547 p.

Ohlendorf, H.M., 1993, Marine birds and trace elements in the temperate North Pacific, *in* Vermeer, K., Briggs, K.T., Morgan, K.H., Siegel-Causey, D., eds., The status, ecology, and conservation of marine birds of the North Pacific: Ottawa, Canadian Wildlife Review Special Publication, p. 232–240.

Ohlendorf, H.M., Hoffman, D.J., Saiki, M.K., and Aldrich, T.W., 1986, Embryonic mortality and abnormalities of aquatic birds—Apparent impacts of selenium from irritation drainwater: The Science of the Total Environment, v. 52, no. 1, p. 49–63.

Ohlendorf, H.M., Kilness, A.W., Simmons, J.L., Stroud, R.K., Hoffman, D.J., and Moore, J.F., 1988, Selenium toxicosis in wild aquatic birds: Journal of Toxicology and Environmental Health, v. 24, no. 1, p. 67–92.

Olmsted, F.H., Loeltz, O.J., and Irelan, Burdge, 1973, Geohydrology of the Yuma area, Arizona and California: U.S. Geological Survey Professional Paper 486–H, 227 p.

Radtke, D.B., Kepner, W.G., and Effertz, R.J., 1988, Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Lower Colorado River Valley, Arizona, California, and Nevada: U.S. Geological Survey Water-Resources Investigations Report 88–4002, 77 p.

Rompala, J.M., Rutosky, F.W., and Putnam, D.J., 1984, Concentrations of environmental contaminants from selected waters in Pennsylvania: State College, Pennsylvania, U.S. Fish and Wildlife Service report, 102 p.

Ruiz, L., and Maughan, O.E., 1992, Contaminant characteristics of the Bill Williams National Wildlife Refuge: Tucson, University of Arizona, Cooperative Fish and Wildlife Research Unit, master's thesis, 160 p.

Schmitt, C.J., and Brumbaugh, W.G., 1990, National contaminant biomonitoring program—Concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and zinc in U.S. freshwater fish, 1976–1984: Archives of Environmental

Contamination and Toxicology, v. 19, no. 5, p. 731–747.

Schmitt, C.J., Finger, S.E., May, T.W., and Kaiser, M.S., 1987, Bioavailability of lead and cadmium from mine tailings to the pocketbook mussel (*Lampsilis ventricosa*), *in* Neves, R.J., ed., Proceedings of the workshop on die-offs of freshwater mussels in the U.S: Columbia, Missouri, U.S. Fish and Wildlife Service, p. 115–141.

Schmitt, C.J., Zajicek, J.L., and Peterman, P.H., 1990, National contaminant biomonitoring program—Residues of organochlorine chemicals in U.S. freshwater fish, 1976–1984: Archives of Environmental Contamination and Toxicology, v. 19, no. 6, p. 748–781.

Schroeder, R.A., Palawski, D.U., and Skorupa, J.P., 1988, Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Tulare Lake Bed Area, Southern San Joaquin Valley, California, 1986–87: U.S. Geological Survey Water-Resources Investigations Report 88–4001, 86 p.

Severson, R.C., Wilson, S.A., and McNeal, J.M., 1987, Analyses of bottom sediment collected at nine areas in the western United States for the Department of Interior Irrigation Drainage Task Group: U.S. Geological Survey Open-File Report 87–490, 24 p.

Shacklette, H.T., and Boerngen, J.G., 1984, Element concentrations in soils and other surficial materials of the conterminous United States: U.S. Geological Survey Professional Paper 1270, 105 p.

State of Arizona, 1992, Arizona Administrative Code, 1992: Phoenix, Arizona, Title 18, Chapter 11, Article 1, p. 1–34.

Stickel, L.F., 1973, Pesticide residues in birds and mammals, *in* Edwards, C.A., ed., Environmental Pollution by Pesticides: New York, Plenum Press, p. 254–312.

Sullivan, M.E., 1991, Heavy metal concentration in riparian vegetation exposed to wastewater effluent: Phoenix, Arizona State University, master's thesis, 139 p.

U.S. Department of Commerce, 1986, Climatological data, annual summary, Arizona, 1986: Ashville, North Carolina, National Oceanic and Atmospheric Administration, v. 90, no. 13, 26 p.

___1987, Climatological data, annual summary, Arizona, 1987: Ashville, North Carolina, National Oceanic and Atmospheric Administration, v. 91, no. 13, 26 p.

___1988, Climatological data, annual summary, Arizona, 1988: Ashville, North Carolina, National Oceanic and Atmospheric Administration, v. 92, no. 13, 26 p.

___ 1989, Climatological data, annual summary, Arizona, 1989: Ashville, North Carolina, National Oceanic and Atmospheric Administration, v. 93, no. 13, 26 p.

___ 1990, Climatological data, annual summary, Arizona, 1990: Ashville, North Carolina, National Oceanic and Atmospheric Administration, v. 94, no. 13, 26 p.

___ 1991, Climatological data, annual summary, Arizona, 1991: Ashville, North Carolina, National Oceanic and Atmospheric Administration, v. 95, no. 13, 26 p.

___ 1992, Climatological data, annual summary, Arizona, 1992: Ashville, North Carolina, National Oceanic and Atmospheric Administration, v. 96, no. 13, 26 p.

___ 1993, Climatological data, annual summary, Arizona, 1993: Ashville, North Carolina, National Oceanic and Atmospheric Administration, v. 97, no. 13, 26 p.

___ 1994, Climatological data, annual summary, Arizona, 1994: Ashville, North Carolina, National Oceanic and Atmospheric Administration, v. 98, no. 13, 26 p.

___ 1995, Climatological data, annual summary, Arizona, 1995: Ashville, North Carolina, National Oceanic and Atmospheric Administration, v. 99, no. 13, 26 p.

U.S. Environmental Protection Agency, 1984, Test methods for evaluating solid waste: Washington, D.C., U.S. Environmental Protection Agency Publication No. SW–846, 2nd ed., 2130 p.

___ 1986, Quality criteria for water—1986: Washington, D.C., U.S. Environmental Protection Agency Report EPA–440/5–86–001.

___ 1987, Test methods for evaluating solid waste: Washington, D.C., U.S. Environmental Protection Agency Publication No. SW–846, 3rd ed., 2650 p.

___ 1994a, National revised primary drinking water regulations—Maximum contaminant levels: Washington, D.C., Federal Code of Regulations, Title 40, Subpart G, sections 141.61–141.63, July 1, 1994, p. 750–754.

___ 1994b, National secondary drinking water regulations: Washington, D.C., Federal Code of Regulations, Title 40, part 143, section 143.3, July 1, 1994, p. 836.

U.S. Geological Survey, 1976, Water resources data for Arizona, water year 1975: U.S. Geological Survey Water Data Report AZ–75–1, 404 p.

___1985, Water-quality laboratory services catalog: U.S. Geological Survey Open-File Report 85–171, 5 parts, v.p.

Walsh, D.F., Berger, B.L., and Bean, J.R., 1977, Mercury, arsenic, lead, cadmium, and selenium residues in fish, 1971–1973—National Pesticide Monitoring Program: Pesticides Monitoring Journal, v. 11, no. 1, p. 115–134.

Ward, J.R., and Harr, C.A., eds., 1990, Methods for collection and processing of surface-water and bed-material samples for physical and chemical analyses: U.S. Geological Survey Open-File Report 90–140, 71 p.

Wershaw, R.L., Fishman, M.J., Grabbe, R.R., and Lowe, L.E., 1987, Methods for the determination of organic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A3, 80 p.

—PAGE 25 FOLLOWS—

BASIC DATA

— PAGE 27 FOLLOWS —

Table 7. Analytical results for field blanks, Yuma Valley, Arizona, March and June 1995

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L milligrams per liter; µg/L, micrograms per liter; <, less than]

Date	Specific conductance lab (µS/cm)	Alkalinity, lab (mg/L as $CaCO_3$)	pH, water whole lab standard units)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as K)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)
03–21–95	3	1.0	8.0	0.07	<0.01	<0.20	<0.10	<0.10
06–12–95	4	<1.0	8.1	.03	<.01	<.20	<.10	<.10

Date	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180°C, dissolved (mg/L)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Aluminum, dissolved (µg/L as Al)	Antimony, dissolved (µg/L as Sb)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)
03–21–95	<0.10	<0.10	0.02	1	<0.050	3	<1	<1	<1
06–12–95	.20	<.10	<.01	<1	<.050	3	<1	<1	<1

Date	Beryllium, dissolved (µg/L as Be)	Boron, dissolved (µg/L as B)	Bromide, dissolved (mg/L as Br)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Cobalt, dissolved (µg/L as Co)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)
03–21–95	<1	<10	<0.010	<1	<1	<1	<1	<3	<1
06–12–95	<1	<10	<.010	<1	<1	<1	<1	<3	<1

Date	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	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, natural, dissolved (µg/L as U)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)
03–21–95	<1	<0.1	<1	<1	<1	<1	<1	<1	<1
06–12–95	<1	<.1	<1	<1	<1	2	<1	<1	11

Table 8. Analytical results for surface-water samples, Yuma Valley, Arizona, March and June 1995

[ft^3/s, cubic feet per second; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°C; mg/L milligrams per liter; µg/L, micrograms per liter; <, less than; ---, no data]

Sampling site (see fig. 1)	Date	Time	Discharge, instantaneous, (ft^3/s)	Temperature, water (°C)	Temperature, air (°C)	Oxygen, dissolved (mg/L)	pH, water whole field (standard units)	Specific conductance (µS/cm)	Alkalinity, water, dissolved in field (mg/L as $CaCO_3$)	Carbonate, dissolved (mg/L as CO_3)
1	03–23–95	1015	398	18.5	17.5	9.3	8.1	1,200	152	0
1	06–13–95	1000	374	27.0	32.0	---	8.0	1,400	158	0
2	03–21–95 03–21–95[1]	0915	6.6	20.0	21.5	6.5	7.7	1,860	240	0
2	06–12–95	1215	18	27.0	40.0	8.8	7.8	1,890	232	0
3	03–23–95	1430	75	22.5	24.0	7.3	8.0	1,930	234	0
3	06–13–95	1300	70	25.5	37.0	8.8	7.8	1,830	226	0
4	03–21–95	1530	83	24.5	28.0	8.8	8.2	3,250	254	0
4	06–14–95	0930	3,050	28.5	32.0	7.5	8.2	1,290	158	0
5	03–21–95	1200	168	22.5	22.0	11.5	8.0	4,460	358	0
5	06–12–95	1515	188	27.5	40.0	14.8	7.9	4,500	332	0
6	03–24–95	1130	84	20.5	20.0	8.9	7.9	2,330	238	0
6	06–15–95 06–15–95[1]	1245	72	27.0	32.5	8.7	7.9	2,510	250	0
7	03–24–95	0930	149	18.5	17.0	7.4	7.9	2,420	242	0
7	06–16–95	0945	131	22.5	26.0	7.1	7.9	2,530	230	0
8	03–24–95	1045	126	18.0	18.0	8.6	8.1	2,440	244	0
8	06–16–95	0945	---	18.0	18.0	8.6	7.9	2,440	244	0
9	03–22–95	1545	688	---	24.5	8.9	8.2	1,670	188	0
9	06–15–95	1140	3,150	29.5	37.0	7.9	8.1	1,220	154	0

See footnote at end of table.

Table 8. Analytical results for surface-water samples, Yuma Valley, Arizona, March and June 1995—Continued

Sampling site (see fig. 1)	Date	Bicarbonate, dissolved (mg/L as HCO_3)	Hardness, total (mg/L as $CaCO_3$)	Solids, residue at 180°C, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium-adsorption ratio	Sodium, in percent	Potassium, dissolved (mg/L as K)
1	03–23–95	185	320	790	82	29	120	3	44	5.1
1	06–13–95	193	360	900	90	33	150	3	47	5.3
2	03–21–95	293	480	1,270	120	44	200	4	47	5.2
	03–21–95[1]	---	---	1,260	130	45	210	---	---	5.1
2	06–12–95	283	490	1,270	120	45	220	4	49	5.0
3	03–23–95	285	530	1,300	140	44	200	4	45	5.1
3	06–13–95	276	490	1,240	130	39	180	4	44	4.6
4	03–21–95	310	520	2,080	120	53	480	9	66	6.7
4	06–14–95	193	240	740	60	21	150	4	57	5.1
5	03–21–95	437	750	3,000	180	73	660	10	65	7.4
5	06–12–95	405	760	2,940	180	75	700	11	66	7.6
6	03–24–95	---	540	1,570	140	47	300	6	54	5.1
6	06–15–95	305	570	1,670	150	48	310	6	54	5.5
	06–15–95[1]	---	---	1,660	150	47	300	---	---	5.2
7	03–24–95	---	580	1,620	150	49	300	5	53	5.5
7	06–16–95	281	580	1,670	150	50	310	6	53	5.8
8	03–24–95	298	580	1,630	150	50	310	6	53	5.8
8	06–16–95	295	580	1,660	150	51	320	6	54	5.9
9	03–22–95	229	390	1,070	99	35	190	4	51	5.5
9	06–15–95	188	240	712	63	21	140	4	55	5.0

See footnote at end of table.

Table 8. Analytical results for surface-water samples, Yuma Valley, Arizona, March and June 1995—Continued

Sampling site (see fig. 1)	Date	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Aluminum, dissolved (µg/L as Al)	Antimony, dissolved (µg/L as Sb)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)
1	03–23–95	120	290	0.50	11	0.15	4	<1	3	110
1	06–13–95	140	340	.60	11	.10	4	<1	2	130
2	03–21–95	180	460	.60	19	1.90	3	<1	1	55
	03–21–95[1]	180	450	.60	20	1.80	3	<1	2	53
2	06–12–95	180	460	.70	21	1.40	5	<1	2	51
3	03–23–95	210	460	.50	20	1.20	<1	<1	1	66
3	06–13–95	200	440	.50	19	1.20	6	<1	2	66
4	03–21–95	610	520	1.1	21	1.80	3	<2	12	61
4	06–14–95	220	130	.60	12	.09	8	<1	9	50
5	03–21–95	770	890	1.8	16	2.50	3	<2	11	26
5	06–12–95	790	870	1.9	18	2.80	6	<2	12	29
6	03–24–95	310	510	.60	21	1.30	3	<1	2	63
6	06–15–95	330	550	.60	23	1.30	2	<1	2	70
	06–15–95[1]	330	540	.60	22	1.30	4	<1	2	66
7	03–24–95	340	510	.60	22	1.60	3	<1	2	60
7	06–16–95	350	540	.60	23	1.50	5	<1	2	65
8	03–24–95	360	510	.60	22	1.60	2	<1	2	62
8	06–16–95	340	530	.60	22	1.40	6	<1	2	72
9	03–22–95	210	330	.60	15	.50	3	<1	4	92
9	06–15–95	200	140	.60	12	.05	7	<1	7	58

See footnote at end of table.

Table 8. Analytical results for surface-water samples, Yuma Valley, Arizona, March and June 1995—Continued

Sampling site (see fig. 1)	Date	Beryllium, dissolved (µg/L as Be)	Boron, dissolved (µg/L as B)	Bromide, dissolved (mg/L as Br)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Cobalt, dissolved (µg/L as Co)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)
1	03–23–95	<1	180	0.09	<1.0	3	<1	5	7	1
1	06–13–95	<1	200	.11	<1.0	<1	<1	4	<3	<1
2	03–21–95	<1	290	.16	<1.0	3	<1	6	<3	<1
	03–21–95[1]	<1	300	.17	<1.0	4	<1	7	4	<1
2	06–12–95	<1	290	.17	<1.0	1	<1	2	<3	<1
3	03–23–95	<1	260	.16	<1.0	5	<1	8	<3	<1
3	06–13–95	<1	250	.15	<1.0	2	<1	3	<3	1
4	03–21–95	<2	760	.47	<2.0	4	<2	9	<9	<2
4	06–14–95	<1	290	.12	<1.0	<1	<1	4	5	2
5	03–21–95	<2	1,300	.61	<2.0	6	<2	11	12	<2
5	06–12–95	<2	1,300	.63	<2.0	3	<2	7	<9	4
6	03–24–95	<1	380	.27	<1.0	4	<1	6	12	<1
6	06–15–95	<1	410	.27	<1.0	2	<1	6	<9	<1
	06–15–95[1]	<1	420	.27	<1.0	2	<1	6	<9	<1
7	03–24–95	<1	390	.28	<1.0	4	<1	5	<9	3
7	06–16–95	<1	410	.27	<1.0	3	<1	3	<9	<1
8	03–24–95	<1	390	.28	<1.0	3	<1	5	<9	6
8	06–16–95	<1	400	.26	<1.0	2	1	4	<9	<1
9	03–22–95	<1	280	.16	<1.0	3	<1	7	4	<1
9	06–15–95	<1	260	.10	<1.0	<1	<1	4	<3	15

See footnote at end of table.

Table 8. Analytical results for surface-water samples, Yuma Valley, Arizona, March and June 1995—Continued

Sampling site (see fig. 1)	Date	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Moiyb-denum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Uranium, natural, dissolved (µg/L as U)	Vana-dium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)
1	03–23–95	17	<0.1	7	4	2	<1.0	5.0	4	6
1	06–13–95	11	<.1	7	10	2	<1.0	5.0	4	4
2	03–21–95	72	.3	10	5	2	<1.0	11	6	6
	03–21–95[1]	76	<.1	10	6	2	<1.0	10	6	13
2	06–12–95	160	<.1	9	12	2	<1.0	10	6	3
3	03–23–95	410	1.8	9	6	<1	<1.0	4.0	4	3
3	06–13–95	130	<.1	7	10	<1	<1.0	3.0	3	10
4	03–21–95	240	<.1	15	6	8	<2.0	7.0	22	6
4	06–14–95	30	.2	5	8	<1	<1.0	4.0	13	6
5	03–21–95	200	<.1	38	9	2	<2.0	16	54	9
5	06–12–95	170	.2	35	13	<1	<2.0	18	22	7
6	03–24–95	170	<.1	12	7	<1	<1.0	5.0	8	4
6	06–15–95	150	<.1	11	13	<1	<1.0	5.0	7	4
	06–15–95[1]	140	<.1	11	12	<1	<1.0	5.0	7	4
7	03–24–95	53	<.1	12	6	<1	<1.0	5.0	8	6
7	06–16–95	22	<.1	11	12	1	<1.0	5.0	7	3
8	03–24–95	38	<.1	12	5	1	<1.0	5.0	9	8
8	06–16–95	24	.4	11	13	1	<1.0	5.0	7	4
9	03–22–95	48	<.1	8	5	2	<1.0	5.0	7	6
9	06–13–95	5	<.1	4	8	<1	<1.0	4.0	12	7

[1]Duplicate sample collected for quality assurance.

Table 9. Analytical results for bottom-sediment samples, Yuma Valley, Arizona, June 1995

[µg/g, micrograms per gram; <, less than; µg/kg, micrograms per kilogram. o,p'-DDD, dichlorodiphenyldichloroethane; p,p'-DDD, dichlorodiphenyldichloroethane; o,p'-DDE, o,p'-dichlorodiphenyldichloroethylene; p,p'-DDE, dichlorodiphenylchloroethylene; o,p'-DDT, dichlorodiphenyltrichloroethane; p,p'-DDT, dichlorodiphenyltrichloroethane; PCB. polychlorinated biphenyls; alpha-BHC, alpha benzene hexachloride; beta-BHC, beta benzene hexachloride; DCPA, dacthal]

Sampling site (see fig. 1)	Date	Time	Aluminum, recoverable (percent as Al)	Arsenic, recoverable (µg/g as As)	Barium, recoverable (µg/g as Ba)	Beryllium, recoverable (µg/g as Be)	Bismuth, recoverable (µg/g as Bi)	Boron, recoverable (µg/g as B)	Cadmium, recoverable (percent as Cd)	Calcium, recoverable (percent as Ca)
1	06–13–95	1100	2.2	<10	400	<1	<10	0.3	<2	1.6
2	06–12–95	1400	4.4	<10	470	1	<10	1.2	<2	4.6
3	06–13–95	1430	4.2	<10	500	1	<10	1.1	<2	3.6
4	06–14–95	1000	6.0	11	580	1	<10	.7	<2	3.9
5	06–12–95	1700	5.7	16	590	1	<10	1.1	<2	4.1
6	06–15–95	1400	4.2	<10	530	1	<10	.7	<2	4.0
7	06–16–95	1030	3.9	<10	490	1	<10	.9	<2	3.4
8	06–15–95	1030	6.4	<10	530	2	<10	1.3	<2	5.2
9	06–14–95	1300	5.0	12	450	1	<10	.4	<2	3.5

Sampling site (see fig. 1)	Date	Cerium, recoverable (µg/g as Ce)	Chromium, recoverable (µg/g as Cr)	Colbalt, recoverable (µg/g as Co)	Copper, recoverable (µg/g as Cu)	Europium, recoverable (µg/g as Eu)	Gallium, recoverable (µg/g as Ga)	Gold, recoverable (µg/g as Au)	Holmium, recoverable (µg/g as Ho)	Iron, recoverable (percent as Fe)
1	06–13–95	27	9	2	2	<2	4	<8	<4	0.7
2	06–12–95	46	26	7	13	<2	9	<8	<4	1.6
3	06–13–95	45	26	6	11	<2	9	<8	<4	1.7
4	06–14–95	64	110	18	22	<2	12	<8	<4	3.8
5	06–12–95	44	55	11	9	<2	11	<8	<4	2.5
6	06–15–95	44	27	6	9	<2	9	<8	<4	1.6
7	06–16–95	42	27	6	10	<2	8	<8	<4	1.5
8	06–15–95	65	44	10	23	<2	14	<8	<4	2.5
9	06–14–95	82	170	27	16	<2	9	<8	<4	5.9

Table 9. Analytical results for bottom-sediment samples, Yuma Valley, Arizona, June 1995—Continued

Sampling site (see fig. 1)	Date	Lanthanum, recoverable (µg/g as La)	Lead, recoverable (µg/g as Pb)	Lithium, recoverable (µg/g as Li)	Magnesium, recoverable (percent as Mg)	Manganese, recoverable (µg/g as Mn)	Mercury, recoverable (µg/g as Hg)	Molybdenum, recoverable (µg/g as Mo)	Neodymium, recoverable (µg/g as Nd)	Nickel, recoverable (µg/g as Ni)
1	06–13–95	15	10	7	0.29	260	<0.02	<2	10	3
2	06–12–95	24	15	24	1.0	680	<.02	<2	19	13
3	06–13–95	24	15	22	.95	1,300	<.02	<2	30	12
4	06–14–95	35	13	24	1.2	670	<.02	<2	30	29
5	06–12–95	25	10	16	.75	2,600	<.02	<2	20	16
6	06–15–95	24	11	20	.89	1,500	<.02	<2	19	11
7	06–16–95	22	15	19	.82	1,300	<.02	<2	17	10
8	06–15–95	35	30	38	1.4	1,300	<.02	<2	27	20
9	06–14–95	42	9	18	1.2	1,000	<.02	<2	36	33

Sampling site (see fig. 1)	Date	Niobium, recoverable (µg/g as Nb)	Phosphorus, recoverable (percent as P)	Potassium, recoverable (percent as K)	Scandium, recoverable (µg/g as Sc)	Selenium, recoverable (µg/g as Se)	Silver, recoverable (µg/g as Ag)	Sodium, recoverable (percent as Na)	Strontium, recoverable (µg/g as Sr)	Tantalum, recoverable (µg/g as Ta)
1	06–13–95	<4	0.02	1.1	<2	0.1	<2	0.55	120	<40
2	06–12–95	<4	.06	1.7	5	.7	<2	.62	200	<40
3	06–13–95	<4	.06	1.6	5	.3	<2	.62	200	<40
4	06–14–95	13	.10	1.9	11	.1	<2	1.6	360	<40
5	06–12–95	8	.06	2.1	8	.1	<2	1.7	380	<40
6	06–15–95	<4	.06	1.7	4	.3	<2	.78	230	<40
7	06–16–95	<4	.06	1.6	4	.3	<2	.71	200	<40
8	06–15–95	<4	.07	1.9	8	.6	<2	.66	290	<40
9	06–14–95	23	.12	1.5	14	.1	<2	1.3	280	<40

Table 9. Analytical results for bottom-sediment samples, Yuma Valley, Arizona, June 1995—Continued

Sampling site (see fig. 1)	Date	Thorium, recoverable (µg/g as Th)	Tin, recoverable (µg/g as Sn)	Titanium, recoverable (µg/g as Ti)	Uranium, recoverable (µg/g as U)	Vanadium, recoverable (µg/g as V)	Yttrium, recoverable (µg/g as Y)	Ytterbium, recoverable (µg/g as Yb)	Zinc, recoverable (µg/g as Zn)
1	06–13–95	<4	<5	0.08	<100	17	7	<1	23
2	06–12–95	8	<5	.19	<100	42	15	1	53
3	06–13–95	8	<5	.17	<100	39	14	1	50
4	06–14–95	9	<5	.70	<100	120	26	3	70
5	06–12–95	9	<5	.47	<100	76	18	2	50
6	06–15–95	8	<5	.19	<100	37	14	1	48
7	06–16–95	6	<5	.18	<100	37	13	1	45
8	06–15–95	11	<5	.23	<100	71	20	2	87
9	06–14–95	12	<5	1.3	<100	210	30	3	83

Sampling site (see fig. 1)	Date	Aldrin, total (µg/kg)	Cis-chlordane, total (µg/kg)	Transchlordane, total (µg/kg)	Benzene, hexachloro, total (µg/kg)	o, p'-DDD, total (µg/kg)	p, p'- DDD, total (µg/kg)	o, p'-DDE, total (µg/kg)	p, p'- DDE, total (µg/kg)
1	06–13–95	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
5	06–12–95	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
8	06–15–95	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.4
9	06–14–95	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

Sampling site (see fig. 1)	Date	o, p'-DDT, total (µg/kg)	p,p'- DDT, total (µg/kg)	Dieldrin, total (µg/kg)	Endosulfan, total (µg/kg)	Endrin, total (µg/kg)	Heptachlor, total (µg/kg)	Heptachlor epoxide, total (µg/kg)	Lindane, total (µg/kg)
1	06–13–95	<2.0	<2.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0
5	06–12–95	<2.0	<2.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0
8	06–15–95	<2.0	<2.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0
9	06–14–95	<2.0	<2.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0

Table 9. Analytical results for bottom-sediment samples, Yuma Valley, Arizona, June 1995—Continued

Sampling site (see fig. 1)	Date	Mirex, total (µg/kg)	PCB, total (µg/kg)	Toxaphene, total (µg/kg)	Alpha-BHC, total (µg/kg)	Beta-BHC, total (µg/kg)	Pentachloro-anisole, total (µg/kg)	DCPA, total (µg/kg)	Isodrin, total (µg/kg)
1	06–13–95	<1.0	<50	<200	<1.0	<1.0	<1.0	<5.0	<1.0
5	06–12–95	<1.0	<50	<200	<1.0	<1.0	<1.0	<5.0	<1.0
8	06–15–95	<1.0	<50	<200	<1.0	<1.0	<1.0	<5.0	<1.0
9	06–14–95	<1.0	<50	<200	<1.0	<1.0	<1.0	<5.0	<1.0

Sampling site (see fig. 1)	Date	Oxychlordane, total (µg/kg)	Trans-nonachlor, total (µg/kg)	Cis-nonachlor, total (µg/kg)	o, p'- Methoxy chlor, total (µg/kg)	p,p'-Methoxy chlor, total (µg/kg)	Chloro-neb, total (µg/kg)	Cis-permethrin, total (µg/kg)	Trans-permethrin, total (µg/kg)
1	06–13–95	<1.0	<1.0	<1.0	<5.0	<5.0	<5.0	<5.0	<5.0
5	06–12–95	<1.0	<1.0	<1.0	<5.0	<5.0	<5.0	<5.0	<5.0
8	06–15–95	<1.0	<1.0	<1.0	<5.0	<5.0	<5.0	<5.0	<5.0
9	06–14–95	<1.0	<1.0	<1.0	<5.0	<5.0	<5.0	<5.0	<5.0

Table 10. Residues of organochlorine compounds in fish and birds, Yuma Valley, Arizona, 1995

[N, number of individuals composited per sample; PCB, polychlorinated biphenyls; p,p'DDE, p,p'dichlorodiphenyldichloroethlyene; HCB, hexachlorobenzene; C. carp, common carp; Mullet, striped mullet; C. catfish, channel catfish; F. catfish, flathead catfish; YHBBe, yellow-headed blackbird egg; YHBBc, yellow-headed blackbird carcass; RWBBc, red-winged blackbird carcass; ND, no residue detected at a lower limit of detection of 0.01 µg/g]

Sampling site (see fig. 1)	Sample	N	Weight, in grams	Percent moist	Percent lipid	Concentration, by wet weight, in micrograms per gram				
						PCB total	Dieldrin	p,p' DDE	HCB	Chlordane
1	C. carp	1	1,416	70.7	3.63	ND	ND	0.05	ND	ND
1	C. carp	1	1,266	72.7	6.22	ND	ND	.06	ND	ND
2	C. carp	1	1,782	76.0	1.90	ND	ND	.42	ND	ND
2	C. carp	1	1,341	75.2	1.89	ND	ND	.37	ND	ND
3	C. carp	1	482	77.3	1.28	ND	ND	.11	ND	ND
3	C. carp	1	222	77.3	1.17	ND	ND	.05	ND	ND
4	C. carp	1	887	75.0	2.07	ND	ND	.16	ND	ND
4	C. carp	1	2,070	73.1	3.35	ND	ND	.38	ND	ND
5	C. carp	1	1,936	65.3	12.63	ND	ND	.08	ND	ND
5	C. carp	1	2,400	65.0	10.55	ND	ND	.10	ND	ND
6	C. carp	1	2,330	66.7	10.82	0.07	0.02	1.20	ND	0.01
6	C. carp	1	1,700	66.1	8.22	.07	.02	.92	ND	.01
6	C. carp	1	1,131	72.0	5.04	ND	.01	.47	ND	ND
6	C. carp	1	962	71.9	7.61	ND	.01	.44	ND	ND
8	C. carp	1	738	77.2	8.23	.05	.02	.81	ND	.01
8	C. carp	1	717	76.6	3.05	ND	ND	.55	ND	ND
9	C. carp	1	1,508	71.9	5.59	ND	ND	.10	ND	ND
9	C. carp	1	1,665	66.0	12.86	ND	ND	.19	ND	ND
3	Mullet	5	2,400	66.3	4.02	ND	ND	.27	ND	ND
4	Mullet	5	1,275	65.2	10.00	ND	ND	.16	ND	ND
6	C. catfish	1	720	75.9	3.86	ND	ND	.62	ND	.04
9	F. catfish	1	1,715	72.1	6.59	.13	ND	.77	ND	ND
2	YHBBe	4	2.43	82.0	2.92	ND	ND	.17	ND	ND
2	YHBBc	5	260	67.5	7.01	ND	ND	.75	0.04	ND
6	RWBBc	8	238	67.9	6.33	ND	.02	1.20	.01	ND
4	Killdeer	7	436	62.9	13.07	.06	.02	5.90	.05	.01

NOTE: Alpha-BHC, beta-BHC, gamma-BHC, endrin, heptachlor, epoxide, mirex, and toxaphene were not detected in any samples.

Table 11. Statistical summary of residues of p,p'-dichlorodiphenyldichloroethlyene in common carp, Yuma Valley, Arizona, 1995

[Concentrations are in micrograms per gram wet weight; data from collection sites sharing a common letter are statistically similar (ANOVA, $p \leq 0.05$)]

	Sampling site (see fig. 1)							
	1	2	3	4	5	6	8	9
Geometric mean	0.055	0.394	0.074	0.247	0.089	0.691	0.667	0.138
Minimum	.05	.37	.05	.16	.08	.44	.55	.10
Maximum	.06	.42	.11	.38	.10	1.20	.81	.19
Significance	AD	BC	BD	ABC	AB	C	CE	ABE

Table 12. Concentrations of trace elements in cattails, freshwater clams, and birds, Yuma Valley, Arizona, 1995

[Samples: Freshwater clam; YH blackbird, yellow-headed blackbird; RW blackbird, red-winged blackbird; C. Moorhen, common moorhen; ND, no residue detected]

Site number (see fig. 1)	Sample	Concentrations of trace elements[1], dry weight, in micrograms per gram																	
		Aluminum	Arsenic[2]	Boron	Barium	Beryllium[2]	Cadmium[2]	Chromium[2]	Copper[2]	Iron	Mercury[2]	Magnesium	Manganese	Molybdenum	Nickel[2]	Lead[2]	Selenium[2]	Strontium	Vanadium	Zinc[2]
1	Cattail	2,393	19.50	13.21	71.43	ND	ND	5.26	9.79	6,914	ND	3,300	235	ND	6.06	4.16	2.71	128	7.64	29
2	Cattail	9,548	10.48	20.83	86.31	0.32	ND	11.58	14.64	10,167	0.65	6,464	2,679	ND	9.46	7.93	4.29	133	20.48	38
3	Cattail	11,121	2.24	30.26	140.52	.41	ND	14.48	10.00	13,793	ND	9,138	1,509	ND	9.91	ND	1.55	163	21.90	37
4	Cattail	3,805	5.74	12.13	47.22	.14	ND	11.36	17.57	7,633	ND	4,047	365	ND	10.83	ND	ND	95	24.56	30
6	Cattail	8,010	10.89	15.92	105.76	.33	ND	12.20	14.29	11,204	ND	6,963	1,325	ND	11.31	3.34	1.57	134	16.07	30
7	Cattail	9,938	4.84	18.39	109.32	.37	ND	21.24	13.42	9,317	ND	6,770	807	ND	12.67	3.48	1.61	117	17.45	46
8	Cattail	13,683	5.46	13.11	135.24	.50	.21	17.37	12.95	11,746	ND	8,540	1,473	ND	10.86	3.33	.95	152	20.73	34
9	Cattail	2,284	21.47	19.14	43.88	ND	ND	7.78	11.98	5,474	ND	3,241	624	ND	6.64	ND	1.47	97	14.14	31
1	Freshwater clam	249	7.73	2.07	5.59	ND	.33	1.25	37.70	387	ND	668	30	ND	1.41	ND	6.01	11	.58	85
2	Freshwater clam	471	8.15	2.24	6.05	ND	.32	1.99	25.84	752	ND	1,017	64	ND	2.05	ND	7.27	13	1.20	83
5	Freshwater clam	512	11.53	4.00	14.19	ND	.46	1.85	35.40	841	ND	1,047	51	ND	13.21	ND	8.70	32	1.27	94
6	Freshwater clam	1,000	8.21	4.18	21.28	ND	.34	2.06	21.83	1,647	ND	1,464	359	ND	15.02	ND	3.83	47	2.03	86
8	Freshwater clam	331	8.57	4.15	6.69	ND	.31	1.20	23.94	603	ND	791	63	ND	4.84	ND	5.30	13	.68	68
9	Freshwater clam	393	7.41	2.62	11.13	ND	1.59	3.20	34.85	669	ND	870	52	ND	4.73	ND	5.48	34	1.82	89
2	YH blackbird liver	5	.26	ND	ND	ND	.50	.94	18.89	936	ND	659	4	2.44	.48	ND	4.23	.19	ND	57
2	YH blackbird egg	7	.50	3.84	2.28	ND	ND	1.52	3.72	160	ND	480	4	ND	1.23	ND	3.50	14	ND	48
4	Killdeer liver	21	.37	1.59	ND	ND	1.80	1.01	22.23	851	.56	638	18	2.32	.43	ND	13.57	.74	ND	76
6	RW blackbird liver	12	.19	1.23	ND	ND	.87	.87	15.75	700	ND	619	4	2.19	.45	ND	4.06	.54	ND	54
6	C. Moorhen egg	ND	.45	2.87	3.33	ND	ND	2.39	3.06	154	.17	421	6	ND	1.49	ND	4.33	19	ND	50

[1]Lower limits of detection: Beryllium, ≤0.11; cadmium, ≤0.52; mercury, ≤0.22 for vegetation and ≤0.12 for tissue; molybdenum, ≤3.39; and lead ≤4.23 for vegetation and ≤2.79 for animal tissue.
[2]Priority pollutants of the U.S. Environmental Protection Agency.

Table 13. Concentrations of trace elements in fish, Yuma Valley, Arizona, 1995

[Samples: C. carp, common carp; Mullet, striped mullet; F. catfish, flathead catfish; C. catfish, channel catfish; carp and catfish samples are individual whole-body samples. Five mullet were composited into a single sample at sampling sites 3 and 4. ND, no residue detected]

Site number (see fig. 1)	Sample	Concentrations of trace elements[1], dry weight, in micrograms per gram																		
		Aluminum	Arsenic[2]	Boron	Barium	Beryllium[2]	Cadmium[2]	Chromium[2]	Copper[2]	Iron	Mercury[2]	Magnesium	Manganese	Molybdenum	Nickel[2]	Lead[2]	Selenium[2]	Strontium	Vanadium	Zinc[2]
1	C. carp	173	1.68	1.84	13.13	ND	ND	1.53	3.77	420	ND	1,191	42	ND	0.88	ND	7.79	146	0.73	187
1	C. carp	69	2.03	1.40	12.20	ND	ND	1.76	3.12	212	ND	1,351	22	ND	1.17	ND	5.05	249	.46	156
1	C. carp	212	.96	ND	16.45	ND	ND	2.16	2.77	358	ND	1,652	25	ND	.65	ND	6.21	275	.72	176
1	C. carp	196	1.65	2.96	11.14	ND	ND	1.88	4.54	271	ND	1,396	46	ND	.76	ND	4.36	188	.74	150
1	C. carp	134	1.43	1.99	10.60	ND	ND	1.87	3.60	226	ND	1,506	26	ND	.65	ND	4.53	276	.42	187
2	C. carp	237	1.04	2.76	11.71	ND	ND	2.00	4.50	403	ND	1,554	34	ND	.90	ND	4.75	175	.73	238
2	C. carp	193	.96	2.25	25.15	ND	ND	2.50	4.81	293	0.22	1,569	32	ND	1.02	ND	3.46	212	.72	196
2	C. carp	46	.29	2.75	12.82	ND	ND	2.46	2.83	231	ND	1,780	18	ND	.87	ND	5.50	272	.25	263
2	C. carp	295	1.25	2.99	20.85	ND	ND	2.34	5.28	365	ND	1,956	27	ND	.73	ND	7.74	328	.75	236
3	C. carp	114	.62	3.57	6.26	ND	ND	2.78	5.64	225	ND	1,899	30	ND	.82	ND	4.01	243	.30	168
3	C. carp	17	.70	2.82	7.51	ND	ND	2.33	6.03	89	ND	1,856	24	ND	.64	ND	2.66	255	ND	185
3	C. carp	704	.80	2.69	19.92	ND	ND	3.19	5.80	760	ND	2,496	101	ND	1.22	ND	3.60	276	1.30	257
3	C. carp	167	.48	3.85	8.85	ND	ND	3.28	3.83	408	.12	2,128	43	ND	1.53	ND	2.42	227	.33	288
4	C. carp	44	.56	3.45	7.88	ND	ND	.76	5.52	119	.20	1,712	17	ND	.78	ND	3.56	236	.50	220
4	C. carp	130	.82	1.74	3.24	ND	ND	1.68	3.90	230	.20	1,257	15	ND	1.75	ND	3.12	155	.57	102
5	C. carp	72	1.12	1.58	6.95	ND	ND	.64	2.86	188	ND	1,006	9	ND	.72	ND	4.96	139	.29	238
5	C. carp	486	.60	1.85	8.77	ND	ND	1.87	2.97	663	ND	1,151	20	ND	1.05	ND	3.77	113	1.29	139
5	C. carp	98	1.19	3.44	8.27	ND	ND	1.71	2.62	224	ND	1,112	9	ND	.76	ND	5.34	144	.40	156
6	C. carp	84	1.02	1.31	4.32	ND	ND	1.49	2.86	173	ND	1,129	19	ND	.50	ND	3.48	155	.21	296
6	C. carp	102	.50	1.90	4.07	ND	ND	1.45	1.88	162	ND	1,106	12	ND	.49	ND	2.36	137	.19	251
6	C. carp	44	.71	2.73	3.64	ND	ND	2.19	3.35	132	ND	1,282	18	ND	.95	ND	1.82	145	ND	194
6	C. carp	73	1.64	1.88	3.33	ND	ND	1.47	3.12	225	ND	1,110	16	ND	.65	ND	3.10	111	ND	279
8	C. carp	681	.53	2.14	9.29	ND	ND	3.54	40.62	686	ND	1,796	74	ND	5.75	ND	3.76	185	1.15	211
8	C. carp	1,118	1.10	3.59	15.09	ND	ND	3.38	7.24	1,092	ND	1,965	117	ND	2.35	ND	3.29	215	1.89	195
8	C. carp	885	.81	3.90	10.30	ND	ND	4.27	5.56	709	ND	1,868	91	ND	2.24	ND	3.72	178	1.62	239
9	C. carp	32	.93	ND	7.22	ND	0.22	1.87	3.24	170	.09	1,470	10	ND	.64	ND	3.74	175	.37	200
9	C. carp	31	.71	1.36	5.35	ND	.21	1.54	3.35	126	.12	1,174	9	ND	.54	ND	2.71	144	.56	161
3	Mullet	2,641	2.70	1.58	35.31	0.11	ND	4.72	6.41	3,264	ND	3,442	424	ND	2.52	ND	2.08	149	5.22	42
4	Mullet	1,557	4.89	3.82	47.99	.06	ND	3.42	8.22	2,365	ND	2,075	237	ND	2.83	ND	4.54	178	6.75	41
6	F. catfish	210	.75	3.20	2.68	ND	ND	1.91	12.70	216	ND	1,365	16	ND	2.25	ND	3.20	121	.43	57
9	C. catfish	62	.39	1.63	2.86	ND	ND	1.70	2.29	137	.34	1,168	6	ND	.53	ND	2.37	130	.48	55

[1]Reporting limits: Beryllium, cadmium, and mercury, ≤0.12; molybdenum and lead, ≤2.42.

[2]Priority pollutants of the U.S. Environmental Protection Agency.

Table 14. Statistical summary of trace elements in common carp, Yuma Valley, Arizona, 1995

[N, number of samples analyzed; number in parentheses is number of samples that contained detectable concentrations; data from collection sites sharing a common letter are statistically similar (ANOVA, $p \leq 0.05$)]

Sampling site (see fig. 1)	N	Geometric mean concentration and range in concentration, dry weight, in micrograms per gram						
		Aluminum	Arsenic[1]	Chromium[1]	Copper[1]	Nickel[1]	Selenium[1]	Zinc[1]
1	5	146 (5) AB	1.51 (5) A	1.83 (5) ABC	3.51 (5) A	0.80 (5) A	5.45 (5) A	170 (5) A
		69–212	.96–2.03	1.53–2.16	2.77–4.54	.65–1.17	4.36–7.79	150–187
2	4	158 (4) AB	.76 (4) A	2.32 (4) ABC	4.24 (4) AB	.87 (4) A	5.14 (4) A	232 (4) A
		46–295	.26–1.25	2.00–2.50	2.83–5.28	.73–1.02	3.46–7.74	196–263
3	4	123 (4) AB	.64 (4) A	2.87 (4) ADC	5.24 (4) AB	.99 (4) A	3.10 (4) AB	219 (4) A
		17–704	.48–.80	2.33–3.28	3.83–6.03	.64–1.53	2.42–4.01	168–288
4	2	76 (2) AB	.68 (2) A	1.13 (2) B	4.64 (2) AB	1.16 (2) AB	3.33 (2) AB	150 (2) A
		44–130	.56–.82	.76–1.68	3.90–5.52	.78–1.75	3.12–3.56	102–220
5	3	151 (3) AB	.93 (3) A	1.27 (3) B	2.81 (3) A	.83 (3) A	4.64 (3) AB	173 (3) A
		72–486	.60–1.19	.64–1.87	2.62–2.97	.72–1.05	3.77–5.34	139–238
6	4	72 (4) A	.88 (4) A	1.62 (4) AB	2.73 (4) A	.62 (4) A	2.61 (4) B	252 (4) A
		44–102	.50–1.64	1.45–2.19	1.88–3.35	.49–.95	1.82–3.48	194–296
8	3	877 (3) B	.78 (3) A	3.71 (3) CD	11.78 (3) B	3.11 (3) B	3.58 (3) AB	214 (3) A
		681–1,118	.53–1.10	3.38–4.27	5.56–40.6	2.24–5.75	3.29–3.76	195–211
9	2	31 (2) A	.81 (2) A	1.70 (2) BD	3.29 (2) AB	.59 (2) A	3.18 (2) AB	179 (2) A
		31–32	.71–.93	1.54–1.87	3.24–3.35	.54–.64	2.71–3.74	161–200

[1]Priority pollutants of the U.S. Environmental Protection Agency. Other priority pollutants including antimony, beryllium, cadmium, lead, silver, and thallium were not detected.

Table 15. Comparison of concentrations of trace elements in samples of fish, Yuma Valley, Arizona, 1995, to the 85th percentile of the National Contaminant Biomonitoring Program

[NCBP, National Contaminant Biomonitoring Program (Schmitt and Brumbaugh, 1990). Carp, common carp; Mullet, striped mullet; F. catfish, flathead catfish; C. catfish, channel catfish. Carp and catfish are individual whole-body samples. Five mullet were composited into a single sample at sites 3 and 4]

Sampling site (see fig. 1)	Sample	Concentrations of trace elements, wet weight, in micrograms per gram				
		Arsenic	Copper	Mercury	Selenium	Zinc
NCBP 85 percentile		0.27	1.00	0.17	0.73	0.27
1	Carp	.44	.66	ND	2.04	49.1
1	Carp	.59	.91	ND	1.47	45.3
1	Carp	.28	.81	ND	1.82	51.6
1	Carp	.45	1.24	ND	1.19	40.9
1	Carp	.38	.96	ND	1.20	49.6
2	Carp	.25	1.08	ND	1.14	57.2
2	Carp	.25	1.25	.06	.90	51.0
2	Carp	.06	.59	ND	1.15	55.0
2	Carp	.31	1.31	ND	1.92	58.6
3	Carp	.14	1.28	ND	.91	38.2
3	Carp	.16	1.38	ND	.61	42.3
3	Carp	.20	1.45	ND	.90	64.2
3	Carp	.11	.87	.03	.55	65.3
4	Carp	.14	1.38	.05	.89	55.1
4	Carp	.22	1.08	.05	.84	27.4
5	Carp	.39	.99	ND	1.72	82.5
5	Carp	.21	1.04	ND	1.32	48.8
5	Carp	.35	.77	ND	1.57	45.9
6	Carp	.20	.94	ND	.51	54.3
6	Carp	.46	.88	ND	.87	78.3
6	Carp	.34	.95	ND	1.16	98.5
6	Carp	.17	.64	ND	.80	85.2
8	Carp	.12	9.18	ND	.85	47.6
8	Carp	.25	1.65	ND	.75	44.5
8	Carp	.19	1.13	ND	.87	56.0
9	Carp	.26	.91	.02	1.05	56.2
9	Carp	.24	1.14	.04	.92	54.8
3	Mullet	.91	2.16	ND	.70	14.2
4	Mullet	1.70	2.86	ND	1.58	14.3
6	F. catfish	.18	3.06	ND	.77	13.7
9	C. catfish	.11	.64	.10	.66	15.3

Table 16. Selenium concentrations in whole carp from various locations in Arizona

Location	Year	Number of samples	Mean, wet weight, in micrograms per gram	Range, wet weight, in micrograms per gram	Reference
Havasu National Wildlife Refuge	1994	3	2.17	1.8–2.4	Andrews and others (1997)
Imperial National Wildlife Refuge	1991	16	2.10	1.0–3.5	Lusk (1993)
National Wildlife Refuges	1988–89	4	1.75	1.2–2.4	King and others (1993)
Lower Colorado River Valley	1986	31	1.49	.6–4.0	Radtke and others (1988)
Yuma Valley Colorado River	1995	7	1.38	.9–2.0	This study[1]
Yuma Valley Irrigation drainwater	1995	20	1.01	.6–1.9	This study[2]
Lower Gila River	1994–95	28	.64	.1–1.5	King and others (1997)
Bill Williams River National Wildlife Refuge	1991	7	.63	.5–.9	Ruiz and Maughan (1992)
Interior Arizona[3]	1988	7	.55	.4–1.0	King and others (1991)

[1]Sites 1 and 9, Colorado River (see fig. 1).

[2]Sites 2, 3, 4, 5, 6, and 8, irrigation drain water (see fig. 1).

[3]Includes Lake Pleasant, Alamo Lake, Roosevelt Lake, San Carlos Reservoir, and the Verde and Salt Rivers.