# Selected Chemical Characteristics and Acute Toxicity of Urban Stormwater, Streamflow, and Bed Material, Maricopa County, Arizona

By THOMAS J. LOPES and KENNETH D. FOSSUM

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 95—4074

Prepared in cooperation with the
ARIZONA DEPARTMENT OF
ENVIRONMENTAL QUALITY

Tucson, Arizona
1995

(page iii follows)

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

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director



---

For additional information write to:

District Chief
U.S. Geological Survey
Water Resources Division
375 South Euclid Avenue
Tucson, AZ 85719-6644

Copies of this report can be purchased from:

U.S. Geological Survey
Earth Science Information Center
Open-File Reports Section
Box 25286, MS 517
Denver Federal Center
Denver, CO 80225

# CONTENTS



## FIGURES

# CONTENTS—Continued

FIGURES—Continued Page



TABLES

# CONTENTS—Continued

## CONVERSION FACTORS

| Multiply | By | To obtain |
|---|---|---|
| inch (in.) | 25.4 | millimeter |
| inch (in.) | 2.540 | centimeter |
| foot (ft) | 0.3048 | meter |
| mile (mi) | 1.609 | kilometer |
| square mile ($mi^2$) | 2.590 | square kilometer |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second |
| pound (lb) | 0.907 | megagram |

In this report, temperature is reported in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by the following equation:

$$^{\circ}C = (^{\circ}F - 32)/1.8$$

## ABBREVIATED WATER-QUALITY UNITS

Chemical concentrations are given only in metric units. Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the solute mass 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 (ppm). Specific conductance is given in microsiemens per centimeter (µS/cm) at 25°C.

## VERTICAL DATUM

*Sea level*: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—A geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called "Sea Level Datum of 1929."

# Selected Chemical Characteristics and Acute Toxicity of Urban Stormwater, Streamflow, and Bed Material, Maricopa County, Arizona

*By* Thomas J. Lopes *and* Kenneth D. Fossum

## Abstract

The chemistry and toxicity of urban stormwater, streamflow, and bed material in the Phoenix, Arizona, area were characterized to determine if urban stormwater could degrade the quality of streams. Toxic phases of stormwater (oil and grease, suspended solids, dissolved metals, and dissolved organics) were identified to aid water-quality managers minimize the sources of toxicants. Acute aquatic toxicity tests were done using the water flea *Ceriodaphnia dubia* and fathead minnows (*Pimaphales promelas*), and acute sediment toxicity tests were done using the amphipod *Hyalella azteca*. Statistical analyses also were used to determine the effect of urbanization on the quality of water and bed material and to identify toxic constituents.

Statistical analyses indicated that urban stormwater could degrade the quality of streamflow with oil and grease, pesticides, dissolved trace metals, and ammonia, and that ammonia, lead, cadmium, and zinc are released by urban activities and accumulate in bed material. Ammonia may be from fertilizers, fecal matter, and other sources. Lead probably is from vehicles that use leaded gasoline. Cadmium and zinc could be from particulate metal in oil, brake pads, and other sources.

Samples of the initial runoff from urban drainage basins appeared to be more toxic than flow-weighted composite samples, and stormwater was more harmful to fathead minnows than to *Ceriodaphnia dubia*. Streamflow samples from the Salt River were not toxic to either species, which indicates that urban stormwater could degrade the quality of the Salt River. The enhanced mortality rate of fathead minnows exposed to urban stormwater from most urban drainage basins indicated that the toxicants were more detrimental to fish than to insects and could be present in stormwater throughout the Phoenix area. The most toxic stormwater samples were collected from the drainage basins with residential and commercial land use, and the toxicity probably was due to surfactants and (or) other constituents leached from asphalt and resealant. Results of toxicity identification evaluations indicated that the toxicity of stormwater mostly was due to organic constituents; dissolved zinc and copper also appeared to contribute to stormwater toxicity. Statistical comparisons of chemical data to toxicity data indicated that organophosphate pesticides were not the toxic constituents, and the toxicity generally was due to organic constituents that were not analyzed.

The most toxic bed-material samples were collected from a drainage basin with undeveloped land use. In these bed-material samples, mortality rates were significantly higher than in samples from ephemeral channels. Comparisons between the toxicity of bed-material samples from undeveloped and urban drainage basins and between urban drainage basins and ephemeral channels showed no significant difference. In urban drainage basins, bed-material samples collected from areas where stormwater accumulates appeared to be more toxic than samples collected from areas where stormwater does not accumulate.

For bed-material samples from the undeveloped drainage basin, mortality rates strongly correlated with recoverable concentrations of zinc and moderately correlated with recoverable concentrations of copper. The high mortality rate probably was due to naturally occurring trace metals. For bed-material samples from urban drainage basins, mortality rates significantly correlated with recoverable concentrations of cadmium and zinc, which resulted from urban activities. The bioavailability of trace metals in bed material appeared to be controlled by the adsorption properties of organic carbon, iron, and manganese. Organochlorine pesticides were detected in most bed-material samples; however, mortality rates were poorly correlated with pesticide concentrations.

# INTRODUCTION

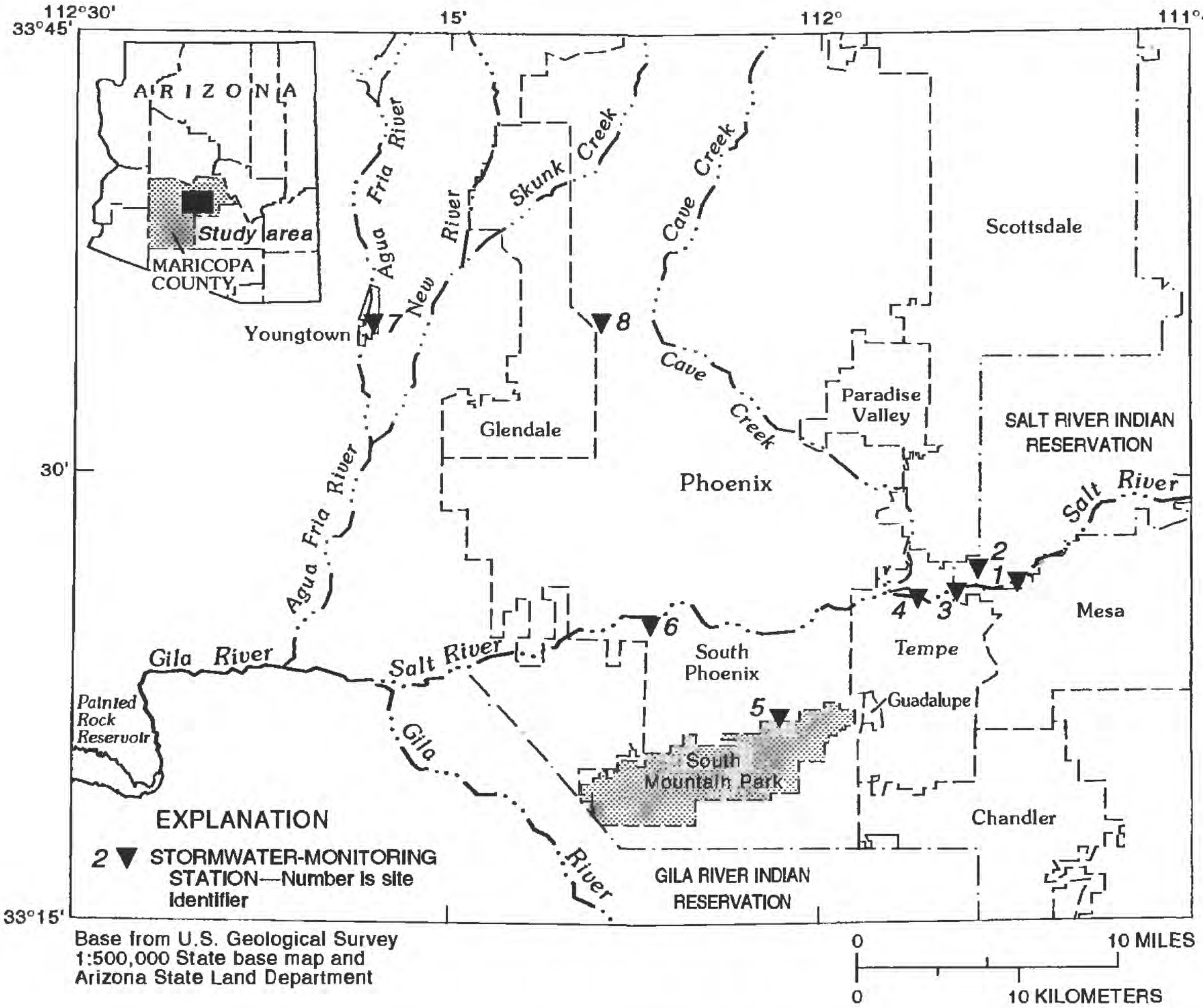
Protecting ecosystems that are influenced by human activities has become a primary goal in managing public lands. Some land-use activities release toxic chemicals that could inhibit the survival, growth, and reproduction of fauna and flora in aquatic ecosystems. Thousands of chemicals are used in urban activities, and some of these chemicals accumulate on impervious surfaces and in sediments. Storms flush chemicals and sediments from streets, parking lots, and rooftops. These flushes could produce surges of toxic stormwater that are discharged into streams and lakes. Most urban stormwater in the Phoenix area is routed into drainage channels, which are tributary to ephemeral streams that include the Gila, Salt, New, and Agua Fria Rivers. Accumulation of sediments in depositional environments, such as lakes and reservoirs, could adversely affect benthic organisms because many chemicals in urban stormwater are associated with the solid phase (Lopes and others, 1995).

Analyzing stormwater for a myriad of constituents is not an efficient way to determine whether stormwater degrades the quality of receiving streams. Toxicity testing is an alternative technique that screens stormwater for toxic constituents by measuring the adverse effect of stormwater on selected species. Acute toxicity tests are used to determine if solutions and sediment are toxic to selected species during short-duration (between 2 to 10 days) exposures. Acute toxicity testing of urban stormwater and bed material measures the effect of land use on the quality of receiving streams and identifying the toxic phases of stormwater can help water-quality managers implement strategies to minimize the sources of toxicants.

In 1992, the U.S. Geological Survey (USGS) in cooperation with the Arizona Department of Environmental Quality began a study of the quality of urban stormwater. The objectives of this study were to (1) characterize the chemistry and acute toxicity of stormwater from drainage basins with urban and undeveloped land use and of streamflow from the Salt River (fig. 1), (2) identify the phases of stormwater (oil and grease, suspended solids, dissolved trace metals, and dissolved organic compounds) that are causing the toxic effect, and (3) characterize the chemistry and acute toxicity of bed material from drainage basins with urban and undeveloped land use and ephemeral streams that receive urban runoff. The USGS monitored stormwater in Phoenix, Tempe, and unincorporated Maricopa County, and estimated constituent loads for Phoenix and the surrounding municipalities (Lopes and others, 1995). Data on the chemistry of urban stormwater were used in this study to focus on the constituents that were most likely to be toxic to aquatic organisms.

## Purpose and Scope

This report presents selected chemical and toxicological characteristics of stormwater and bed material from urban drainage basins, characteristics of streamflow and bed material from the Salt River, and characteristics of bed material from a drainage basin with undeveloped land use and the Agua Fria River. An evaluation also is presented of phases of stormwater and constituents in bed material that caused the toxic response.




| Site | Station number | Station name |
|---|---|---|
| *1* | 09512060 | Salt River at Alma School Road, near Mesa |
| *2* | 09512162 | Indian Bend Wash at Curry Road, at Tempe |
| *3* | 09512165 | Salt River at Priest Drive, at Phoenix |
| *4* | 09512184 | Box culvert at 48th Street drain |
| *5* | 09512200 | Salt River tributary in South Mountain Park, at Phoenix |
| *6* | 09512403 | 27th Avenue at Salt River |
| *7* | 09513700 | Agua Fria River tributary at Youngtown |
| *8* | 09513885 | 43rd and Peoria |

**Figure 1.** Study area and stormwater-monitoring stations, Maricopa County, Arizona.

## Approach

Monitoring stations were installed in drainage basins with residential, commercial, light industrial, heavy industrial, and undeveloped land use (table 1). Criteria for the selection of drainage basins included (1) drainage basins with a predominant land use so that stormwater and bed material from different land uses could be characterized, (2) an outfall at which a stage-discharge rating could be developed so that stream discharge could be computed, and (3) definite drainage-basin boundaries so that drainage-basin characteristics could be quantified. Drainage basins with mixed land use were sampled to characterize the composite effect of many land uses on the chemistry and toxicity of urban stormwater and bed material. Streamflow and bed material were

**Table 1.** Drainage-basin area, land use, and impervious area of drainage basins monitored for stormwater and bed-material characteristics, Maricopa County, Arizona

[ND, industrial land uses were not differentiated, and all industrial land use was assumed to be light. NA, insufficient data to calculate percentages]

| Station number | Station name or local identifier | Area of drainage basin, in acres | Land use, in percent | | | | | Impervious area, in percent |
|---|---|---|---|---|---|---|---|---|
| | | | Residential | Light industry | Heavy industry | Commercial | Undeveloped | |
| **Urban drainage basins** | | | | | | | | |
| 09512162 | Indian Bend Wash at Curry Road, at Tempe, Arizona | 52,480 | 31 | 5.6 | ND | 2.4 | 61 | 16 |
| 09512184 | Box culvert at 48th Street drain | 39 | 0 | 85 | 0 | 8 | 7 | 80 |
| 09512200 | Salt River tributary in South Mountain Park, at Phoenix, Arizona | 1,120 | 0 | 0 | 0 | 0 | 99 | 1 |
| 09512403 | 27th Avenue at Salt River | 45 | 6 | 0 | 94 | 0 | 0 | 15 |
| 09513885 | 43rd and Peoria | 3.4 | 0 | 0 | 0 | 97 | 3 | 94 |
| 09513700 | Agua Fria tributary at Youngtown, Arizona | 81 | 90 | 0 | 0 | 10 | 0 | 33 |
| 333543112090501 | Arizona Canal Diversion Channel | 32,770 | 34 | 12 | ND | 5.9 | 53 | 24 |
| **Salt River** | | | | | | | | |
| 09512165 | Salt River at Priest Drive, at Phoenix, Arizona | 846,336 | NA | NA | NA | NA | NA | NA |

sampled from the Salt River, and bed material was sampled from South Mountain Park to characterize the chemistry and toxicity of nonurban water and bed material and to determine whether urban activities could degrade water and bed-material quality. Stormwater was not sampled from South Mountain Park because of lack of flow; therefore, comparisons between urban stormwater and stormwater from an undeveloped drainage basin were not possible.

The concentration of constituents in sediment depends on the chemical composition of sediments and sediment-grain size; the largest concentrations are associated with fine-grained particles (Horowitz and Elrick, 1987). Samples of bed material were sieved, and particles less than 63 microns (silt and clay) were analyzed to characterize the grain size that contains most toxicants and to make comparisons between different sites. A previous study in these basins showed that suspended solids in urban stormwater are fine sand or less in size (Lopes and others, 1995).

The duration of stormflow typically is short and makes sampling difficult. Streamflow-gaging stations in urban drainage basins were instrumented with equipment that allowed remote monitoring of rainfall and stream discharge so that field crews could collect manual grab samples before flow stopped. Streamflow-gaging stations were instrumented with automatic-pumping samplers to collect samples for the duration of each storm and to reduce the personnel requirements for the study. The Salt River, Arizona Canal Diversion Channel (ACDC), and Indian Bend Wash were sampled using manual techniques, and stream discharge was monitored at or near the sampling locations.

Stormwater samples were collected between January 1993 and May 1994 from six drainage basins with residential, commercial, light industrial, heavy industrial, and mixed land use. During the study, there was insufficient flow to characterize stormwater from the drainage basin with undeveloped land use; therefore, only bed-material samples were collected from this drainage basin.

Streamflow samples were collected from the Salt River in December 1992 and January 1993. Bed-material samples were collected from the urban and undeveloped drainage basins and ephemeral channels in September 1992 and June 1993.


## Acknowledgments

The Flood Control District of Maricopa County (FCDMC) granted access to gaging stations that were used to monitor stormwater chemistry. Mattie Cahill and Jess and Sons, an auto recycler, allowed access through their property at 27th Avenue.


# DESCRIPTION OF THE STUDY AREA

The study area is about 1,000 $mi^2$ in a broad, flat basin in south-central Arizona, and much of the urbanization has occurred on land that was previously used for agriculture. The basin is between 1,000 and 1,300 ft above sea level and slopes downward from east to west. The highest peak in the surrounding mountains is about 2,700 ft above sea level in South Mountain Park.

The combined population of the Phoenix area is about 2,090,000 (Maricopa Association of Governments, 1993), which is about 90 percent of the total population of Maricopa County. Residential and open spaces are the most abundant land-use types and constitute about 62 and 18 percent of the Phoenix area, respectively (Maricopa Association of Governments, 1989). The remaining 20 percent includes other land uses such as commercial and industrial land use, parks, and schools.

Maricopa County is in the northern part of the Sonoran Desert climatic zone. The mean monthly maximum temperature is 105°F in the summer, and the mean monthly minimum temperature is 40°F in the winter (U.S. Department of Commerce, 1990). Mean annual rainfall at Sky Harbor International Airport is 7.11 in. Most of the annual rainfall occurs from two weather patterns that have the same mean storm rainfall (0.46 in.) and differ mostly in storm duration (Lopes and others, 1995). About 40 percent of the annual rainfall occurs between July and October from subtropical monsoons that originate from the Gulf of Mexico and Gulf of California and typically are short duration, high-intensity thunderstorms. About 50 percent of the annual rainfall occurs between November and March from cold fronts that originate in the Gulf of Alaska and are typically long duration, low-intensity storms. The remaining 10 percent of the annual rainfall occurs between April and June and could be the result of either type of weather pattern.

Stormwater and bed material were sampled from a drainage basin with residential land use near the intersection of Oregon and Peoria Avenues in Youngtown (USGS streamflow-gaging station 09513700, Agua Fria River tributary at Youngtown, Arizona). This site is an open channel that is tributary to the Agua Fria River, and discharge was monitored by the USGS from 1961 to 1968. About 50 percent of the homes in the basin have desert landscaping and about 50 percent have irrigated lawns. Commercial areas in the northern part of the drainage basin consist of two small shopping malls with parking lots, a gas station, and an automobile-repair shop. Peoria Avenue was resurfaced with asphalt in January 1993. The street was flushed by several storms before samples were collected; however, the asphalt may have affected the chemistry and toxicity of all stormwater samples.

Stormwater and bed material were sampled from a drainage basin with commercial land use at the northwest corner of Peoria and 43rd Avenues in Phoenix (09513885, 43rd and Peoria). Runoff at this site flows through a weir and into the ACDC, which is a stormwater conveyance that discharges into Skunk Creek. About 50 percent of the pervious area is undeveloped and about 50 percent has desert landscaping with some irrigation. Commercial businesses include a restaurant and retail stores. Resurfacing of the parking lot in March 1993 may have affected the chemistry and toxicity of the stormwater samples collected on March 26, August 24, and October 6, 1993.

Stormwater and bed material were sampled from a drainage basin with light industrial land use in Tempe near the intersection of 48th Street and the 48th Street drain (09512184, Box Culvert at 48th Street Drain). Stormwater flows through a 120-inch-wide box culvert and discharges into the 48th Street drain, which is a stormwater conveyance that discharges to the Salt River. Most of the pervious area has irrigated landscaping. Light industrial businesses include office parks, warehouses, small manufacturing shops, and heavy-equipment rental. Commercial land use includes a hotel and a restaurant.

Stormwater and bed material were sampled from a drainage basin with heavy industrial land use in Phoenix near the intersection of Broadway and 27th Avenue (09512403, 27th Avenue at Salt River). Stormwater flows through a 96-inch-diameter culvert and discharges into the Salt River. All businesses are automobile recycling and repair shops that operate on unpaved lots except for a precast concrete-products plant, a chemical-storage facility, and a mobile-home park.

Bed material was sampled from a drainage basin with undeveloped land use at South Mountain Park (09512200, Salt River tributary in South Mountain Park, at Phoenix, Arizona), where continuous stream-discharge records have been collected since 1961. In 1973, the drainage basin was designated as a mountain preserve and is used as an outdoor recreation area. The drainage basin is tributary to the Salt River; however, in 1979, a retention pond that reduces the amount of streamflow that reaches the river was constructed downstream from the streamflow-gaging station. During the study, there was insufficient flow at this site to collect stormwater samples.

Stormwater was sampled from the ACDC at 51st Avenue (333543112090501). Bed material was sampled from the ACDC where it intersects 51st, 59th, and 67th Avenues. ACDC is an urban stormwater conveyance that is concrete lined to 51st Avenue and grass lined from 51st Avenue to Skunk Creek. The grass-lined sections are irrigated and used for recreation.

Stormwater was sampled from Indian Bend Wash at the streamflow-gaging station, Indian Bend Wash at Curry Road, at Tempe, Arizona (09512162). Two bed-material samples were collected from Indian Bend Wash where it intersects Shea Boulevard and Curry Road. The drainage area at Curry Road is about 82 $mi^2$ and is tributary to the Salt River. About 39 percent of the drainage basin is developed; however, about 70 percent of the basin near the streamflow-gaging station is urbanized. Indian Bend Wash was sampled when streamflow consisted of runoff from the City of Scottsdale and the northern part of the City of Phoenix. Runoff from undeveloped parts of the drainage basin contribute to streamflow only during large storms. Much of Indian Bend Wash is grass lined and used for recreation and includes several golf courses and manmade lakes.

Streamflow was sampled from the Salt River at the streamflow-gaging station, Salt River at Priest Drive, at Phoenix, Arizona (09512165). Bed material was sampled from the Salt River where it intersects Priest Drive, 24th Street, and 35th Avenue. The Salt River is ephemeral and typically flows when dams upstream from Maricopa County release water or during large storms in the Phoenix area. Streamflow samples were collected between December 1992 and February 1993 when water was released from dams on the Verde and Salt Rivers. Streamflow reached a maximum of 129,000 $ft^3/s$ on January 8, 1993. Most ephemeral channels in the Phoenix area were flooded, which probably scoured bed material and chemicals that had accumulated in the Salt River, ACDC, and Indian Bend Wash before samples were collected in June 1993.

Bed material was sampled from the Agua Fria River, which drains a mostly undeveloped area of about 2,000 $mi^2$ at the sampling sites. Samples were collected upstream, downstream, and at the mouth of the tributary that drains urban stormwater from Youngtown (09513700). Samples were collected in September 1992 and were not affected by floods.

## DATA-COLLECTION METHODS

Runoff and precipitation data were collected at urban drainage basins between January 1993 and March 1994 using the following equipment:

- Campbell Scientific Instruments, Inc., CR10 datalogger and SM192 storage module;
- Sierra-Misco Environment Ltd., model 2500 tipping-bucket rain gage;
- Druck PDCR 940 pressure transducer;
- Conoflow and pressure-regulator system;
- Isco, Inc., Model 3700 automatic-pumping sampler; and
- Motorola MC310 cellular telephone.

The datalogger was programmed to record instrument readings, calculate stream discharge, and activate the automatic-pumping sampler when a specified volume of water had been discharged from the drainage basin. The datalogger also initiated a telephone call to a hydrologist when precipitation or discharge was measured so that the hydrologist could make manual discharge measurements and collect grab samples during runoff. Data were recorded at 1-minute intervals when either rainfall or stream discharge was measured. Data were recorded once a day (at midnight) if dry conditions persisted.

## Precipitation

Precipitation was measured in urban drainage basins and at South Mountain Park with a tipping-bucket rain gage that was calibrated to tip when 0.01 in. of rainfall was collected. A pulse was transmitted to the datalogger each time 0.01 in. of rainfall was collected. The number of pulses in each minute was recorded to measure rainfall intensity. Rainfall during each successive minute was recorded and summed to obtain accumulated rainfall.

## Stream Discharge

Gage height was measured at urban drainage basins and South Mountain Park using a Conoflow and pressure-regulator system. The Conoflow and pressure regulator maintain a constant rate of nitrogen flowing through a tube that extends from the gaging station to an orifice at the bottom of the channel or culvert. Greater pressure is required to maintain a constant flow rate through the tube as stage increases. Pressure in the tube was measured with the pressure transducer, which was calibrated to within 0.02 ft and, except for 27th Avenue, was placed 3 to 5 ft underground to reduce effects of temperature on pressure-transducer measurements. At 27th Avenue, the transducer was placed in the culvert and insulated. Temperature of the pressure transducer varied by about 4°F/d, and temperature corrections were not necessary. Gage height at the ACDC was measured by the Flood Control District of Maricopa County using a pressure transducer. Gage height at Indian Bend Wash was measured by a float, and gage height at the Salt River at Priest Drive was measured using a wire-weight gage.

Stage-discharge ratings for all urban drainage basins were developed on the basis of channel geometry and slope by using the slope-conveyance method (Kennedy, 1984). A stage-discharge rating that was based on manual discharge measurements had been developed at South Mountain Park. Instantaneous discharge measurements were made when water samples were collected from the Salt River and the ACDC. Stream-discharge measurements were made at all streamflow-gaging stations using either a pygmy or Price AA meter and the 0.6-depth or 0.2- and 0.8-depth wading method or a calibrated bucket (Rantz and others, 1982). Stream-discharge measurements and associated gage heights compared well with developed stage-discharge ratings.

Instantaneous discharge rates at urban drainage basins and South Mountain Park were computed by programming the data logger with a log-normal regression equation that was fit to the stage-discharge rating of each site (Kolb, 1983). The log-normal equations compared well with all discharge ratings (correlation coefficients were 0.99 or greater). Stream-discharge volumes were computed by multiplying the mean of two consecutive discharge-rate measurements by 60 seconds to obtain the mean volume of stream discharge during that 1-minute interval. The mean volumes were summed to obtain the total volume of runoff.

## Stormwater, Streamflow, and Bed-Material Samples

Stormwater samples were collected from urban drainage basins by automatic-pumping samplers and automatic-grab samplers to collect flow-weighted composite samples and samples of the initial runoff from a storm (first flush). The automatic-pumping sampler is a portable, nonrefrigerated unit calibrated to pump a specified volume of stormwater. Twenty-four 1-liter, teflon-lined, polyethylene bottles were used to hold discrete samples for chemical analyses. Samples were pumped when a specified volume of water discharged from the drainage basin. Discrete samples were later combined to obtain a flow-weighted composite sample. Samples for toxicity analyses were collected with another automatic-pumping sampler that was equipped with 24 1-liter polyethylene bottles. The automatic-grab sampler is an 8-liter Nalgene carboy fitted with a float valve and placed in the ground so that the top of the carboy is level with the ground surface. Initial runoff from a storm flows into the carboy, and the float minimizes mixing of the first-flush water with the rest of the runoff. A steel grate, coated with an epoxy-based paint, was used to prevent the first-flush samplers from floating away and to keep traffic from damaging the samplers. Two or three automatic-grab samplers were installed at each site to collect enough water for chemical and toxicity analyses.

Streamflow samples were collected from the Salt River, ACDC, and Indian Bend Wash by using the equal-width-increment method and by collecting grab samples. Equal-width-increment samples were collected at equal distances perpendicular to the direction of streamflow. Samples were then composited to obtain a single sample that is representative of the stream at a discrete time.

Stormwater and streamflow samples were placed on ice and transported to the field office for processing. Samples for chemical analyses were poured into a teflon-lined, stainless-steel churn splitter to split the samples into the bottles required for each analysis. Samples for toxicity analyses were poured into 8-liter Nalgene carboys and chilled at 39°F. Samples for dissolved-constituent analyses were filtered using a 0.45-micron effective pore-size cellulose filter. Preservatives then were added to sample bottles as required. All components of the sampling equipment that came in contact with samples for chemical analyses were constructed of either glass, teflon, or stainless steel except for the distribution hose in the automatic-pumping sampler, which was silicon rubber. Samples for toxicity analyses came into contact with glass, teflon, stainless steel, polyethylene, and the Nalgene carboys. Equipment that was in contact with sample water was cleaned by washing with Liquinox followed by rinsing with large quantities of tap water, a rinse of ultrapure methanol, and a final rinse of deionized water.

Bed-material samples from urban drainage basins, South Mountain Park, and the Agua Fria River were collected at specific points. Bed-material samples were collected at equal increments across each reach of the Salt River, ACDC, and Indian Bend Wash and were composited for chemical and toxicity analyses. Bed material was sieved, and particles that were less than 63 microns were collected for analyses. Samples for trace-metal, nutrient, inorganic plus organic carbon, inorganic carbon, and toxicity analyses were collected using plastic trowels and plastic sieves and screens. Samples for organochlorine and organophosphate pesticide analysis were collected using stainless-steel spoons and brass sieves and screens. Whole-sediment samples were collected using stainless-steel spoons for oil and grease and particle-size distribution analyses. All equipment that came in contact with sediment were washed with Liquinox followed by rinsing with large quantities of tap water and a final rinse of deionized water.

Quality-assurance procedures were followed throughout the study to identify potential problems in data collection caused by sampling methods or equipment contamination. These procedures included the use of duplicate and equipment-blank samples. Duplicate samples of stormwater and bed material were used to check the precision of laboratory analyses and the sample-splitting process. Analyses from duplicate samples indicated that laboratory analyses and the sample-splitting process were producing consistent results. Equipment-blank samples were collected by pumping and processing inorganic-free and organic-free water in the same manner as sample water and by rinsing the automatic-grab sampler and epoxy-painted grates with deionized water. Analyses from equipment blanks indicated that minimal cross contamination occurred between sampled storms and that the grates were not contaminating samples with trace metals.

The representativeness of samples collected with the automatic-pumping sampler was evaluated by collecting manual, depth-integrated samples simultaneously with automatically collected samples. Samples were analyzed for concentrations of nutrients, selected metals, and suspended solids. Results indicated that flow in shallow, swift channels is well mixed and can be accurately represented by samples collected at a single point.

Samples for chemical analyses were shipped to the USGS National Water Quality Laboratory for analysis. Acute toxicity, total hardness, pH, specific conductance, total alkalinity, total chlorine, and total ammonia were analyzed by Aquatic Consulting and Testing, Inc., Tempe, Arizona. Dissolved and total alkalinity concentrations were measured in the Tempe office of the USGS.

## METHODS OF MEASURING THE ACUTE TOXICITY OF WATER AND SEDIMENT

Acute toxicity tests that were performed on water samples were dilution series, static renewal tests, which were done using standard procedures (U.S. Environmental Protection Agency, 1990). Stormwater and streamflow samples were diluted with moderately hard reconstituted water (MHRW) to obtain mixtures that had 100, 50, 25, 12.5, and 6.25 percent (by volume) of stormwater or streamflow; mixtures were kept between 66° to 70°F during the test. MHRW was prepared from reagent grade salts and had a total hardness of 80 to 100 mg/L as $CaCO_3$ and pH of 7.4 to 7.8. Fathead minnows (*Pimaphales promelas*; 5- to 10-days old) and the water flea *Ceriodaphnia dubia* (hereafter referred to as *C. dubia*; less than 24-hours old) were used as surrogate species and fed before testing. The mixtures were renewed every 24 hours to more accurately simulate a natural environment where the amount of toxicants in the water is not limited. Acute toxicity tests using fathead minnows lasted 96 hours and tests using *C. dubia* lasted 48 hours. The trimmed Spearman-Karber, probit, or graphical methods (Rand and Petrocelli, 1985) were used to estimate the concentration of stormwater (in percent, by volume) that caused a certain mortality rate (for example, percentage of stormwater that killed 50 percent of the organisms, LC50). Water and bed-material samples were considered acutely toxic if 20 percent or more of the organisms died when exposed to 100 percent of the sample; a mortality rate of 20 percent is significantly different from the mortality rate measured in positive controls (U.S. Environmental Protection Agency, 1990).

The toxic strength of a constituent or sample can be expressed in toxic units (TU), which is the concentration of a constituent or sample divided by the LC50 value (Rand and Petrocelli, 1985). For example, a stormwater sample with an LC50 value of 25 percent has 4 TU (100 percent stormwater divided by the LC50). TU values are used instead of LC50 values because TU values increase as toxicant concentrations increase, whereas LC50 values decrease as toxicant concentrations increase.

Fathead minnows and *C. dubia* were selected as surrogate species because: (1) no native species inhabit ephemeral streams in urbanized Maricopa County; (2) these are standard species used in toxicity testing; (3) substantial data exist on their mortality rates when exposed to a large number of toxicants; and (4) their mortality rates have been correlated with the mortality rates of other organisms (Mayer and Ellersieck, 1986). Mayer and Ellersieck (1986) compared mortality rates of species exposed to pesticides and determined that insects generally were the most sensitive species, followed by crustaceans, fish, and amphibians. Of the most commonly tested organisms, daphnids were more sensitive 58 percent of the time, rainbow trout, 35 percent; blue gill, 5 percent; and fathead minnows, 2 percent.

All aquatic toxicity tests were performed in duplicate to check precision of the test. Positive controls using only MHRW were performed with all samples to ensure that mortality was caused by exposure to stormwater rather than by poor health of the organisms. Negative controls, using copper sulfate, were performed monthly to check laboratory protocol and to ensure that the brood stock produced organisms that responded within acceptable limits to a toxicant with a known LC50 value. Analyses from duplicate samples, positive controls, and negative controls indicated that the laboratory was producing consistent results, that toxic constituents in samples caused the mortality, and that the mortality of organisms was predictable when exposed to various concentrations of a known toxicant.

Toxicity identification evaluations (TIE's) were performed on most stormwater samples that were toxic. TIE is a method of identifying the toxic components of a solution and consists of three procedures: (1) toxicity characterization (U.S. Environmental Protection Agency, 1991); (2) toxicity identification (U.S. Environmental Protection Agency, 1993a); and (3) toxicity confirmation (U.S. Environmental Protection Agency, 1993b). Toxicity characterization was the only procedure performed for this study because toxicity-reduction strategies would probably focus on certain phases of stormwater rather than a specific constituent. Results of a previous study (Lopes and others, 1995) indicated that oil and grease, suspended solids, dissolved metals, and dissolved organic compounds were the most likely phases of stormwater that could be toxic. Volatile organic compounds were seldom detected, and the pH of most stormwater samples was typical of most rivers, indicating that these constituents were unlikely to cause toxicity in stormwater.

TIE's were performed by sequentially extracting oil and grease, suspended solids, dissolved metals, and dissolved organic compounds from toxic samples. After extracting potentially toxic phases, toxicity tests were performed on the solutions. A reduction in mortality indicated that the extracted phase caused a toxic response. Stormwater samples were split into five subsamples when a toxic response was measured during the definitive acute toxicity (original) test (fig. 2). Oil and grease were extracted from one of the subsamples by decanting the upper inch of water, passing it through activated carbon and glass wool, and returning the water to the container. Oil and grease were extracted, and then suspended solids were removed from the second subsample by filtering the subsample through a 0.45-micron polycarbonate filter. After extracting oil and grease and suspended solids from the third subsample, dissolved metals were chelated with various concentrations of ethylenediaminetetraacetic acid (EDTA), which reduces the toxicity of dissolved metals (U.S. Environmental Protection Agency, 1991). If more EDTA is added than is needed to chelate dissolved metals, the excess EDTA can be toxic. Oil and grease were extracted, and suspended solids were filtered from a fourth subsample using an 0.7-micron glass-fiber filter. Next, two aliquots of the fourth subsample were adjusted to either pH 3 or 9 with hydrochloric acid or sodium hydroxide and a third aliquot was untreated. The three aliquots were passed through a column of octadecyl to extract anionic, cationic, and neutral organic compounds, and then the pH of the aliquots was adjusted to the initial pH. The fifth subsample was the baseline and was untreated. The baseline was used to determine if sample degradation occurred between the time the original test and TIE were performed and to measure reduction in toxicity due to each extraction. Acute toxicity tests were performed concurrently on the baseline, the extracted solutions, and the positive controls.

Quality assurance of each TIE included use of duplicates and positive controls. Duplicates were performed on the oil and grease and suspended-solids extractions and on the organics extraction using solutions after 25 and 150 mL had passed through the octadecyl column. The extraction procedure was performed on dilution water and was used as a positive control. Duplicates compared well, and significant mortality was not observed in the controls. This comparison and absence of mortality indicated that procedures for removing oil and grease, suspended solids, and organic compounds did not contribute to the toxicity of stormwater samples.

Acute sediment toxicity tests were performed on urban bed-material samples using guidelines of the American Society of Testing and Materials (1990). Sediment toxicity tests consisted of placing 100 g of sieved (less than 63 microns) bed material in each of five 1-liter glass beakers, adding 400 mL of hard reconstituted water (HRW; hardness of 160 to 180 mg/L as $CaCO_3$; pH 7.6 to 8.0), and letting the mixtures equilibrate for 24 hours. After equilibration, 20 *Hyalella azteca* (hereafter referred to as *H. azteca*; less than 16-days old, 2 to 3 mm in size) were added to each beaker and observed for 10 days. Organisms remained in the same mixture during the test and were fed Tetramin three times a week. *H. azteca* is an epibenthic amphipod that can live in a wide range of sediment grain size (Ingersoll and Nelson, 1990) and is a sensitive indicator of the presence of contaminants associated with sediments (Ingersoll and Nelson, 1990; Landrum and Scavia, 1983; Nebeker and others, 1984). The acute mortality rate, in percent, was calculated at the end of the test by counting the number of organisms that died.

All sediment toxicity tests were performed with five replicates to check the precision of the test and to ensure that equipment contamination did not cause the mortality. Positive controls consisted of silica sand and HRW, and had mortality rates of 2 and 8 percent. Sand was purchased from a hardware store and tested as a positive control, but was unsuitable because significant mortality rate (19 percent) was measured. Negative controls

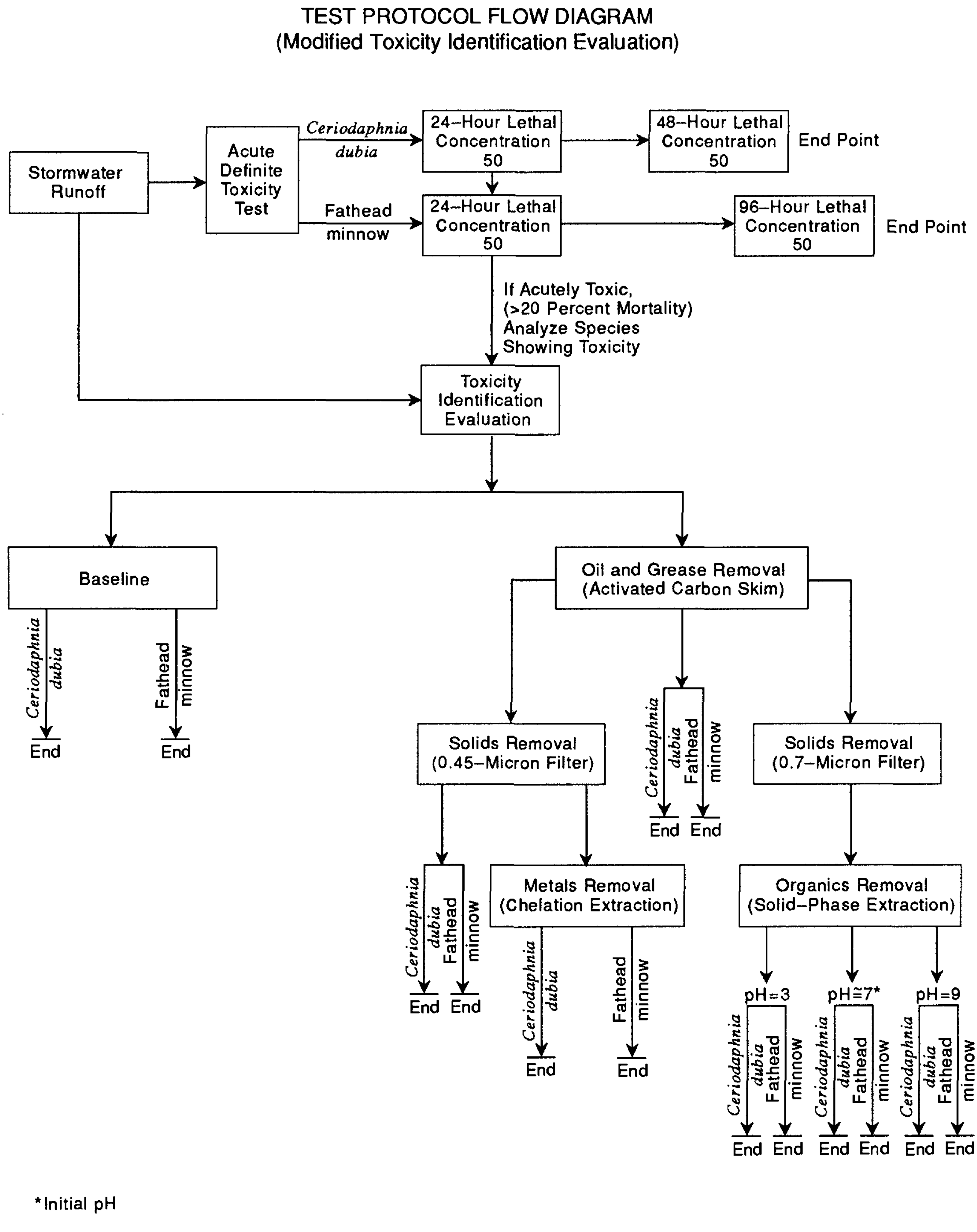



**Figure 2.** Extraction sequence for toxicity identification.

consisted of copper sulfate, silica sand, and HRW and were used to ensure that organisms responded to a known toxicant. Negative controls done in September 1992 and June 1993 yielded the same LC50 for copper (70 μg/L). This value compares well with results of another study (Schubauer-Berigan and Dierkes, 1993), which calculated an LC50 for copper of 87 μg/L in very hard (300 mg/L as $CaCO_3$) reconstituted water. Analyses of replicates, positive controls, and negative controls indicated that the laboratory was producing consistent results, that mortality was caused by exposure to bed-material samples, and that the mortality of organisms was predictable when exposed to various concentrations of a known toxicant.

## CHEMICAL CHARACTERISTICS OF URBAN STORMWATER, STREAMFLOW, AND BED MATERIAL

A total of 36 water samples were collected, including 14 first-flush samples, 14 flow-weighted composite samples, 4 equal-width-increment samples from urbanized tributaries, and 4 equal-width-increment samples from the Salt River. First-flush samples were collected at the drainage basins with a single land use during the first few minutes of flow. Equal-width-increment samples from the ACDC and Indian Bend Wash were collected near the peaks and tails of the hydrographs, and samples from the Salt River were collected at various discharge rates.

All water samples were analyzed for oil and grease, suspended solids, total chlorine, total ammonia, total hardness, dissolved trace metals, and acute toxicity. Organophosphate pesticides also were analyzed in flow-weighted composite and equal-width-increment samples. Organochlorine pesticides, acid/base/neutral organic compounds, and volatile organic compounds were not analyzed because concentrations of these constituents in flow-weighted composite and streamflow samples collected during an earlier study typically were less than detection limits (Lopes and others, 1995).

A total of 30 bed-material samples were collected including 13 samples from urban drainage basins, 11 samples from ephemeral channels, and 6 samples from South Mountain Park. All bed-material samples were analyzed for oil and grease, organic and inorganic carbon, total recoverable trace metals and nutrients, organochlorine and organophosphate pesticides, and acute toxicity.

Lead, molybdenum, beryllium, and silver had the lowest concentrations of dissolved trace metals that were tested and were detected in one to four samples of stormwater and streamflow. Total chlorine and the pesticides—parathion, trithion, disyston, phorate, DEF, and fonofos—were detected in zero to four samples of stormwater and streamflow. Perthane, endosulfan, aldrin, endrin, heptachlor, ethion, malathion, methylparathion, parathion, trithion, polychlorinated naphthalene (PCN), methoxychlor, and mirex were detected in five or fewer bed-material samples. Chemical analyses indicated that these constituents were not significant in stormwater and bed material from the Phoenix area.

### Urban Stormwater

Initial runoff from Youngtown, Peoria, and 48th Street was typically black in color, which could be from oil and grease, particulates from ground-up tires, or other sources. The strainer for the automatic-pumping sampler at Youngtown and Peoria was coated with oil and grease after most storms. Oil and grease were detected in about 80 percent of urban stormwater samples, and the median concentration was 4 mg/L for first-flush and for flow-weighted composite samples. Concentrations of oil and grease in samples from the ACDC and Indian Bend Wash ranged from less than 1 to 8 mg/L, and the maximum concentration measured in all urban stormwater samples was 10 mg/L.

Total ammonia was detected in about 80 percent of urban stormwater samples, and the median concentration measured in first-flush and flow-weighted composite samples was 1.3 and 0.6 mg/L, respectively. The concentration of total ammonia in samples from the ACDC and Indian Bend Wash ranged from less than 0.1 to 8.9 mg/L, and the maximum concentration measured in all stormwater samples was 11.0 mg/L from Peoria.

Median total hardness concentrations of first-flush and flow-weighted composite samples were 150 and 48 mg/L as $CaCO_3$, respectively, and ranged from 36 to 500 mg/L and from 20 to 228 mg/L, respectively. Total hardness in samples from the ACDC and Indian Bend Wash ranged from 44 to 92 mg/L. About 50 percent of all stormwater samples were soft (less than 60 mg/L), 30 percent were moderately hard to hard (between 61 and 180 mg/L), and 20 percent were very hard (more than 180 mg/L). Soft stormwater typically was associated with flow-weighted composite samples. Hardness affects the toxicity of certain constituents (Rand and Petrocelli, 1985).

Median specific-conductance values of first-flush and flow-weighted composite samples were 296 and 142 µS/cm, respectively, and values ranged from 84 to 7,100 µS/cm and from 44 to 414 µS/cm, respectively. Specific-conductance values in samples from Indian Bend Wash and the ACDC ranged from 138 to 251 µS/cm. In general, specific-conductance values were higher in first-flush samples than flow-weighted composite samples, indicating that soluble constituents were washed from exposed surfaces during the initial part of a storm and diluted during the latter part of the storm (figs. 3 and 4). Specific conductance, however, increased during some storms at 48th Street and 27th Avenue. The increase could be due to an uneven distribution of rainfall in the drainage basin and runoff arriving at the gaging station at different times. Large concentrations of toxicants could be associated with high specific-conductance values, which did not always occur with the first flush.

Median concentrations of suspended solids were about 160 mg/L for first-flush and flow-weighted composite samples. Suspended-solids concentrations ranged from 45 to 1,190 mg/L in first-flush samples and from 40 to 544 mg/L in flow-weighted composite samples. Suspended-

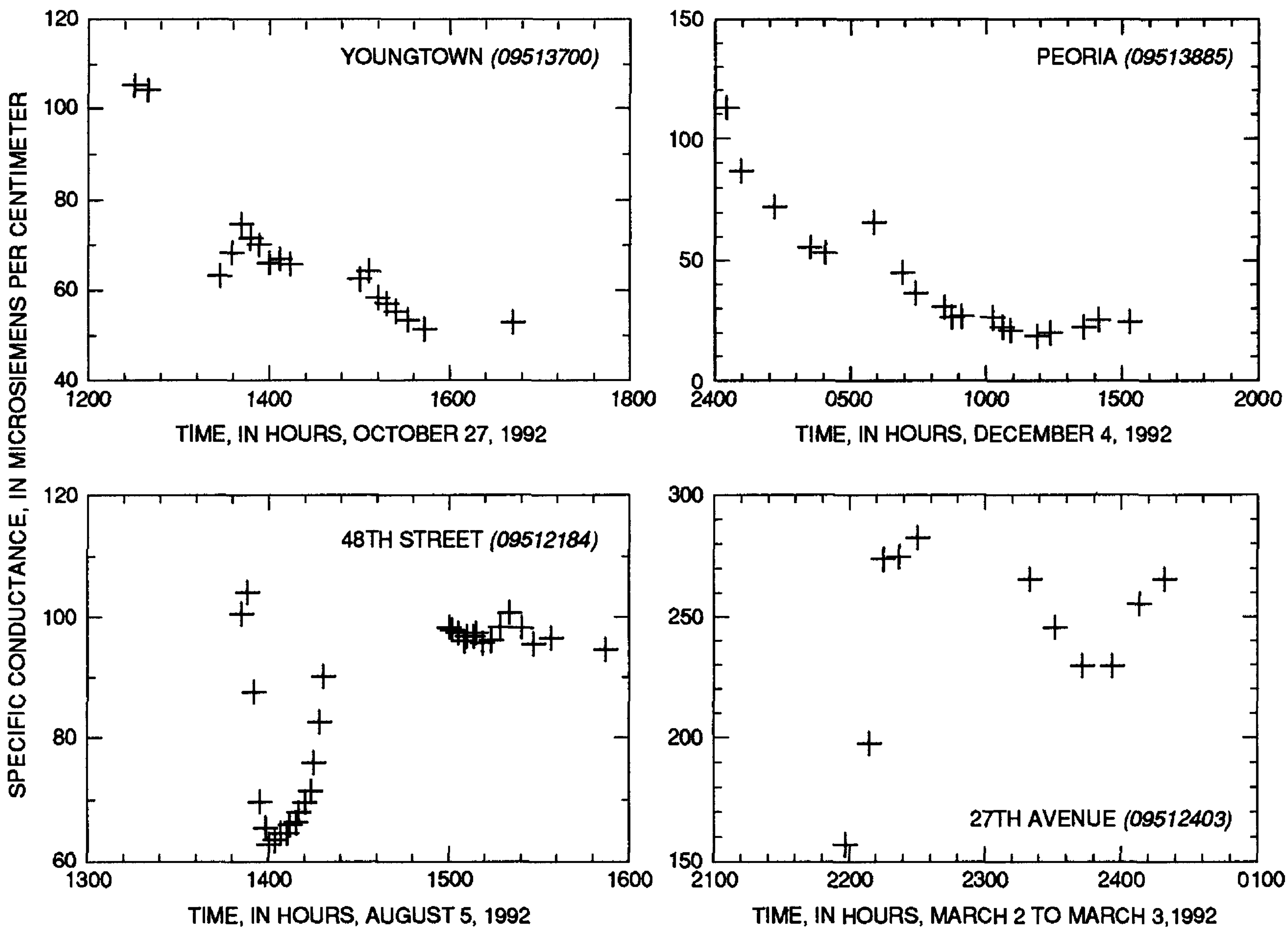



**Figure 3.** Specific conductance of stormwater as a function of time during a storm, Maricopa County, Arizona. Time refers to Mountain Standard Time and is given according to the 24-hour clock. U.S. Geological Survey stormwater-monitoring station number is in italics.

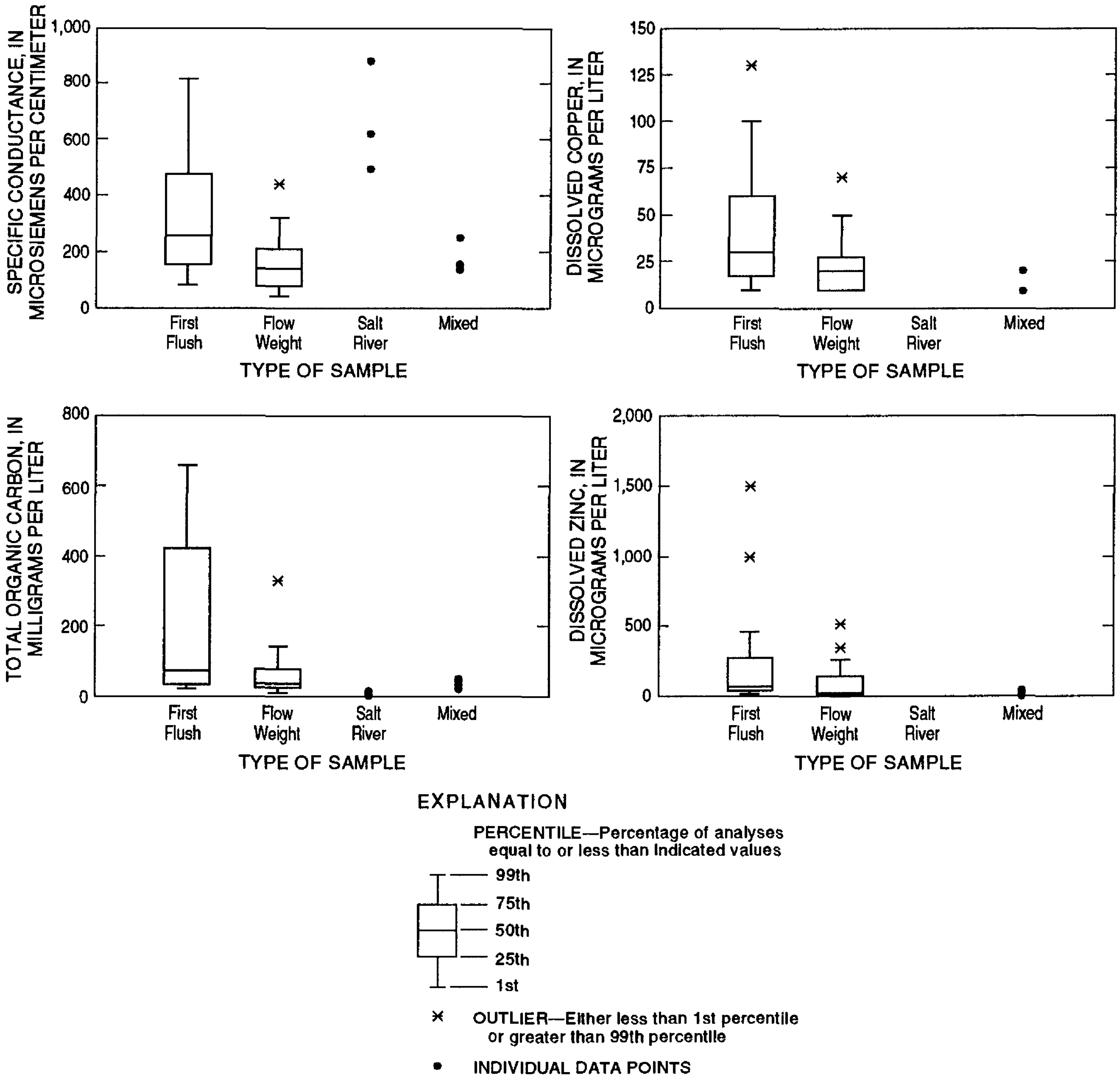



**Figure 4.** Ranges in specific-conductance values and constituent concentrations in stormwater and streamflow, Maricopa County, Arizona. The sample of the intitial runoff (first flush) collected near 43rd Avenue and Peoria (USGS streamflow-gaging station 09813885), August 24, 1994, which had 5,000 milligrams per liter of total organic carbon and a specific conductance of 7,100 microsiemens per centimeter, was not included in the boxplots. Constituent concentrations measured in this outlier were too extreme to plot.

solids concentrations ranged from 30 to 394 mg/L in samples from the ACDC and Indian Bend Wash.

The median concentrations of total organic carbon in first-flush and flow-weighted composite samples were 80 and 36 mg/L, respectively, and are larger than concentrations found in bogs (Thurman, 1985). Concentrations of total organic carbon ranged from 23 to 49 mg/L in samples from the ACDC and Indian Bend Wash. Total organic carbon in first-flush samples had a significant rank correlation with suspended-solids concentrations (0.85), which indicates that most organic carbon occurred as particulates. The rank correlation is the correlation of two variables using their relative ranking rather than absolute values, which gives outliers less weight in the correlation. Total organic carbon in flow-weighted composite samples and samples from the ACDC and Indian Bend Wash did not correlate with suspended solids (–0.05). Samples commonly had a brown color after filtering with an 0.45-micron filter indicating that organic carbon was in the dissolved phase.

Concentrations of the organophosphate pesticides, diazinon and malathion, ranged from 0.01 to 1.1 µg/L and were detected in 94 percent of urban stormwater samples. The largest concentrations of diazinon and malathion were measured in samples from the ACDC. Concentrations of chlorpyrifos ranged from 0.02 to 0.13 µg/L and were detected in 66 percent of urban stormwater samples. Chlorpyrifos was the only other pesticide that was detected in samples from the ACDC and Indian Bend Wash. Methylparathion, dysiston, DEF, and phorate were detected in 7 to 42 percent of flow-weighted composite samples, and concentrations ranged from less than 0.01 to 0.11 µg/L. Organophosphate pesticides commonly are used in urban environments and are applied frequently because they readily degrade into nontoxic compounds (Fukato, 1987). The weak correlation of diazinon and malathion to suspended solids (0.25 and 0.20, respectively) and to total organic carbon (–0.18 and 0.09, respectively) indicated that these pesticides were associated with the dissolved phase.

Certain organic compounds are weak acids that appear to make urban stormwater slightly acidic. pH values of stormwater were typically between 6 and 7; whereas, most streams in Arizona have alkaline pH values (pH values are typically between 7.5 and 9.0; Smith and others, 1994). Total organic carbon significantly correlated with the pH of urban stormwater and streamflow samples (–0.58; fig. 5). The lowest pH value (4.9) was measured in a first-flush sample from Peoria and the highest values (between 7.0 and 7.8) were measured in samples from 27th Avenue and Indian Bend Wash. Peoria has 94 percent impervious area and little exposed soil to react with stormwater, whereas 27th Avenue and Indian Bend Wash have mostly pervious area. The pH of stormwater appears to be a function of the percentage of impervious area in a drainage basin.

pH measurements made on unfiltered samples for chemical analyses differed from pH measurements made on unfiltered samples for toxicity testing by as much as 1.4 units. pH in unfiltered samples for chemical analyses were significantly biased to lower pH values, and the median difference was 0.4 units less than the pH in samples for toxicity testing (fig. 5). pH varied by about 0.1 to 0.2 units during the toxicity test; one sample changed by 0.7 units. The stable pH during the toxicity test indicated that stormwater and sediments reached equilibrium by the time tests started.

Concentrations of dissolved trace metals were typically larger in first-flush than in flow-weighted composite samples (fig. 4). These larger concentrations could be due to flushing of metal salts in the initial runoff, dilution of the flow-weighted composite samples, or because metals are more soluble in first-flush water. Statistical comparisons between first-flush samples and flow-weighted composite samples, however, indicated that first-flush samples had significantly larger concentrations only for dissolved barium, strontium, calcium, magnesium, and cadmium. Flow-weighted composite samples and samples from drainage basins with mixed land use had similar concentrations. An insufficient number of data, however, were collected to make statistical comparisons between stormwater samples from mixed land-use basins and samples from single land-use basins. Comparisons were made using a one-way analysis of variance (ANOVA) with Tukey's W multiple-comparison test (Statware, Inc., 1990).

Dissolved iron, manganese, barium, strontium, and zinc were detected in all stormwater samples. Median concentrations of dissolved iron and manganese were 80 and 66 µg/L, respectively, and concentrations ranged from 10 to 25,000 µg/L. Median concentrations of dissolved barium and strontium were 24 and 135 µg/L, respectively, and concentrations ranged from 6 to 770 µg/L. The median concentration of dissolved zinc was 42 µg/L, and concentrations ranged from 4 to 1,500 µg/L. Dissolved copper was detected in 75 percent of stormwater samples, had a median concentration of 20 µg/L, and concentrations ranged from 10 to 130 µg/L. Other dissolved trace metals were detected in about 50 percent or fewer of the stormwater samples.

Aerated streams with pH values between 6.5 and 8 typically have about 10 µg/L of dissolved

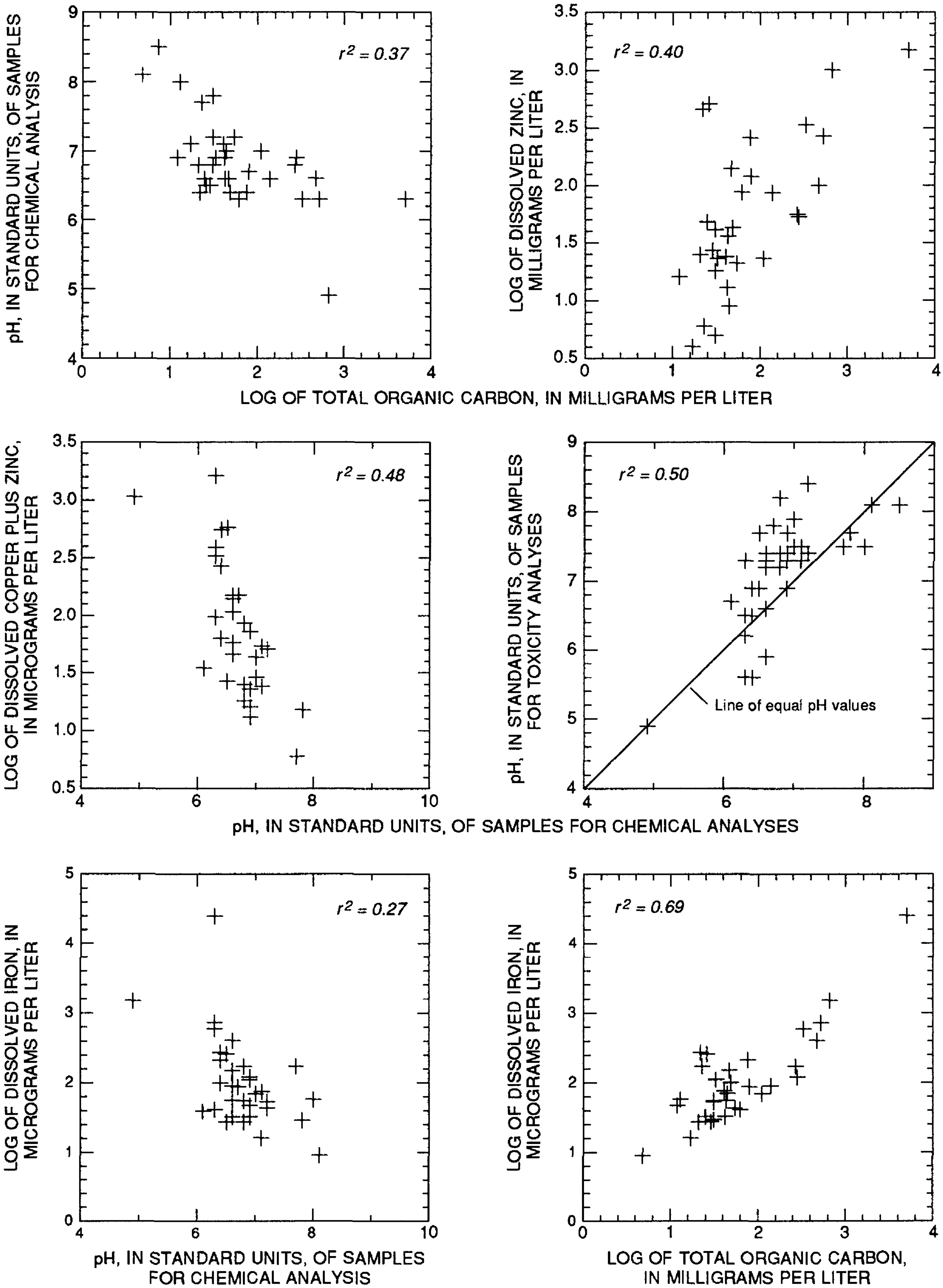



**Figure 5.** Concentration of selected constituents as a function of concentration of total organic carbon and as a function of pH, and pH measured in samples for toxicity analyses as a function of pH measured in samples for chemical analyses, Maricopa County, Arizona.

iron (Hem, 1985). The large concentrations of dissolved iron indicate that iron is either stabilized by organic complexes and (or) reducing conditions exist in stormwater. Oxidation of organic carbon by dissolved oxygen lowers the oxidation-reduction (redox) potential if concentrations of organic carbon are larger than dissolved oxygen concentrations. Iron and manganese solubility increase as the pH and redox potential decrease (Hem, 1985). For all samples, dissolved iron and manganese concentrations were positively correlated with total organic carbon (0.64 and 0.75, respectively), inversely correlated with dissolved oxygen (–0.93 and –0.72, respectively), and inversely correlated with pH (–0.48 and –0.68, respectively; fig. 5). The large concentrations of organic carbon appeared to lower the pH, and may form stable complexes with iron, lower the redox potential of stormwater, and control trace-metal solubility. Trace metals that adsorbed to iron and manganese oxyhydroxides would be released into solution when the oxyhydroxides dissolve. These releases could account for the strong correlation between iron, manganese, and dissolved trace-metal concentrations (correlations were between 0.4 and 0.9 for most trace metals). Iron and manganese oxyhydroxides have a large adsorption capacity and concentrate trace metals in sediments (Horowitz and Elrick, 1987).

The concentrations of dissolved trace metals measured in urban stormwater may be different from the concentrations that organisms were exposed to during the acute toxicity test. Samples for trace-metal analyses were filtered and preserved soon after collection; equilibrium between the solution and suspended solids probably was not established before samples were filtered. Samples for toxicity analyses were not filtered and stored at 39°F in sealed containers for 1 to 3 days. The lack of filtration would allow more time for solutions and suspended solids to equilibrate. Lowering the redox potential in the sealed containers would increase the solubility of certain trace metals. The redox potential probably changed again during the toxicity test when samples were aerated to maintain 40 percent or greater saturation of dissolved oxygen. The changes in pH and redox potential probably affected dissolved trace-metal concentrations, and the concentrations measured in stormwater may not represent the concentrations that organisms were exposed to during the toxicity test.

Dissolved trace-metal concentrations, percentage of land use, and percentage of impervious area were not significantly correlated at a level of 5 percent, except for zinc. Correlations were calculated using concentrations of dissolved trace metals measured in flow-weighted composite samples collected from the urban drainage basins since 1991. Dissolved zinc positively correlated with the percentage of commercial land use (0.60), percentage of undeveloped land use (0.52), percentage of impervious area (0.75), and inversely correlated with percentage of industrial land use (–0.50) and percentage of residential land use (–0.42). Dissolved trace-metal concentrations and rainfall were inversely correlated (correlations ranged from –0.34 to –0.57) indicating that large storms dilute constituent concentrations.

## Streamflow

Streamflow samples were collected during the flood that occurred in 1993 when dams upstream from Maricopa County released water into the Salt River. Stream discharge reached a maximum of 129,000 $ft^3/s$ on January 8, 1993, at Salt River at Alma School Road near Mesa, Arizona (09512060), which is about 6 mi upstream from Salt River at Priest Drive (09512165). Three samples were collected at discharge rates of 10 (first-flush sample), 8,600, and 47,800 $ft^3/s$ for constituent concentrations and acute toxicity. Another sample was collected at 25,500 $ft^3/s$ after a landfill collapsed into the Salt River and was analyzed only for constituent concentrations.

Concentrations of oil and grease, organophosphate pesticides, and dissolved zinc, copper, cadmium, nickel, chromium, and cobalt were less than detection limits in samples from the Salt River, but were detected in 28 to 100 percent of urban stormwater samples. Total ammonia was detected only in the first-flush sample (0.36 mg/L). These data indicate that urban stormwater could degrade the quality of streamflow with oil and grease, pesticides, dissolved trace metals, and ammonia.

Total hardness of streamflow ranged from 152 to 216 mg/L as $CaCO_3$, which was harder than most stormwater samples. Suspended-solids concentrations ranged from 9 to 318 mg/L and were significantly correlated with stream discharge (0.77). Specific conductance of streamflow steadily decreased from 880 to 299 µS/cm during the floods (fig. 6) indicating that salts were flushed from the channel, diluted, or that runoff had a short retention time in the reservoirs. Specific-conductance values of streamflow were larger than most values of urban stormwater indicating that streamflow is saltier than urban stormwater. The pH of streamflow was 8.9 in the first-flush sample and about 8 in other samples.

ANOVA results indicated that concentrations of dissolved strontium, magnesium, and lithium in streamflow samples were significantly larger than

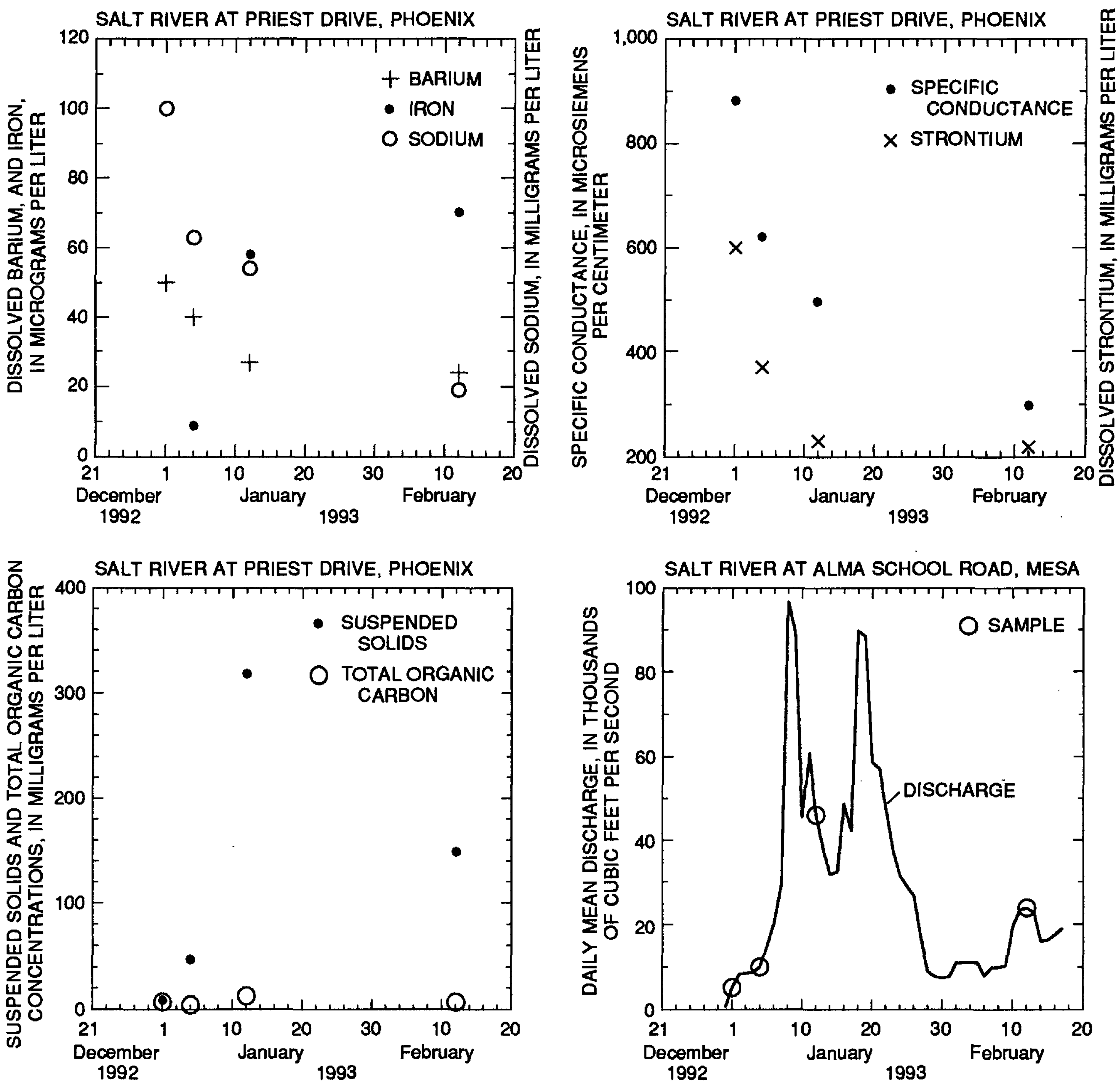



**Figure 6.** Concentrations of selected constituents and specific conductance in streamflow from the Salt River at Priest Drive, Phoenix, Arizona, as a fuction of time, and daily mean discharge of the Salt River at Alma School Road, near Mesa, Arizona, as a function time.

in urban stormwater samples. Concentrations of these constituents steadily decreased with time during the flood and did not vary with discharge (fig. 6). Concentrations of dissolved iron and manganese steadily increased during the flood from less than 3 to 70 µg/L and from 1 to 4 µg/L, respectively. Concentrations of dissolved molybdenum, vanadium, and silver were near the detection limits in the first-flush sample from the Salt River and were not detected in other samples.

The increase in iron and manganese concentrations at pH values of about 8 could be due to complexation with dissolved organic carbon, changes in the redox potential of streamflow, or an increase in the amount of colloids smaller than 0.45 µm during the flood. Dissolved oxygen concentration was near saturation, and total organic carbon concentrations ranged from 4.8 to 13 mg/L. These concentrations are typical of most rivers and lakes (Thurman, 1985). These data indicate that redox and complexation probably did not affect iron and manganese concentrations and that concentrations are probably due to colloids.

## Bed Material

Urban activities appear to have increased the concentrations of certain constituents above natural concentrations. The natural concentration of constituents depends primarily on the geology of the source areas for bed material. Most urbanization has occurred on bed material deposited by the Salt, Verde, and Agua Fria Rivers, which originate from the White Mountains, Verde Valley, and Chino Valley, respectively. The geology of South Mountain Park is the primary factor affecting constituent concentrations in bed material from the drainage basin with undeveloped land use. Constituent concentrations in bed material from urban drainage basins should be similar to concentrations in bed material from ephemeral channels. Urban activities, however, release certain constituents that accumulate in bed material, which increases the concentration of these constituents above natural concentrations.

ANOVA results indicate that urban activities increased the recoverable concentrations of ammonia, lead, cadmium, and zinc in bed-material samples from urban drainage basins compared to recoverable concentrations in samples from ephemeral channels (fig. 7). Ammonia could be from fertilizers, fecal matter, and other sources. Lead is probably from vehicles that use leaded gasoline. Cadmium and zinc could be from particulate metal in oil, brake pads, and other sources. Recoverable concentrations of other constituents, including pesticides, were not significantly different between bed-material samples from urban drainage basins and ephemeral streams.

ANOVA results also indicate that recoverable concentrations of manganese were larger and recoverable concentrations of arsenic were smaller in bed-material samples from South Mountain Park than samples from either urban drainage basins or ephemeral channels. Recoverable concentrations of copper were smaller in bed-material samples from South Mountain Park than in samples from urban drainage basins, and phosphorous concentrations were smaller in bed-material samples from South Mountain Park than in samples from ephemeral channels. Recoverable concentrations of other constituents, including pesticides, were not statistically different among bed-material samples from South Mountain Park, urban drainage basins, and ephemeral streams. Manganese is a common constituent in bed material, and the large recoverable concentrations probably are due to the geology of South Mountain Park.

Organic carbon and oxyhydroxides of iron and manganese remove metals from solution because of their large adsorption capacities (Horowitz and Elrick, 1987; Drever, 1988). The percentage of organic carbon significantly correlated with recoverable concentrations of zinc and cadmium in bed material from urban drainage basins (table 2 and fig. 8) and indicates that most metals released by urban activities are associated with organic matter. Lead, however, was not significantly correlated with organic carbon, iron, or manganese. Lead is emitted in automobile exhaust as halide salts (Post and Buseck, 1984), which could explain the lack of correlation with adsorbing materials. Naturally occurring trace metals in bed material from urban drainage basins strongly correlated with iron and manganese and poorly correlated with organic carbon.

Trace metals in bed-material samples collected from ephemeral channels and South Mountain Park

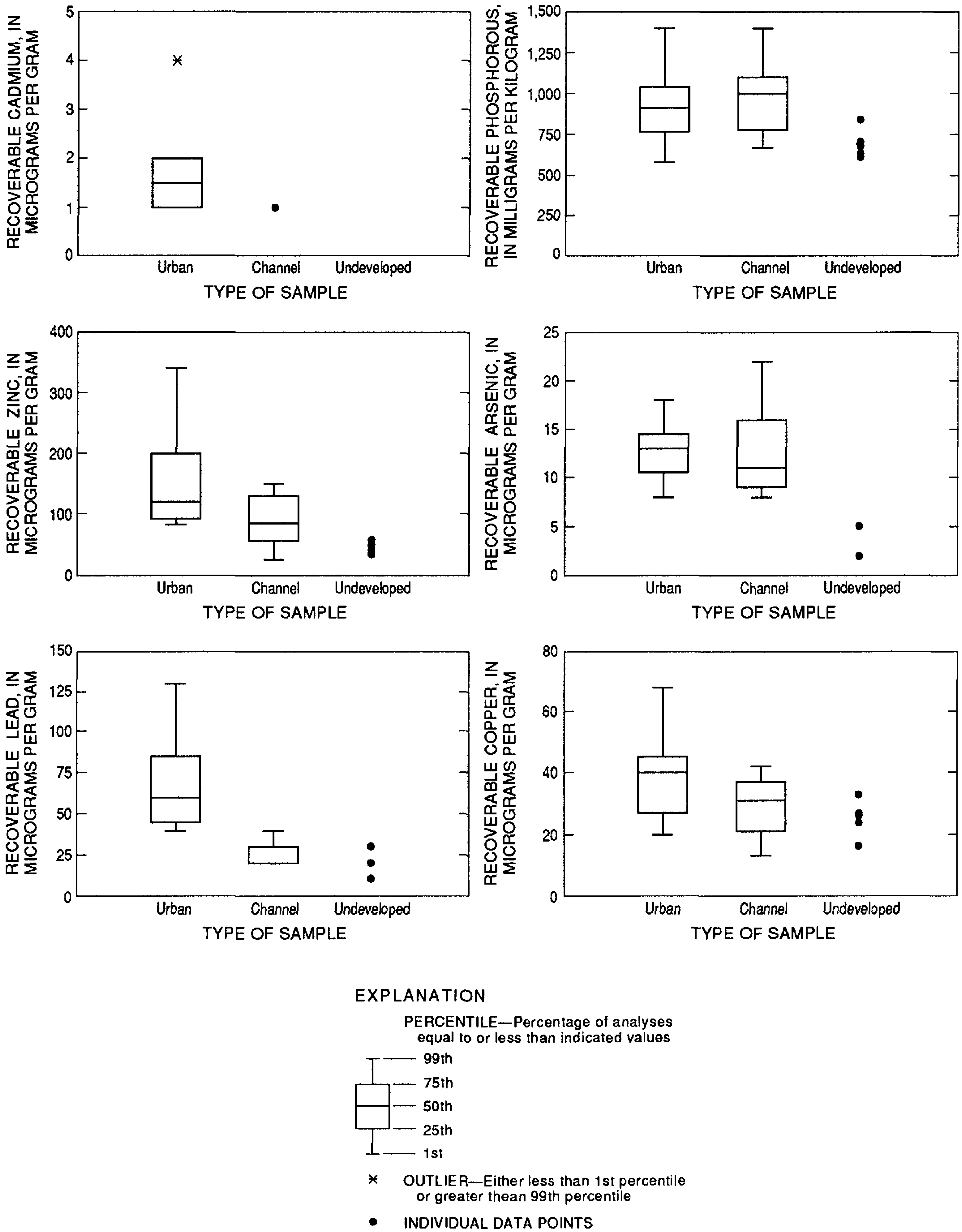



**Figure 7.** Ranges in constituent concentrations in bed material from urban drainage basins, ephemeral channels, and South Mountain Park, which is an undeveloped drainage basin, Maricopa County, Arizona.

**Table 2.** Spearman rank correlations of trace metals and pesticides to recoverable iron and manganese and organic carbon in bed material, Maricopa County, Arizona

[Trace elements, in micrograms per gram are total recoverable; pesticides are given in micrograms per kilogram; ----, dashes indicate there were an insufficient number of detections to compute correlations; DDE, dichlorodiphenylethylene; DDT, dichlorodiphenyltrichloroethane]

| Trace metal | Number of samples | Correlation to total recoverable iron | Correlation to total recoverable manganese | Correlation to organic carbon, in percent | Pesticide | Number of samples | Correlation to total recoverable iron | Correlation to total recoverable manganese | Correlation to organic carbon, in percent |
|---|---|---|---|---|---|---|---|---|---|
| **Urban drainage basins** | | | | | | | | | |
| Arsenic | 13 | [1]0.79 | 0.36 | –0.16 | Chlordane | 11 | 0.40 | 0.01 | 0.12 |
| Cadmium | 12 | [1]–.61 | –.28 | [1].60 | DDE | 12 | .25 | –.08 | –.28 |
| Chromium | 13 | [1].67 | .08 | .14 | DDT | 12 | .20 | –.02 | –.44 |
| Copper | 13 | .46 | [1].62 | .07 | Dieldrin | 11 | .19 | .26 | .33 |
| Lead | 13 | –.47 | [1]–.70 | –.06 | Toxaphene | 12 | –.04 | .12 | –.22 |
| Zinc | 13 | –.13 | .11 | [1].80 | Diazinon | 12 | [1]–.64 | –.46 | .47 |
| **Ephemeral streams** | | | | | | | | | |
| Arsenic | 11 | .19 | .20 | .33 | Chlordane | 11 | –.07 | –.38 | .43 |
| Cadmium | 3 | ------- | ------- | ------- | DDE | 11 | .03 | –.38 | .06 |
| Chromium | 11 | [1].81 | .36 | .52 | DDT | 11 | –.37 | –.43 | –.43 |
| Copper | 11 | .50 | .54 | .46 | Dieldrin | 9 | .14 | –.27 | .15 |
| Lead | 11 | .28 | –.25 | [1].64 | Toxaphene | 10 | –.52 | –.54 | –.52 |
| Zinc | 11 | .33 | .02 | [1].63 | Diazinon | 8 | –.01 | –.42 | [1].70 |
| **Undeveloped drainage basin** | | | | | | | | | |
| Arsenic | 6 | .65 | –.40 | .13 | Chlordane | 4 | .40 | [1]1.0 | .40 |
| Cadmium | 0 | ------- | ------- | ------- | DDE | 4 | .60 | .74 | [1]1.0 |
| Chromium | 6 | –.13 | .66 | .65 | DDT | 2 | ------- | ------- | ------- |
| Copper | 6 | .23 | [1]1.0 | .67 | Dieldrin | 3 | .50 | .50 | [1]1.0 |
| Lead | 6 | .28 | [1].89 | .62 | Toxaphene | 6 | –.03 | [1].84 | .54 |
| Zinc | 6 | .48 | [1].93 | .77 | Diazinon | 1 | ------- | ------- | ------- |

[1]Correlation was significant at a level of 5 percent.

significantly correlated with the percentage of organic carbon and (or) recoverable concentrations of iron and manganese (table 2). Streamflow may partially solubilize metal oxyhydroxides and release trace metals from adsorbing materials. The trace metals would adsorb onto the organic carbon and metal oxyhydroxides after flow ceases. The redistribution of metals between adsorbing materials could account for the difference in correlations between naturally occurring constituents in bed material from urban drainage basins, ephemeral channels, and South Mountain Park.

Toxaphene, dichlorodiphenylethylene (DDE), dichlorodiphenyltrichloroethane (DDT), chlordane, and dieldrin were detected in 77 to 93 percent of all bed-material samples and had recoverable concentrations between 0.6 and 1,800 µg/kg.

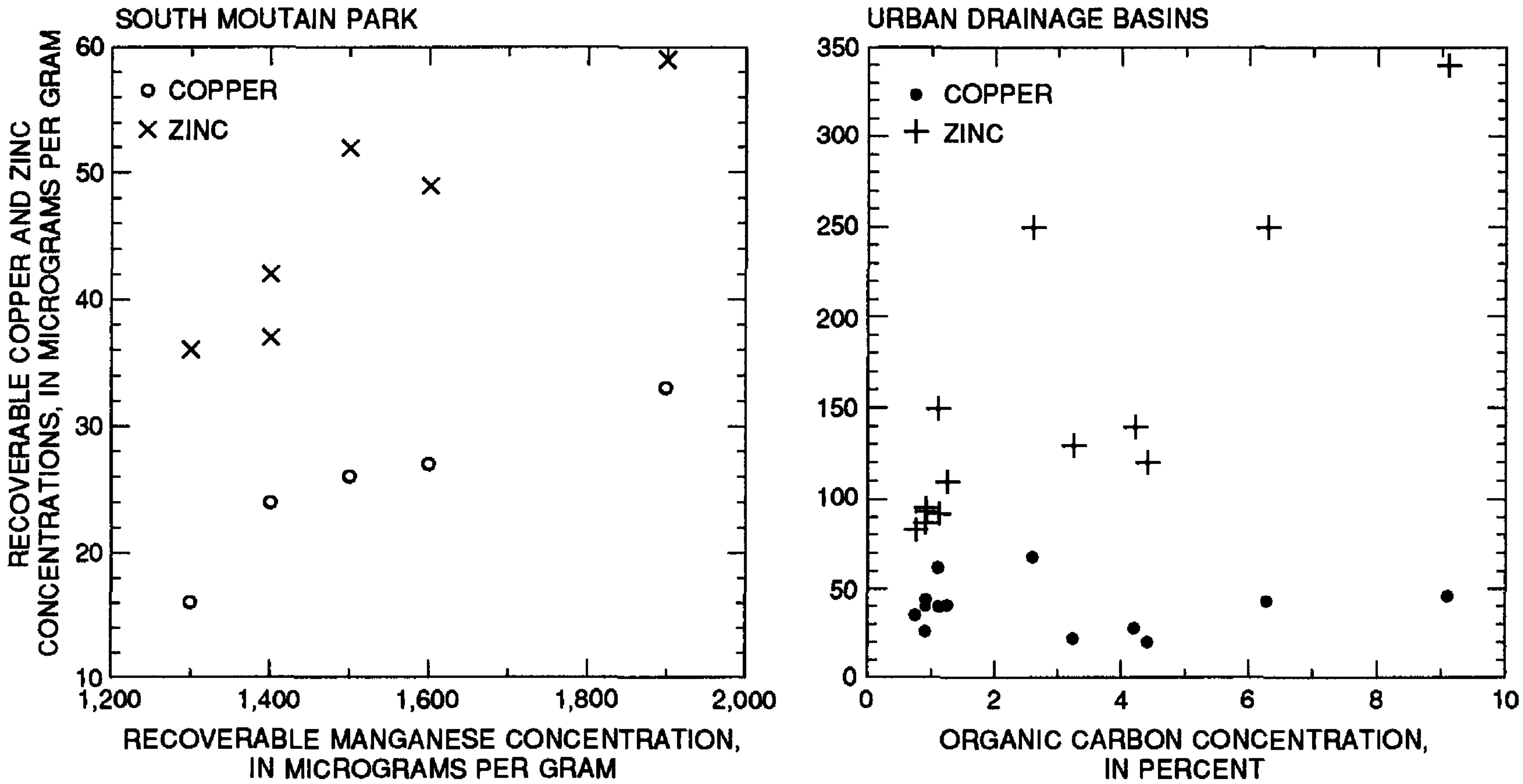



**Figure 8.** Constituent concentrations of manganese and organic carbon in bed material, Maricopa County, Arizona. Bed-material samples were sieved, and the fraction less than 63 microns was analyzed for constituent concentrations.

Toxaphene and DDT were heavily applied in the Phoenix area during the 1950's and 1960's when much of the area was used for agriculture (Hanks, 1988) and probably are residues from agricultural practices rather than urban activities. Overspraying of nearby fields, illegal dumping, or wind-blown particulates could account for the pesticides at South Mountain Park.

Diazinon was detected in 70 percent of all bed-material samples and had recoverable concentrations between 0.1 and 690 µg/kg. Other organophosphate pesticides were detected in less than 17 percent of all bed-material samples and, when detected, were typically in bed material from urban drainage basins.

Organochlorine pesticides were weakly correlated with the percentage of organic carbon and recoverable concentrations of iron and manganese (table 2) except for heptepoxy, which significantly correlated with iron (0.95) in urban bed material. Organochlorine pesticides also could be adsorbed onto clay minerals, but the mineralogy of bed-material samples was not determined. Diazinon was moderately to strongly correlated with the percentage of organic carbon.

The particle-size distribution of bed-material samples was variable and ranged from less than 1 to 75 percent silt and clay, which was the particle size that was analyzed for chemical concentrations and acute toxicity. Bed-material samples from urban drainage basins and ephemeral streams had similar median percentages of silt and clay-size particles. South Mountain, which has steep slopes and boulder terrain, had the coarsest bed material.

## ACUTE TOXICITY OF URBAN STORMWATER, STREAMFLOW, AND BED MATERIAL

Acute toxicity was measured in all stormwater and bed-material samples and in three of four streamflow samples that were analyzed for constituent concentrations. TIE's, using either fathead minnows or *C. dubia*, were performed on 11 first-flush samples, 5 flow-weighted composite samples, and 3 samples from drainage basins with mixed land use.

## Urban Stormwater

First-flush samples generally were more toxic than flow-weighted composite samples and urban stormwater was more harmful to fathead minnows than to *C. dubia*. About 71 percent of first-flush samples were toxic to fathead minnows, and 28 percent were toxic to *C. dubia* (table 3). About 36 percent of flow-weighted composite samples were toxic to fathead minnows, and 14 percent were toxic to *C. dubia*. Most of the toxic stormwater samples were from the drainage basins with commercial and residential land use. For toxic stormwater samples, however, the LC50 values of first-flush and flow-weighted composite samples were not significantly different. The enhanced mortality rate of fathead minnows by urban stormwater from most drainage basins indicated that the toxicants were more detrimental to fish and could be present in stormwater throughout the Phoenix area.

Toxicants are not always in the initial runoff. The flow-weighted composite sample collected from 27th Avenue on March 25, 1994, was toxic to fathead minnows; however, the first-flush sample was nontoxic. The difference in toxicity between these samples could be due to the retention time of toxicants in the drainage basin, and specific-conductance values measured at this site indicated that the largest concentrations of constituents are not always associated with the first flush (fig. 3).

Two of four stormwater samples collected from drainage basins with mixed land use were toxic to fathead minnows, and one was toxic to *C. dubia*. An insufficient number of data, however, were collected to compare the toxicity of stormwater samples from drainage basins with mixed land use to first-flush or flow-weighted composite samples

**Table 3.** Summary of toxicity tests conducted on urban stormwater and streamflow, Maricopa County, Arizona

[LC20 is the percent of stormwater that causes 20-percent mortality; ----, dashes indicate there were an insufficient number of toxic samples to calculate descriptive statistics; descriptive statistics were calculated using the log-probability method (Helsel and Cohn, 1988)]

| Type of sample | Species | Number of samples | Number of toxic samples[1] | Percent toxic samples | Median LC20 | Mean LC20 | Standard deviation of LC20 |
|---|---|---|---|---|---|---|---|
| **Stormwater from urban drainage basins with single land use Peoria, Youngtown, 48th Street, and 27th Avenue** | | | | | | | |
| First flush | Fathead minnow | 14 | 10 | 71 | 54 | 48 | 77 |
| First flush | *Ceriodaphnia dubia* | 14 | 4 | 28 | 100 | 79 | 65 |
| Composite | Fathead minnow | 14 | 5 | 36 | 76 | 70 | 82 |
| Composite | *Ceriodaphnia dubia* | 14 | 2 | 14 | -- | --- | --- |
| **Stormwater from urban drainage basins with mixed land use Indian Bend Wash at Curry Road, at Tempe, Arizona, and Arizona Canal Diversion Channel** | | | | | | | |
| Equal width | Fathead minnow | 4 | 2 | 50 | -- | --- | --- |
| Equal width | *Ceriodaphnia dubia* | 4 | 1 | 25 | -- | --- | --- |
| **Streamflow from dams upstream from Phoenix, which is a nonurban source Streamflow in the Salt River at Priest Drive, at Phoenix, Arizona** | | | | | | | |
| Equal width | Fathead minnow | 3 | 0 | 0 | -- | --- | --- |
| Equal width | *Ceriodaphnia dubia* | 3 | 0 | 0 | -- | --- | --- |

[1]Toxicity is defined as causing mortality in 100-percent stormwater of 20 percent or more.

and to determine if stormwater was more harmful to fathead minnows than to *C. dubia*.

The most toxic stormwater samples, indicated by TU values, were collected from Youngtown on March 26, 1993, and from Peoria on August 24, 1993. Toxicity probably was due to asphalt and resealant. The street at Youngtown was repaved with asphalt in late January 1993, and the parking lot at Peoria was resealed with oil on or about March 20, 1993. The accumulated rainfall between the resurfacing and sample collection was 1.52 in. at Youngtown and 1.03 in. at Peoria. The first-flush and flow-weighted composite samples collected from Youngtown on March 26 were toxic to *C. dubia* (TU values were 5.6 and 3.9, respectively); however, only the first-flush sample was toxic to fathead minnows (TU value was 1.5). Stormwater sampled at Youngtown after March 1993 was toxic only to fathead minnows and TU values ranged from 1.5 to 4.4. The first-flush sample collected from Peoria on August 24 was toxic to fathead minnows and *C. dubia* (TU values were 11.4 for both species); however, the flow-weighted composite sample was not toxic to either species. First-flush and flow-weighted composite samples collected from Peoria on October 6, 1993, were toxic only to fathead minnow (TU values were 3.8 and 1.6, respectively).

Stormwater at Youngtown and Peoria had a yellowish foam that was not present before the resurfacing. The foam was absent after several storms had occurred at each site, indicating that surfactants and possibly other constituents were leached from the asphalt and resealant. Surfactants are a complex group of ionic and nonionic chemicals that are most commonly used as cleaning agents, such as detergents and fabric softeners, and were identified as constituents that are toxic to *C. dubia* (Ankley and Burkhard, 1992). The TU values of samples from Youngtown indicated that toxicants leached from asphalt and resealant were harmful to *C. dubia* and that fathead minnows may be unaffected by these constituents. After about 3 in. of accumulated precipitation at Youngtown and Peoria, toxicants that were harmful to *C. dubia* appeared to be leached from the asphalt and resealant or concentrations were too small to have an acute effect. Sources other than asphalt and resealant could have caused the toxic response; however, these other sources would not account for the foam and the difference in toxicity of stormwater to *C. dubia* after several storms occurred at each site.

Of the toxic stormwater samples, the least toxic samples were collected from Peoria on January 6, 1993 (before resealant was applied), 48th Street on March 26, 1993, and the ACDC on March 7, 1994. At least 20 percent of the organisms died; however, less than 50 percent died in 100 percent stormwater. LC50 and TU values could not be calculated for these samples and, although these samples were toxic, the data were not used in comparisons between toxicity and constituent concentrations.

Stormwater toxicity decreased in most samples between the time the original test and the TIE were conducted, which was about 2 to 4 days (compare baseline with original in fig. 9). The median mortality rate, in 100-percent stormwater, was 100 percent for the original test and 50 percent for the baseline test, indicating that about 50 percent of the toxicity was lost due to volatilization, adsorption, biodegradation, or other processes in the sample containers. The flow-weighted composite sample collected from 27th Avenue on February 7, 1994, and the sample collected from the ACDC on March 7, 1994, were nontoxic (less than 20 percent mortality) by the time the TIE's were performed, which invalidated the TIE results. The mortality rate of *C. dubia* did not change in stormwater samples collected soon after asphalt and resealant were applied at Youngtown (March 26, 1993) and at Peoria (August 24, 1993).

Confirming that specific constituents are causing toxicity can be done by adding TU values for each toxicant in a sample. If all toxicants are accounted for and are additive, the sum of TU values will equal the TU value of a stormwater sample. Confirmation also can be done by correlating and regressing the TU of several samples with constituent concentrations. Comparisons between TU values of stormwater and toxicants are questionable because: (1) effects from mixtures of toxicants are not always additive; (2) the LC50 of certain toxicants depends on many factors; and (3) concentrations of toxicants measured in stormwater samples may not represent concentrations that organisms were exposed to during the toxicity test. Certain mixtures of toxicants, such as copper and zinc (Rand and Petrocelli, 1985), are not additive because the mixture can have a smaller (antagonistic) or larger (synergistic) effect than expected on the basis of exposure to individual toxicants. Reactions likely occurred that changed constituent concentrations during sample storage, and the concentrations that were measured in stormwater samples may not represent concentrations to which organisms were exposed. The LC50 of trace metals can change by an order of magnitude with a change of 1 pH unit (Schubauer-Berigan and Dierkes, 1993) and also is dependent on other factors such as hardness, salinity, and speciation (Rand and Petrocelli, 1985; Goyer and Mehlman, 1977). A detailed evaluation of which constituents could be toxic to fathead minnows is not possible because of the changes in sample chemistry that occur during storage and the many factors that control constituent toxicity. A general evaluation, using rank correlations and linear relations between TU values of stormwater and constituent concentrations, was done to identify toxic constituents. Constituents that were not analyzed also could be contributing to the toxicity of stormwater and bed material.

Organic compounds and (or) toxicants that are pH dependent appeared to be the primary toxicants in most stormwater samples. Extraction of neutral and cationic organic compounds caused the largest reduction in mortality rates of either species. Metal hydroxides, however, could have precipitated when samples were adjusted to pH 9 and could have been filtered by the octadecyl column. Comparison of mortality rates between extractions at pH 3, pH 9, and the initial pH indicated which group of organic compounds caused the toxic response. An equal reduction in mortality rates at the three pH levels indicates that toxicant extraction is unaffected by pH, and neutral organic compounds probably caused the toxic response. A reduction in mortality rates at pH 3 or pH 9 without a reduction in mortality rates at the initial pH indicates that the toxicants are anionic or cationic organic compounds, respectively.

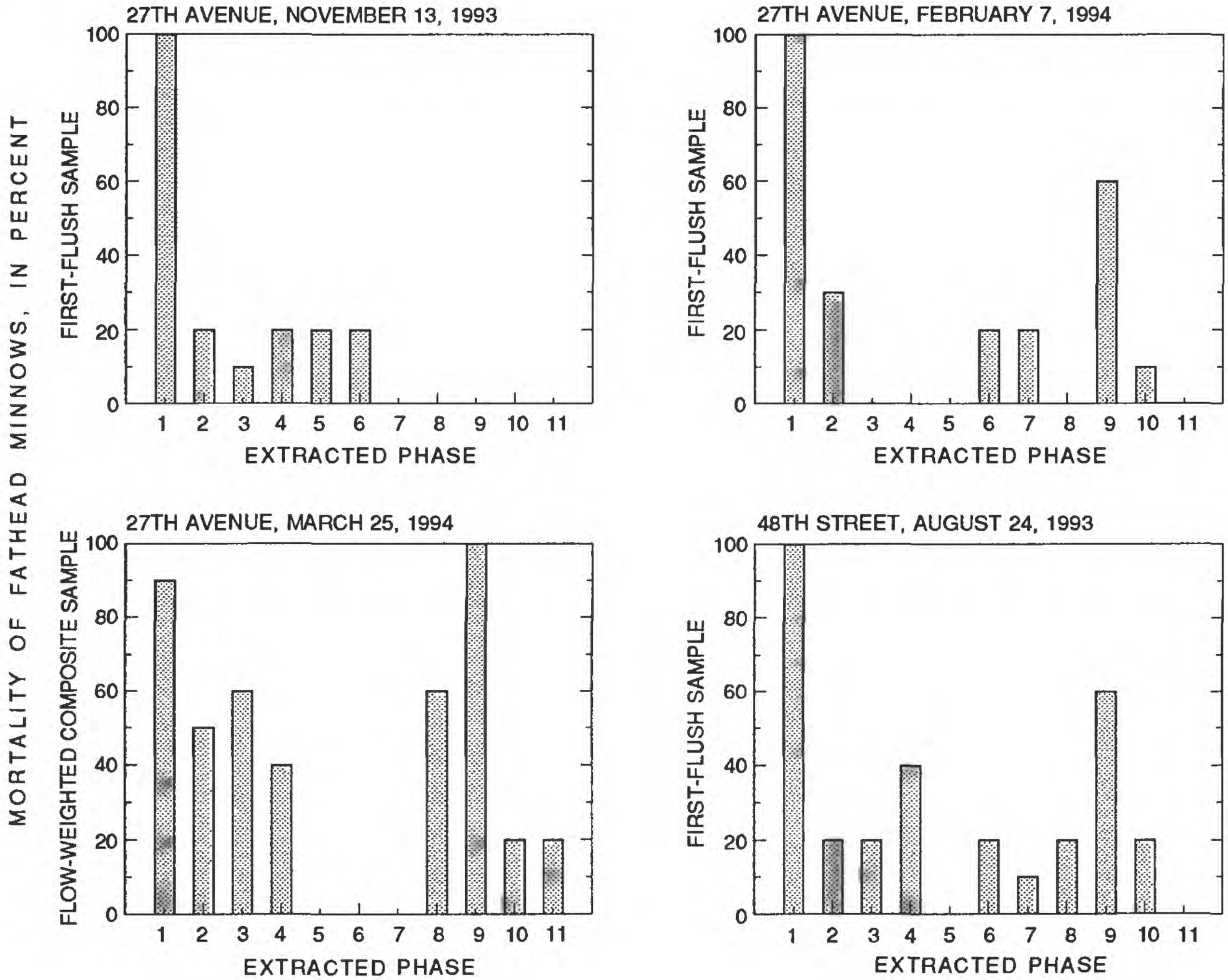
Of the organic constituents that were analyzed, TU values for fathead minnows were significantly correlated with total organic carbon (0.67), were not significantly correlated with oil and grease (0.20), and were inversely correlated with the sum of organophosphate pesticides concentrations (–0.89). A positive correlation between TU values and constituent concentrations indicates that the most toxic stormwater was associated with the largest constituent concentration, which is the expected trend if the constituent is toxic. A negative correlation indicated that the mortality of fathead minnows was not due to organophosphate pesticides. The acute toxicity of organophosphate pesticides to fathead minnows was found to be small in waters of varying hardness (20 and 400 mg/L as $CaCO_3$; Henderson and others, 1960). Mortality of fathead minnows probably was due to organic constituents that were not analyzed.

Few stormwater samples were toxic to *C. dubia*, so correlations between TU values and constituent concentrations were not significant. The LC50 of diazinon to *C. dubia* is 0.35 μg/L (Norberg-King and others, 1989). TU values for diazinon in stormwater samples ranged from 0.03 to 1.6 and exceeded 1 TU in six samples. Samples with TU values greater than 1 would indicate that at least 50 percent of the organisms should have died in these samples. Of the samples with diazinon exceeding 1 TU, however, only one was toxic to *C. dubia*. Stormwater samples may not have been toxic because organophosphate pesticides readily degrade and (or) pesticides were not biologically available to *C. dubia*.

Trends in the mortality rate when increasing amounts of EDTA were added to the subsamples indicated that dissolved metals contributed to the toxicity of certain stormwater samples. Toxicity from dissolved metals was indicated when small amounts of EDTA were added to the samples and the mortality rate decreased; the mortality rate increased when larger amounts of EDTA were added to samples. This trend of decreasing then increasing mortality rates occurs when EDTA chelates with dissolved metals and reduces metal toxicity; then EDTA causes a toxic response when more EDTA is added than is needed to chelate the dissolved metals. Dissolved metals appeared to contribute to stormwater toxicity in samples collected from Youngtown, 27th Avenue, Peoria, and the ACDC (fig. 9).

Concentrations of dissolved zinc weakly correlated with TU values for fathead minnows. Dissolved zinc and copper had a roughly linear relation between log-transformed values (table 4 and fig. 10), and were greater in some stormwater samples than the LC50 values of zinc and copper to fathead minnows in very hard water

*A*




EXPLANATION

EXTRACTED PHASE

1 ORIGINAL (UNTREATED)
2 BASELINE (UNTREATED)
3 OIL AND GREASE
4 SUSPENDED SOLIDS

METALS CHELATED USING ETHYLENEDIAMINE-TETRAACETIC ACID (EDTA)
5 0.0 milliiters EDTA
6 0.012 milliiters EDTA
7 0.025 milliiters EDTA
8 0.50 milliiters EDTA

9 ORGANICS EXTRACTED AT pH3
10 ORGANICS EXTRACTED AT INITIAL pH
11 ORGANICS EXTRACTED AT pH9

**Figure 9.** Mortality rates of fathead minnows and *Ceriodaphnia dubia* as a function of phases extracted from stormwater samples, Maricopa County, Arizona, March 26, 1993, through March 25, 1994. *A*, 27th Avenue and 48th Street. *B*, Youngtown. *C*, Youngtown and Arizona Canal Diversion Channel. *D*, Peoria.

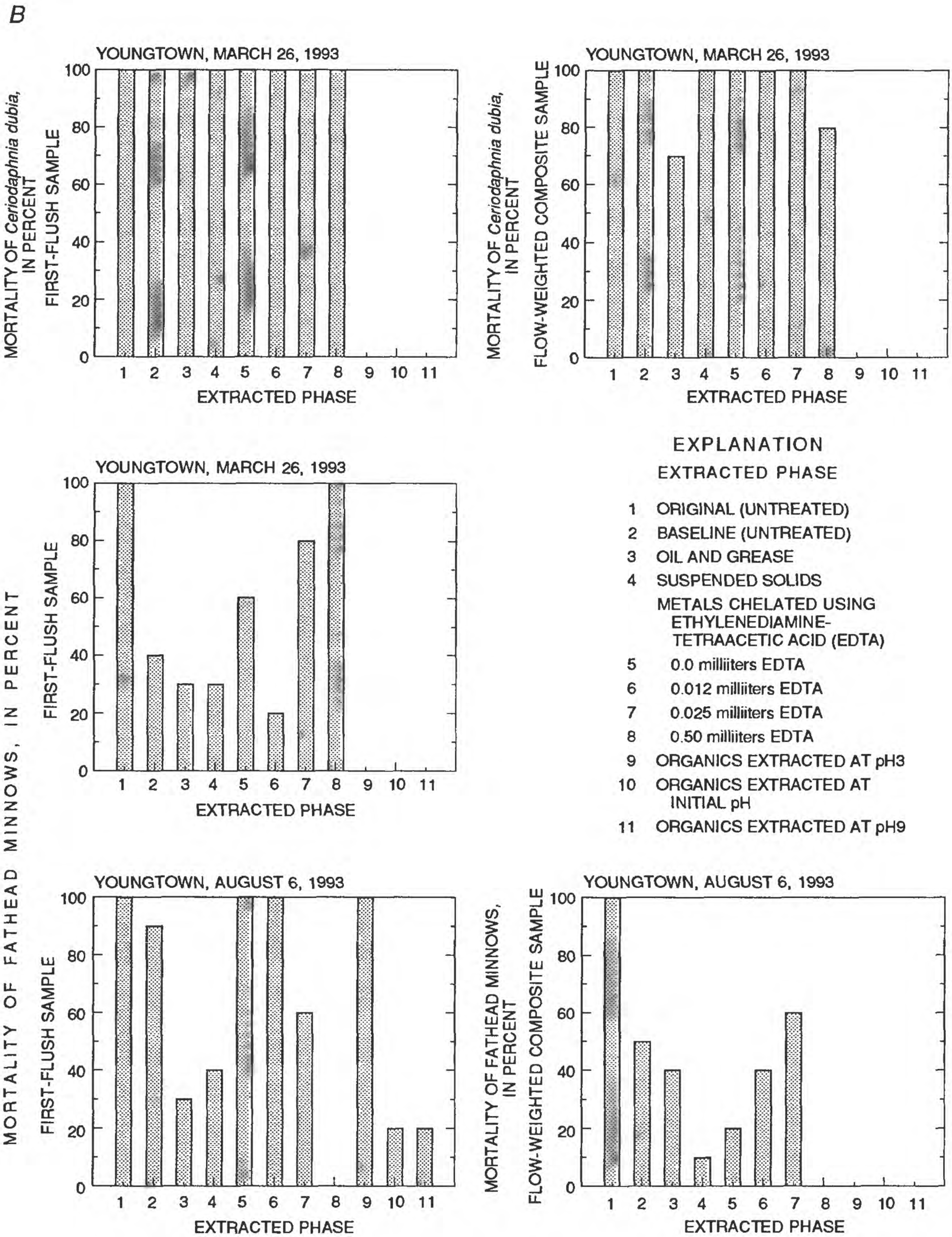



**Figure 9.** Continued.

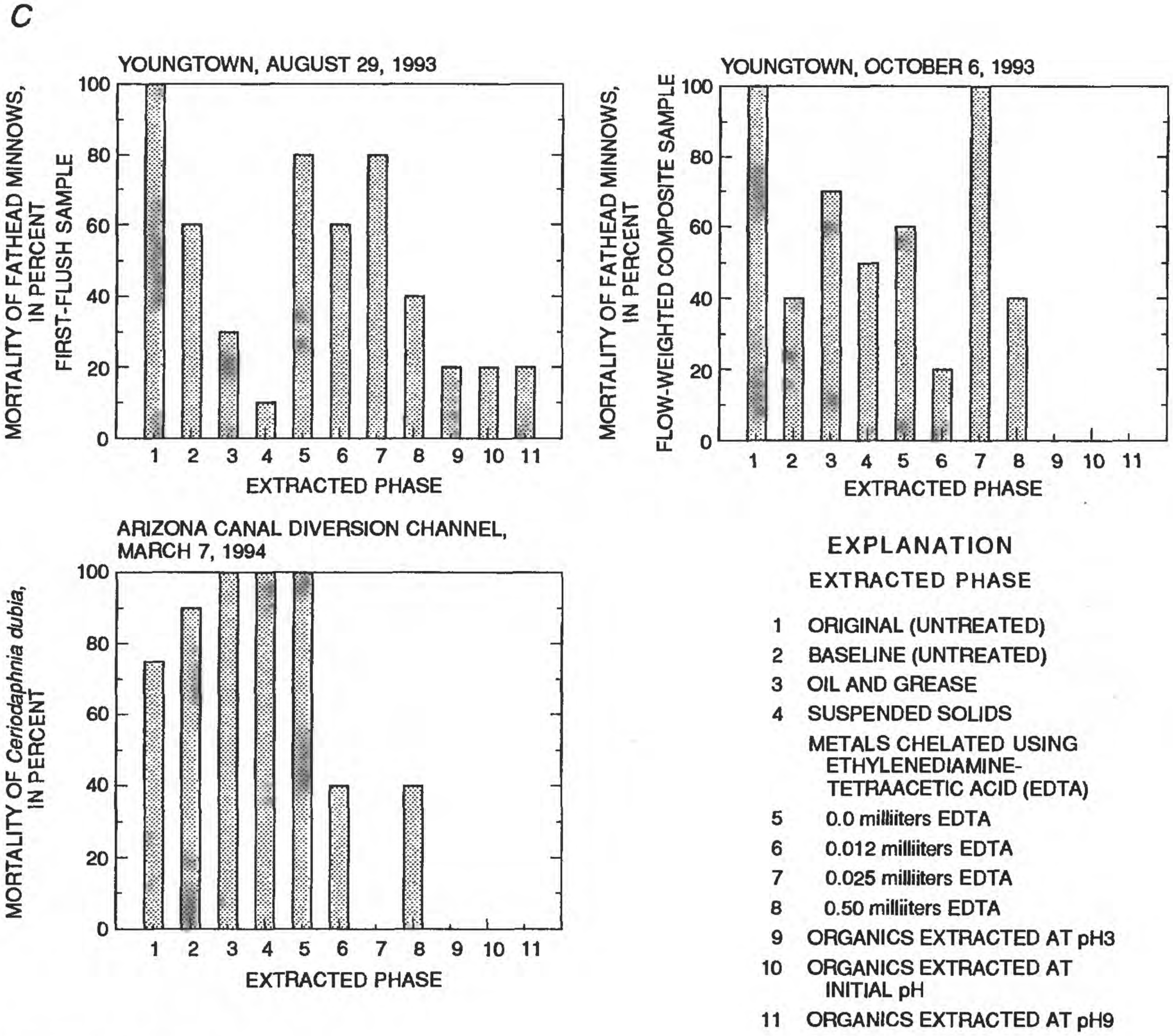



**Figure 9.** Continued.

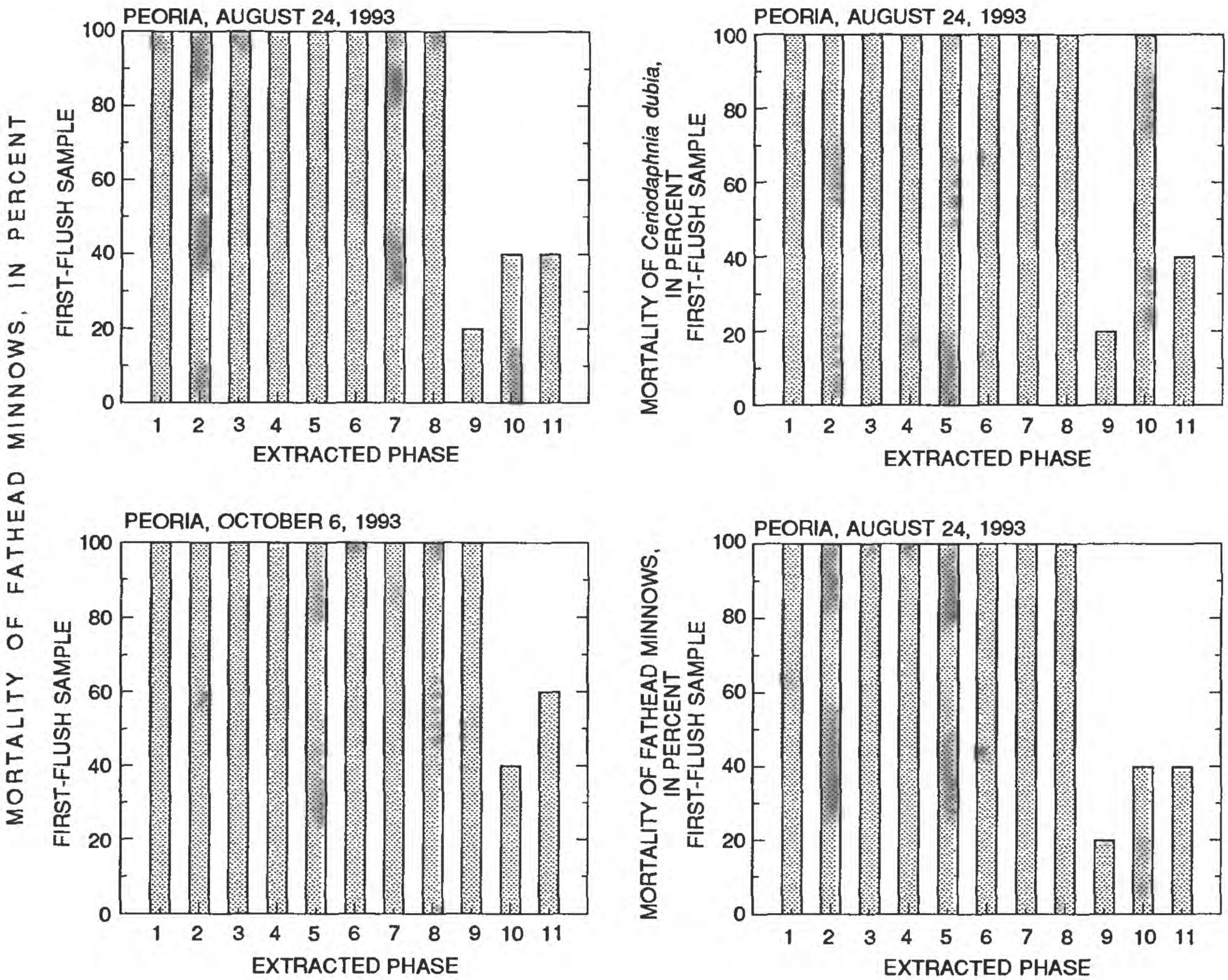
(Schubauer-Berigan and Dierkes, 1993). The toxicity of trace metals generally increases as hardness decreases (Rand and Petrocelli, 1985). About 50 percent of the stormwater samples were soft; the softness indicated that concentrations of dissolved zinc and copper in stormwater could be greater than 1 TU. Other trace-metal concentrations were weakly correlated with TU values for fathead minnows.

Extraction of oil and grease and suspended solids usually did not reduce stormwater toxicity, but these constituents could have contributed to the toxicity of two samples from Youngtown and one sample from Peoria (fig. 9). Concentrations of oil and grease and suspended solids were not significantly correlated with TU values for either fathead minnows or *C. dubia.*

## Streamflow

Streamflow samples collected from the Salt River were not toxic to either fathead minnows or *C. dubia*, and most toxic constituents that were analyzed were not detected in streamflow. These data indicate that the Salt River could support an

*D*




EXPLANATION

EXTRACTED PHASE

1 ORIGINAL (UNTREATED)
2 BASELINE (UNTREATED)
3 OIL AND GREASE
4 SUSPENDED SOLIDS

METALS CHELATED USING ETHYLENEDIAMINE-TETRAACETIC ACID (EDTA)
5 0.0 milliiters EDTA
6 0.012 milliiters EDTA
7 0.025 milliiters EDTA
8 0.50 milliiters EDTA

9 ORGANICS EXTRACTED AT pH3
10 ORGANICS EXTRACTED AT INITIAL pH
11 ORGANICS EXTRACTED AT pH9

**Figure 9.** Continued.

**Table 4.** Spearman rank correlations of dissolved trace metals and organophosphate pesticides to toxic units of stormwater for fathead minnows, Maricopa County, Arizona

[The toxic unit of stormwater to fathead minnows is equal to 100 divided by the LC50. The LC50 is the concentration of stormwater, in percent, by volume, that killed 50 percent of the organisms. Significance is the probability that the variables are independent]

| Trace metal and organophosphate pesticide | Number of samples | Correlation of toxic unit of stormwater for fathead minnows | Significance |
|---|---|---|---|
| Copper, dissolved | 13 | 0.15 | 0.62 |
| Zinc, dissolved | 15 | .39 | .14 |
| Sum of dissolved zinc and copper | 15 | .44 | .10 |
| Iron, dissolved | 15 | .45 | .09 |
| Manganese, dissolved | 15 | .40 | .14 |
| Vanadium, dissolved | 11 | .26 | .44 |
| Cadmium, dissolved | 7 | .41 | .36 |
| Cobalt, dissolved | 7 | .63 | .13 |
| Total organic carbon | 14 | .67 | .01 |
| Diazinon, total | 4 | –.50 | .50 |
| Sum of total organophosphate pesticides, total | 4 | –.89 | .11 |

aquatic ecosystem if the river were perennial or intermittent and that the quality of streamflow could be degraded by toxic constituents in urban stormwater. Constituents, however, could be diluted to nontoxic concentrations by the time stormwater flows into the streams and would be diluted by streamflow if the Salt River were perennial.

## Bed Material

The most toxic bed-material samples, indicated by the mean and median mortality rate of *H. azteca* (table 5), were collected from South Mountain Park. ANOVA results indicated that the mortality rates of *H. azteca* in bed-material samples from South Mountain Park were significantly higher than in samples from ephemeral channels. Significant differences in mortality rates were not indicated between samples from South Mountain Park and urban drainage basins and between urban drainage basins and ephemeral channels. Of the bed-material samples collected, 83 percent from South Mountain Park were toxic (greater than 20 percent mortality), 85 percent from urban drainage basins were toxic, and 45 percent from ephemeral streams were toxic.

The high mortality rate of *H. azteca* in bed-material samples from South Mountain Park appeared to be due to trace metals. Several mining

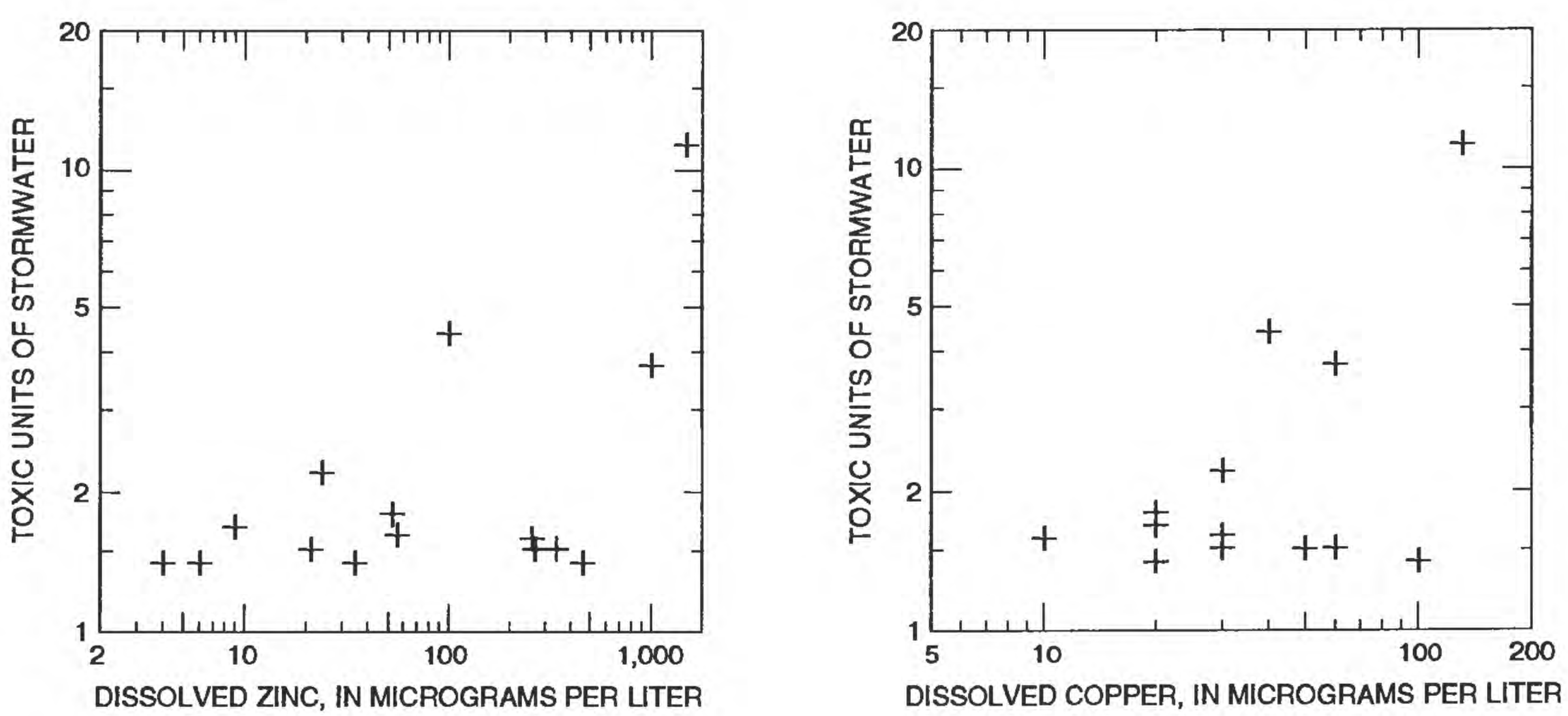



**Figure 10.** Toxic units of stormwater to fathead minnows as a function of dissolved trace-metal concentrations, Maricopa County, Arizona.

**Table 5.** Summary of acute toxicity tests of sediment, Maricopa County, Arizona.

| Number of samples | Number of toxic samples[1] | Percent toxic samples | Median percent mortality | Mean percent mortality | Standard deviation of percent mortality |
|---|---|---|---|---|---|
| **Bed material from urban drainage basins with single land use<br>Peoria, Yoongtown, 48th Street, and 27th Avenue** | | | | | |
| 13 | 11 | 85 | 61 | 57 | 33 |
| **Bed material from ephemeral channels<br>Indian Bend Wash, Arizona Canal Diversion Channel, Agua Fria River, and Salt River at Priest Drive** | | | | | |
| 11 | 5 | 45 | 16 | 28 | 33 |
| **Bed material from a drainage basin with undeveloped land use<br>South Mountain Park** | | | | | |
| 6 | 5 | 83 | 81 | 76 | 30 |

[1]Toxicity is defined as causing a mortality rate of 20 percent or more.

prospects are in the drainage basin, and erosion of mine spoils could affect bed-material chemistry. Mortality rates ranged from 76 to 100 percent, except for one sample (17 percent). Samples from the Salt River had 95-, 86-, and 10-percent mortality and were collected after floods scoured urban debris that had accumulated in the channel; the toxicity of these samples probably was caused by naturally occurring toxicants.

Mortality rates of *H. azteca* in bed-material samples from South Mountain Park strongly correlated with recoverable concentrations of zinc (0.71; table 6, fig. 11) and moderately correlated with recoverable concentrations of copper (0.46). Few samples, however, were collected from South Mountain Park; therefore, the correlations were not significant at a level of 5 percent. The high pH values and hard water used in the sediment toxicity test were similar to conditions that increase the toxicity of zinc, cadmium, and nickel to *H. azteca* and decrease the toxicity of copper and lead (Schubauer-Berigan and Dierkes, 1993). Organochlorine pesticides were detected in most bed-material samples from South Mountain Park, urban drainage basins, and ephemeral channels. Mortality rates of *H. azteca*, however, poorly correlated with pesticide concentrations.

The dissolved concentrations of zinc and copper that organisms were exposed to depends on the solubility of zinc in hard water with a pH of about 8, and on the adsorption properties of the bed material. Recoverable concentrations of zinc and copper strongly correlated with concentrations of manganese in bed material from South Mountain Park (0.93 and 1.0, respectively). The median recoverable concentration of zinc in bed material from South Mountain Park was 45 μg/g, and the median recoverable concentration of zinc in a beaker with 100 grams of bed material and 400 milliliters of hard water was 11,250 μg/L. About 2.6 percent of the recoverable zinc would have to be in solution for organisms to be exposed to the reported LC50 of 290 μg/L for *H. azteca* in very hard water (Schubauer-Berigan and Dierkes, 1993).

Bed-material samples collected from areas where urban stormwater accumulates appeared to be more toxic than samples collected from areas where stormwater does not accumulate. The mortality rate for *H. azteca* was 3 percent in a bed-material sample collected from an undeveloped lot in the drainage basin with light industrial land use; the mortality rates were 77- to 100-percent in samples collected from an urban stormwater conveyance and a dry puddle that accumulates runoff from a freeway. The mortality rate for *H. azteca* was 28 percent in a bed-material sample collected from a dirt lot in the drainage basin with commercial land use and 56 percent in a bed-material sample collected from a dry puddle that accumulates runoff from the parking lot. The difference in mortality rates between these samples indicated that accumulation of constituents in stormwater increased the toxicity of bed material.

Bed-material samples from Youngtown were collected at the streamflow-gaging station in September 1992 and June 1993. Samples from the Agua Fria River were collected at the tributary that drains Youngtown and upstream and downstream from the tributary in September 1993. The mortality

**Table 6.** Spearman rank correlations of selected recoverable constituents in bed material to mortality rates of *Hyalella azteca*, Maricopa County, Arizona

[mg/kg, milligrams per kilogram; (µg/g), micrograms per gram; (µg/kg), micrograms per kilogram; ----, dashes indicate that there were too few data to compute correlations; DDE, dichlorodiphenylethylene; DDT, dichlorodiphenyltrichloroethane]

| Constituents | Mortality rate of *Hyalella azteca*, in percent: Urban drainage basin | Ephemeral channels | Undeveloped basin | Constituents | Mortality rate of *Hyalella azteca*, in percent: Urban drainage basin | Ephemeral channels | Undeveloped basin |
|---|---|---|---|---|---|---|---|
| Ammonia (mg/kg) | 0.04 | 0.37 | -0.32 | Zinc (µg/g) | [1]0.70 | -0.30 | 0.71 |
| Arsenic (µg/g) | -.52 | [1].60 | .39 | Chlordane (µg/kg) | -.19 | -.28 | .40 |
| Cadmium (µg/g) | [1].81 | ------- | ------- | DDE (µg/kg) | -.28 | -.42 | .60 |
| Chromium (µg/g) | -.35 | -.31 | .13 | DDT (µg/kg) | -.48 | .00 | ------- |
| Cobalt (µg/g) | [1]-.72 | -.22 | ------- | Diazinon (µg/kg) | .51 | -.04 | ------- |
| Copper (µg/g) | .29 | .26 | .46 | Dieldrin (µg/kg) | -.13 | -.52 | .50 |
| Lead (µg/g) | .45 | -.46 | .59 | Toxaphene (µg/kg) | -.16 | -.26 | .08 |
| Mercury (µg/g) | .02 | .23 | .31 | | | | |

[1]Significant at a level of 5 percent

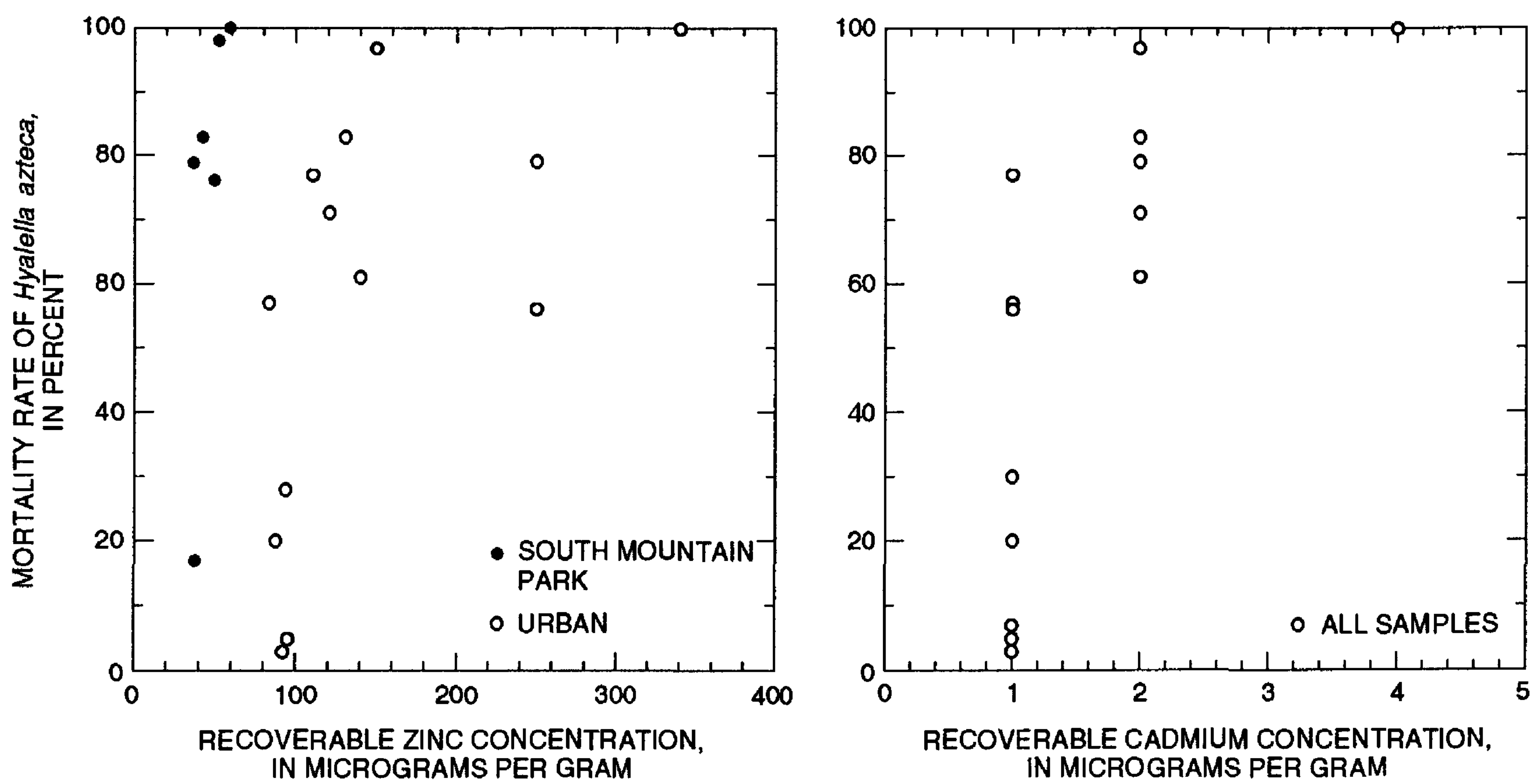



**Figure 11.** Mortality rates of *Hyalella azteca* as a function of recoverable constituent concentrations in bed material, Maricopa County, Arizona. Bed-material samples were sieved, and the fraction less than 63 microns was analyzed for constituent concentrations and acute toxicity.

rate of *H. azteca* was 61 to 83 percent in bed-material samples from Youngtown and was 16 to 29 percent in samples from the Agua Fria River.

Comparisons between mortality rates for *H. azteca* in bed-material samples from Youngtown and in samples from the Agua Fria River also indicated that urban stormwater affects the toxicity of bed material. The difference in mortality rates indicated that toxicants from urban activities accumulate in bed material and that toxicants are either degraded or diluted by bed material from nonurban sources.

Mortality rates in bed-material samples from urban drainage basins significantly correlated with recoverable concentrations of cadmium (0.81) and zinc (0.70), which were significantly larger in urban bed-material samples than in samples from ephemeral channels. The median recoverable concentrations of cadmium and zinc in urban bed material were 1.5 and 120 μg/g, respectively, and recoverable concentrations were moderately to strongly correlated with the percentage of organic carbon. The median recoverable concentration of cadmium and zinc in each beaker of the toxicity test was 375 and 30,000 μg/L, respectively. Estimates indicate that about 1 percent of the recoverable cadmium and zinc would have to desorb from the organic carbon for *H. azteca* to be exposed to the LC50 of 5 μg/L for cadmium and 290 μg/L for zinc in very hard water (Schubauer-Berigan and Dierkes, 1993).

The recoverable concentration of zinc that appeared to cause a certain mortality rate was about three times larger in urban bed-material samples than in samples from South Mountain Park (fig. 11); recoverable cadmium was not detected at South Mountain Park. Larger recoverable concentrations of zinc in urban bed material would be needed to cause the same effect as bed material from South Mountain Park. These concentrations are caused by the different adsorption properties and solubility of zinc, organic carbon, and manganese in hard water. Zinc was associated with organic carbon in urban bed-material samples and with manganese in samples from South Mountain Park. Sulfide precipitation, iron oxides, manganese oxides, and organic carbon are effective at controlling dissolved trace-metal concentrations and, in general, iron oxyhydroxides are the most important adsorbing material, followed by organic carbon and manganese oxyhydroxides (Horowitz and Elrick, 1987; Jenne, 1976; Jenne and Luoma, 1977). The material that toxic constituents are adsorbed onto appears to control the concentration in solution to which organisms are exposed, and thus the bioavailability of the constituent.

Toxicants in bed material from urban drainage basins could be diluted or degraded to nontoxic concentrations in ephemeral channels. The mortality rates of *H. azteca* in bed-material samples from the ACDC, Indian Bend Wash, and Agua Fria River were less than 30 percent, although most of the streamflow in these channels is urban stormwater. Low mortality rates could be caused by dilution of bed material from urban sources with bed material from nonurban sources, biodegradation, leaching, or other processes. Metals accumulated in urban bed material could be leached, and organic constituents could be degraded in the ACDC and Indian Bend Wash, which are grass lined and irrigated. ANOVA results indicated that bed-material samples collected from grass-lined channels were significantly less toxic than samples collected from bare soil. A population of bacteria could be supported in these channels and degrade organic constituents, and irrigation could leach trace metals into lower soil horizons.

Recurrent sampling at the drainage basins with residential and heavy industrial land use indicated that the toxicity of bed material can change significantly. *H. azteca* in a bed-material sample collected adjacent to a catch basin at 27th Avenue in September 1992 had a 97-percent mortality rate, and a sample collected at the same catch basin in June 1993 had a 5-percent mortality rate. The mortality rates for duplicate samples collected at Youngtown in September 1992 compared well and had 71- and 83-percent mortality, indicating that the sampling procedure and toxicity analysis produced consistent results. *H. azteca* in a sample collected at Youngtown in June 1993 had a 61-percent mortality rate, which did not appear to be significantly different from those of the duplicate samples.

## SUMMARY

The chemistry and toxicity of urban stormwater, streamflow, and bed material were characterized to determine if urban stormwater could degrade the quality of streams in Maricopa County. Toxic phases of stormwater (oil and grease, suspended solids, dissolved metals, and dissolved organics) were identified to aid water-quality managers identify and minimize the sources of toxicants. Samples of stormwater were collected from drainage basins with residential, commercial, industrial, and mixed land use; streamflow was sampled from the Salt River; and bed material was sampled from urban drainage basins, South Mountain Park (an undeveloped drainage basin), and ephemeral channels that receive urban stormwater.

Selected constituents and acute toxicity were analyzed in water and bed-material samples. Acute aquatic toxicity tests were done using *C. dubia* and fathead minnows and acute sediment toxicity tests were done using *H. azteca*. TIE's, using either *C. dubia* or fathead minnows, were done on toxic stormwater samples. Statistical analyses were used to determine the effect of urbanization on the quality of water and bed material and to identify toxic constituents.

Concentrations of oil and grease, organophosphate pesticides, and dissolved zinc, copper, cadmium, nickel, chromium, and cobalt were less than detection limits in four streamflow samples collected from the Salt River, but were detected in 28 to 100 percent of 32 urban stormwater samples. Total ammonia was detected in one streamflow sample and 80 percent of stormwater samples. These data indicated that urban stormwater could degrade the quality of streamflow with oil and grease, pesticides, dissolved trace metals, and ammonia.

Recoverable concentrations of ammonia, lead, cadmium, and zinc in bed-material samples from urban drainage basins were significantly larger than recoverable concentrations in samples from ephemeral channels. Ammonia could be from fertilizers, fecal matter, and other sources. Lead is probably from vehicles that use leaded gasoline. Cadmium and zinc could be from particulate metal in oil, brake pads, and other sources. Recoverable concentrations of other constituents, including pesticides, were not significantly different between bed-material samples from urban drainage basins and ephemeral streams.

The percentage of organic carbon was significantly correlated with recoverable concentrations of zinc and cadmium in bed material from urban drainage basins; this correlation indicates that most metals released by urban activities are associated with organic matter. Lead, however, which is emitted in automobile exhaust as halide salts, could explain the lack of correlation with adsorbing materials. Recoverable concentrations of other trace metals in bed-material samples from urban drainage basins and trace metals in samples from ephemeral channels and South Mountain Park strongly correlated with recoverable concentrations of iron and manganese.

First-flush samples appeared to be more toxic than flow-weighted composite samples, and urban stormwater was more harmful to fathead minnows than to *C. dubia*. Streamflow samples were not toxic to either species, indicating that urban stormwater could degrade the quality of the Salt River. In a comparison of species mortality rates, daphnids were typically more sensitive than fish to toxicants. The enhanced mortality rate of fathead minnows to urban stormwater from most drainage basins indicated that the toxicants were more detrimental to fish and could be present in stormwater throughout the Phoenix area.

The most toxic stormwater samples were collected from the drainage basins with residential and commercial land use, and the toxicity probably was from asphalt and resealant. The street and parking lot at these basins were resurfaced before sampling, and the toxicity of stormwater to test species changed after storms rinsed the asphalt and resealant. Stormwater sampled from these drainage basins soon after resurfacing was toxic to *C. dubia*. Stormwater sampled after several storms had rinsed the street and parking lot was toxic only to fathead minnows. Stormwater at these drainage basins had a yellowish foam that was not present before the resurfacing. The absence of foam after several storms had occurred at each site indicated that surfactants and (or) other constituents that leached from the asphalt and resealant were toxic to *C. dubia*.

About 50 percent of the toxicity of stormwater samples was lost between the time the original toxicity test and TIE's were performed (about 2 to 4 days). Reduction in stormwater toxicity was caused by volatilization, adsorption, biodegradation, or other processes in the sample containers. The toxicity of stormwater appeared to be caused mostly by organic constituents; dissolved metals also appeared to contribute to stormwater toxicity. Statistical analyses indicated that toxicity was not caused by organophosphate pesticides.

The most toxic bed-material samples were collected from South Mountain Park, and the mortality rates were significantly higher than in samples from ephemeral channels. The mortality rate of *H. azteca* was not significantly different between bed-material samples from undeveloped and urban drainage basins and between urban drainage basins and ephemeral channels. Within urban drainage basins, bed-material samples collected from areas where stormwater accumulates appeared to be more toxic than samples collected from areas unaffected by stormwater.

Mortality rates in bed-material samples from South Mountain strongly correlated with recoverable concentrations of zinc and moderately correlated with recoverable concentrations of copper. The high mortality rate of *H. azteca* samples from South Mountain probably was caused by naturally occurring trace metals. Mortality rates in bed-material samples from urban drainage basins significantly correlated with recoverable concentrations of cadmium and zinc, which were significantly larger in urban bed-material samples than in samples from ephemeral channels. Organochlorine pesticides were detected in most bed-material samples from South Mountain Park, urban drainage basins, and ephemeral channels. Mortality rates, however, were poorly correlated with pesticide concentrations.

The bioavailability of trace metals in bed material could be controlled by the adsorption properties and solubility of trace metals, organic carbon, and manganese. Zinc and cadmium were associated with organic carbon in urban bed-material samples, and zinc was associated with manganese in samples from South Mountain Park. The material that toxic constituents are adsorbed onto appears to control the concentration in solution to which organisms are exposed, and thus the bioavailability of the constituent.

## REFERENCES CITED


American Society of Testing and Materials, 1990, Standard guide for conducting sediment toxicity test with freshwater invertebrates: American Society of Testing and Materials, 1991 Annual Book of ASTM Standards, v. 11.04, E1383, p. 20.

Ankley, G.T., and Burkhard, L.P., 1992, Identification of surfactants as toxicants in a primary effluent: Environmental Toxicology and Chemistry, v. 11, p. 1235–1248.

Drever, J.I., 1988, The geochemistry of natural waters: Englewood Cliffs, New Jersey, Prentice Hall, p. 437.

Fukato, T.R., 1987, Organophosphorus and carbamate esters: The anticholinesterase insecticides, *in* Biggar, J.W., and Seiber, J.N., eds., Fate of pesticides in the environment: Oakland, California, University of California, Agriculture Experiment Station, Division of Agriculture and Natural Resources Publication 3320, p. 5–18.

Goyer, R.A., and Mehlman, M.A., 1977, Toxicology of trace elements, *in* Advances in modern toxicology: New York, John Wiley and Sons, v. 2, 303 p.

Hanks, K., 1988, DDT use in the bollworm eradication program of 1958–60: Phoenix, Arizona Department of Environmental Quality report, p. 9.

Helsel, D.R., and Cohn, T.A., 1988, Estimation of descriptive statistics for multiply censored water quality data: American Geophysical Union, Water Resources Research, v. 24, no. 12, p. 1997–2004.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Henderson, C., Pickering, Q.H., and Tarzwell, C.M., 1960, The toxicity of organic phosphorus and chlorinated hydrocarbon insecticides to fish, *in* Biological problems in water pollution: U.S. Department of Health, Education, Welfare, and Public Health Services, Division of Water Supply and Pollution Control Transactions, Cincinnati, Ohio, p. 76–88.

Horowitz, A.J., and Elrick, K.A., 1987, The relation of stream sediment surface area, grain size and composition to trace metal chemistry: Applied Geochemistry, v. 2, p. 437–451.

Ingersoll, C.G., and Nelson, M.K., 1990, Testing sediment toxicity with *Hyalella azteca* (Amphipoda) and *Chironomus riparius* (Diptera), *in* 13th Symposium on Aquatic Toxicology and Risk Assessment: American Society of Testing and Materials Special Technical Publication 1096, p. 93–109

Jenne, E., 1976, Trace element sorption by sediments and soils—Sites and processes, *in* Chappell, W., and Peterson, K., eds., Symposium on Molybdenum: Marcel-Dekker, v. 2, p. 425–453.

Jenne, E., and Luoma, S., 1977, Forms of trace elements in soils, sediments and associated waters: an overview of their determination and biological availability, *in* Wildung, R. and Drucker, H., eds., Biological Implication of Metals in the Environment: U.S. Department of Commerce, National Technical Information Services CONF-750929, p. 110–143.

Kennedy, E.J., 1984, Discharge ratings at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A10, 59 p.

Kolb, W.M., 1983, Curve fitting for programmable calculators: Bowie, Maryland, IMTEC, 94 p.

Landrum, P.F., and Scavia, D., 1983, Influence of sediment on anthracene uptake, depuration, and biotransformation by the amphipod *Hyalella azteca*: Canadian Journal of Fisheries and Aquatic Science, v. 40, p. 298–305.

Lopes, T.J., Fossum, K.D., Phillips, J.V., and Monical, J.E., 1995, Statistical summary of selected physical, chemical, and microbial characteristics, and estimates of constituent loads in urban stormwater, Maricopa County, Arizona: U.S. Geological Survey Water-Resources Investigations Report 94–4240, 62 p.

Maricopa Association of Governments, 1989, 1989 MAG regional development summary—A report on population, employment, housing and commerce in Maricopa County: Phoenix, Arizona, Maricopa Association of Governments report, 58 p.

_____ 1993, Update of the population and socioeconomic database for Maricopa County: Phoenix, Arizona, Maricopa Association of Governments report, 257 p.

Mayer, F.L., and Ellersieck, M.R., 1986, Manual of acute toxicity: Interpretation and data base for 410 chemical and 66 species of freshwater animals: U.S. Fish and Wildlife Resource Publication 160, 63 p.

Nebeker, A.V., Cairns, M.A., Gakstatter, J.H., Malueg, K.W., Schuytema, G.S., and Krawczyk, D.F., 1984, Biological methods for determining toxicity of contaminated freshwater sediments to invertebrates: Environmental Toxicology and Chemistry, v. 3, p. 617–630.

Norberg-King, T., Lukasewcys, M., and Jenson, J., 1989, Results of Diazinon levels in POTW effluents in the United States: Duluth, Minnesota, U.S. Environmental Protection Agency, National Effluent Toxicity Assessment Center, Technical Report 14–89, v.p.

Post, J.E., and Buseck, P.R., 1984, Characterization of individual particles in the Phoenix urban aerosol using electron-beam instruments: Environmental Science and Technology, v. 18, no. 1, p. 35–42

Rantz, S.E., and others, 1982, Measurement and computation of streamflow—Volume 1, Measurement of stage and discharge: U.S. Geological Survey Water-Supply Paper 2175, 284 p.

Rand, G.M., and Petrocelli, S.R., 1985, Fundamentals of aquatic toxicology: Washington, Hemisphere Publishing Corporation, 666 p.

Schubauer-Berigan, M.K., and Dierkes, J.R., 1993, pH-dependent toxicity of Cd, Cu, Ni, Pb and Zn to Ceriodaphnia dubia, Pimephales promelas, *Hyalella azteca* and *Lumbriculus variegatus*: Environmental Toxicology and Chemistry, v. 12, p. 1261–1266.

Smith, C.F., Rigas, P.D., Ham, L.K., Duet, N.R., and Anning, D.W., 1994, Water resources data, Arizona, water year 1993: U.S. Geological Survey Water-Data Report AZ–93–1, 360 p.

Statware, Inc., 1990, STATIT—Statistics reference manual: Corvallis, Oregon, Statware, Inc., v.p.

Thurman, E.M., 1985, Organic geochemistry of natural waters: Lancaster, Pennsylvania, Martinus Nijhoff/Dr .W. Junk Publishers, 497 p.

U.S. Department of Commerce, 1990, Local climatological data—Annual summary with comparative data, Phoenix, Arizona: National Oceanic and Atmospheric Administration Publication ISSN 0198–0572, 8 p.

U.S. Environmental Protection Agency, 1990, Methods for measuring the acute toxicity of effluents and receiving waters to freshwater and marine organisms: U.S. Environmental Protection Agency report EPA/600/4–90/027, 293 p.

_____ 1991, Methods for aquatic toxicity identification evaluations—Phase I, Toxicity characterization procedures, second edition: U.S. Environmental Protection Agency report EPA–600/6–91/003, 76 p.

_____ 1993a, Methods for aquatic toxicity identification evaluations—Phase II, Toxicity identification procedures for samples exhibiting acute and chronic toxicity: U.S. Environmental Protection Agency report EPA–600/R–92/080, 52 p.

_____ 1993b, Methods for aquatic toxicity identification evaluations—Phase III, Toxicity confirmation procedures for samples exhibiting acute and chronic toxicity: U.S. Environmental Protection Agency report EPA–600/R–92/081, 24 p.

# TABLES 7–11



(page 39 follows)

**Table 7.** Selected water-quality data for stormwater and streamflow samples, Maricopa County, Arizona

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

| Station number (See table 1 and figure 1 for station names) | Date | pH, water, whole, field (standard units) | pH, water, whole, lab (standard units) | Oxygen, dissolved (mg/L) | Specific conductance, lab (µS/cm) | Barium, dissolved (µg/L as Ba) | Cobalt, dissolved (µg/L as Co) | Iron, dissolved (µg/L as Fe) | Lead, dissolved (µg/L as Pb) | Manganese, dissolved (µg/L as Mn) | Molybdenum, dissolved (µg/L as Mo) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 09512162 | 02-08-94 | 7.6 | 7.7 | ----- | 155 | 16 | <3 | 170 | <10 | 10 | <10 |
| 09512165 | 12-31-92 | 8.9 | 8.5 | ----- | 880 | 50 | <3 | <3 | <10 | 1 | 10 |
| | 01-04-93 | 7.9 | 8.1 | 10.2 | 620 | 40 | <3 | 9 | <10 | 2 | <10 |
| | 01-12-93 | 8.2 | 8.0 | 8.1 | 496 | 27 | <3 | 58 | <10 | 2 | <10 |
| | 02-11-93 | 8.0 | 8.1 | 8.7 | 299 | 24 | <3 | 70 | <10 | 4 | <10 |
| 09512184 | 02-28-93 | ---- | 6.6 | ----- | 84 | 15 | <3 | 32 | <10 | 22 | <10 |
| | 02-28-93 | 6.9 | 6.9 | 8.4 | 62 | 12 | <3 | 47 | <10 | 15 | <10 |
| | 03-26-93 | ---- | 6.7 | ----- | 176 | 25 | <3 | 86 | <10 | 80 | <10 |
| | 03-26-93 | 6.8 | 6.6 | 3.8 | 158 | 29 | <3 | 90 | <10 | 59 | <10 |
| | 08-24-93 | ---- | 6.4 | ----- | 248 | 40 | 5 | 270 | 10 | 200 | <10 |
| | 08-25-93 | 6.9 | 6.5 | ----- | 321 | 42 | 5 | 260 | <10 | 210 | <10 |
| 09512403 | 11-13-93 | ---- | 7.2 | ----- | 232 | 34 | <3 | 43 | <10 | 21 | <10 |
| | 11-13-93 | 8.4 | 7.8 | ----- | 151 | 16 | <3 | 29 | <10 | 13 | <10 |
| | 02-07-94 | ---- | 7.1 | ----- | 259 | 34 | <3 | 75 | <10 | 32 | <10 |
| | 02-07-94 | 7.4 | 7.1 | ----- | 230 | 28 | <3 | 16 | <10 | 22 | <10 |
| | 03-25-94 | ---- | 7.2 | ----- | 452 | 70 | <3 | 53 | <10 | 100 | <10 |
| | 03-25-94 | 8.2 | 7.0 | ----- | 208 | 22 | <3 | 70 | <10 | 18 | <10 |
| 09513700 | 03-26-93 | ---- | 6.8 | ----- | 414 | 140 | 5 | 170 | <10 | 280 | <10 |
| | 03-26-93 | 6.7 | 7.0 | 7.0 | 192 | 43 | <3 | 69 | <10 | 94 | <10 |
| | 08-06-93 | ---- | 6.3 | ----- | 714 | 260 | 10 | 730 | <10 | 1,300 | <10 |
| | 08-06-93 | 6.7 | 6.3 | 4.6 | 439 | 140 | 6 | 600 | <10 | 1,100 | <10 |
| | 08-29-93 | ---- | 6.9 | ----- | 333 | 80 | <3 | 120 | <10 | 290 | <10 |
| | 08-29-93 | 7.3 | 6.9 | ----- | 79 | 12 | <3 | 32 | <10 | 55 | <10 |
| | 10-06-93 | ---- | 6.6 | ----- | 558 | 170 | 7 | 400 | <10 | 660 | <10 |
| | 10-06-93 | 7.6 | 6.8 | ----- | 117 | 20 | <3 | 55 | <10 | 21 | <10 |
| 09513885 | 01-06-93 | ---- | 6.1 | ----- | 99 | 12 | <3 | 39 | <10 | 72 | <10 |
| | 01-06-93 | 6.8 | 6.8 | 8.6 | 44 | 6 | <3 | 27 | <10 | 28 | <10 |
| | 02-08-93 | ---- | 6.3 | ----- | 87 | 15 | <3 | 41 | <10 | 90 | <10 |
| | 02-08-93 | 6.3 | 6.5 | 8.2 | 49 | 7 | <3 | 27 | <10 | 47 | <10 |
| | 08-24-93 | ---- | 6.3 | ----- | 7,100 | 24 | 20 | 25,000 | <50 | 630 | <40 |
| | 08-24-93 | 6.5 | 6.6 | ----- | 121 | 10 | <3 | 150 | <10 | 140 | <10 |
| | 10-06-93 | ---- | 4.9 | ----- | 819 | 83 | 10 | 1,500 | <10 | 900 | <10 |
| | 10-06-93 | 7.0 | 6.4 | ----- | 133 | 16 | <3 | 210 | <10 | 160 | <10 |
| 333543112090501 | 02-07-94 | 7.1 | 6.9 | ----- | 155 | 18 | <3 | 110 | <10 | 18 | <10 |
| | 03-07-94 | 6.8 | 6.6 | ----- | 138 | 18 | <3 | 56 | <10 | 21 | <10 |
| | 05-25-94 | 7.4 | 6.4 | ----- | 251 | 35 | 4 | 100 | 10 | 23 | 10 |

**Table 7.** Selected water-quality data for stormwater and streamflow samples, Maricopa County, Arizona—Continued

| Station number (See table 1 and figure 1 for station names) | Date | Strontium, dissolved (µg/L as Sr) | Vanadium, dissolved (µg/L as V) | Beryllium, dissolved (µg/L as Be) | Copper, dissolved (µg/L as Cu) | Calcium, dissolved (mg/L as Ca) | Magnesium, dissolved (mg/L as Mg) | Lithium, dissolved (µg/L as Li) | Silica, dissolved (mg/L as $SiO_2$) | Zinc, dissolved (µg/L as Zn) | Cadmium, dissolved (µg/L as Cd) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 09512162 | 02-08-94 | 110 | <6 | <0.5 | <10 | 8.5 | 3.5 | 10 | 4.4 | 6 | <1.0 |
| 09512165 | 02-31-92 | 600 | 7 | <0.5 | <10 | 43 | 20 | 61 | 7.1 | <3 | <1.0 |
| | 01-04-93 | 370 | <6 | <0.5 | <10 | 37 | 12 | 42 | 16 | <3 | <1.0 |
| | 01-12-93 | 230 | <6 | <0.5 | <10 | 29 | 8.3 | 35 | 15 | <3 | <1.0 |
| | 02-11-93 | 220 | <6 | <0.5 | <10 | 27 | 8.6 | 13 | 15 | <3 | <1.0 |
| 09512184 | 02-28-93 | 40 | <6 | <0.5 | 10 | 8.3 | 0.78 | <4 | 1.2 | 48 | <1.0 |
| | 02-28-93 | 36 | <6 | <0.5 | <10 | 6.9 | 0.62 | <4 | 1.5 | 16 | <1.0 |
| | 03-26-93 | 84 | 8 | <0.5 | 30 | 17 | 2.0 | 6 | 1.5 | 120 | <1.0 |
| | 03-26-93 | 73 | <6 | <0.5 | 20 | 14 | 1.5 | 6 | 1.9 | 87 | <1.0 |
| | 08-24-93 | 160 | 16 | <0.5 | 100 | 27 | 4.3 | 14 | 3.2 | 460 | 5.0 |
| | 08-25-93 | 180 | 15 | <0.5 | 70 | 30 | 4.8 | 23 | 3.3 | 510 | 1.0 |
| 09512403 | 11-13-93 | 180 | 6 | <0.5 | 30 | 19 | 2.7 | 7 | 5.2 | 21 | <1.0 |
| | 11-13-93 | 99 | <6 | <0.5 | 10 | 13 | 1.6 | 7 | 3.1 | 5 | 2.0 |
| | 02-07-94 | 190 | <6 | <0.5 | 30 | 21 | 3.7 | 9 | 3.9 | 24 | <1.0 |
| | 02-07-94 | 150 | <6 | 0.6 | 20 | 19 | 2.7 | 7 | 3.6 | 4 | 1.0 |
| | 03-25-94 | 430 | <6 | <0.5 | 10 | 49 | 8.0 | 22 | 13 | 41 | <1.0 |
| | 03-25-94 | 130 | 9 | <0.5 | 20 | 16 | 2.2 | 8 | 3.9 | 9 | <1.0 |
| 09513700 | 03-26-93 | 530 | 20 | <0.5 | 30 | 71 | 6.2 | 8 | 2.9 | 56 | 2.0 |
| | 03-26-93 | 190 | 12 | <0.5 | 20 | 25 | 2.4 | 4 | 3.5 | 23 | <1.0 |
| | 08-06-93 | 770 | 51 | 0.8 | 60 | 130 | 11 | 12 | 4.7 | 270 | <1.0 |
| | 08-06-93 | 420 | 44 | <0.5 | 50 | 77 | 7.3 | 8 | 5.3 | 340 | <1.0 |
| | 08-29-93 | 370 | 27 | <0.5 | 20 | 64 | 5.8 | 14 | 9.6 | 53 | 5.0 |
| | 08-29-93 | 50 | 11 | <0.5 | <10 | 10 | 0.94 | <4 | 2.9 | 13 | <1.0 |
| | 10-06-93 | 540 | 25 | <0.5 | 40 | 95 | 8.4 | 11 | 6.7 | 100 | 2.0 |
| | 10-06-93 | 92 | 9 | <0.5 | <10 | 12 | 1.2 | <4 | 1.7 | 18 | <1.0 |
| 09513885 | 01-06-93 | 70 | <6 | <0.5 | <10 | 9.3 | 1.4 | <4 | 2.4 | 35 | <1.0 |
| | 01-06-93 | 28 | <6 | <0.5 | <10 | 4.9 | 0.53 | <4 | 1.8 | 25 | <1.0 |
| | 02-08-93 | 71 | <6 | <0.5 | 10 | 11 | 1.5 | <4 | 2.2 | 87 | <1.0 |
| | 02-08-93 | 31 | <6 | <0.5 | <10 | 4.9 | 0.66 | <4 | 1.1 | 27 | 3.0 |
| | 08-24-93 | 290 | 46 | <2 | 130 | 90 | 32 | 56 | 170 | 1,500 | 15 |
| | 08-24-93 | 63 | 9 | 0.6 | 10 | 11 | 1.4 | <4 | 1.1 | 140 | <1.0 |
| | 10-06-93 | 370 | 21 | <0.5 | 60 | 67 | 9.9 | 11 | 2.3 | 1,000 | 3.0 |
| | 10-06-93 | 83 | 10 | <0.5 | 10 | 13 | 2.0 | <4 | 1.4 | 260 | <1.0 |
| 333543112090501 | 02-07-94 | 140 | <6 | <0.5 | <10 | 13 | 2.3 | <4 | 3.0 | 23 | <1.0 |
| | 03-07-94 | 110 | <6 | <0.5 | 10 | 12 | 1.5 | <4 | 2.1 | 36 | <1.0 |
| | 05-25-94 | 240 | 7 | <0.5 | 20 | 24 | 4.3 | 9 | 4.8 | 43 | <1.0 |

**Table 7.** Selected water-quality data for stormwater and streamflow samples, Maricopa County, Arizona—Continued

| Station number (See table 1 and figure 1 for station names) | Date | Sodium, dis-solved (mg/L as Na) | Nickel, dis-solved (µg/L as Ni) | Chro-mium, dis-solved (µg/L as Cr) | Silver, dis-solved (µg/L as Ag) | Oil and grease, total recov., gravi-metric (mg/L) | Residue, total at 105°C, sus-pended (mg/L) | Carbon, organic, total (mg/L as C) | Diazinon, total (µg/L) | Ethion, total (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| 09512162 | 02-08-94 | 12 | <10 | <5 | <1.0 | --- | 394 | 23 | 0.12 | <0.01 |
| 09512165 | 12-31-92 | 100 | <10 | <5 | 2.0 | <1 | 9 | 7.3 | ------- | ------- |
| | 01-04-93 | 63 | <10 | <5 | <1.0 | <1 | 47 | 4.8 | <0.01 | <0.01 |
| | 01-12-93 | 54 | <10 | <5 | <1.0 | <1 | 318 | 13 | <0.01 | <0.01 |
| | 02-11-93 | 19 | <10 | <5 | <1.0 | <1 | 149 | 6.7 | <0.01 | <0.01 |
| 09512184 | 02-28-93 | 2.9 | <10 | <5 | 2.0 | <1 | 66 | 25 | ------- | ------- |
| | 02-28-93 | 1.9 | <10 | <5 | 3.0 | <1 | 50 | 12 | 0.07 | <0.01 |
| | 03-26-93 | 8.2 | <10 | <5 | <1.0 | 4 | 340 | 80 | ------- | ------- |
| | 03-26-93 | 5.7 | <10 | <5 | <1.0 | 4 | 175 | 140 | 0.01 | <0.01 |
| | 08-24-93 | 13 | 20 | <5 | <1.0 | 3 | 58 | 22 | ------- | ------- |
| | 08-25-93 | 18 | 20 | <5 | <1.0 | 3 | 124 | 26 | 0.08 | <0.01 |
| 09512403 | 11-13-93 | 12 | <10 | <5 | <1.0 | 5 | 128 | 54 | ------- | ------- |
| | 11-13-93 | 9.3 | <10 | <5 | <1.0 | 4 | 216 | 31 | 0.20 | <0.01 |
| | 02-07-94 | 13 | <10 | <5 | <1.0 | 4 | 246 | 41 | ------- | ------- |
| | 02-07-94 | 14 | <10 | <5 | <1.0 | 6 | 168 | 17 | 0.48 | <0.01 |
| | 03-25-94 | 27 | <10 | <5 | <1.0 | 5 | 124 | 31 | ------- | ------- |
| | 03-25-94 | 10 | <10 | <5 | <1.0 | 4 | 524 | 44 | <0.20 | <0.01 |
| 09513700 | 03-26-93 | 7.2 | 30 | 6 | <1.0 | 5 | 271 | 270 | ------- | ------- |
| | 03-26-93 | 6.4 | 10 | 7 | <1.0 | 3 | 277 | 110 | 0.18 | <0.01 |
| | 08-06-93 | 9.8 | 120 | 20 | <1.0 | 5 | 572 | 520 | ------- | ------- |
| | 08-06-93 | 7.9 | 70 | 9 | <1.0 | 4 | 212 | 330 | 0.09 | <0.01 |
| | 08-29-93 | 6.3 | 40 | 6 | <1.0 | 4 | 152 | 280 | ------- | ------- |
| | 08-29-93 | 1.6 | 10 | <5 | <1.0 | <1 | 140 | 42 | 0.14 | <0.01 |
| | 10-06-93 | 8.0 | 60 | 9 | <1.0 | 10 | 156 | 470 | ------- | ------- |
| | 10-06-93 | 2.1 | <10 | <5 | <1.0 | 2 | 544 | 31 | 0.36 | <0.01 |
| 09513885 | 01-06-93 | 6.2 | <10 | <5 | <1.0 | 3 | 45 | ------- | ------- | ------- |
| | 01-06-93 | 1.5 | <10 | <5 | <1.0 | 5 | 240 | 21 | 0.38 | <0.01 |
| | 02-08-93 | 4.2 | <10 | <5 | <1.0 | 4 | 96 | 62 | ------- | ------- |
| | 02-08-93 | 1.7 | <10 | <5 | <1.0 | 5 | 144 | 29 | 0.15 | <0.01 |
| | 08-24-93 | 1,600 | <50 | 40 | <4.0 | --- | 1,190 | 5,000 | ------- | ------- |
| | 08-24-93 | 5.7 | <10 | <5 | <1.0 | 2 | 42 | 47 | 0.06 | <0.01 |
| | 10-06-93 | 62 | 40 | 5 | <1.0 | 4 | 348 | 660 | ------- | ------- |
| | 10-06-93 | 8.4 | <10 | <5 | <1.0 | 1 | 40 | 76 | 0.12 | <0.01 |
| 333543112090501 | 02-07-94 | 7.7 | <10 | <5 | <1.0 | 8 | 172 | 33 | 0.58 | <0.01 |
| | 03-07-94 | 6.2 | <10 | <5 | 3.0 | 5 | 176 | 43 | 0.54 | <0.01 |
| | 05-25-94 | 17 | <10 | <5 | 2.0 | <1 | 30 | 49 | 0.43 | <0.01 |

**Table 7.** Selected water-quality data for stormwater and streamflow samples, Maricopa County, Arizona—Continued

| Station number (See table 1 and figure 1 for station names) | Date | Malathion, total (µg/L) | Methyl parathion, total (µg/L) | Parathion, total (µg/L) | Total trithion (µg/L) | Disyston, total (µg/L) | Phorate, total (µg/L) | Chlorpyrifos, total recov. (µg/L) | DEF, total (µg/L) | Fonofos (dyfonate), water, whole, total recov. (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| 09512162 | 02-08-94 | 0.37 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.13 | <0.01 | <0.01 |
| 09512165 | 12-31-92 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 01-04-93 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| | 01-12-93 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| | 02-11-93 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| 09512184 | 02-28-93 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 02-28-93 | 0.09 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.05 | <0.01 | <0.05 |
| | 03-26-93 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 03-26-93 | 0.13 | 0.03 | <0.01 | <0.01 | 0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| | 08-24-93 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 08-25-93 | 0.04 | 0.05 | <0.01 | <0.01 | <0.01 | <0.01 | 0.01 | <0.01 | <0.01 |
| 09512403 | 11-13-93 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 11-13-93 | 0.03 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.11 | <0.01 |
| | 02-07-94 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 02-07-94 | 0.08 | <0.01 | <0.01 | <0.01 | <0.01 | 0.02 | 0.01 | 0.05 | ------- |
| | 03-25-94 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 03-25-94 | <0.10 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| 09513700 | 03-26-93 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 03-26-93 | 1.0 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.03 | <0.01 | <0.01 |
| | 08-06-93 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 08-06-93 | 0.08 | 0.02 | <0.01 | <0.01 | <0.01 | <0.01 | 0.01 | <0.01 | <0.01 |
| | 08-29-93 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 08-29-93 | 0.05 | 0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.02 | <0.01 | <0.01 |
| | 10-06-93 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 10-06-93 | 0.04 | 0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.03 | 0.11 | <0.01 |
| 09513885 | 01-06-93 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 01-06-93 | 0.20 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.02 | <0.01 | <0.01 |
| | 02-08-93 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 02-08-93 | 0.09 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| | 08-24-93 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 08-24-93 | 0.06 | 0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.03 | <0.01 | <0.01 |
| | 10-06-93 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 10-06-93 | 0.04 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.01 | 0.03 | <0.01 |
| 333543112090501 | 02-07-94 | 1.1 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.05 | <0.01 | <0.01 |
| | 03-07-94 | 0.83 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.06 | <0.01 | <0.01 |
| | 05-25-94 | 0.30 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.02 | <0.01 | <0.01 |

**Table 8.** Selected chemical data for bed-material samples, Maricopa County, Arizona

[μg/g, micrograms per gram; mg/kg, milligrams per kilogram; μg/kg, micrograms per kilogram; g/kg, gram per kilogram; mm, millimeter; DDD, dichlorodiphenyldichloroethane; DDE, dichlorodiphenylethylene; DDT, dichlorodiphenyltrichloroethane; PCB, polychlorinated biphenyl; PCN, polychlorinated naphthalene]

| Station number (See table 1 and figure 1 for station names) | Date | Moisture content, dry wt. (percent of total) | Iron, recov. (μg/g as Fe) | Cadmium, recov. (μg/g as Cd) | Chromium, recov. (μg/g as Cr) | Cobalt, recov. (μg/g as Co) | Copper, recov. (μg/g as Cu) | Lead, recov. (μg/g as Pb) | Mercury, recov. (μg/g as Hg) | Manganese, recov. (μg/g as Mn) |
|---|---|---|---|---|---|---|---|---|---|---|
| 09512090 | 06-09-93 | 4 | 12,000 | <1 | 20 | 170 | 30 | 30 | 0.04 | 390 |
| 09512162 | 06-09-93 | 3 | 14,000 | <1 | 20 | 20 | 20 | 20 | <0.01 | 540 |
| 09512165 | 06-14-93 | 3 | 15,000 | <1 | 20 | 20 | 40 | 20 | 0.07 | 800 |
| 09512190 | 06-09-93 | 2 | 12,000 | <1 | 20 | 10 | 40 | 30 | 0.08 | 400 |
| 09512200 | 09-04-92 | 2 | 7,500 | <1 | 10 | <5 | 30 | 30 | 0.03 | 1,500 |
| | 09-24-92 | -- | -------- | --- | --- | ---- | --- | ---- | ------ | ------- |
| 09512405 | 06-09-93 | 2 | 13,000 | <1 | 20 | 20 | 40 | 20 | 0.14 | 810 |
| 09513700 | 09-09-92 | 2 | 3,700 | 2 | 20 | <5 | 20 | 70 | 0.02 | 190 |
| | 09-25-92 | -- | -------- | --- | --- | --- | --- | ---- | ------ | ------- |
| | 06-03-93 | 4 | 11,000 | 2 | 30 | 10 | 30 | 70 | 0.03 | 290 |
| 332007112054301 | 09-04-92 | 3 | 6,300 | <1 | 10 | 10 | 20 | 10 | 0.03 | 1,400 |
| | 09-24-92 | -- | -------- | --- | --- | --- | --- | ---- | ------ | ------- |
| 332025112050801 | 09-04-92 | 2 | 6,700 | <1 | 10 | <5 | 20 | 20 | 0.02 | 1,400 |
| | 09-24-92 | -- | -------- | --- | --- | --- | --- | ---- | ------ | ------- |
| 332109112041401 | 09-08-92 | 2 | 6,200 | <1 | 10 | <5 | 30 | 30 | 0.03 | 1,600 |
| | 09-24-92 | -- | -------- | --- | --- | --- | --- | ---- | ------ | ------- |
| 332116112040501 | 09-08-92 | 2 | 6,900 | <1 | 8 | <5 | 20 | 10 | 0.02 | 1,300 |
| | 09-24-92 | -- | -------- | --- | --- | --- | --- | ---- | ------ | ------- |
| 332119112041001 | 09-08-92 | 3 | 8,600 | <1 | 10 | 10 | 30 | 30 | 0.04 | 1,900 |
| | 09-24-92 | -- | -------- | --- | --- | --- | --- | ---- | ------ | ------- |
| 332405111583801 | 06-14-93 | 2 | 3,800 | 4 | 7 | 10 | 50 | 50 | 0.04 | 810 |
| 332414111583701 | 06-02-93 | 2 | 12,000 | 2 | 20 | 10 | 70 | 90 | 0.05 | 360 |
| 332425112062401 | 09-09-92 | 2 | 5,300 | 1 | 9 | 10 | 30 | 50 | 0.02 | 370 |
| | 09-25-92 | -- | -------- | --- | --- | --- | --- | ---- | ------ | ------- |
| 332425112064001 | 09-09-92 | 1 | 5,600 | 1 | 9 | 10 | 40 | 120 | 0.02 | 320 |
| | 09-25-92 | -- | -------- | --- | --- | --- | --- | ---- | ------ | ------- |
| 332425112065501 | 09-08-92 | 1 | 5,500 | 2 | 10 | 10 | 60 | 130 | 0.05 | 370 |
| | 09-25-92 | -- | -------- | -- | --- | --- | --- | ---- | ------ | ------- |
| | 06-08-93 | 2 | 15,000 | 1 | 20 | 20 | 40 | 60 | 0.04 | 440 |
| 332509111584001 | 06-02-93 | 2 | 12,000 | 1 | 10 | 10 | 40 | 40 | 0.02 | 450 |
| 332513111582601 | 06-02-93 | 3 | 13,000 | 1 | 20 | 20 | 40 | 40 | 0.04 | 530 |
| 333435112181401 | 09-25-92 | 4 | 8,700 | <1 | 10 | 10 | 20 | 20 | 0.02 | 370 |
| 333438112181401 | 09-25-92 | 3 | 9,100 | <1 | 9 | <5 | 10 | 20 | 0.02 | 280 |
| 333439112181701 | 09-25-92 | 3 | 12,000 | <1 | 10 | 10 | 30 | 20 | 0.05 | 550 |
| 333458112090401 | 06-03-93 | 3 | 25,000 | <1 | 40 | 20 | 40 | 40 | 0.04 | 780 |
| 333459112090401 | 06-03-93 | 3 | 17,000 | 1 | 30 | 20 | 40 | 50 | 0.08 | 640 |
| 333543112090501 | 06-03-93 | 0.3 | 16,000 | 1 | 30 | 20 | 40 | 40 | 0.05 | 500 |
| 333627112110601 | 06-03-93 | 6 | 13,000 | 1 | 20 | 20 | 30 | 30 | 0.04 | 460 |
| 333704112120501 | 06-03-93 | 4 | 13,000 | 1 | 20 | 20 | 40 | 30 | 0.04 | 530 |

**Table 8.** Selected chemical data for bed-material samples, Maricopa County, Arizona—Continued

| Station number (See table 1 and figure 1 for station names) | Date | Zinc, recov. (µg/g as Zn) | Arsenic, total (µg/g as As) | Nitrogen, $NO_2$+$NO_3$, total (mg/kg as N) | Phos-phorus, total (mg/kg as P) | Nitrogen, $NH_4$, total (mg/kg as N) | Nitrogen, $NH_4$+org., total (mg/kg as N) | Perthane, total (µg/kg) | Endo-sulfan, total (µg/kg) | Aldrin, total (µg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| 09512090 | 06-09-93 | 150 | 9 | 46 | 690 | 11 | 910 | <1.00 | <0.3 | <0.1 |
| 09512162 | 06-09-93 | 60 | 9 | 15 | 960 | 11 | 460 | <1.00 | <0.1 | <0.1 |
| 09512165 | 06-14-93 | 60 | 16 | 18 | 1,000 | 58 | 2,000 | <1.00 | <0.4 | <0.1 |
| 09512190 | 06-09-93 | 140 | 10 | 35 | 670 | 14 | 710 | <1.00 | <0.2 | <0.1 |
| 09512200 | 09-04-92 | 50 | 5 | 31 | 610 | 8.5 | 1,300 | <10.0 | <0.2 | <0.2 |
| | 09-24-92 | ---- | --- | ------ | ------- | ------- | ------- | ------- | ----- | ----- |
| 09512405 | 06-09-93 | 90 | 22 | 25 | 1,400 | 54 | 720 | <1.00 | <0.2 | <0.1 |
| 09513700 | 09-09-92 | 130 | 13 | 5.0 | 670 | 16 | 1,300 | <1.00 | <0.1 | <0.1 |
| | 09-25-92 | ---- | --- | ------ | ------- | ------- | ------- | ------- | ----- | ----- |
| | 06-03-93 | 140 | 11 | 43 | 580 | 17 | 1,200 | <3.00 | <0.3 | <0.3 |
| 332007112054301 | 09-04-92 | 40 | 5 | 64 | 700 | 16 | 1,200 | <1.00 | <0.1 | <0.1 |
| | 09-24-92 | ---- | --- | ------ | ------- | ------- | ------- | ------- | ----- | ----- |
| 332025112050801 | 09-04-92 | 40 | 5 | 19 | 640 | 7.4 | 780 | <1.00 | <0.1 | <0.1 |
| | 09-24-92 | ---- | --- | ------ | ------- | ------- | ------- | ------- | ----- | ----- |
| 332109112041401 | 09-08-92 | 50 | 2 | 60 | 690 | 11 | 1,100 | <1.00 | <0.1 | <0.1 |
| | 09-24-92 | ---- | --- | ------ | ------- | ------- | ------- | ------- | ----- | ----- |
| 332116112040501 | 09-08-92 | 40 | 5 | 16 | 680 | 5.5 | 490 | <1.00 | <0.1 | <0.1 |
| | 09-24-92 | --- | --- | ------ | ------- | ------- | ------- | ------- | ----- | ----- |
| 332119112041001 | 09-08-92 | 60 | 5 | 69 | 840 | 11 | 1,300 | <1.00 | <0.1 | <0.1 |
| | 09-24-92 | ---- | --- | ------ | ------- | ------- | ------- | ------- | ----- | ----- |
| 332405111583801 | 06-14-93 | 340 | 8 | 170 | 890 | 130 | 8,100 | <1.00 | <0.1 | <0.1 |
| 332414111583701 | 06-02-93 | 250 | 15 | 140 | 1,100 | 140 | 1,700 | <1.00 | <0.1 | <0.1 |
| 332425112062401 | 09-09-92 | 90 | 13 | 43 | 940 | 12 | 590 | <10.0 | <0.2 | <0.2 |
| | 09-25-92 | ---- | --- | ------ | ------- | ------- | ------- | -------- | ----- | ----- |
| 332425112064001 | 09-09-92 | 80 | 10 | 54 | 910 | 16 | 470 | <10.0 | <0.2 | <0.2 |
| | 09-25-92 | ---- | --- | ------ | ------- | ------- | ------- | -------- | ----- | ----- |
| 332425112065501 | 09-08-92 | 150 | 11 | 13 | 930 | 18 | 580 | <10.0 | <0.2 | <0.2 |
| | 09-25-92 | ---- | --- | ------ | ------- | ------- | ------- | -------- | ----- | ----- |
| | 06-08-93 | 100 | 16 | 310 | 860 | 43 | 570 | <1.00 | <0.1 | <0.3 |
| 332509111584001 | 06-02-93 | 110 | 13 | 22 | 880 | 200 | 960 | <1.00 | <0.1 | <0.1 |
| 332513111582601 | 06-02-93 | 90 | 14 | 28 | 980 | 200 | 860 | <1.00 | <0.1 | <1.0 |
| 333435112181401 | 09-25-92 | 40 | 12 | 19 | 1,100 | 4.3 | 490 | <1.00 | <0.1 | 0.1 |
| 333438112181401 | 09-25-92 | 30 | 11 | 2.0 | 790 | 3.0 | 400 | <1.00 | <0.1 | <0.1 |
| 333439112181701 | 09-25-92 | 60 | 8 | 28 | 1,000 | 7.9 | 850 | <1.00 | <0.1 | <0.1 |
| 333458112090401 | 06-03-93 | 90 | 14 | 33 | 1,400 | 17 | 840 | <20.0 | <2.0 | <2.0 |
| 333459112090401 | 06-03-93 | 250 | 18 | 120 | 1,300 | 120 | 2,000 | <3.00 | <0.3 | <0.3 |
| 333543112090501 | 06-03-93 | 130 | 10 | 18 | 1,100 | 16 | 840 | <1.00 | <0.1 | <1.0 |
| 333627112110601 | 06-03-93 | 100 | 18 | 27 | 980 | 11 | 860 | <1.00 | <0.1 | <1.0 |
| 333704112120501 | 06-03-93 | 120 | 14 | 30 | 1,300 | 22 | 1,100 | <1.00 | <0.1 | <0.7 |

**Table 8.** Selected chemical data for bed-material samples, Maricopa County, Arizona—Continued

| Station number (See table 1 and figure 1 for station names) | Date | Chlordane, total (µg/kg) | DDD, total (µg/kg) | DDE, total (µg/kg) | DDT, total (µg/kg) | Dieldrin, total (µg/kg) | Endrin, total (µg/kg) | Heptachlor, total (µg/kg) | Heptachlor epoxide, total (µg/kg) | Lindane, total (µg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| 09512090 | 06-09-93 | 110 | 3.9 | 24 | 1.4 | 5.2 | <0.1 | <0.2 | 0.3 | <0.1 |
| 09512162 | 06-09-93 | 1.0 | 0.4 | 20 | 1.6 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| 09512165 | 06-14-93 | 3.0 | 0.3 | 7.6 | 0.7 | 0.8 | <0.1 | <0.1 | 0.1 | <0.2 |
| 09512190 | 06-09-93 | 53 | 2.2 | 8.6 | 6.5 | 7.6 | <0.3 | <0.2 | 0.2 | <0.1 |
| 09512200 | 09-04-92 | 8.0 | <0.2 | 51 | 4.9 | 0.7 | <4.0 | <0.2 | <0.2 | <0.2 |
| | 09-24-92 | -------- | ------ | ------- | ------- | ------- | ------- | ------ | ------ | ------ |
| 09512405 | 06-09-93 | 16 | 2.4 | 13 | 9.5 | 3.9 | <0.1 | <0.1 | <0.1 | <0.1 |
| 09513700 | 09-09-92 | <100 | <0.1 | 150 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 09-25-92 | -------- | ------ | ------- | ------- | ------- | ------- | ------ | ------ | ------ |
| | 06-03-93 | 35 | 2.3 | 32 | 3.2 | 3.9 | <0.3 | <0.3 | <0.3 | <0.3 |
| 332007112054301 | 09-04-92 | <1.0 | <0.1 | 16 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 09-24-92 | -------- | ------ | ------- | ------- | ------- | ------- | ------ | ------ | ------ |
| 332025112050801 | 09-04-92 | 2.0 | <0.1 | 12 | 0.7 | 0.1 | <0.7 | <0.1 | <0.1 | <0.1 |
| | 09-24-92 | -------- | ------ | ------- | ------- | ------- | ------- | ------ | ------ | ------ |
| 332109112041401 | 09-08-92 | 12 | <2.0 | <0.1 | <1.0 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 09-24-92 | -------- | ------ | ------- | ------- | ------- | ------- | ------ | ------ | ------ |
| 332116112040501 | 09-08-92 | <2.0 | <0.1 | <0.1 | <0.1 | <0.1 | <2.0 | <0.1 | <0.1 | <0.1 |
| | 09-24-92 | -------- | ------ | ------- | ------- | ------- | ------- | ------ | ------ | ------ |
| 332119112041001 | 09-08-92 | 16 | <2.0 | 30 | <0.1 | 0.2 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 09-24-92 | -------- | ------ | ------- | ------- | ------- | ------- | ------ | ------ | ------ |
| 332405111583801 | 06-14-93 | 9.0 | 0.7 | 7.3 | 0.6 | 6.3 | <0.1 | <0.1 | <0.1 | <0.1 |
| 332414111583701 | 06-02-93 | 37 | 2.0 | 29 | 3.4 | 2.5 | <0.1 | <0.2 | 0.2 | 0.3 |
| 332425112062401 | 09-09-92 | 13 | <0.2 | 91 | 11 | 0.3 | <4.0 | <0.2 | <0.2 | <0.2 |
| | 09-25-92 | -------- | ------ | ------- | ------- | ------- | ------- | ------ | ------ | ------ |
| 332425112064001 | 09-09-92 | 7.0 | <0.5 | 39 | 5.0 | 0.8 | <2.0 | <0.2 | <0.2 | <0.2 |
| | 09-25-92 | -------- | ------ | ------- | ------- | ------- | ------- | ------ | ------ | ------ |
| 332425112065501 | 09-08-92 | 22 | <0.2 | 97 | 26 | <0.2 | <5.0 | <0.2 | <0.2 | <0.2 |
| | 09-25-92 | -------- | ------ | ------- | ------- | ------- | ------- | ------ | ------ | ------ |
| | 06-08-93 | 10 | 8.2 | 130 | 40 | 3.9 | <0.1 | <0.1 | <0.1 | 0.5 |
| 332509111584001 | 06-02-93 | 15 | 1.2 | 30 | 4.2 | 1.5 | <0.1 | <0.1 | 0.1 | 0.1 |
| 332513111582601 | 06-02-93 | 280 | 8.6 | 30 | 9.5 | 150 | <0.1 | <0.1 | 0.8 | 0.1 |
| 333435112181401 | 09-25-92 | 4.0 | <0.1 | 34 | 4.8 | 0.7 | 2.4 | <0.1 | <0.1 | <0.1 |
| 333438112181401 | 09-25-92 | 9.0 | <0.1 | 13 | 17 | <0.1 | 3.3 | <0.1 | <0.1 | <0.1 |
| 333439112181701 | 09-25-92 | 3.0 | <0.1 | 11 | 1.2 | 0.2 | 1.0 | <0.1 | <0.1 | <0.1 |
| 333458112090401 | 06-03-93 | 130 | 80 | 620 | 300 | 70 | <60 | <0.4 | 1.5 | <0.3 |
| 333459112090401 | 06-03-93 | 11 | 0.5 | 140 | 9.0 | 2.1 | <0.3 | <0.3 | <0.3 | <0.3 |
| 333543112090501 | 06-03-93 | 32 | 2.1 | 35 | 3.8 | 4.8 | <0.1 | <0.2 | 0.2 | 0.2 |
| 333627112110601 | 06-03-93 | 26 | 2.2 | 20 | 3.5 | 3.7 | <0.1 | <0.1 | <0.1 | 0.2 |
| 333704112120501 | 06-03-93 | 13 | 0.6 | 24 | 2.2 | 2.0 | <0.1 | <0.1 | <0.1 | 0.1 |

**Table 8.** Selected chemical data for bed-material samples, Maricopa County, Arizona—Continued

| Station number (See table 1 and figure 1 for station names) | Date | Toxaphene, total (µg/kg) | Diazinon, total (µg/kg) | Ethion, total (µg/kg) | Malathion, total (µg/kg) | Methyl parathion, total (µg/kg) | Parathion, total (µg/kg) | Trithion, total (µg/kg) | PCB, total (µg/kg) |
|---|---|---|---|---|---|---|---|---|---|
| 09512090 | 06-09-93 | 40 | 7.6 | <0.1 | 0.4 | <0.1 | <0.1 | <0.1 | 5 |
| 09512162 | 06-09-93 | <10 | 0.2 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <1 |
| 09512165 | 06-14-93 | 20 | 0.4 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 13 |
| 09512190 | 06-09-93 | 20 | 0.2 | <0.1 | 0.4 | <0.1 | <0.1 | <0.1 | 20 |
| 09512200 | 09-04-92 | 140 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <10 |
| | 09-24-92 | ------- | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 09512405 | 06-09-93 | 30 | 0.2 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 17 |
| 09513700 | 09-09-92 | 830 | 9.4 | <2.0 | 5.8 | <2.0 | <2.0 | <2.0 | <1 |
| | 09-25-92 | ------- | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| | 06-03-93 | 80 | 0.6 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 11 |
| 332007112054301 | 09-04-92 | 130 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <1 |
| | 09-24-92 | ------- | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 332025112050801 | 09-04-92 | 30 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 6 |
| | 09-24-92 | ------- | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 332109112041401 | 09-08-92 | 170 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <1 |
| | 09-24-92 | ------- | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 332116112040501 | 09-08-92 | 90 | 0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <1 |
| | 09-24-92 | ------- | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 332119112041001 | 09-08-92 | 160 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <1 |
| | 09-24-92 | ------- | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 332405111583801 | 06-14-93 | 110 | 3.2 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 12 |
| 332414111583701 | 06-02-93 | 80 | 3.5 | <0.1 | 0.4 | 0.2 | <0.1 | <0.1 | 19 |
| 332425112062401 | 09-09-92 | 390 | 0.8 | <0.1 | <0.3 | 1.0 | <0.1 | <0.1 | 120 |
| | 09-25-92 | ------- | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 332425112064001 | 09-09-92 | 80 | 0.2 | <0.1 | <0.1 | 0.4 | <0.1 | <0.1 | <1 |
| | 09-25-92 | ------- | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 332425112065501 | 09-08-92 | 380 | 0.3 | <0.1 | 0.3 | 0.8 | <0.1 | <0.1 | 240 |
| | 09-25-92 | ------- | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| | 06-08-93 | 240 | 0.4 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 30 |
| 332509111584001 | 06-02-93 | 50 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 13 |
| 332513111582601 | 06-02-93 | 110 | 0.2 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 65 |
| 333435112181401 | 09-25-92 | 160 | 0.4 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <1 |
| 333438112181401 | 09-25-92 | 280 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <1 |
| 333439112181701 | 09-25-92 | 70 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <1 |
| 333458112090401 | 06-03-93 | 1,800 | 0.3 | <0.1 | <0.1 | <0.1 | 0.1 | <0.1 | 16 |
| 333459112090401 | 06-03-93 | 200 | 0.3 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 4 |
| 333543112090501 | 06-03-93 | 50 | 3.7 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 8 |
| 333627112110601 | 06-03-93 | 40 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 6 |
| 333704112120501 | 06-03-93 | 40 | 5.0 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 4 |

**Table 8.** Selected chemical data for bed-material samples, Maricopa County, Arizona—Continued

| Station number (See table 1 and figure 1 for station names) | Date | PCN, total (µg/kg) | Meth-oxychlor, total (µg/kg) | Mirex, total (µg/kg) | Carbon, inorganic, total (g/kg as C) | Carbon, inorganic+ organic, total (g/kg as C) | Oil and grease, total, gravi-metric (mg/kg) | Bed material, sieve diameter, percent finer than 0.062 mm | Bed material, sieve diameter, percent finer than 0.125 mm |
|---|---|---|---|---|---|---|---|---|---|
| 09512090 | 06-09-93 | <1.0 | 0.5 | <0.1 | 4.5 | 18 | 300 | 18 | 32 |
| 09512162 | 06-09-93 | <1.0 | <0.1 | <0.1 | 4.9 | 10 | <100 | 47 | 71 |
| 09512165 | 06-14-93 | <1.0 | <0.1 | <0.1 | 4.6 | 20 | <100 | 61 | 77 |
| 09512190 | 06-09-93 | <1.0 | <1.0 | <0.1 | 5.3 | 15 | <100 | 24 | 70 |
| 09512200 | 09-04-92 | <1.0 | <1.0 | <0.2 | 2.5 | 16 | -------- | 0 | 1 |
| | 09-24-92 | ----- | ------ | ----- | ----- | ------ | <1,000 | --- | --- |
| 09512405 | 06-09-93 | <1.0 | <1.0 | <0.1 | 7.2 | 14 | <100 | 75 | 83 |
| 09513700 | 09-09-92 | <1.0 | <0.1 | <0.1 | 9.6 | 42 | -------- | 31 | 68 |
| | 09-25-92 | ----- | ------ | ----- | ----- | ------ | 2,200 | --- | --- |
| | 06-03-93 | <3.0 | <0.3 | <0.3 | 10 | 52 | 920 | 37 | 60 |
| 332007112054301 | 09-04-92 | <1.0 | ----- | <0.1 | 8.5 | 19 | -------- | 0 | 1 |
| | 09-24-92 | ----- | ----- | ----- | ----- | ------ | <1,000 | --- | --- |
| 332025112050801 | 09-04-92 | <1.0 | <0.1 | <0.1 | 2.3 | 8.4 | -------- | 2 | 3 |
| | 09-24-92 | ----- | ----- | ----- | ----- | ------ | 1,100 | --- | --- |
| 332109112041401 | 09-08-92 | <1.0 | 0.8 | <0.1 | 2.3 | 12 | -------- | 2 | 4 |
| | 09-24-92 | ----- | ----- | ----- | ----- | ------ | <1,000 | --- | --- |
| 332116112040501 | 09-08-92 | <1.0 | <0.1 | <0.1 | 3.1 | 6.7 | -------- | 2 | 5 |
| | 09-24-92 | ----- | ----- | ----- | ----- | ------ | 1,200 | --- | --- |
| 332119112041001 | 09-08-92 | <1.0 | 0.3 | <0.1 | 3.8 | 15 | -------- | 60 | 66 |
| | 09-24-92 | ----- | ----- | ----- | ----- | ------ | <1,000 | --- | --- |
| 332405111583801 | 06-14-93 | <1.0 | <0.1 | <0.1 | 49 | 140 | 110 | 4 | 6 |
| 332414111583701 | 06-02-93 | <1.0 | <0.1 | <0.1 | 11 | 37 | 230 | 25 | 42 |
| 332425112062401 | 09-09-92 | <1.0 | <1.0 | <0.2 | 11 | 20 | -------- | 36 | 59 |
| | 09-25-92 | ----- | ----- | ----- | ----- | ------ | <1,000 | --- | --- |
| 332425112064001 | 09-09-92 | <1.0 | <1.0 | <0.2 | 9.5 | 17 | -------- | 21 | 42 |
| | 09-25-92 | ----- | ----- | ----- | ----- | ------ | <1,000 | --- | --- |
| 332425112065501 | 09-08-92 | <1.0 | <1.0 | <0.2 | 10 | 21 | -------- | 17 | 31 |
| | 09-25-92 | ----- | ----- | ----- | ----- | ------ | <1,000 | --- | --- |
| | 06-08-93 | <1.0 | <1.0 | <0.2 | 9.9 | 19 | 200 | 18 | 32 |
| 332509111584001 | 06-02-93 | <1.0 | <0.1 | <0.1 | 7.5 | 20 | <100 | 23 | 39 |
| 332513111582601 | 06-02-93 | <1.0 | <0.1 | <0.1 | 8.8 | 20 | <100 | 16 | 26 |
| 333435112181401 | 09-25-92 | <1.0 | <0.1 | <0.1 | 5.5 | 11 | <1,000 | 6 | 15 |
| 333438112181401 | 09-25-92 | <1.0 | <0.1 | <0.1 | 5.9 | 11 | <1,000 | 38 | 56 |
| 333439112181701 | 09-25-92 | <1.0 | <0.1 | <0.1 | 2.5 | 10 | <1,000 | 59 | 80 |
| 333458112090401 | 06-03-93 | <1.0 | <2.0 | <0.1 | 0.8 | 10 | <100 | 27 | 41 |
| 333459112090401 | 06-03-93 | <3.0 | <1.0 | <0.3 | 2.2 | 65 | 1,200 | 12 | 17 |
| 333543112090501 | 06-03-93 | <1.0 | <1.0 | <0.3 | 5.4 | 18 | <100 | 22 | 31 |
| 333627112110601 | 06-03-93 | <1.0 | <1.0 | <0.1 | 5.7 | 25 | <100 | 10 | 20 |
| 333704112120501 | 06-03-93 | <1.0 | <0.1 | <0.1 | 5.3 | 22 | 160 | 11 | 16 |

**Table 8.** Selected chemical data for bed-material samples, Maricopa County, Arizona—Continued

| Station number (See table 1 and figure 1 for station names) | Date | Bed material, sieve diameter, percent finer than 0.250 mm | Bed material, sieve diameter, percent finer than 0.500 mm | Bed material, sieve diameter, percent finer than 1.00 mm | Bed material, sieve diameter, percent finer than 2.00 mm | Bed material, sieve diameter, percent finer than 4.00 mm | Bed material, sieve diameter, percent finer than 8.00 mm | Bed material, sieve diameter, percent finer than 16.0 mm | Bed material, sieve diameter, percent finer than 32.0 mm |
|---|---|---|---|---|---|---|---|---|---|
| 09512090 | 06-09-93 | 67 | 97 | 99 | 100 | 100 | ---- | ---- | ---- |
| 09512162 | 06-09-93 | 85 | 93 | 97 | 98 | 99 | 100 | ---- | ---- |
| 09512165 | 06-14-93 | 92 | 99 | 100 | 100 | 100 | ---- | ---- | ---- |
| 09512190 | 06-09-93 | 96 | 98 | 99 | 100 | 100 | 100 | ---- | ---- |
| 09512200 | 09-04-92 | 4 | 12 | 26 | 52 | 91 | 99 | 100 | ---- |
| | 09-24-92 | --- | --- | ---- | ---- | ---- | ---- | ---- | ---- |
| 09512405 | 06-09-93 | 95 | 99 | 100 | 100 | 100 | 100 | ---- | ---- |
| 09513700 | 09-09-92 | 81 | 87 | 93 | 97 | 99 | 100 | ---- | ---- |
| | 09-25-92 | --- | --- | ---- | ---- | ---- | ---- | ---- | ---- |
| | 06-03-93 | 73 | 81 | 90 | 96 | 98 | 99 | 100 | ---- |
| 332007112054301 | 09-04-92 | 1 | 3 | 21 | 47 | 71 | 93 | 100 | ---- |
| | 09-24-92 | --- | --- | ---- | ---- | ---- | ---- | ---- | ---- |
| 332025112050801 | 09-04-92 | 8 | 24 | 47 | 65 | 77 | 85 | 95 | 100 |
| | 09-24-92 | --- | --- | ---- | ---- | ---- | ---- | ---- | ---- |
| 332109112041401 | 09-08-92 | 9 | 25 | 50 | 73 | 90 | 97 | 100 | ---- |
| | 09-24-92 | --- | --- | ---- | ---- | ---- | ---- | ---- | ---- |
| 332116112040501 | 09-08-92 | 10 | 16 | 24 | 43 | 79 | 97 | 100 | ---- |
| | 09-24-92 | --- | --- | ---- | ---- | ---- | ---- | ---- | ---- |
| 332119112041001 | 09-08-92 | 77 | 93 | 100 | 100 | ---- | ---- | ---- | ---- |
| | 09-24-92 | --- | --- | ---- | ---- | ---- | ---- | ---- | ---- |
| 332405111583801 | 06-14-93 | 8 | 10 | 19 | 49 | 75 | 85 | 94 | 100 |
| 332414111583701 | 06-02-93 | 60 | 78 | 91 | 97 | 98 | 99 | 100 | ---- |
| 332425112062401 | 09-09-92 | 76 | 86 | 91 | 93 | 94 | 96 | 100 | ---- |
| | 09-25-92 | --- | --- | ---- | ---- | ---- | ---- | ---- | ---- |
| 332425112064001 | 09-09-92 | 60 | 68 | 74 | 77 | 80 | 88 | 100 | ---- |
| | 09-25-92 | --- | --- | ---- | ---- | ---- | ---- | ---- | ---- |
| 332425112065501 | 09-08-92 | 47 | 64 | 82 | 91 | 94 | 96 | 100 | ---- |
| | 09-25-92 | --- | --- | ---- | ---- | ---- | ---- | ---- | ---- |
| | 06-08-93 | 44 | 50 | 54 | 57 | 60 | 67 | 85 | 100 |
| 332509111584001 | 06-02-93 | 53 | 66 | 78 | 86 | 91 | 95 | 97 | 100 |
| 332513111582601 | 06-02-93 | 36 | 47 | 62 | 73 | 79 | 86 | 94 | 100 |
| 333435112181401 | 09-25-92 | 38 | 66 | 86 | 95 | 97 | 99 | 100 | ---- |
| 333438112181401 | 09-25-92 | 67 | 79 | 90 | 96 | 99 | 100 | ---- | ---- |
| 333439112181701 | 09-25-92 | 93 | 98 | 99 | 100 | ---- | ---- | ---- | ---- |
| 333458112090401 | 06-03-93 | 51 | 58 | 71 | 81 | 88 | 96 | 100 | ---- |
| 333459112090401 | 06-03-93 | 25 | 33 | 41 | 50 | 68 | 92 | 100 | ---- |
| 333543112090501 | 06-03-93 | 41 | 53 | 68 | 78 | 85 | 92 | 100 | ---- |
| 333627112110601 | 06-03-93 | 31 | 45 | 60 | 73 | 82 | 89 | 96 | 100 |
| 333704112120501 | 06-03-93 | 23 | 33 | 49 | 65 | 77 | 83 | 87 | 100 |

**Table 9.** Results of acute toxicity analyses of urban stormwater and streamflow, Maricopa County, Arizona

[LC50 and LC20, concentration of stormwater (in percent, by volume) that killed 50 or 20 percent of the organisms, respectively; LOEC, lowest observed effect concentration; NOEC, no observed effect concentration; >, greater than]

| Date | Land use | Sample type | Species | LC50 | LC20 | LOEC | NOEC |
|---|---|---|---|---|---|---|---|
| **Indian Bend Wash at Curry Road, at Tempe, Arizona (09512162)** | | | | | | | |
| 02–08–94 | Stream channel | Streamflow | Fathead minnow | 70.7 | 58 | 100 | 50 |
| 02–08–94 | Stream channel | Streamflow | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| **Salt River at Priest Drive, at Phoenix, Arizona (09512165)** | | | | | | | |
| 12–31–92 | Stream channel | Streamflow | Fathead minnow | >100 | >100 | >100 | 100 |
| 12–31–92 | Stream channel | Streamflow | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 01–04–93 | Stream channel | Streamflow | Fathead minnow | >100 | >100 | >100 | 100 |
| 01–04–93 | Stream channel | Streamflow | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 01–12–93 | Stream channel | Streamflow | Fathead minnow | >100 | >100 | >100 | 100 |
| 01–12–93 | Stream channel | Streamflow | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| **Box culvert at 48th Street drain (09512184)** | | | | | | | |
| 02–28–93 | Light industry | First flush | Fathead minnow | >100 | >100 | >100 | 100 |
| 02–28–93 | Light industry | First flush | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 02–28–93 | Light industry | Flow weight | Fathead minnow | >100 | >100 | >100 | 100 |
| 02–28–93 | Light industry | Flow weight | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 03–26–93 | Light industry | First flush | Fathead minnow | >100 | >100 | >100 | 100 |
| 03–26–93 | Light industry | First flush | *Ceriodaphnia dubia* | >100 | 100 | 100 | 50 |
| 03–26–93 | Light industry | Flow weight | Fathead minnow | >100 | >100 | >100 | 100 |
| 03–26–93 | Light industry | Flow weight | *Ceriodaphnia dubia* | >100 | 100 | 6.25 | 6.25 |
| 08–24–93 | Light industry | First flush | Fathead minnow | 70.7 | 58 | 100 | 50 |
| 08–24–93 | Light industry | First flush | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 08–24–93 | Light industry | Flow weight | Fathead minnow | >100 | >100 | >100 | 100 |
| 08–24–93 | Light industry | Flow weight | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| **27th Avenue at Salt River (09512403)** | | | | | | | |
| 11–13–93 | Heavy industry | First flush | Fathead minnow | 66 | 55 | 100 | 50 |
| 11–13–93 | Heavy industry | First flush | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 11–13–93 | Heavy industry | Flow weight | Fathead minnow | >100 | >100 | >100 | 100 |
| 11–13–93 | Heavy industry | Flow weight | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 02–07–94 | Heavy industry | First flush | Fathead minnow | 45.2 | 26 | 50 | 25 |
| 02–07–94 | Heavy industry | First flush | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 02–07–94 | Heavy industry | Flow weight | Fathead minnow | 70.7 | 58 | 100 | 50 |
| 02–07–94 | Heavy industry | Flow weight | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 03–25–94 | Heavy industry | First flush | Fathead minnow | >100 | >100 | 6.25 | <6.25 |
| 03–25–94 | Heavy industry | First flush | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 03–25–94 | Heavy industry | Flow weight | Fathead minnow | 59 | 36 | 100 | 50 |
| 03–25–94 | Heavy industry | Flow weight | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| **Agua Fria River tributary at Youngtown, Arizona (09513700)** | | | | | | | |
| 03–26–93 | Residential | First flush | Fathead minnow | 61.6 | 55 | 25 | 12.5 |

**Table 9.** Results of acute toxicity analyses of urban stormwater and streamflow, Maricopa County, Arizona

| Date | Land use | Sample type | Species | LC50 | LC20 | LOEC | NOEC |
|---|---|---|---|---|---|---|---|
| **Agua Fria River tributary at Youngtown, Arizona (09513700)—Continued** | | | | | | | |
| 03–26–93 | Residential | First flush | *Ceriodaphnia dubia* | 17.7 | 14.7 | 25 | 12.5 |
| 03–26–93 | Residential | Flow weight | Fathead minnow | >100 | >100 | >100 | 100 |
| 03–26–93 | Residential | Flow weight | *Ceriodaphnia dubia* | 25.7 | 10 | 12.5 | 6.25 |
| 08–06–93 | Residential | First flush | Fathead minnow | 66 | 55 | 100 | 50 |
| 08–06–93 | Residential | First flush | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 08–06–93 | Residential | Flow weight | Fathead minnow | 66 | 55 | 100 | 50 |
| 08–06–93 | Residential | Flow weight | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 08–29–93 | Residential | First flush | Fathead minnow | 55.5 | 35 | 50 | 25 |
| 08–29–93 | Residential | First flush | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 08–29–93 | Residential | Flow weight | Fathead minnow | >100 | >100 | >100 | 100 |
| 08–29–93 | Residential | Flow weight | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 10–06–93 | Residential | First flush | Fathead minnow | 22.7 | 13.8 | 25 | 12.5 |
| 10–06–93 | Residential | First flush | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 10–06–93 | Residential | Flow weight | Fathead minnow | >100 | >100 | >100 | 100 |
| 10–06–93 | Residential | Flow weight | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| **43rd and Peoria (09513885)** | | | | | | | |
| 01–06–93 | Commercial | First flush | Fathead minnow | 70.7 | 58 | 100 | 50 |
| 01–06–93 | Commercial | First flush | *Ceriodaphnia dubia* | 70.7 | 58 | 100 | 50 |
| 01–06–93 | Commercial | Flow weight | Fathead minnow | >100 | 66 | 100 | 50 |
| 01–06–93 | Commercial | Flow weight | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 02–08–93 | Commercial | First flush | Fathead minnow | >100 | >100 | >100 | 100 |
| 02–08–93 | Commercial | First flush | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 02–08–93 | Commercial | Flow weight | Fathead minnow | >100 | >100 | >100 | 100 |
| 02–08–93 | Commercial | Flow weight | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 08–24–93 | Commercial | First flush | Fathead minnow | 8.8 | 7.5 | 6.25 | <6.25 |
| 08–24–93 | Commercial | First flush | *Ceriodaphnia dubia* | 8.8 | 7.5 | 6.25 | <6.25 |
| 08–24–93 | Commercial | Flow weight | Fathead minnow | >100 | >100 | >100 | 100 |
| 08–24–93 | Commercial | Flow weight | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 10–06–93 | Commercial | First flush | Fathead minnow | 26.6 | 18 | 25 | 12.5 |
| 10–06–93 | Commercial | First flush | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 10–06–93 | Commercial | Flow weight | Fathead minnow | 62.5 | 31.4 | 25 | 12.5 |
| 10–06–93 | Commercial | Flow weight | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| **Arizona Canal Diversion Channel (333543112090501)** | | | | | | | |
| 02–07–94 | Drainage channel | Streamflow | Fathead minnow | >100 | >100 | >100 | 100 |
| 02–07–94 | Drainage channel | Streamflow | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |
| 03–07–94 | Drainage channel | Streamflow | Fathead minnow | >100 | 85 | 100 | 50 |
| 03–07–94 | Drainage channel | Streamflow | *Ceriodaphnia dubia* | >100 | 73 | 25 | 12.5 |
| 05–25–94 | Drainage channel | Streamflow | Fathead minnow | >100 | >100 | >100 | 100 |
| 05–25–94 | Drainage channel | Streamflow | *Ceriodaphnia dubia* | >100 | >100 | >100 | 100 |

**Table 10.** Results of toxicity identification evaluations of urban stormwater and streamflow, Maricopa County, Arizona

[EDTA, ethylenediaminetetraacetic acid; mL, milliliter; Mx, mixed land use; LI, light industry; HI, heavy industry; R, residential; C, commercial; EWI, equal-width increment; FF, first flush; FW, flow weight; ----, dashes indicate no data]

| Dste | Land use | Sam-ple type | Species | Mortality of species, in percent | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Original | Base-line | Oil snd grease skim | Solids filtrs-tion | EDTA (0.0 mL) | EDTA (0.012 mL) | EDTA (0.025 mL) | EDTA (0.050 mL) | Anionic organics (pH 3) | Neutral orgsnics (initisl pH) | Cationic orgsnics (pH 9) |
| **Indian Bend Wash at Curry Road, at Tempe, Arizona (09512162)** | | | | | | | | | | | | | | |
| 02–08–94 | Mx | EWI | Fathead minnow | 100 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 |
| **Box culvert at 48th Street drain (09512184)** | | | | | | | | | | | | | | |
| 08–24–93 | LI | FF | Fathead minnow | 100 | 20 | 20 | 40 | 0 | 20 | 10 | 20 | 60 | 20 | 0 |
| **27th Avenue at Salt River (09512403)** | | | | | | | | | | | | | | |
| 11–13–93 | HI | FF | Fathead minnow | 100 | 20 | 10 | 20 | 20 | 20 | 0 | 0 | 0 | 0 | 0 |
| 02–07–94 | HI | FF | Fathead minnow | 100 | 30 | 0 | 0 | 0 | 20 | 20 | 0 | 60 | 10 | 0 |
| 02–07–94 | HI | FW | Fathead minnow | 100 | 0 | 30 | 10 | 0 | 0 | 0 | 0 | 80 | 20 | 0 |
| 03–25–94 | HI | FW | Fathead minnow | 90 | 50 | 60 | 40 | 0 | 0 | 0 | 60 | 100 | 20 | 20 |
| **Agua Fria River tributary at Youngtown, Arizona (09513700)** | | | | | | | | | | | | | | |
| 03–26–93 | R | FF | Fathead minnow | 100 | 40 | 30 | 30 | 60 | 20 | 80 | 100 | 0 | 0 | 0 |
| 03–26–93 | R | FF | *Ceriodaphnia dubia* | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 0 | 0 | 0 |
| 03–26–93 | R | FW | *Ceriodaphnia dubia* | 100 | 100 | 70 | 100 | 100 | 100 | 100 | 100 | 0 | 0 | 0 |
| 08–06–93 | R | FF | Fathead minnow | 100 | 90 | 30 | 40 | 100 | 100 | 60 | --- | 100 | 20 | 20 |
| 08–06–93 | R | FW | Fathead minnow | 100 | 50 | 40 | 10 | 20 | 40 | 60 | --- | 0 | 0 | 0 |
| 08–29–93 | R | FF | Fathead minnow | 100 | 60 | 30 | 10 | 80 | 60 | 80 | 40 | 20 | 20 | 0 |
| 10–06–93 | R | FF | Fathead minnow | 100 | 40 | 70 | 50 | 60 | 20 | 100 | 40 | 0 | 0 | 0 |
| **43rd and Peoria (09513885)** | | | | | | | | | | | | | | |
| 08–24–93 | C | FF | Fathead minnow | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 20 | 40 | 40 |
| 08–24–93 | C | FF | *Ceriodaphnia dubia* | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 20 | 100 | 40 |
| 10–06–93 | C | FF | Fathead minnow | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 40 | 60 |
| 10–06–93 | C | FW | Fathead minnow | 80 | 80 | 60 | 70 | 100 | 80 | 20 | 40 | 100 | 100 | 20 |
| **Arizona Canal Drainage Channel (333543112090501)** | | | | | | | | | | | | | | |
| 03–07–94 | Mx | EWI | Fathead minnow | 25 | 10 | 10 | 0 | 0 | 0 | 20 | 60 | 0 | 0 | 0 |
| 03–07–94 | Mx | EWI | *Ceriodaphnia dubia* | 75 | 90 | 100 | 100 | 100 | 40 | 0 | 40 | 0 | 0 | 0 |

**Table 11.** Results of acute toxicity analyses of sediment, Maricopa County, Arizona

[ACDC, Arizona Canal Diversion Channel]

| Station number | Site description | Date | Land use | Soil cover | Mortality rate of *Hyalella azteca*, in percent[1] |
|---|---|---|---|---|---|
| 332425112065501 | 27th Street, 1st catch basin | 09–08–92 | Heavy industry | Bare soil | 97 |
| 332425112065501 | 27th Street, 1st catch basin | 06–08–93 | Heavy industry | Bare soil | 5 |
| 332425112064001 | 27th Street, 2nd catch basin | 09–09–92 | Heavy industry | Bare soil | 57 |
| 332425112062401 | 27th Street, 5th catch basin | 09–09–92 | Heavy industry | Bare soil | 20 |
| 09513700 | Agua Fria River tributary at Youngtown, Arizona | 09–09–92 | Residential | Bare soil | 83 |
| 09513700 | Agua Fria River tributary at Youngtown, Arizona[2] | 09–09–92 | Residential | Bare soil | 71 |
| 09513700 | Agua Fria River tributary at Youngtown, Arizona | 06–03–93 | Residential | Bare soil | 61 |
| 332513111582601 | 48th Street, undeveloped lot | 06–02–93 | Light industry | Bare soil | 3 |
| 332509111584001 | 48th Street, near freeway | 06–02–93 | Light industry | Bare soil | 77 |
| 332414111583701 | 48th Street, near restaurant | 06–02–93 | Light industry | Bare soil | 79 |
| 332405111583801 | 48th Street, near gaging station | 06–14–93 | Light industry | Bare soil | 100 |
| 333459112090401 | Peoria, parking lot | 06–03–93 | Commercial | Bare soil | 56 |
| 333458112090401 | Peoria, dirt lot | 06–03–93 | Commercial | Bare soil | 28 |
| 09512162 | Indian Bend Wash at Curry Road, at Tempe, Arizona | 06–09–93 | Channel[3] | Grass | 0 |
| 09512090 | Indian Bend Wash at Shea | 06–09–93 | Channel | Grass | 5 |
| 333543112090501 | ACDC at 51st Avenue | 06–03–93 | Channel | Grass | 3 |
| 333627112110601 | ACDC at 59th Avenue | 06–03–93 | Channel | Grass | 7 |
| 333704112120501 | ACDC at 67th Avenue | 06–03–93 | Channel | Grass | 30 |
| 332007112054301 | South Mountain Park, Prospects | 09–04–92 | Undeveloped | Bare soil | 17 |
| 332025112050801 | South Mountain Park, above track | 09–04–92 | Undeveloped | Bare soil | 83 |
| 09512200 | Salt River tributary in South Mountain Park, at Phoenix, Arizona | 09–04–92 | Undeveloped | Bare soil | 98 |
| 332119112041001 | South Mountain Park, retention pond #1 | 09–08–92 | Undeveloped | Bare soil | 100 |
| 332116112040501 | South Mountain Park, retention pond #2 | 09–08–92 | Undeveloped | Bare soil | 79 |
| 332109112041401 | South Mountain Park, retention pond #3 | 09–08–92 | Undeveloped | Bare soil | 76 |
| 333439112181701 | Agua Fria above Youngtown | 09–25–92 | Channel | Bare soil | 26 |
| 333438112181401 | Agua Fria at Youngtown | 09–25–92 | Channel | Bare soil | 16 |
| 333435112181401 | Agua Fria below Youngtown | 09–25–92 | Channel | Bare soil | 29 |
| 09512165 | Salt River at Priest Drive, at Phoenix, Arizona | 06–14–93 | Channel | Bare soil | 95 |
| 09512190 | Salt River at 24th Street | 06–09–93 | Channel | Bare soil | 10 |
| 09512405 | Salt River at 35th Avenue | 06–09–93 | Channel | Bare soil | 86 |

[1]*Hyalella azteca* was exposed to 100 grams of bed material, sieved to less than 63 micron, and 400 milliliters of hard reconstituted water.
[2]Duplicate sample.
[3]Channel samples were taken from ephemeral channels.