U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Assessment of Selected Inorganic Constituents in Streams in the Central Arizona Basins Study Area, Arizona and Northern Mexico, through 1998

Water-Resources Investigations Report 03—4063

National Water-Quality Assessment Program

USGS
science for a changing world

Cover photograph courtesy of Arizona-Sonora Desert Museum, Tucson, Arizona

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Assessment of Selected Inorganic Constituents in Streams in the Central Arizona Basins Study Area, Arizona and Northern Mexico, through 1998

By David W. Anning

Water-Resources Investigations Report 03—4063

National Water-Quality Assessment Program

Tucson, Arizona
2003

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

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

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Box 25286
Federal Center
Denver, CO 80225–0046

Information about U.S. Geological Survey programs in Arizona is available online at http://az.water.usgs.gov.

FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. (http://www.usgs.gov/). Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity and quality, even more critical to the long-term sustainability of our communities and ecosystems.

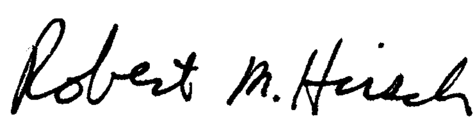
The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. (http://water.usgs.gov/nawqa/). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. (http://water.usgs.gov/nawqa/nawqamap.html). Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings. (http://water.usgs.gov/nawqa/natsyn.html).

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.



Robert M. Hirsch
Associate Director for Water

CONTENTS

FIGURES

TABLES

Page

CONVERSION FACTORS AND DATUMS

Multiply	By	To obtain
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile
liter (L)	1.057	quart
liter (L)	0.2642	gallon
cubic meter per second (m^3/s)	35.31	cubic foot per second
cubic meter per second (m^3/s)	70.07	acre-foot per day
cubic meter per second (m^3/s)	22.83	million gallons per day
kilogram (kg)	2.205	pound avoirdupois
kilograms per square kilometer per year (kg/km^2)/yr	0.008921	pounds per acre per year

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8°C)+32$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929; horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27). **Altitude**, as used in this report, refers to distance above or below NGVD 29.

ABBREVIATED WATER-QUALITY UNITS

Chemical concentration and water temperature 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 (milligrams) per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations lower than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

ABBREVIATIONS

NAWQA	National Water-Quality Assessment
NWIS	National Water Information System
SEP	Standard error of prediction, as a percentage
SMCL	Secondary Maximum Contaminant Level
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Assessment of Selected Inorganic Constituents in Streams in the Central Arizona Basins Study Area, Arizona and Northern Mexico, through 1998

By David W. Anning

Abstract

Stream properties and water-chemistry constituent concentrations from data collected by the National Water-Quality Assessment and other U.S. Geological Survey water-quality programs were analyzed to (1) assess water quality, (2) determine natural and human factors affecting water quality, and (3) compute stream loads for the surface-water resources in the Central Arizona Basins study area. Stream temperature, pH, dissolved-oxygen concentration and percent saturation, and dissolved-solids, suspended-sediment, and nutrient concentration data collected at 41 stream-water quality monitoring stations through water year 1998 were used in this assessment.

Water-quality standards applicable to the stream properties and water-chemistry constituent concentration data for the stations investigated in this study generally were met, although there were some exceedences. In a few samples from the White River, the Black River, and the Salt River below Stewart Mountain Dam, the pH in reaches designated as a domestic drinking water source was higher than the State of Arizona standard. More than half of the samples from the Salt River below Stewart Mountain Dam and almost all of the samples from the stations on the Central Arizona Project Canal—two of the three most important surface-water sources used for drinking water in the Central Arizona Basins study area—exceeded the U.S. Environmental Protection Agency drinking water Secondary Maximum Contaminant Level for dissolved solids. Two reach-specific standards for nutrients established by the State of Arizona were exceeded many times: (1) the annual mean concentration of total phosphorus was exceeded during several years at stations on the main stems of the Salt and Verde Rivers, and (2) the annual mean concentration of total nitrogen was exceeded during several years at the Salt River near Roosevelt and at the Salt River below Stewart Mountain Dam.

Stream properties and water-chemistry constituent concentrations were related to streamflow, season, water management, stream permanence, and land and water use. Dissolved-oxygen percent saturation, pH, and nutrient concentrations were dependent on stream regulation, stream permanence, and upstream disposal of wastewater. Seasonality and correlation with streamflow were dependant on stream regulation, stream permanence, and upstream disposal of wastewater.

Temporal trends in streamflow, stream properties, and water-chemistry constituent concentrations were common in streams in the Central Arizona Basins study area. Temporal trends in the streamflow of unregulated perennial reaches in the Central Highlands tended to be higher from 1900 through the 1930s, lower from the 1940s through the 1970s, and high again after the 1970s. This is similar to the pattern observed for the mean annual precipitation for the Southwestern United States and indicates long-term trends in flow of streams draining the Central Highlands were driven by long-term trends in climate.

Streamflow increased over the period of record at stations on effluent-dependent reaches as a result of the increase in the urban population and associated wastewater returns to the Salt and Gila Rivers in the Phoenix metropolitan area and the Santa Cruz River in the Tucson metropolitan area. Concentrations of dissolved solids decreased in the Salt River below Stewart Mountain Dam and in the Verde River below Bartlett Dam. This decrease represents an improvement in the water quality and resulted from a concurrent increase in the amount of runoff entering the reservoirs.

Stream loads of water-chemistry constituents were compared at different locations along the streams with one another, and stream loads were compared to upstream inputs of the constituent from natural and anthropogenic sources to determine the relative importance of different sources and to determine the fate of the water-chemistry constituent. Of the dissolved solids transported into the Basin and Range Lowlands each year from the Central Arizona Project Canal and from streams draining the Central Highlands, about 1.2 billion kilograms accumulated in the soil, unsaturated zone, and aquifers in agricultural and urban areas as a result of irrigating crops and urban vegetation. Stream loads of phosphorus decreased from the 91st Avenue Wastewater-Treatment Plant downstream to the Gila River at Gillespie Dam, probably as a result of adsorption of phosphorus to the streambed sediments. In this same reach, stream loads of nitrogen increased, most likely because of inputs from fertilizers.

The annual mass of nitrogen and phosphorus input to developed basins from quantifiable sources was much larger than the mass input to basins that had little or no municipal or agricultural development. These computed inputs exclude the mass of nitrogen and phosphorus from sources such as geologic formations and soils that could not be quantified. The quantifiable annual inputs of nitrogen and phosphorus for the upper Salt River Basin and the upper Verde River Basin were similar to those for the West Clear Creek Basin. This similarity suggests that the small amount of municipal and agricultural development in the upper Salt River and the upper Verde River Basins did not greatly change the basin input flux. For basins with minimal urban and agricultural development, the largest quantifiable source of nitrogen was precipitation, and the largest source of phosphorus was human bodily waste treated by sewer and septic systems. This was in contrast to developed basins, for which fertilizer was the largest quantifiable source of both nutrients. For most basins examined, quantifiable inputs of nitrogen and phosphorus from nonpoint sources were greater than inputs from point sources. This relation emphasizes the importance of land- and water-management policies that protect surface-water resources from nonpoint sources of nutrients as well as from point sources. The amount of nitrogen and phosphorus transported out of basins was a small fraction of the total for the quantifiable inputs. This result indicated that most of the nutrients input to basins were not transported out of the basins in surface water, but rather were transported to the subsurface (the soil, unsaturated zone, or aquifer), released to the atmosphere (such as volatilized ammonia), or incorporated into the biomass.

INTRODUCTION

The objective of the National Water-Quality Assessment (NAWQA) program is to describe the status and trends in the quality of a large, representative part of the Nation’s surface-water and ground-water resources and to provide a sound, scientific understanding of the primary natural and human factors affecting the quality of these resources (Gilliom and others, 1995). As part of the NAWQA program design, 59 study areas were selected to represent most of the major river basins and aquifer systems in the United States. The Central Arizona Basins study area includes most of central and southern Arizona and a small area in northern Mexico. The study area is one of the most arid study areas of the NAWQA program and differs from most others because the demand for water exceeds the available renewable water supply. This imbalance has resulted in a managed hydrologic system and also places a high value on the quality of water. The primary natural and human factors that affect the quality of surface-water and ground-water resources in this arid region will be described and evaluated as part of the Central Arizona Basins NAWQA program.

As part of the NAWQA design, each study area conducts surface-water quality, ground-water quality, and aquatic-ecology investigations on a multiyear cycle beginning with 2 years of planning and evaluation of existing information, 3 years of intensive data collection and analysis, and 5 years of low-intensity data collection. In the Central Arizona Basins study area, the intensive data collection and analysis were conducted from 1996 to 1998 and included monthly sampling at nine surface-water quality stations and twice-per-month sampling at two surface-water quality stations. Field measurements were made for stream temperature, pH, dissolved oxygen, specific conductance, and alkalinity, and samples were analyzed for concentrations of major ions, dissolved solids, suspended sediment, nutrients, pesticides, and volatile organic compounds. Results from these measurements and analyses are used by the local NAWQA program to determine natural and human factors that affect the water quality in the study area. Data from these 11 stations, as well as data from stations in the other 58 study areas, are synthesized by the NAWQA program at the national level to determine the spatial and temporal trends in water quality and the natural and human factors that affect water quality across the country.

Purpose and Scope

This report presents results from an analysis of streamflow and water-quality conditions for surface-water resources in the Central Arizona Basins study area collected by the NAWQA and other USGS water-quality monitoring programs. This report contains the results of three interpretive analyses of surface-water quality: (1) an assessment of the quality of surface-water resources by a comparison of data to regulatory standards, (2) an exploration of the relation of selected stream properties and water-chemistry constituent concentrations to natural and human factors, and (3) an investigation of the relation between stream loads of nutrients and dissolved solids and upstream conditions. The information provided in this report will provide a general understanding of the effect of natural and human factors on the water quality of the surface-water resources of central Arizona.

Description of the Central Arizona Basins Study Area

The study area covers 90,000 km^2 within Arizona and northern Mexico and includes six major river systems tributary to the Gila River: the San Pedro, Santa Cruz, Salt, Verde, Agua Fria, and Hassayampa Rivers (fig. 1). A brief description of the study area is given here; a more detailed discussion is provided by Cordy and others (1998).

Physiography

The study area is within the Basin and Range Physiographic Province (Fenneman, 1931) and includes three hydrologic provinces: the Plateau Uplands, the Central Highlands, and the Basin and Range Lowlands (fig. 1; Arizona State Land Department, 1969). For simplicity, the small areas of the Plateau Uplands in the study area are considered in this report to be part of the Central Highlands Province.

Basins of the Basin and Range Lowlands and the Central Highlands differ physiographically and hydrogeologically. In the Basin and Range Lowlands, the basins are greater in areal extent than the mountains and typically contain thick sequences of basin-fill deposits (fig. 2; Cordy and others, 1998, fig. 4; Robertson, 1991). In contrast, basins in the Central Highlands have a smaller areal extent than the mountains and contain shallow alluvial deposits. The Central Highlands is generally higher in altitude than the Basin and Range Lowlands, and streams that drain the Central Highlands flow into the Basin and Range Lowlands.

Climate

The climate of the study area ranges from arid to semiarid and is characterized by its spatial and annual variability (Cordy and others, 1998, figs. 6 and 7). Altitude is one of the most important factors controlling climate in the study area. Precipitation increases and temperature decreases with increasing altitude during all seasons of the year. The large topographic relief within the study area contributes to the spatial variability of precipitation and temperature.

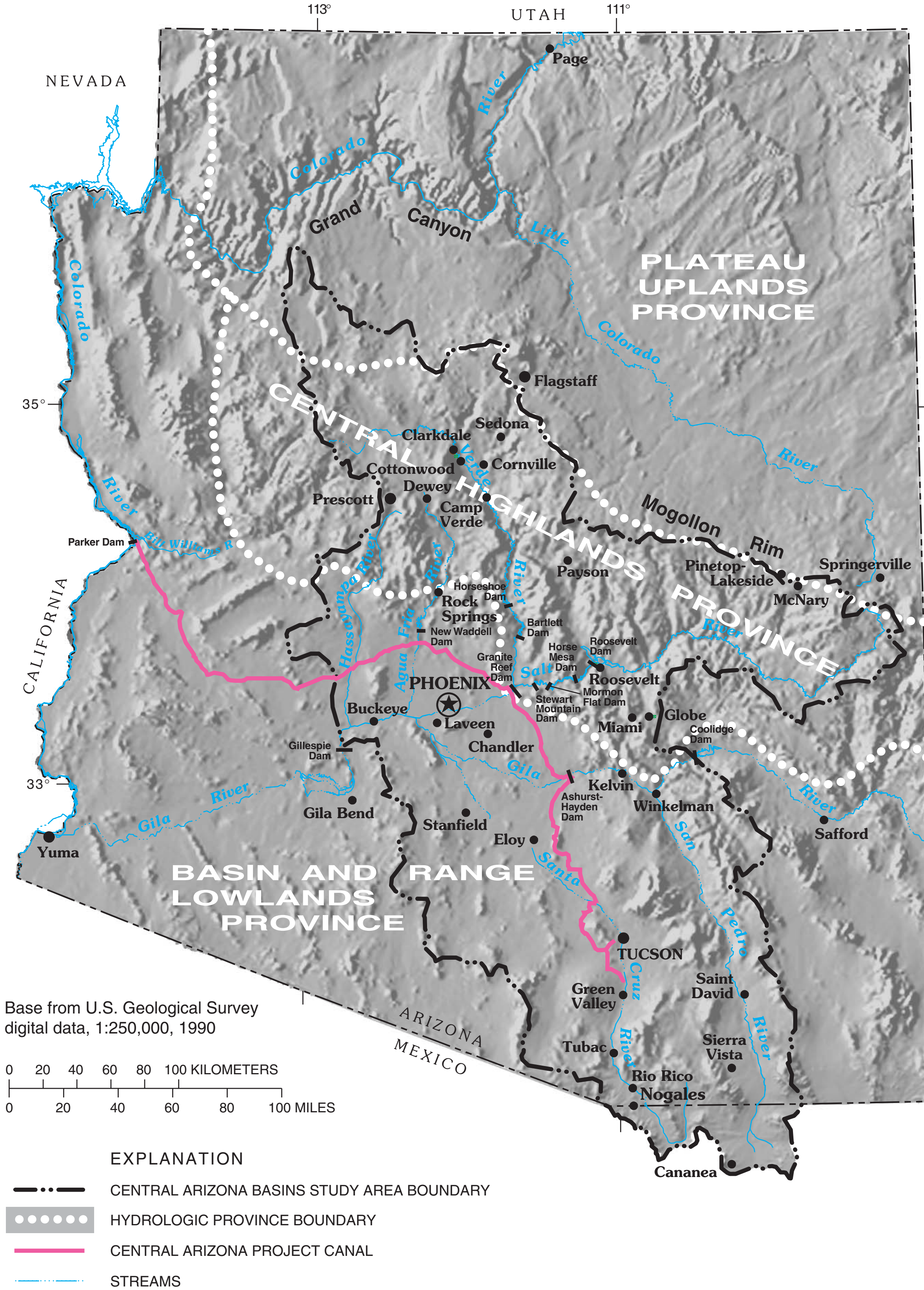


Figure 1. Physiography, hydrologic provinces, and physical features of the Central Arizona Basins study area.

Figure 2. Principal streams by type of streamflow and generalized geology of the Central Arizona Basins study area (geologic information modified from Reynolds, 1988; and Coordinacion General de Los Servicios Nationales de Estadistica, Geografia E Informatica, 1981, 1983a, 1983b; type of streamflow information modified from Brown and others, 1981; and State of Arizona, 1996).

Temperatures range from more than 46°C on summer afternoons in the lowest valleys to less than -18°C on winter nights in the higher mountains (Sellers and Hill, 1974). Mean annual precipitation ranges from less than 25 cm on the lowest valley floors to more than 64 cm at some places in the mountains of the Central Highlands (Sellers and Hill, 1974). Annual precipitation increases from northwest to southeast in the Basin and Range Lowlands and from southwest to northeast in the Central Highlands. Winter precipitation constitutes about 60 percent of annual precipitation throughout the Central Highlands (Arizona State Climatologist, 1975). In the Basin and Range Lowlands, winter precipitation constitutes about 35 percent of annual precipitation in the southeastern part, and about 60 percent in the northwestern part. Throughout the study area, the variability of annual precipitation is high; annual precipitation in wet years can be three times greater than in dry years.

Surface-Water Hydrology

The study area contains six major rivers tributary to the middle Gila River: the San Pedro River, the Santa Cruz River, the Salt River, the Verde River (tributary to the Salt River), the Agua Fria River, and the Hassayampa River (fig. 1). The upper reaches of the Salt, Verde, Agua Fria, and Hassayampa Rivers drain the Central Highlands, and the lower reaches of these rivers, as well as the San Pedro and the Santa Cruz Rivers, drain the Basin and Range Lowlands. The Gila River upstream from the study area boundary at Coolidge Dam drains areas in the eastern Central Highlands that extend into New Mexico.

Mean annual streamflow in this arid to semiarid study area is low and parallels the spatial patterns of mean annual precipitation (Cordy and others, 1998, figs. 6 and 8). Mean annual streamflow for drainage basins in the Central Highlands is greater than that of drainage basins in the Basin and Range Lowlands. For 1951–80, mean annual streamflow[1] ranged from less than 0.3 cm in some areas of the Basin and Range Lowlands to more than 25 cm in higher altitudes of the Central Highlands (Gebert and others, 1987).

[1]This annual streamflow, which is calculated as the runoff volume divided by the drainage area, is reported as an average depth over the entire basin.

The upper Agua Fria, Gila, Salt, and Verde Rivers have the greatest mean annual streamflow (Cordy and others, 1998, fig. 18) and provide the largest supplies of nonimported surface water in the study area. These streams and their tributaries drain the Central Highlands and flow into large reservoirs near the boundary with the Basin and Range Lowlands. The reservoirs on the Agua Fria, Gila, Salt, and Verde Rivers capture about 85 percent of the flow in these streams (Cordy and others, 1998) and maximize use of the water supply by allowing the surface water to be used throughout the year. Diversions from the reservoirs are delivered to a large area in the Basin and Range Lowlands through a large network of canals (Cordy and others, 1998, fig. 12). Where surface water is unavailable, ground water is used. Throughout much of the Basin and Range Lowlands in the study area, ground-water withdrawals have exceeded ground-water recharge, and as a result, ground-water levels have declined more than 20 m in many areas (Anderson and others, 1992, pl. 2). The Central Arizona Project was built to reduce ground-water overdraft by importing water from the Colorado River to central Arizona. The Central Arizona Project began providing water to users in 1985, and is the single largest source of surface water in the study area. In 1997, the annual flow in the Central Arizona Project Canal[2] where it enters the study area was about 80 percent of the combined average annual outflows (for the period of record) from reservoirs on the Agua Fria, Gila, Salt, and Verde Rivers.

As a result of water-management practices, some aspects of the hydrologic system have been significantly altered. More than 400 km of stream reaches in the study area that were once perennial are now ephemeral because of stream diversions or lowered ground-water levels (Brown and others, 1981). In contrast, more than 80 km of perennial reaches have been established or re-established by the discharge of treated municipal or irrigation wastewater back to

[2]The Central Arizona Project consists of a series of aqueducts and pumping plants that transport water from the Colorado River to central Arizona, including the Phoenix and Tucson metropolitan areas. Although the Bureau of Reclamation has established individual names for each aqueduct, the aqueducts will be referred to as the "Central Arizona Project Canal" in this report for simplicity and to be consistent with terminology used to name USGS water-quality monitoring stations on the aqueducts.

streams (Brown and others, 1981). These streams are termed "effluent dependent" in this report because their flow consists mostly of effluent, except during runoff events. Effluent-dependent streams are an important source of ground-water recharge and surface-water supply. In the study area, effluent is used for industrial cooling and for irrigation of turf and certain crops, such as cotton, that are not consumed by humans.

The seasonal and spatial variability of streamflow in regulated and effluent-dependent reaches is controlled by water managers. Water typically is delivered from April through October for crop irrigation, and year-round for municipal use. Wastewater is discharged downstream from the users and follows the same seasonal patterns as the deliveries.

In contrast to streamflow in regulated and effluent-dependent reaches, the seasonal and spatial variability of streamflow in unregulated reaches is determined by natural factors. Streamflow increases in response to runoff from frontal storms or snowmelt during the winter and spring, and from thunderstorms during the summer (Cordy and others, 1998, sites 1, 9, and 12, fig. 18). As a result, streamflow is seasonally bimodal in the study area. For streams in the Central Highlands, mean monthly streamflow typically is greater for winter months than for summer months; whereas, for streams in the Basin and Range Lowlands, mean monthly streamflow is equal to or greater for summer months than for winter months. During the spring and fall, streamflow is maintained by springs in the case of perennial streams, or may cease in the case of intermittent or ephemeral streams.

The spatial distribution of perennial, intermittent, and ephemeral stream reaches is controlled by hydro-geologic factors. Stream reaches in areas with shallow bedrock and small and thin deposits of basin fill tend to be perennial, whereas stream reaches in areas with extensive and deep basin-fill deposits tend to be intermittent or ephemeral (fig. 2). As a result of this hydrogeologic control and the different typical basin structures for the two hydrologic provinces, most perennial streams in the study area occur in either the Central Highlands or in the higher altitude mountain ranges in the Basin and Range Lowlands, and most streams in the Basin and Range Lowlands are intermittent or ephemeral.

STREAM-PROPERTY AND WATER-CHEMISTRY DATA

Streamflow, stream-property, and water-chemistry data for surface-water stations in the study area that were collected as part of the NAWQA and other USGS surface-water quality monitoring programs were extracted from the National Water Information System (NWIS) database of the USGS and stored in a local database for analyses used in this study. These and other data in the NWIS database are available online (http://az.waterdata.usgs.gov/nwis) and from the Arizona District. Most of the data used in this report have been published in the annual series of reports, Water Resources Data, Arizona" (for example, Tadayon and others, 1999).

Sample results in the local database were evaluated to ensure that they were appropriate for at least one of the three interpretive analyses discussed in this report: (1) an assessment of water quality and comparison to regulatory standards, (2) an exploration of the relation of water quality to natural and human factors, and (3) an investigation of the relation between stream loads of dissolved solids and nutrients and upstream conditions. In addition to the water-quality data, daily mean values of streamflow measured by the USGS were used in the analyses. These data represent the continuous streamflow record and were used in several sections of the report to characterize the streamflow at the water-quality monitoring stations.

Data Selection and Station Categorization

Water-quality data for monitoring stations on streams, canals, and stormwater drainages were retrieved from the NWIS database for the local database. Only stations with 10 or more samples collected during a period greater than 12 months were included in the local database so that water-quality conditions would be adequately characterized at a given location. This eliminated several stations that were sampled only a few times. For cases in which replicate samples were collected, only the results from one sample were included in the local database. Time-composited samples also were excluded so that the data set consisted only of results from instantaneous water-quality samples. The data retrieved from the NWIS database include stream properties (instantaneous discharge, stream temperature, pH, dissolved-oxygen concentration, dissolved-oxygen percent saturation) and concentrations of water-chemistry constituents (dissolved solids, suspended sediment, dissolved orthophosphate, total phosphorus, ammonia, nitrate, total ammonia plus organic nitrogen, and total nitrogen). Sample results were excluded from the local database if there were not data for at least one of the stream properties besides instantaneous streamflow or one of the water-chemistry constituents.

The data in the local database were collected as a part of many different USGS water-quality programs with different objectives, and as a result, nitrogen-concentration data were recorded as several different species. Nitrogen-concentration data were aggregated into the following categories for this study so that comparisons between different stations and (or) time periods could be made:

- **Ammonia as N**; includes ammonium ions and un-ionized ammonia.
- **Nitrate as N**; includes nitrate in every sample, and includes nitrite in many samples.
- **Total ammonia plus organic nitrogen as N**; includes ammonium ions, un-ionized ammonia, and nitrogen chemically bound in organic molecules such as proteins, amines, and amino acids.
- **Total nitrogen as N**; includes nitrate and total ammonia plus organic nitrogen (as described above).

Data for samples analyzed for nitrate plus nitrite were considered nitrate data because in surface-water samples the nitrite concentration usually is insignificant compared to the nitrate concentration. For nitrate and ammonia, laboratory analyses of filtered and unfiltered samples typically yield the same concentrations because these species occur predominantly in the dissolved phase. For this reason, concentration data presented in this report for ammonia and for nitrate include data from both filtered and unfiltered samples. This resulted in a more complete data set because there was a lack of consistency of filtered and unfiltered analyses between stations and over time at individual stations.

A classification system for the stream reaches in the study area was devised to help determine some of the natural and human factors that affect surface-water quality. The system differentiates monitoring stations on the basis of stream regulation, streamflow permanence, streamflow seasonality, upstream disposal of municipal or agricultural wastewater, and land use. For the first level of the classification, water-quality monitoring stations are classified as being on predominantly unregulated, regulated, or effluent-dependent stream reaches so that the effects of water storage, withdrawal and use of surface water, and return of wastewater to streams could be determined.

Stations on unregulated reaches are further classified on the basis of stream permanence as either perennial, intermittent, or ephemeral, which contrasts the effects of climate and hydrogeology (Meinzer, 1923, p. 57 and 58). Perennial streams have flow at all times that is sustained by surface flow from springs and (or) by ground water in reaches where the streambed is lower than the water table and is supplemented by rainfall or snowmelt runoff. Intermittent streams flow only during certain times of the year when continuous flow is sustained by surface flow from springs, ground water in reaches where the streambed is lower than the water table, or in some cases, by prolonged snowmelt. Ephemeral streams only flow in direct response to precipitation and do not receive water from springs, ground water, or prolonged snowmelt.

Stations on unregulated reaches also were classified on the basis of the major land use in the respective basin. Land use of the basin upstream from the monitoring station was classified as minimally developed, urban, or agricultural on the basis of land uses identified in Cordy and others (1998, fig. 10).

Stations on effluent-dependent reaches were further classified as receiving effluent from municipal wastewater-treatment plants, irrigation runoff, or both. Note that water-quality data for stations on effluent-dependent reaches reflects the effects of water manage-ment and also of the land and water use associated with the two types of effluent. For example, effluent from a municipal wastewater-treatment plant represents municipal land and water uses, and effluent from irrigated fields represents agricultural land and water uses.

For many streams, physical properties and water-chemistry constituent concentrations are correlated with streamflow. For this reason, the seasonality of streamflow was classified to help define possible seasonal patterns in the stream properties and water-chemistry constituent concentrations. The seasonality of streamflow at stations was classified as uniform, unimodal, or bimodal on the basis of a 3-month running sum of the mean monthly streamflow volume.

Streams with at least one 3-month running sum greater than 30 percent of the mean annual streamflow volume were considered seasonal; otherwise they were considered uniform. Streams with seasonal streamflow were further classified as unimodal or bimodal. Seasonally unimodal streams have one 3-month running sum of the mean monthly streamflow that contains more than 30 percent of the annual streamflow volume. Seasonally bimodal streams have two 3-month running sums that contain more than 30 percent of the annual streamflow volume and also are at least 3 months apart.

Distribution of Stream-Property and Water-Chemistry Data

The local database contained results from 5,980 samples collected at 41 water-quality monitoring stations (fig. 3, table 1) through water year 1998 that included results from more than 300 samples that were collected as part of the Central Arizona Basins NAWQA program during water years 1996–98. Not all samples were analyzed for every stream property and water-chemistry constituent. The percentage of samples for which data for a given property or constituent existed ranged from 32 percent for ammonia to 87 percent for pH (table 2). Samples were not analyzed routinely for dissolved oxygen or nutrients until about 1970; therefore, typically only streamflow, temperature, pH, dissolved-solids, and (or) suspended-sediment data are available for samples collected prior to about 1970.

Spatial distribution of stations

Data from 41 surface-water quality monitoring stations were included in the database—21 of these stations were within the Central Highlands, and 20 were within the Basin and Range Lowlands (table 1). Twenty-seven stations were on unregulated stream reaches, 7 were on regulated reaches, and 7 were on effluent-dependent reaches (table 1).

Of the 27 stations on unregulated reaches, 17 were on perennial stream reaches, 5 were on intermittent reaches, and 5 were on ephemeral reaches. Most of the stations on unregulated perennial reaches were in the Central Highlands, and the stations on ephemeral reaches were in the Basin and Range Lowlands. Although streamflow at two stations on the main stem of the upper Verde River and at three stations on Oak Creek was affected partly by diversions for agriculture during the summer, these stations were considered unregulated because streamflow was not impounded in a reservoir. The five stations on ephemeral reaches were on urban stormwater drainages rather than on natural streams. Because land use in these basins was mostly urban (Lopes and Fossum, 1995), the water quality at these stations could have been affected more by land use than by the ephemeral nature of the streamflow. These stations were termed “unregulated urban ephemeral” reaches to recognize this strong bias in land use and were included to provide information on the urban stormwater, which is an important source of aquifer recharge in urban areas of the Basin and Range Lowlands. There were no routinely sampled stations in the NWIS database that were on ephemeral reaches of minimally developed basins that could serve as a reference site for ambient water-quality conditions in ephemeral streams.

Stations on regulated reaches tended to be near the boundary between the Basin and Range Lowlands and the Central Highlands (fig. 3). An exception is the Central Arizona Project Canal near Parker, Arizona, which is outside of the study area near the Arizona-California border. Lake Pleasant has been used to store water from the upper Agua Fria River since 1927, and water from the Central Arizona Project Canal since 1992. Inflow from the Central Arizona Project Canal typically has been much larger than inflow from the Agua Fria River. This difference is important to consider when interpreting the water-quality data for releases from the lake.[3]

All the stations on effluent-dependent reaches are in the Basin and Range Lowlands. On the upper Santa Cruz River, the stations at Rio Rico and Tubac are downstream from the Nogales International Wastewater-Treatment Plant, and the station at Cortaro is downstream from two wastewater-treatment plants that serve the Tucson metropolitan area. Wastewater from much of metropolitan Phoenix is returned to the lower Salt River and is sampled at the 91st Avenue Wastewater-Treatment Plant outfall (site 38, fig. 3).

---

[3]Water-quality downstream from Lake Pleasant is monitored at the Agua Fria River below Waddell Dam and at the Central Arizona Project Canal near Phoenix. The New Waddell Dam, shown in fig.1, replaced Waddell Dam as part of the Central Arizona Project; however, for simplicity, the name of the water-quality monitoring station was not changed from “Agua Fria River below Waddell Dam.

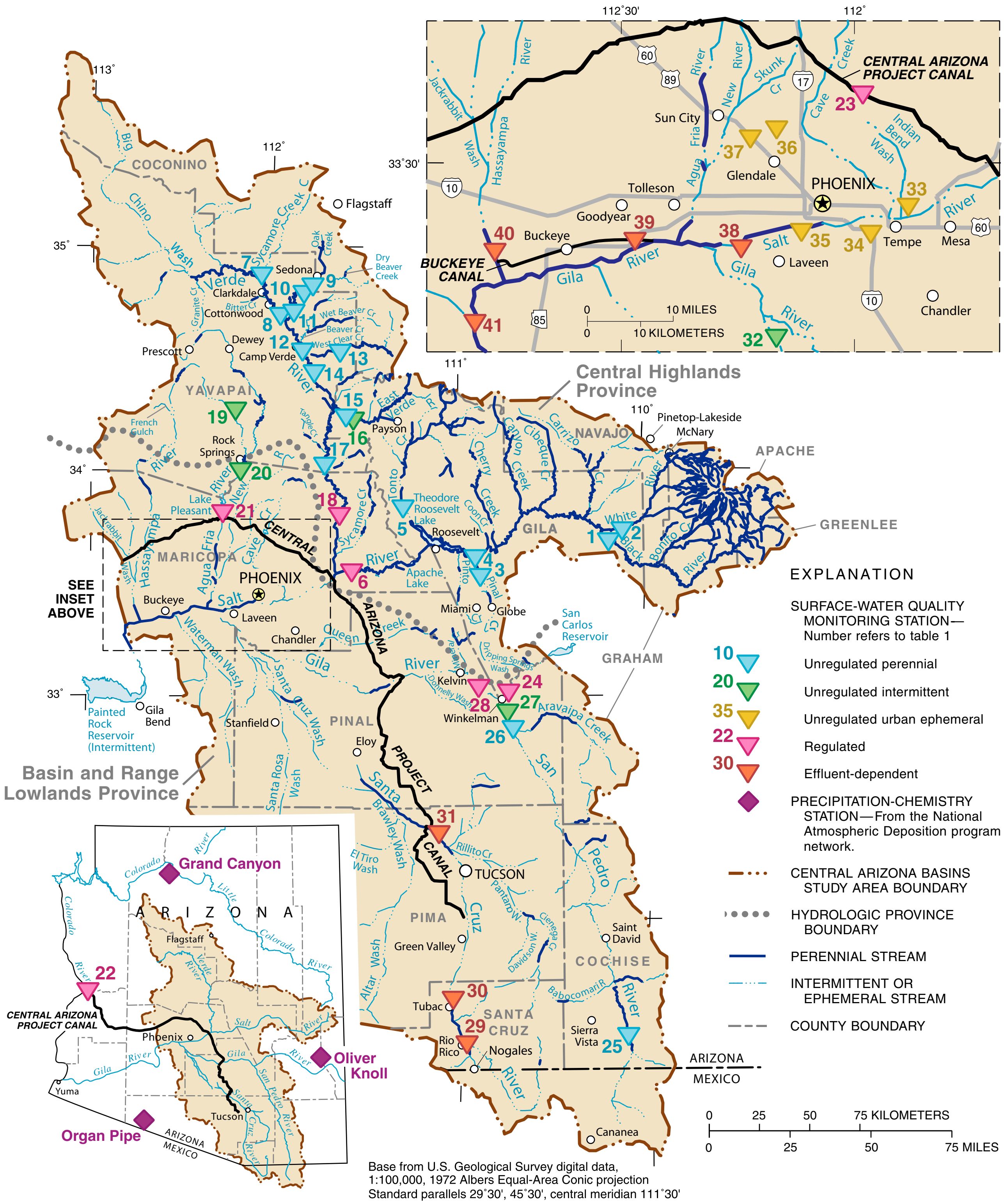


Figure 3. U.S. Geological Survey surface-water quality monitoring stations in the Central Arizona Basins study area and National Atmospheric Deposition Program precipitation-chemistry stations in Arizona.

Table 1. Selected basin and streamflow characteristics for surface-water quality and streamflow monitoring stations in the Central Arizona Basins study area, through 1998

[Streamflow data are from the National Water Information System, except for streamflow at the 91st Avenue Wastewater Treatment Plant outfall, which is from the City of Phoenix. ---, not available or not applicable; n/c, not classified; land use is the predominant land use that affects the water quality at the station and may areally represent a small portion of the basin; seasonality is the type of seasonal distribution of streamflow and, if unimodal or bimodal, the month(s) in the middle of the mode; streamflow duration percentiles indicate the percentage of time that the tabulated discharge was equaled or exceeded]

			Basin Characteristics				Streamflow characteristics						
									Mean daily discharge, in cubic meters per second				
							Seasonality			Duration percentile			Period, in water years
Site number	Station name (abbreviated)	U.S. Geological Survey station identification number	Altitude, in meters	Drainage area, in square kilometers	Land use	Streamflow type	Type	Peak month	Mean	10	50	90	
						Central Highlands							
1	Black River	09490500	1,324	3,190	Minimally developed	Unregulated perennial	Unimodal	March	11.7	32.3	2.94	1.10	1957–98
2	White River	09494000	1,331	1,640	Minimally developed	Unregulated perennial	Unimodal	April	13.8	15.6	2.49	.99	1957–98
3	Pinal Creek	09498400	853	505	n/c	Unregulated perennial	Unimodal	February	.40	.34	.22	.14	1980–98
4	Salt River near Roosevelt[1]	09498500	664	11,200	Minimally developed	Unregulated perennial	Unimodal	March	26.0	59.2	9.60	4.59	1914–98
5	Tonto Creek	09499000	769	1,750	Minimally developed	Unregulated perennial	Unimodal	February	4.56	7.79	.65	.14	1941–98
6	Salt River below Stewart Mountain Dam	09502000	418	16,100	n/c	Regulated	Unimodal	July	29.8	53.8	22.8	.08	1934–98
7	Verde River near Clarkdale	09504000	1,067	9,070	Minimally developed	Unregulated perennial	Unimodal	February	5.18	5.47	2.35	2.07	1965–98
8	Verde River near Cornville	09504200	---	---	Agricultural	Unregulated[2] perennial	Unimodal	February	---	---	---	---	---
9	Oak Creek near Sedona	09504420	1,271	603	Minimally developed	Unregulated perennial	Unimodal	March[3]	2.60	4.47	.91	.76	1982–98
10	Oak Creek at Red Rock Crossing	09504440	---	653	Minimally developed	Unregulated perennial	Unimodal	March[3]	---	---	---	---	---
11	Oak Creek near Cornville	09504500	1,058	919	Minimally developed	Unregulated perennial	Unimodal	March	2.55	4.02	.91	.51	1940–45, 1948–98
12	Verde River above West Clear Creek[1]	09505570	914	12,200	Agricultural	Unregulated[2] perennial	Unimodal	February[3]	---	---	---	---	---
13	West Clear Creek[1]	09505800	1,106	624	Minimally developed	Unregulated perennial	Unimodal	March	1.91	3.17	.51	.42	1965–98
14	Verde River near Camp Verde	09506000	876	13,000	Agricultural	Unregulated[2] perennial	Unimodal	February	12.9	22.8	5.32	2.27	1935–45, 1988–98
15	East Verde River	09507980	762	857	Minimally developed	Unregulated perennial	Unimodal	February	1.98	3.11	.68	.07	1962–64, 1968–98
16	Wet Bottom Creek	09508300	707	94	Minimally developed	Unregulated intermittent	Unimodal	February	.44	.65	.01	0	1967–98
17	Verde River below Tangle Creek[1]	09508500	618	15,200	Minimally developed	Unregulated perennial	Unimodal	February	16.7	26.6	6.74	3.45	1946–98

See footnotes at end of table.

Table 1. Selected basin and streamflow characteristics for surface-water quality and streamflow monitoring stations in the Central Arizona Basins study area, through 1998—Continued

Site number	Station name (abbreviated)	U.S. Geological Survey station identification number	Basin Characteristics			Streamflow characteristics							
			Altitude, in meters	Drainage area, in square kilometers	Land use	Streamflow type	Seasonality		Mean daily discharge, in cubic meters per second				
							Type	Peak month	Mean	Duration percentile			Period, in water years
										10	50	90	
Central Highlands, continued													
18	Verde River below Bartlett Dam[4]	09510000	479	16,000	n/c	Regulated	Unimodal	February	16.8	33.7	8.49	1.22	1939–98
						Unregulated perennial		March	24.4	44.2	8.07	3.79	1904–38[5]
19	Turkey Creek	09512600	957	232	Minimally developed	Unregulated intermittent	Unimodal	March	.31	.57	0	0	1980–92
20	Agua Fria River near Rock Springs	09512800	549	2,880	Minimally developed	Unregulated intermittent	Unimodal	February	2.66	3.34	.09	.01	1970–98
21	Agua Fria River below Waddell Dam	09513600	439	3,780	n/c	Regulated	Unimodal	May[3]	---	---	---	---	---
Basin and Range Lowlands													
22	Central Arizona Project Canal near Parker	09426700	366	--	n/c	Regulated	Unimodal	April	27.0	73.4	15.5	0	1985–98
23	Central Arizona Project Canal at Phoenix	09427100	351	--	n/c	Regulated	Unimodal	July[3]	---	---	---	---	---
24	Gila River at Winkelman	09470000	586	34,400	n/c	Regulated	Unimodal	July	11.4	26.0	6.12	.27	1941–80, 1984–94
25	San Pedro River at Charleston[1]	09471000	1,205	3,200	Agricultural	Unregulated perennial	Unimodal	August	1.33	1.64	.37	.10	1935–98
26	San Pedro River below Aravaipa Creek	09473100	648	11,200	Agricultural	Unregulated perennial	Unimodal	August	1.36	1.39	.34	.15	1980–83
27	San Pedro River at Winkelman	09473500	587	11,500	Agricultural	Unregulated intermittent	Unimodal	August	1.25	1.50	.10	0	1966–78
28	Gila River at Kelvin[1,4]	09474000	532	46,600	n/c	Regulated	Bimodal	January, August	13.5	28.2	8.04	.85	1928–98
						Unregulated perennial	Unimodal	July	22.4	48.1	5.83	.34	1911–27
29	Santa Cruz River at Rio Rico	09481710	0	2,600	n/c	Effluent-dependent	Bimodal	January, August[3]	---	---	---	---	---
30	Santa Cruz River at Tubac[1]	09481740	969	3,130	n/c	Effluent-dependent	Bimodal	January, August	.63	1.05	.45	.10	1996–98

See footnotes at end of table.

Table 1. Selected basin and streamflow characteristics for surface-water quality and streamflow monitoring stations in the Central Arizona Basins study area, through 1998—Continued

Site number	Station name (abbreviated)	U.S. Geological Survey station identification number	Basin Characteristics: Altitude, in meters	Drainage area, in square kilometers	Land use	Streamflow type	Streamflow characteristics: Seasonality: Type	Seasonality: Peak month	Mean daily discharge, in cubic meters per second: Mean	Duration percentile: 10	50	90	Period, in water years
Basin and Range Lowlands, continued													
31	Santa Cruz River at Cortaro[1]	09486500	650	9,070	n/c	Effluent-dependent	Bimodal	August, January	1.53	1.87	.06	0	1940–47, 1950–84, 1990–98
32	Santa Cruz River near Laveen	09489000	311	22,200	n/c	Unregulated intermittent	Unimodal	January	.58	.24	0	0	1940–98
33	Indian Bend Wash at Curry Road	09512162	351	212	Urban	Unregulated urban ephemeral	Bimodal	January, September	.19	0	0	0	1993–98
34	Box Culvert at 48th Street Drain[6]	09512184	344	0.16	Urban	Unregulated urban ephemeral	Bimodal	January, September[3]	---	---	---	---	---
35	27th Avenue at Salt River[6]	09512403	317	0.18	Urban	Unregulated urban ephemeral	Bimodal	January, September[3]	---	---	---	---	---
36	43rd Avenue and Peoria Avenue[6]	09513885	373	0.01	Urban	Unregulated urban ephemeral	Bimodal	January, September[3]	---	---	---	---	---
37	Olive Avenue and 67th Avenue[6]	09513925	352	0.07	Urban	Unregulated urban ephemeral	Bimodal	January, September[3]	---	---	---	---	---
38	91st Avenue Wastewater-Treatment Plant outfall[1]	09512407	293	---	n/c	Effluent-dependent	Uniform	---	4.04	5.27	3.91	3.17	1996–98
39	Gila River at Buckeye Canal[1,7]	09514000	278	---	n/c	Effluent-dependent	Uniform	---	5.52	6.60	5.35	4.36	1997–98
40	Hassayampa River[1]	09517000	254	3,810	n/c	Effluent-dependent	Unimodal	January	1.80	3.11	1.44	.42	1990–98
41	Gila River at Gillespie Dam	09518000	230	128,000	n/c	Effluent-dependent	Unimodal	February	15.4	9.68	2.10	.34	1940–71, 1974–98

[1]Station is part of the National Water-Quality Assessment program surface-water-quality network.
[2]Low flow is regulated partly by diversions.
[3]Seasonality estimated on the basis of data from nearby upstream or downstream stations, or on the basis of monthly streamflow data.
[4]Streamflow type and characteristics are given for period before and after streamflow was regulated by an upstream dam.
[5]Record is fragmented into several periods.
[6]Storm runoff in an unnatural channel is monitored at this station.
[7]Includes samples from U.S. Geological Survey station 09513990, Gila River above diversions at the head of Buckeye Canal.

Table 2. Number of surface-water quality samples for which data are stored in the local database, by stream property and water-chemistry constituent, through 1998

[Note: There is a total of 5,980 samples collected from 41 water-quality monitoring stations in the local database]

Stream property or water-chemistry constituent	Number of samples for which data are stored	
	Number	As a percentage of all samples
Instantaneous discharge	3,523	59
Stream temperature	3,791	63
pH	5,302	87
Dissolved oxygen:		
Concentration	2,802	47
Percent saturation	1,974	33
Suspended sediment	2,900	48
Dissolved solids	3,951	66
Phosphorus:		
Total	3,086	52
Dissolved, ortho	2,029	34
Nitrogen:		
Total	2,996	50
Nitrate	3,270	55
Ammonia	1,931	32
Total ammonia plus organic	3,008	50

This effluent flows into the Gila River and is diverted almost entirely into the Buckeye Canal downstream from the mouth of the Agua Fria River. Water quality of the Gila River at Buckeye Canal was characterized by samples collected from two stations: USGS station 09513990, which is at the canal intake, and USGS station 09514000, which was on the canal about a half a kilometer downstream from the intake. The initial samples collected for the Central Arizona Basins NAWQA program were collected at 09513990; however, after 6 months, samples were collected downstream at 09514000 because sampling conditions were better. In this report, data for these stations were combined under the station name "Gila River at Buckeye Canal" (site 39, fig. 3) to simplify data analysis and reporting. Water in the Buckeye Canal is used for irrigation and is supplemented with pumped ground water and irrigation return flows along the length of the canal. At the terminus, the Buckeye Canal empties into the otherwise ephemeral Hassayampa River. The Hassayampa River (site 40, fig. 3) is sampled downstream from the Buckeye Canal outfall and flows into the Gila River, which is sampled at Gillespie Dam (site 41, fig. 3) near the downstream end of the study area. Except during periods of runoff, flow in the Buckeye Canal, the Hassayampa River, and the Gila River at Gillespie Dam consists of a mix of municipal and irrigation wastewater.

Temporal Distribution of Water-Quality Samples

Natural and human factors that affect water quality change seasonally and annually, and consequently, water quality also changes seasonally and annually. Therefore, samples from each season are needed to characterize the seasonal factors affecting water quality. Water-quality data from stations at which samples are collected only during certain seasons are biased by the predominant factors that affect water quality during those seasons. The temporal distribution of samples must be considered when comparing water-quality data from different stations to ensure that differences in the data are the result of differences in the natural and human factors affecting the water quality at the stations rather than the result of differences in sample collection dates.

The temporal distribution of sample collection dates varies greatly among stations (fig. 4). From the early 1950s to the mid-1970s, most samples were collected downstream from the major surface-water reservoirs at a high frequency and typically were analyzed for stream temperature, pH, suspended sediment, dissolved solids, and specific conductance. Beginning in the 1970s, samples were collected from a larger number of stations and typically included the same stream properties and water-chemistry constituent concentrations previously listed, as well as nutrients; however, the frequency was typically much lower. Only a few stations have similar periods of record and sampling frequencies. Stations typically were sampled using one of five different sampling frequencies: quarterly (such as the Central Arizona Project Canal near Parker), every other month (such as the East Verde River), monthly (such as the Agua Fria River near Rock Springs), or twice per month (such as the Hassayampa River during 1997). Sampling was storm based for stations on unregulated urban ephemeral reaches, such as Indian Bend Wash at Curry Road. At many stations, the sampling frequency changed during the period of record.

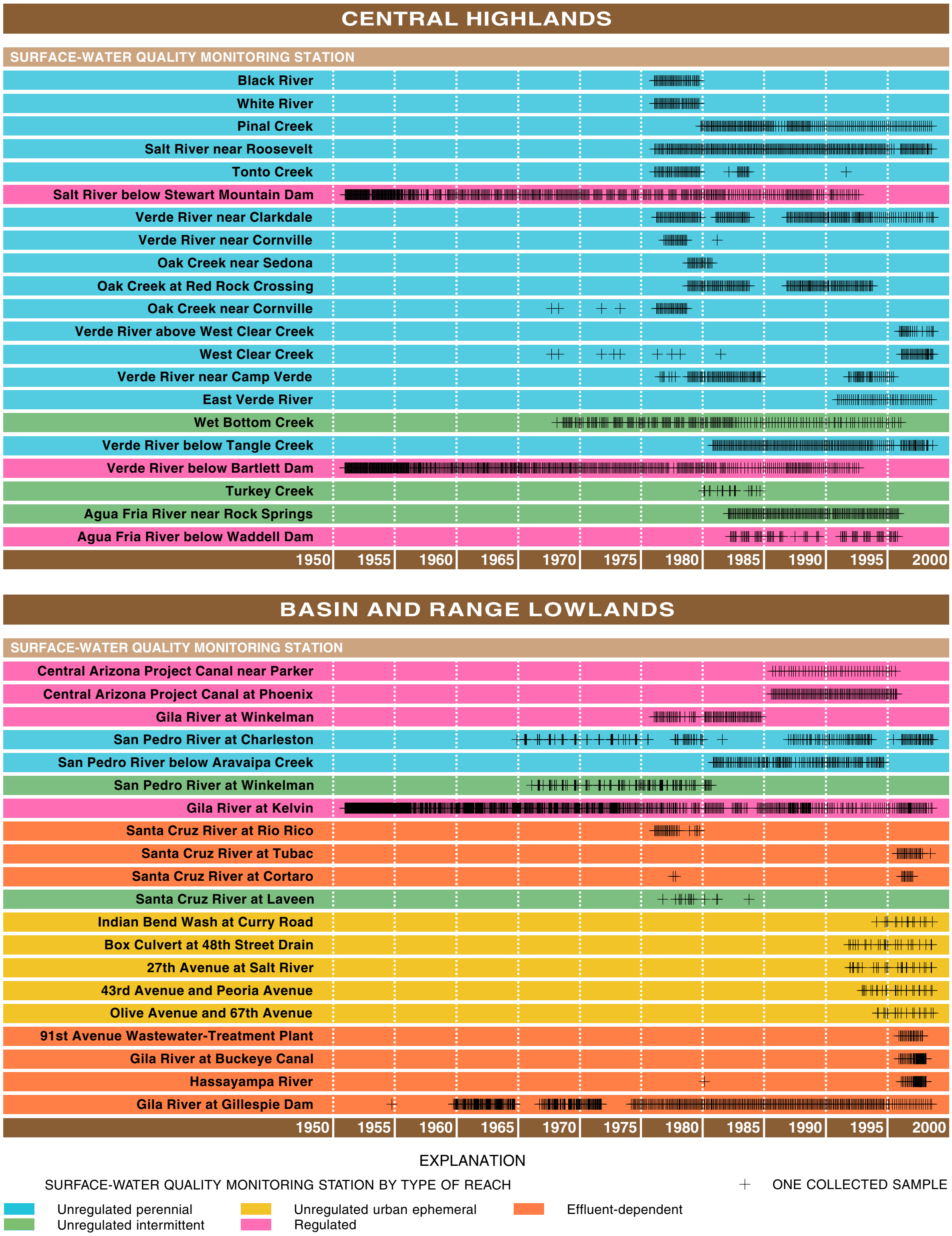


Figure 4. Temporal distribution of samples from surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998.

Generally, samples were distributed uniformly throughout the seasons (table 3). A perfectly uniform seasonal distribution has 17 percent of the samples collected in each 2-month period, as tabulated in table 3. The standard deviation of the percent of samples for the 2-month periods provides a measure of the uniformity of the seasonal sample distribution; a low standard deviation indicates a fairly uniform seasonal distribution. Samples from stations on unregulated perennial reaches tend to be distributed uniformly throughout the seasons, whereas samples from stations on unregulated urban ephemeral reaches tend to have bimodal distributions as a result of having no streamflow during some times of the year. Samples from the Agua Fria River below Waddell Dam are biased toward summer months because reservoir releases are greatest during this period owing to irrigation needs.

Streamflow at the Time of Sampling

Stream properties and water-chemistry constituent concentrations can vary with streamflow because the relative contribution of constituents from different sources varies with streamflow, and because the activity of physical or biological processes that affect stream properties or water-chemistry constituent concentrations varies with streamflow. The distribution of samples with respect to streamflow is, therefore, important to consider when interpreting stream water-quality data. A bias in the values of stream properties and water-chemistry constituent concentrations may result from a bias in the distribution of samples with respect to streamflow at the time of sampling. Stations with a uniform distribution of samples with respect to streamflow at the time of sampling better represent water-quality conditions for the range of streamflow at that station.

Graphs of streamflow duration (fig. 5) were constructed for all stations with continuous streamflow data by using daily values from the periods of record that are listed in table 3. The streamflow-duration curve shows the percentage of time during the period of streamflow record (table 1) that streamflow was equal to or less than a particular discharge. The percentage of total samples collected between two consecutive deciles[4] of streamflow was superimposed on the streamflow-duration graphs. A station with a perfectly uniform distribution of samples with respect to streamflow has 10 percent of its samples between each decile of streamflow.

The shape of the streamflow-duration curve provides information on the variability and sources of streamflow at each station. For stations on unregulated reaches, such as the Verde River near Clarkdale, the left side of the streamflow-duration curve with relatively mild slopes represents the percentage of time that base flow is maintained by steady ground-water inflow from springs or through the channel bottom. The right side of the streamflow-duration curve with relatively steep slopes represents the percentage of time that storm runoff and snowmelt are the main sources of streamflow. Stations on reaches with intermittent or ephemeral streamflow, such as the San Pedro River at Winkelman and Indian Bend Wash, respectively, have zero discharge for one or more percentiles of streamflow. For effluent-dependent reaches, the right side of the streamflow-duration curve with a steep slope represents the percentage of time that flow is primarily from storm runoff. This pattern is similar to that for stations on unregulated reaches. The middle and left side of the streamflow-duration curves, however, represent periods that streamflow is maintained mostly by municipal or agricultural wastewater rather than by spring flow.

In general, the distribution of samples with respect to discharge was least biased for stations on unregulated perennial reaches. The samples from the San Pedro River at Charleston, the Black River, and the Verde River near Clarkdale were biased toward small discharges. The distribution of samples from West Clear Creek was bimodal with many samples that were collected at small or large discharges but few samples collected at medium discharges. The distribution of samples from stations on unregulated intermittent reaches and unregulated urban ephemeral reaches generally was biased with samples collected at larger discharges. In some cases this was simply because there is zero discharge for the lower streamflow percentiles (the stream is dry), such as at Wet Bottom Creek. For other cases, such as Turkey Creek, however, the percentage of total samples increased with increasing streamflow deciles. The distribution of samples from Indian Bend Wash (fig. 5) is representative of stations on unregulated urban ephemeral reaches that could be sampled only during periods of runoff.

---

[4]A percentile is any one of the numbers or values in a series dividing the distribution of individuals in the series into 100 groups of equal frequency. Similarly, a decile is any one of the numbers or values in a series dividing the distribution of individuals in the series into 10 groups of equal frequency.

Table 3. Number of samples and percentage of total samples by months at water-quality monitoring stations in the Central Arizona Basins study area, through 1998

Station	Total Samples	Percentage of total samples						
		Jan–Feb	Mar–Apr	May–June	July–Aug	Sept–Oct	Nov–Dec	Standard deviation
Central Highlands								
Black River	44	16	18	18	18	16	14	1.9
White River	45	18	16	20	18	16	13	2.3
Pinal Creek	161	16	17	17	17	16	17	.9
Salt River near Roosevelt	267	17	19	17	17	16	15	1.1
Tonto Creek	56	16	18	18	20	16	13	2.5
Salt River below Stewart Mountain Dam	509	14	18	19	20	18	11	3.3
Verde River near Clarkdale	192	15	18	18	18	18	14	1.9
Verde River near Cornville	24	21	17	17	17	13	17	2.6
Oak Creek near Sedona	23	17	13	17	17	17	17	1.8
Oak Creek at Red Rock Crossing	147	17	16	16	18	16	17	.7
Oak Creek near Cornville	35	11	26	17	14	20	12	5.5
Verde River above West Clear Creek	21	14	19	19	19	19	10	3.9
West Clear Creek	47	13	32	17	13	17	9	8.1
Verde River near Camp Verde	112	16	15	17	17	20	15	1.7
East Verde River	47	17	17	19	19	13	15	2.5
Wet Bottom Creek	182	21	18	14	12	13	23	4.4
Verde River below Tangle Creek	199	16	20	16	16	17	17	1.5
Verde River below Bartlett Dam	638	17	17	15	18	16	16	1.0
Turkey Creek	72	15	11	1	63	1	8	23.1
Agua Fria River near Rock Springs	168	16	16	17	18	17	15	1.1
Agua Fria River below Waddell Dam	75	7	32	28	27	7	0	13.7
Total	**3,064**							
Basin and Range Lowlands								
Central Arizona Project near Parker	41	17	20	12	27	7	17	6.6
Central Arizona Project at Phoenix	123	15	18	15	18	17	17	1.3
Gila River at Winkelman	86	17	20	17	17	13	15	2.4
San Pedro River at Charleston	177	10	9	12	40	18	11	11.6
San Pedro River below Aravaipa Creek	134	16	17	17	17	16	17	.8
San Pedro River at Winkelman	120	13	9	6	46	16	10	14.7
Gila River at Kelvin	1,268	19	12	10	24	19	17	5.1
Santa Cruz River at Rio Rico	29	17	14	21	17	14	17	2.6
Santa Cruz River at Tubac	28	14	14	18	22	14	18	3.0
Santa Cruz River at Cortaro	15	13	13	13	20	27	13	5.6
Santa Cruz River at Laveen	16	31	25	0	6	31	6	14.1
Indian Bend Wash at Curry Road	19	37	5	0	26	16	16	13.5
Box Culvert at 48th Street Drain	26	15	15	8	31	12	19	8.0
27th Avenue at Salt River	28	25	18	0	29	4	25	12.1
43rd Avenue and Peoria Avenue	25	28	8	0	36	8	20	13.7
Olive Avenue and 67th Avenue	19	26	11	0	32	16	16	11.3
91st Avenue Wastewater-Treatment Plant outfall	24	17	17	17	17	13	21	2.7
Gila River at Buckeye Canal	40	23	15	15	15	13	20	3.8
Hassayampa River	50	20	14	12	24	18	12	4.8
Gila River at Gillespie Dam	648	14	12	15	25	19	14	4.6
Total	**2,916**							

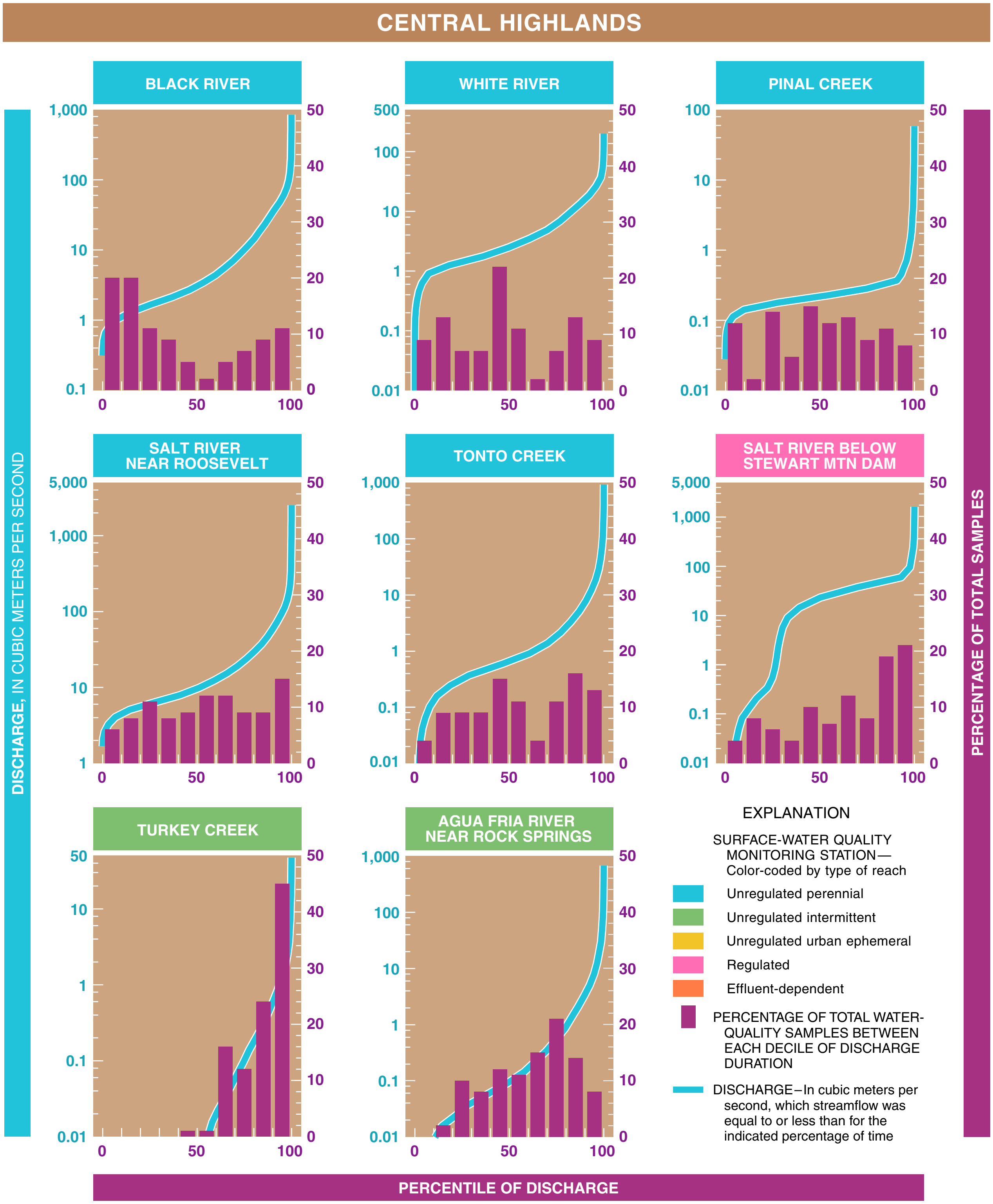


Figure 5. Discharge-duration curve and percentage of total samples collected by deciles of discharge at selected surfacewater quality monitoring stations in the Central Arizona Basins study area, through 1998. Discharge percentiles are for the period of record listed in table 1.

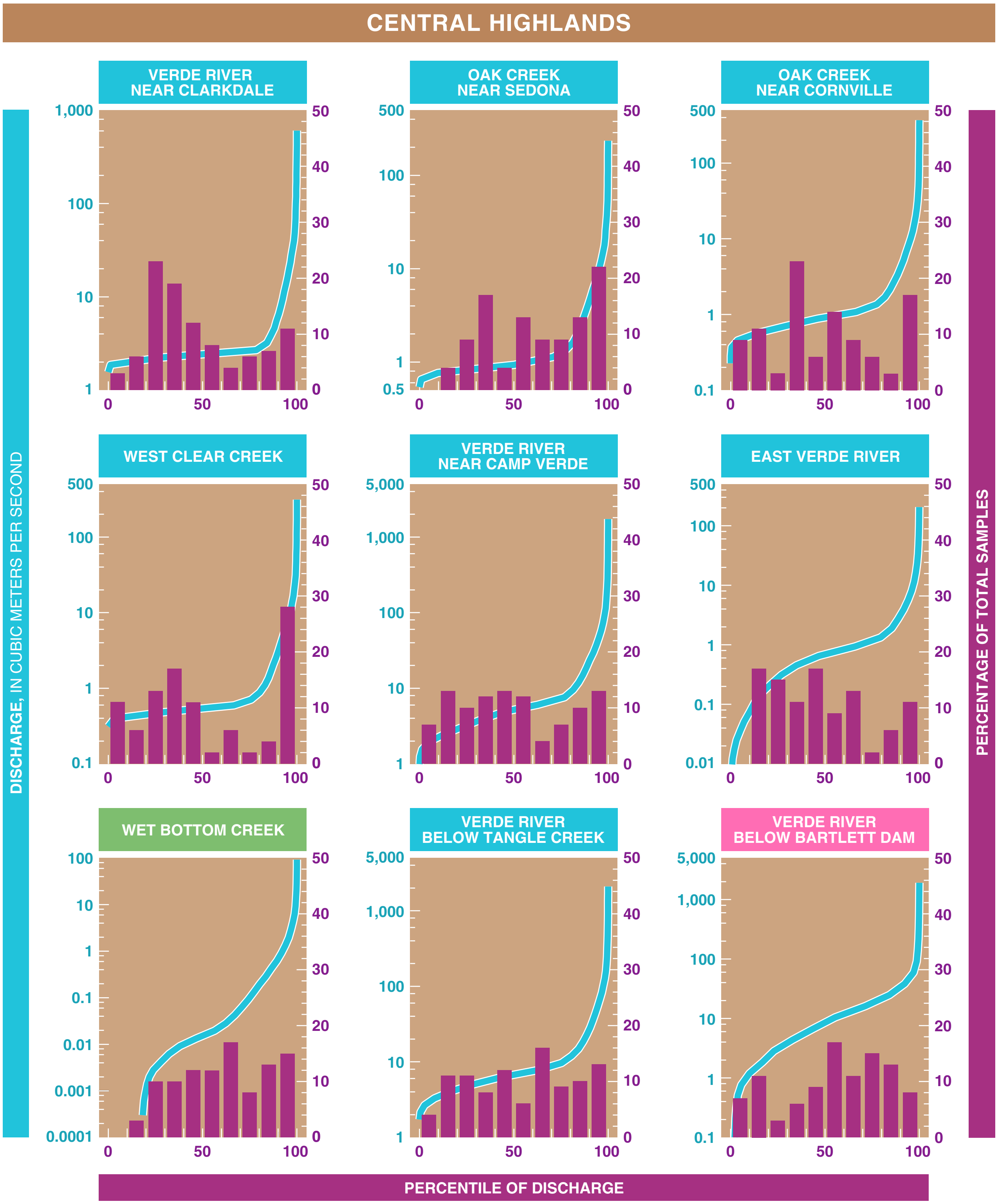


Figure 5. Continued.

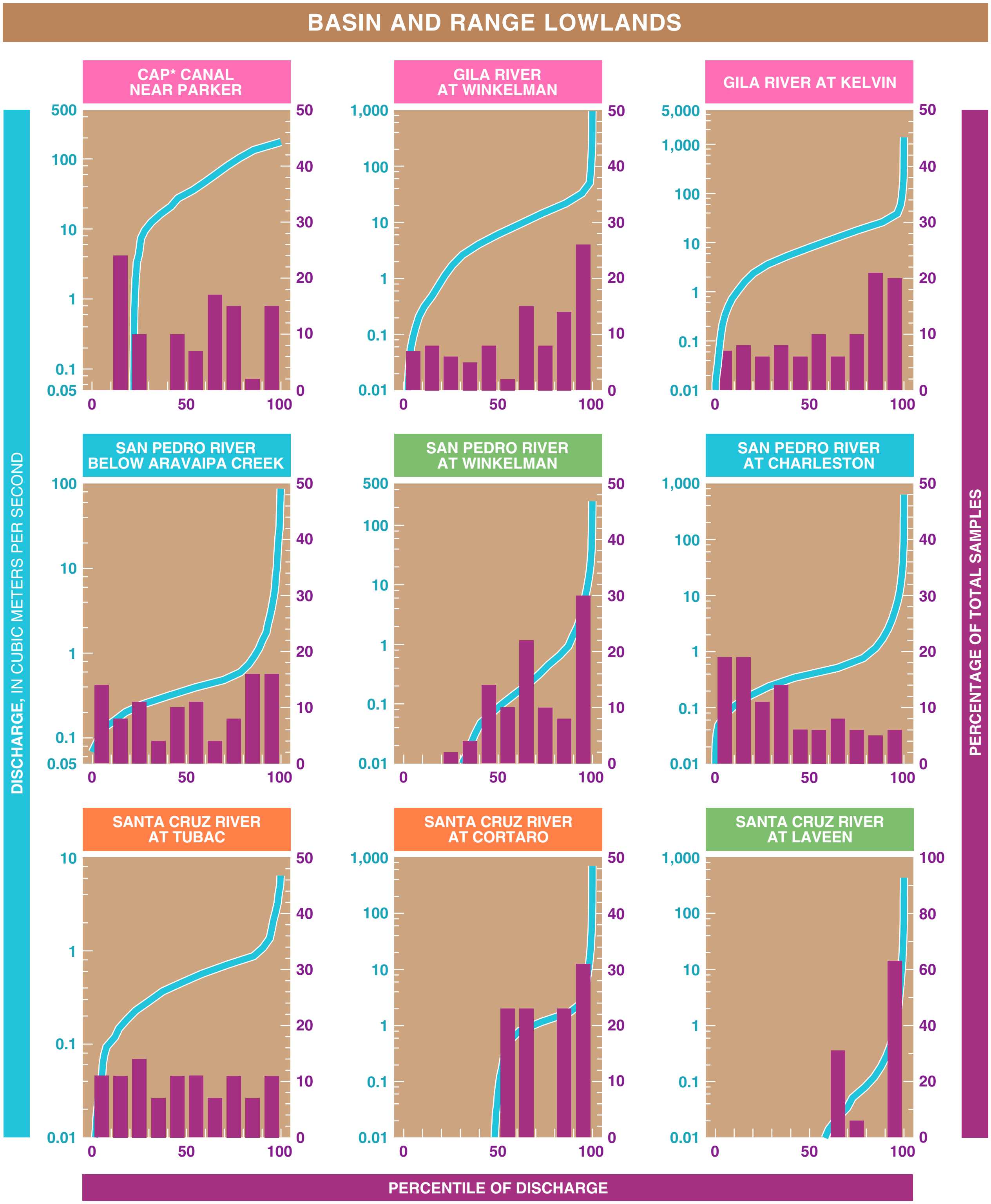


Figure 5. Continued. *Central Arizona Project.

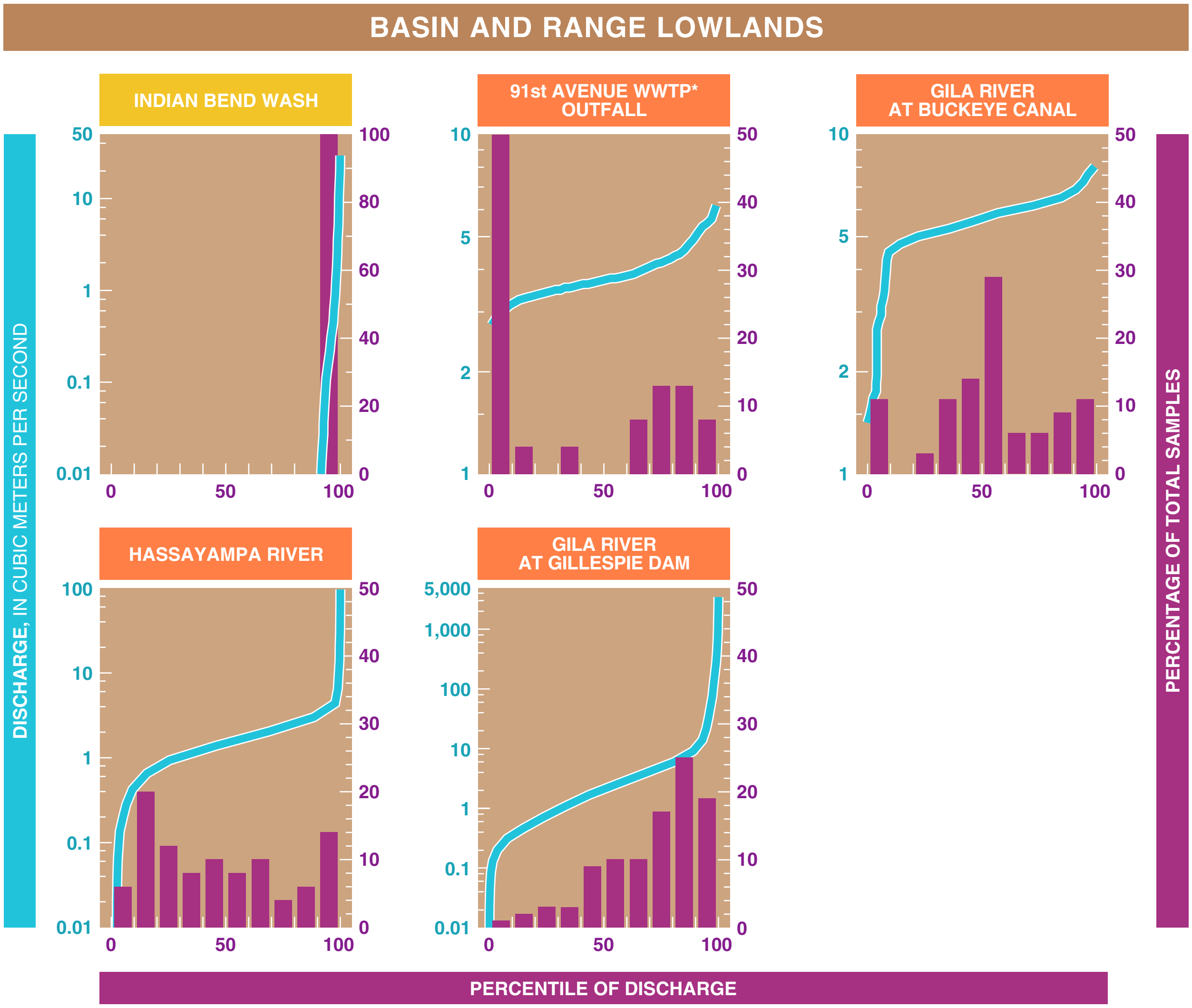


Figure 5. Continued. *Wastewater-Treatment Plant

The distributions of samples from stations on regulated reaches were slightly biased with more samples that were collected at larger discharges; the Central Arizona Project Canal near Parker is an exception. Several samples were collected from this station shortly after the pumping plant was shut off, resulting in little or no flow at the time of sampling (represented by the bar to the left of the streamflow duration curve in figure 5).

Of the stations on effluent-dependent reaches, the distributions of samples from the Santa Cruz River at Tubac and the Hassayampa River were unbiased with respect to discharge. The distributions of samples from the Santa Cruz River at Cortaro and the Gila River at Gillespie Dam were biased toward samples collected at larger discharges. The distribution for the 91st Avenue Wastewater-Treatment Plant outfall was biased toward samples collected at small discharges, in part because most samples were collected in the midmorning. At this station, discharge typically is small during the morning, increases during the day, and decreases during the night. This large diel variation in discharge does not occur at the stations on unregulated and regulated reaches; and therefore, biases in sampling time do not result in biases related to discharge at the time of sampling at stations on these reaches.

ASSESSMENT OF WATER QUALITY BY COMPARISONS TO REGULATORY STANDARDS

Distributions of stream property and water-chemistry data at surface-water quality monitoring stations were examined and compared to regulatory standards to assess the suitability of surface water in the study area for specific uses. As part of the water-quality regulations (State of Arizona, 1996), specific designated uses have been assigned to the reaches of major streams in Arizona. The designated uses are: domestic water source; full and partial body contact; fish consumption; aquatic and wildlife, which is subset into cold water fishery, warm water fishery, ephemeral stream, and effluent-dependent water; agricultural irrigation; and agricultural livestock watering. Water-quality standards for each stream property and water-chemistry constituent vary by designated use. In addition to the standards for designated uses, some stream reaches have specific water-quality standards for concentrations of total nitrogen and total phosphorous (State of Arizona, 1996). Stream-property and water-chemistry data also were compared to U.S. Environmental Protection Agency (USEPA) Primary and Secondary Drinking-Water Regulations. These regulations apply to water supplied to the public; therefore, comparison of data to these standards indicates only the potential for actual exceedences of these regulations. Results from this assessment are limited in scope to only those stream properties and water-chemistry constituents examined; the suitability of the water for various uses may be limited by other concentrations of water-chemistry constituents not examined in this report.

The assessment of the general water quality of streams in the study area was made by comparing data from the local database to the water-quality standards for designated uses and specific stream reaches at 36 of the 41 stations. Data from the five stations on unregulated urban ephemeral reaches were excluded because there are no applicable standards for ephemeral streams. Results of the comparison are presented for each station as the relative frequency of samples that exceeded designated-use water-quality standards for pH, dissolved oxygen, dissolved solids, ammonia, and nitrate (table 4), and stream-reach specific water-quality standards for total nitrogen and total phosphorus (table 5). This assessment is meant to reflect general conditions over several years and may not represent recent conditions; in fact, many of the samples used in this assessment were collected before the standards were established. Complementing the comparison to water-quality standards is a graphical summary of the statistical distributions of stream temperature, pH, dissolved oxygen, dissolved solids, suspended sediment, and nutrients for each of the 41 stations (fig. 6). Stations were grouped by hydrologic province and presented in downstream order, with the exception of stations on unregulated urban ephemeral reaches in the Basin and Range Lowlands. Plots for these stations were placed next to each other to facilitate visual comparison of the data. In addition, the statistical summaries of the stream properties and water-chemistry constituents in figure 6 are tabulated in appendix 1.

Stream temperature, pH, and dissolved oxygen

Water temperature influences many physical, chemical, and biological characteristics of aquatic systems. Most chemical equilibria are dependent on physical properties of the water, such as temperature. Aquatic species have certain tolerances of exposure to high and low stream temperatures. Stream temperatures within the study area ranged from just above 0°C at several stations in the Central Highlands to 39°C at the San Pedro River at Winkelman, and are variable at any given station (fig. 6 and appendix 1). There are water-quality standards for temperature for surface-water resources in the study area; however, they are generally specific to individual point sources. For example, in streams designated for cold water fishery uses, the water temperature should not increase more than 1°C because of inflows from point sources. Locations of surface-water quality monitoring stations included in this study were not appropriate for evaluating conformity to these types of standards.

Like water temperature, pH also influences many physical, chemical, and biological characteristics of aquatic systems. Most chemical equilibria are dependent on pH as well as temperature. Aquatic species have certain tolerances of compounds, such as un-ionized ammonia, that are pH and temperature dependent. Most of the samples from stations in the study area were alkaline (pH > 7 standard units), with the exception of some samples from three stations on unregulated urban ephemeral reaches—Box Culvert at 48th Street drain, 43rd Avenue and Peoria Avenue, and Olive Street and 67th Avenue—that had values of pH as low as 6 standard units (fig. 6 and appendix 1).

Table 4. Number of samples that exceeded designated-use water-quality standards at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998

[Designated uses and the numeric water-quality standards are from State of Arizona (1996), except for the domestic water source Secondary Maximum Contaminant Level for dissolved solids, which is from the U.S. Environmental Protection Agency (1996). Stations were evaluated on the basis of samples collected over the period of record, and in some cases exceedences occur for samples collected before the standards were established. Exceedences are expressed as a fraction of the total number of samples analyzed for that constituent. SMCL, Secondary Maximum Contaminant Level; mg/L, milligrams per liter; >, greater than; <, less than; ---, the stream reach for the station is not designated for this use, or data are not available for evaluation]

	pH				Dissolved oxygen			Dissolved solids	Ammonia		Nitrate
			Agricultural		Aquatic and wildlife				Aquatic and wildlife		
Designated use for water body:	Aquatic and wildlife, full and partial body contact	Domestic water source	Irrigation	Livestock watering	Warm-water fishery	Cold-water fishery	Effluent dependent	Domestic water source SMCL	Warm-water fishery	Cold-water fishery	Domestic water source
Range of values in compliance with standard:	>6.5 and <9.0 standard pH units	>5.0 and <9.0 standard pH units	>4.5 and <9.0 standard pH units	>6.5 and <9.0 standard pH units	>6.0 mg/L	>7.0 mg/L	>1.0 mg/L[1] >3.0 mg/L[2]	<500 mg/L	Varies by stream temperature and pH		<10 mg/L
Central Highlands											
Black River	2/41	2/41	2/41	2/41	---	2/35	---	0/44	---	---	0/44
White River [3,4]	4/44	3/44	3/44	4/44	---	2/37	---	0/44	---	---	0/44
Pinal Creek	3/158	---	---	3/158	3/154	---	---	---	0/91	---	---
Salt River near Roosevelt	1/264	---	1/264	1/264	2/240	---	---	---	0/156	---	---
Tonto Creek	0/55	---	0/55	0/55	---	4/40	---	---	---	---	---
Salt River below Stewart Mountain Dam	3/496	2/496	2/496	3/496	---	27/119	---	249/389	---	0/117	0/163
Verde River near Clarkdale	0/188	---	0/188	0/188	1/176	---	---	---	0/105	---	---
Verde River near Cornville	0/24	---	0/24	0/24	0/20	---	---	---	---	---	---
Oak Creek near Sedona	0/20	0/20	0/20	0/20	---	0/19	---	0/23	---	---	0/21
Oak Creek at Red Rock Crossing	0/141	0/141	0/141	0/141	---	0/138	---	0/116	---	0/77	0/127
Oak Creek at Cornville	0/35	0/35	0/35	0/35	---	2/24	---	0/34	---	---	0/32
Verde River above West Clear Creek	0/21	---	0/21	0/21	0/20	---	---	---	0/20	0/20	---
West Clear Creek	0/47	---	---	0/47	---	0/38	---	---	---	0/39	---
Verde River near Camp Verde	2/108	---	1/108	2/108	2/98	---	---	---	0/26	---	---
East Verde River	0/46	0/46	0/46	0/46	1/46	---	---	0/47	0/42	---	0/42
Wet Bottom Creek	2/169	---	1/169	2/169	4/117	---	---	---	0/80	---	---
Verde River below Tangle Creek	2/198	---	1/198	2/198	0/191	---	---	---	0/159	---	---
Verde River below Bartlett Dam	0/603	0/603	0/603	0/603	0/115	---	---	1/429	0/115	---	0/185
Turkey Creek	0/37	---	0/37	0/37	0/5	---	---	---	0/25	---	---
Agua Fria River near Rock Springs	0/166	0/166	0/166	0/166	9/162	---	---	6/162	0/63	---	0/166
Agua Fria River below Waddell Dam	0/75	---	---	0/75	---	---	---	---	---	---	---

See footnotes at end of table.

Table 4. Number of samples that exceeded designated-use water-quality standards at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998—Continued

	pH				Dissolved oxygen			Dissolved solids	Ammonia		Nitrate
	Aquatic and wildlife, full and partial body contact		Agricultural		Aquatic and wildlife				Aquatic and wildlife		
Designated use for stream reach where station is located:		Domestic water source	Irrigation	Livestock watering	Warm-water fishery	Cold-water fishery	Effluent dependent	Domestic water source SMCL	Warm-water fishery	Cold-water fishery	Domestic water source
Range of values in compliance with standard:	>6.5 and <9.0 standard pH units	>5.0 and <9.0 standard pH units	>4.5 and <9.0 standard pH units	>6.5 and <9.0 standard pH units	>6.0 mg/L	>7.0 mg/L	>1.0 mg/L[1] >3.0 mg/L[2]	<500 mg/L	Varies by stream temperature and pH		<10 mg/L
Basin and Range Lowlands											
Central Arizona Project Canal near Parker	---	0/41	0/41	0/41	---	---	---	39/41	---	---	0/140
Central Arizona Project Canal at Phoenix	---	0/123	0/123	0/123	---	---	---	111/123	---	---	0/123
Gila River at Winkelman	0/85	---	0/85	0/85	2/77	---	---	---	0/8	---	---
San Pedro River at Charleston	0/87	---	0/87	0/87	5/85	---	---	---	0/83	---	---
San Pedro River below Aravaipa Creek	0/38	---	---	0/38	3/37	---	---	---	0/35	---	---
San Pedro River at Winkelman	0/38	---	---	0/38	1/22	---	---	---	0/16	---	---
Gila River at Kelvin	10/996	---	6/996	10/996	2/68	---	---	---	0/51	---	---
Santa Cruz River at Rio Rico	0/26	---	---	0/26	---	---	0/26	---	---	---	---
Santa Cruz River at Tubac	0/28	---	---	0/28	---	---	0/27	---	---	---	---
Santa Cruz River at Cortaro	0/13	---	---	---	---	---	6/12	---	---	---	---
91st Avenue Wastewater-Treatment Plant outfall[4]	0/24	---	0/24	---	---	---	0/24	---	---	---	---
Gila River at Buckeye Canal[4]	---	---	0/40	0/40	---	---	---	---	---	---	---
Hassayampa River[4]	1/49	---	1/49	1/49	---	---	0/43	---	---	---	---
Gila River at Gillespie Dam	5/646	---	4/646	5/646	---	---	0/222	---	---	---	---

[1]Applies from sunset to 3 hours after sunrise. If greater than 90 percent saturation, then a lower concentration is acceptable.
[2]Applies from 3 hours after sunrise to sunset. If greater than 90 percent saturation, then a lower concentration is acceptable.
[3]The standard does not apply legally because the station is on Native American land, but the standard was used in this study to identify river reaches with impaired water quality.
[4]Designated use determined on the basis of other nearby stream reaches or known water uses.

Table 5. Number of samples that exceeded stream-reach specific water-quality standards for total nitrogen and total phosphorus concentrations at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998

[Standards are from State of Arizona (1996). Stations were evaluated on the basis of samples collected over the period of record, and in some cases exceedences occur for samples collected before the standards were established. mg/L, milligrams per liter; N, total nitrogen; P, total phosphorus; ---, no standard]

Station	Number of years in which annual mean concentration exceeded criterion/number of years evaluated		90th percentile for concentration,[1] in mg/L		Number of samples that exceeded single-sample maximum criterion/number of samples analyzed	
	N	P	N	P	N	P
Black River, Tonto Creek, and their tributaries						
Concentration not to be exceeded, in mg/L	0.50	0.10	1.00	0.20	2.00	0.80
Black River	0/4	0/4	0.56	0.12	0/43	0/43
White River[2]	1/4	1/4	0.95	0.15	0/43	0/43
Tonto Creek	2/6	0/6	0.78	0.06	1/54	0/54
Salt River and tributaries above Theodore Roosevelt Lake, excluding the Black River, the White River, and Pinal Creek						
Concentration not to be exceeded, in mg/L	0.60	0.12	1.20	0.30	2.00	1.0
Salt River near Roosevelt	12/23	10/23	1.15	0.25	9/256	3/260
Salt River, from Stewart Mountain Dam to the confluence with the Verde River						
Concentration not to be exceeded, in mg/L	0.60	0.05	---	---	3.0	0.20
Salt River below Stewart Mountain Dam	6/19	4/19	0.84	0.07	1/144	1/145
Oak Creek, including the West Fork of Oak Creek						
Concentration not to be exceeded, in mg/L	1.0	0.10	1.50	0.25	2.50	0.30
Oak Creek near Sedona	0/3	0/3	0.74	0.10	0/22	0/22
Oak Creek at Red Rock Crossing	0/13	0/13	0.80	0.07	2/131	1/141
Oak Creek near Cornville	0/3	0/3	0.70	0.10	0/29	1/30
Verde River and its tributaries, excluding Oak Creek, from the headwaters to Bartlett Lake						
Concentration not to be exceeded, in mg/L	1.0	0.10	1.50	0.30	3.00	1.00
Verde River near Clarkdale	1/19	3/19	0.90	0.17	2/178	2/188
Verde River near Cornville	0/3	3/3	0.76	[3]0.35	0/23	0/23
Verde River above West Clear Creek	0/3	0/3	0.63	0.15	0/20	0/20
West Clear Creek	0/3	0/3	0.39	0.09	0/39	0/39
Verde River near Camp Verde	1/13	4/13	1.06	0.19	0/95	1/104
East Verde River	0/9	0/9	0.42	0.04	0/42	0/47
Wet Bottom Creek	0/18	0/18	0.70	0.04	0/76	0/100
Verde River above Tangle Creek	0/18	4/18	0.90	0.13	2/191	0/197

[1]Number listed is the 90th percentile concentration for all samples collected at that station.
[2]The standard does not apply legally because the station is on Native American land, but the standard was used in this study to identify river reaches with impaired water quality.
[3]Exceeds criterion.

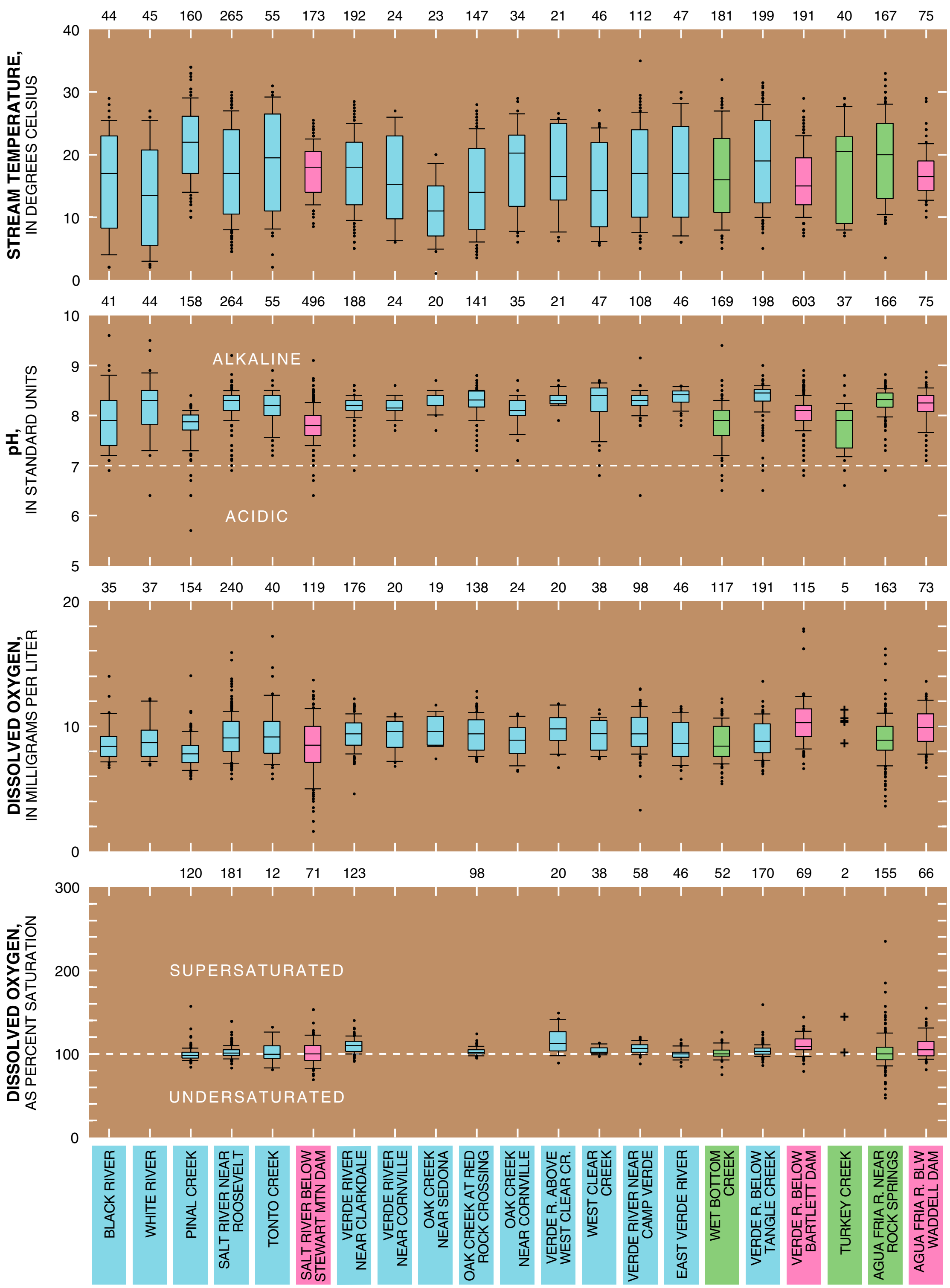


Figure 6. Distributions of stream properties and water-chemistry constituent concentrations at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998. **CENTRAL HIGHLANDS**. Explanation on page 32.

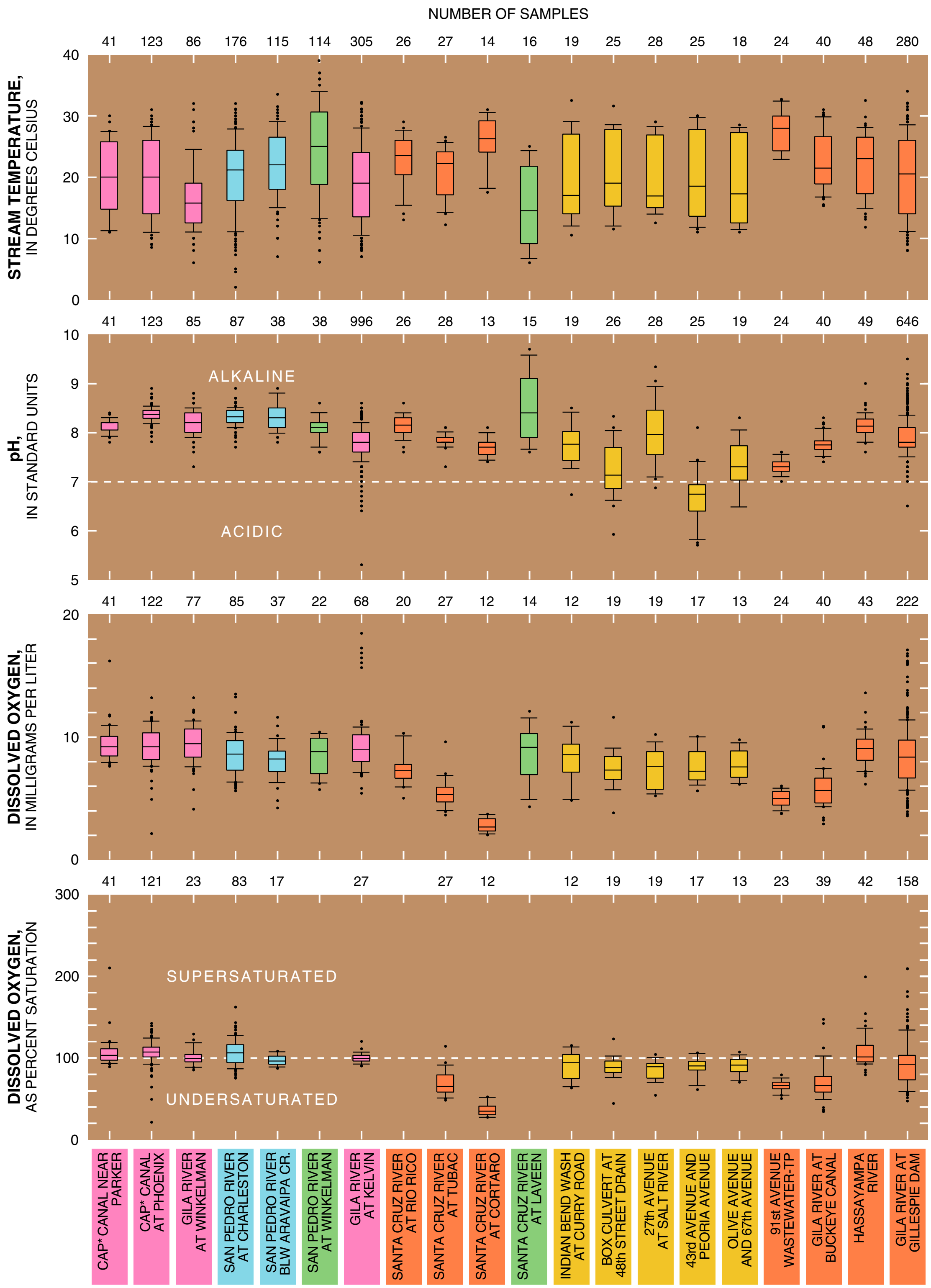


Figure 6. Continued. **BASIN AND RANGE LOWLANDS**. *Central Arizona Project. Explanation on page 32.

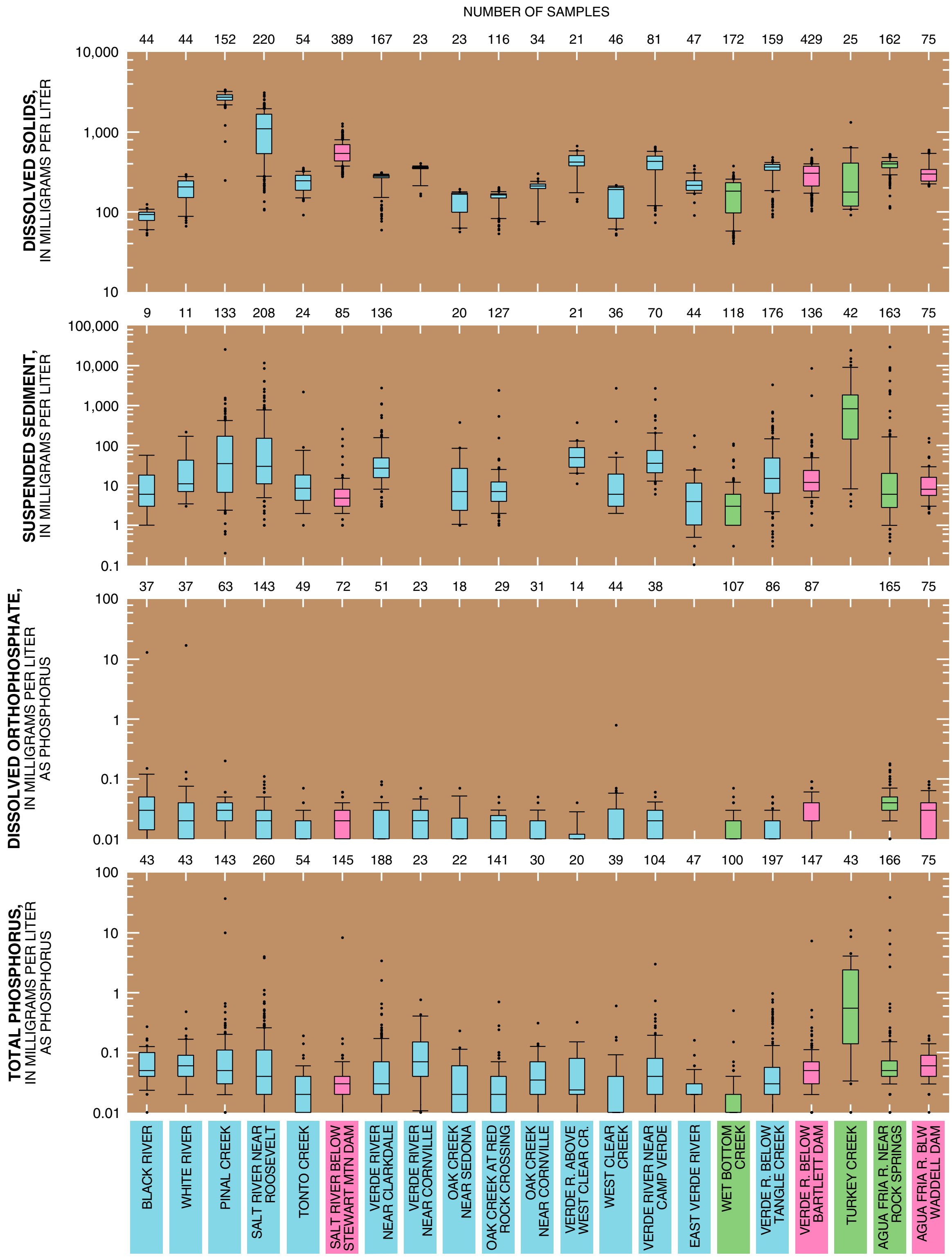


Figure 6. Continued. **CENTRAL HIGHLANDS**. Explanation on page 32.

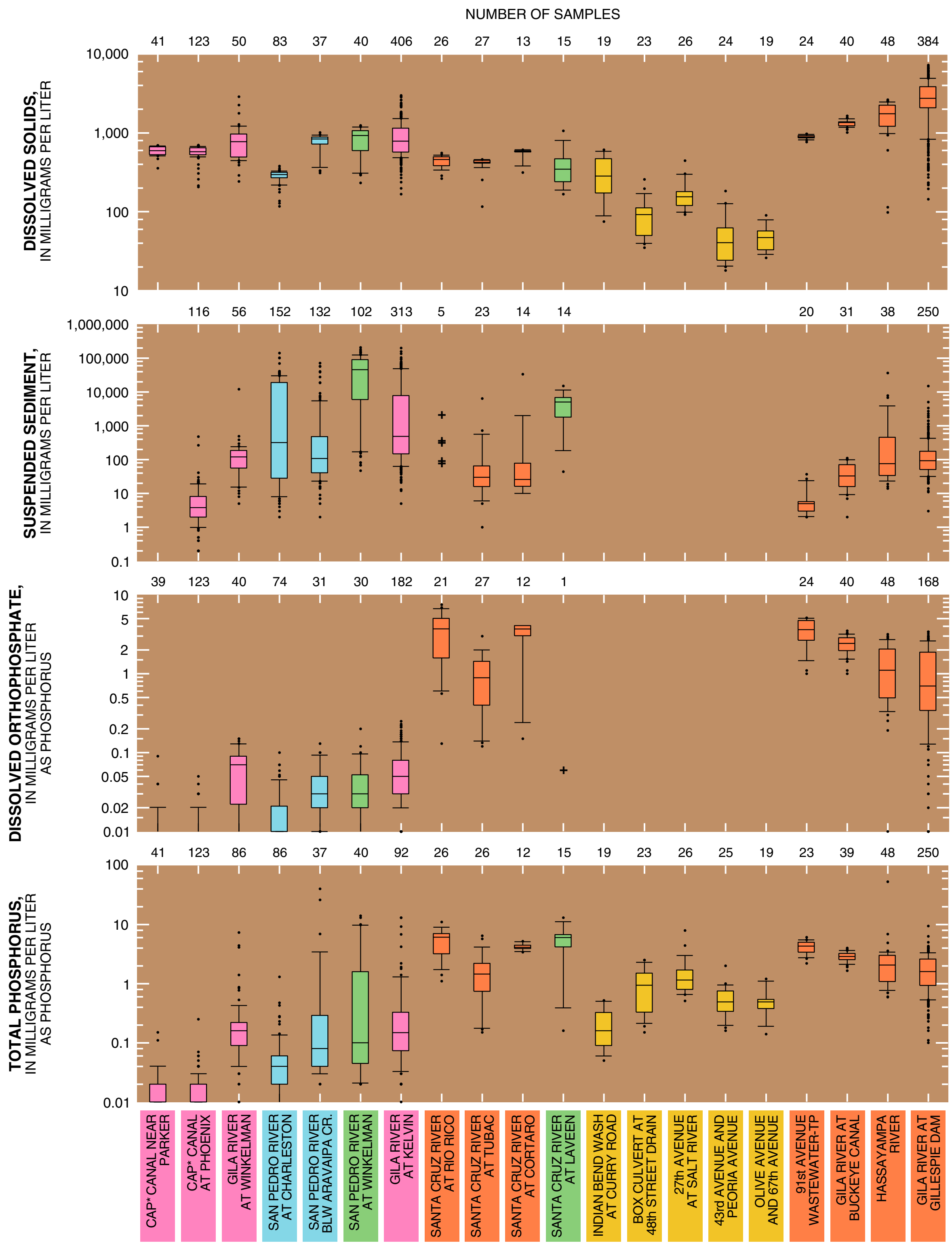


Figure 6. Continued. **BASIN AND RANGE LOWLANDS**. *Central Arizona Project. Explanation on page 32.

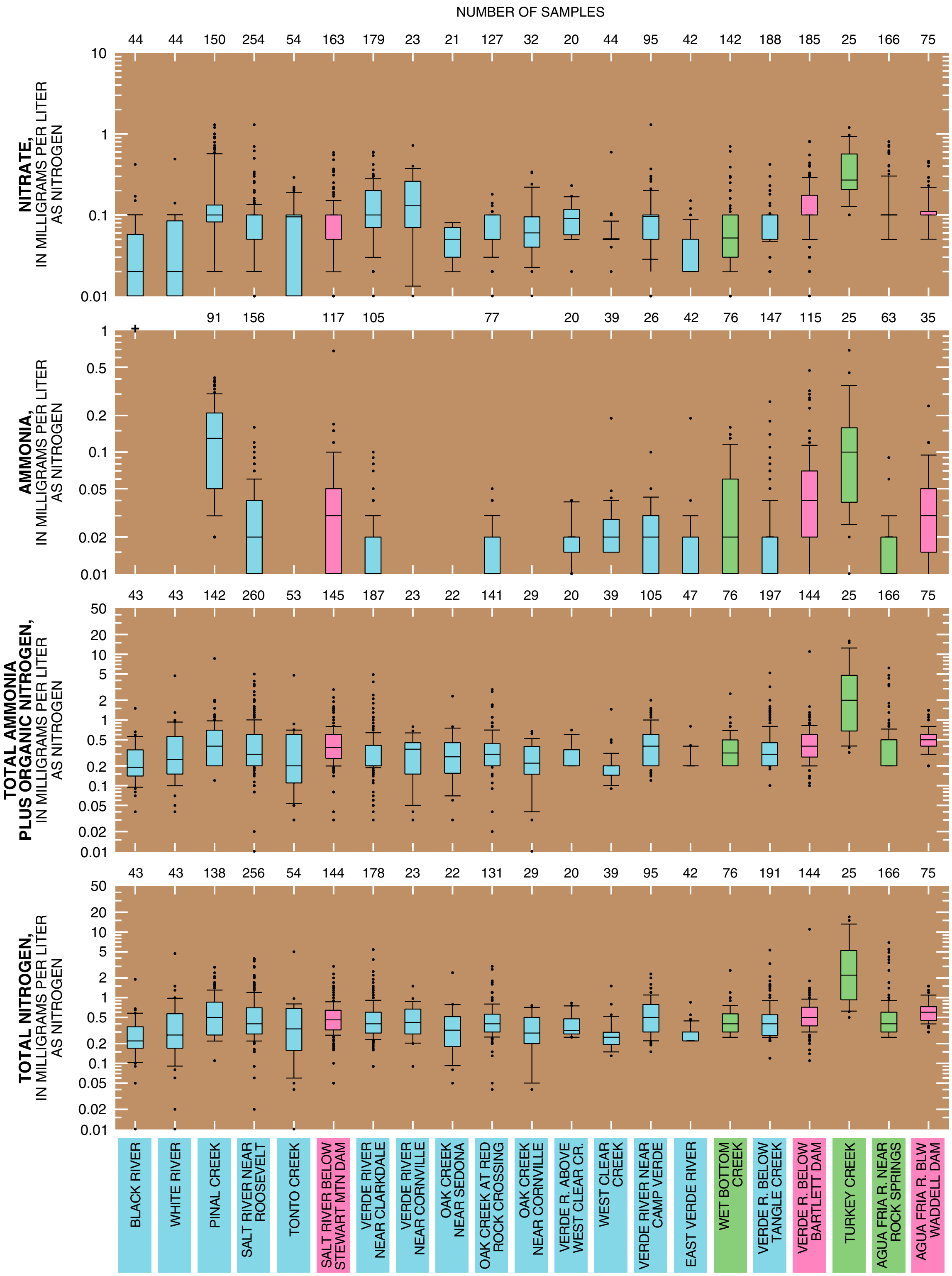


Figure 6. Continued. **CENTRAL HIGHLANDS**. Explanation on page 32.

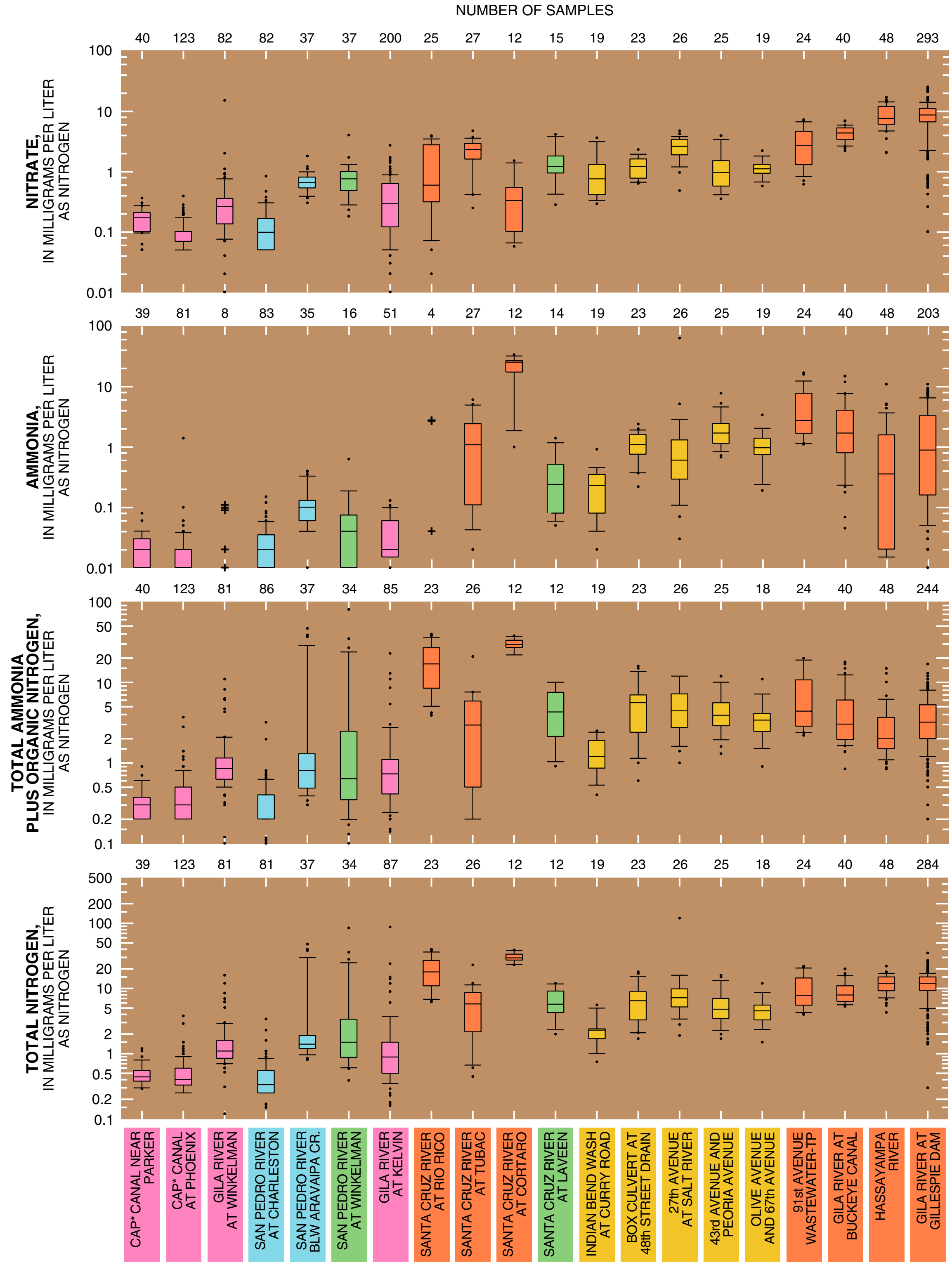
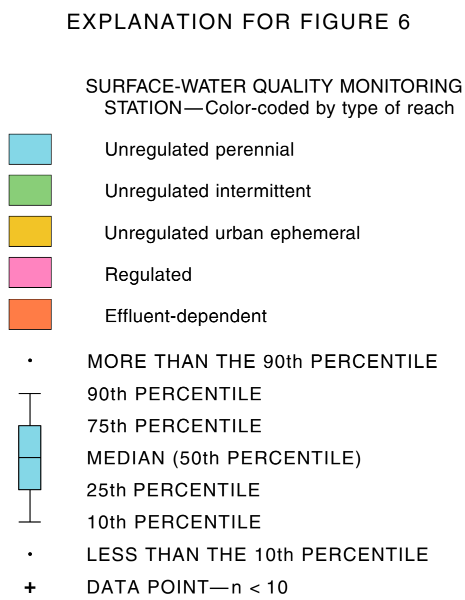


Figure 6. Continued. **BASIN AND RANGE LOWLANDS**. *Central Arizona Project. Explanation on page 32.



The State of Arizona promulgates four sets of designated-use standards that require pH to be within a specified range (table 4; State of Arizona, 1996): domestic water sources (between 5.0 and 9.0 standard pH units); aquatic and wildlife, full and partial body contact (between 6.5 and 9.0); agricultural irrigation (between 4.5 and 9.0); and agricultural livestock watering (between 6.5 and 9.0). Given that the standards require that pH be within a specified range, the term "exceedence" is used in this report when pH is either above or below the range. Overall, surface-water resources in the study area generally met the water-quality standards for pH. The pH standard was not exceeded in any samples for 8 out of the 11 stations on reaches designated as a domestic drinking water source, and pH was higher than allowed by the standard in only a few samples at the White River, the Black River, and the Salt River below Stewart Mountain Dam. At 21 of 32 stations having established pH standards, there were no samples that exceeded the standards for aquatic and wildlife, and full and partial body contact designated uses. Of the stations that had one or more samples exceeding the standard, only the Black River and the White River had more than 5 percent of the total samples exceed the standards. Of the 27 stations on streams designated for agricultural irrigation, 10 had one or more samples exceed the irrigation water-quality standards, but of these stations, most had only 1 or 2 percent of the total samples exceed standards. Of the 33 stations on streams designated for agricultural livestock watering, 11 stations had one or more samples exceed the standards. However, of these 11 stations, only the Black River and the White River had more than 5 percent of the total samples exceed the standards.

Dissolved oxygen is consumed or produced in many chemical reactions and is necessary for respiration and photosynthesis of aquatic biota. Minimum levels of dissolved oxygen in the water are required for the survival of fish and aquatic invertebrates. The concentration of dissolved oxygen in water is dependent on temperature and, owing to the equilibrium between oxygen in the air and the oxygen dissolved in the water, atmospheric pressure as well. For this reason, it is useful to report dissolved oxygen as a concentration and as percent saturation. The equilibrium (100 percent saturation) concentration of dissolved oxygen in water increases as water temperature decreases and as atmospheric pressure increases. Stream temperature and atmospheric pressure vary greatly throughout the study area because of the large variation in land-surface altitudes, and as a result, the equilibrium concentration for dissolved oxygen is spatially variable. By standardizing dissolved-oxygen concentration data as a percentage of the saturated concentration, samples collected at different stream temperatures and atmospheric pressures can be compared directly. Most samples with dissolved-oxygen concentration data also had the oxygen content expressed as a percentage of the saturation concentration; however, at eight stations the percent of saturation was not computed for any samples. Concentrations of dissolved oxygen in the study area typically were between 8 and 11 mg/L and between 80 and 120 percent saturation (fig. 6 and appendix 1). Exceptions to this are several samples from stations on effluent-dependent and unregulated urban ephemeral reaches that typically were below 100 percent saturation and as low as 27 percent saturation for the Santa Cruz River at Cortaro Road (fig. 6 and appendix 1).

The State of Arizona dissolved-oxygen standards for the three subcategories of aquatic and wildlife uses are (State of Arizona, 1996): warm water fisheries (minimum of 6.0 mg/L), cold water fisheries (minimum of 7.0 mg/L), and effluent-dependent stream reaches (minimum of 1.0 mg/L from sunset to 3 hours after sunrise, or a minimum of 3.0 mg/L otherwise).

Concentrations of dissolved oxygen lower than these standard values on a regular basis indicate that a stream may not be able to support aquatic life. Concentrations of dissolved oxygen in the study area generally met the standards for aquatic and wildlife uses (table 4). Twelve of the 17 stations on warm water fishery reaches had dissolved-oxygen concentrations lower than the standard; however, of these 12 stations, only the Agua Fria River near Rock Springs and the 3 stations on the San Pedro River had concentrations lower than the standard in more than 5 percent of the total samples. Five of the 8 stations on cold water fishery reaches had one or more samples with concentrations of dissolved oxygen lower than the standard. Of these 5 stations, the Salt River below Stewart Mountain Dam had the highest percentage of total samples with dissolved-oxygen concentrations lower than the standard—about 20 percent. Of the 6 stations on effluent-dependent reaches, only the Santa Cruz River at Cortaro had samples with dissolved-oxygen concentrations lower than the standards; however, half of the total samples collected there had concentrations lower than the standard.

Dissolved solids and suspended sediment

Dissolved solids are inorganic and organic materials dissolved in the water, and by mass they are composed mostly of common anions and cations. Common anions include bicarbonate, chloride, sulfate, and nitrate; common cations include calcium, magnesium, sodium, and potassium. Weathered rock and atmospheric deposition are natural sources of these ions; agricultural, industrial, and urban activities are anthropogenic sources. Water having high concentrations of dissolved solids can have an unpleasant taste, can cause salt to deposit in pipes and household appliances, and can result in salinized soil in irrigated areas. For a water supply to be well suited for a particular use, concentrations of dissolved solids should be within certain tolerances (table 6; Hem, 1985, p. 212–221). Concentrations of dissolved solids are highly variable in the surface-water resources of the study area and ranged from 18 mg/L at 43rd Avenue and Peoria Avenue to nearly 8,000 mg/L at the Gila River at Gillespie Dam (fig. 6 and appendix 1).

Table 6. Recommended upper limits of dissolved-solids concentrations for selected water uses

[Data from table 25, an unnumbered table on page 213, and table 29 in Hem, 1985. mg/L, milligrams per liter]

Use	Upper limit for dissolved solids concentration, in mg/L	Original source of data
Drinking water		
Humans	500	(1)
Livestock:		
Poultry	2,860	(2)
Pigs	4,290	(2)
Horses	6,435	(2)
Cattle (dairy)	7,150	(2)
Cattle (beef)	10,100	(2)
Sheep (adult)	12,900	(2)
Industrial uses		
Boiler feedwater pressure (pounds per square inch)		
0–150	700	(3)
150–700	500	(3)
700–1,500	200	(3)
1,500–5,000	0.5	(3)
Wood chemicals	1,000	(3)
Petroleum products	1,000	(3)
Canned, dried, and frozen fruits and vegetables	5	(3)
Soft drinks bottling	10	(3)
Leather tanning (finishing process)	5	(3)

Original data sources:
[1]U.S. Public Health Service (1962).
[2]McKee and Wolf (1963).
[3]U.S. Federal Water Pollution Control Administration (1968).

The USEPA Secondary Maximum Contaminant Level[5] (SMCL) for dissolved solids in drinking water is 500 mg/L (U.S. Environmental Protection Agency, 1996). Five out of the 11 stations that are on domestic water source stream reaches had one or more samples with concentrations higher than the SMCL (table 4). Although less than 5 percent of the samples from the Agua Fria River near Rock Springs and the

[5]An SMCL for a constituent is considered recommended, but nonenforceable, by Federal Guidelines under the Safe Drinking Water Act of 1986.

Verde River below Bartlett Dam had concentrations higher than the SMCL, more than half of the samples collected on the Salt River below Stewart Mountain Dam and nearly all of the samples collected from the two stations on the Central Arizona Project Canal had concentrations higher than the SMCL. As a result of the high concentrations of dissolved solids in the Central Arizona Project Canal and the Salt River, water from these two sources typically would have to be blended with water from other sources that have low dissolved-solids concentrations, such as the Verde River or ground water, in order to meet the SMCL for drinking water.

Suspended sediment is also a product of weathering and consists of solid inorganic and organic particles carried by streams. Phosphorus, certain metals, and hydrophobic organic compounds adsorb to sediment and, therefore, can be transported downstream along with the sediment in the suspended load and the bedload. Suspended-sediment concentration data were available for 33 monitoring stations and are highly variable (fig. 6). Concentrations typically range over several orders of magnitude at any given station and range from 1 mg/L or less at many stations to more than 100,000 mg/L at the San Pedro River at Charleston, the San Pedro River at Winkelman, and the Gila River at Kelvin. There are no water-quality standards for suspended-sediment concentration.

Nutrients

Nitrogen and phosphorus are important nutrients for terrestrial and aquatic plant and animal growth, and occur as several chemical species. Nitrogen in water generally occurs as ammonium (NH_4^+), un-ionized ammonia (NH_3), nitrate (NO_3^-), nitrite (NO_2^-), and as a component of organic molecules. Phosphorus in water generally occurs in the dissolved phase as ortho-phosphate, as a component in an organic compound, or as phosphate sorbed to sediment (Hem, 1985). Dissolved orthophosphate consists of the ion PO_4^{3-} in various combinations with hydrogen: H_3PO_4, $H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-} (Hem, 1985). Nitrogen and phosphorus can be introduced to streams through several processes. Nitrogen oxides in the atmosphere, from lightning or from combusted fossil fuels, can be scavenged by rainfall and transported directly in runoff. Nitrogen gas (N_2) can be converted to other forms of nitrogen by certain algae and bacteria, and these forms can be transported to streams. Phosphorus is a common element in igneous rocks and sediment, and can occur in abundance in marine phosphorite deposits. Fertilizer, livestock waste, and human waste are rich sources of nitrogen and phosphorus that can be introduced to the hydrologic system through runoff processes or directly from wastewater-treatment facilities. Nutrients from these sources can be beneficial in water used for crop irrigation.

Large influxes of nutrients to streams, however, cause eutrophication, the enrichment of water with nutrients, and lead to excessive algae growth. The excessive algae may clog pipes and water courses, require additional water treatment, or cause fish kills that result from depletion of oxygen when the algae decays and from the release of toxins from algae into the water. Excessive nitrate can lead to methemoglobinemia, or "blue baby syndrome," a medical condition generally in infants less than 4 months old in which nitrates prevent the transport of oxygen through the bloodstream to vital organs.

Data for dissolved orthophosphate concentrations were available for 34 of the 41 stations and were typically between 0.01 and 0.10 mg/L, except at stations on effluent-dependent reaches where concentrations were more variable and typically were between 0.10 and 8.0 mg/L (fig. 6 and appendix 1). Data for total phosphorus were available for all 41 stations, and concentrations typically were between 0.01 and 1.0 mg/L at stations on unregulated perennial and regulated reaches. At stations on unregulated intermittent, unregulated urban ephemeral, and effluent-dependent reaches, concentrations of total phosphorus were higher—as much as 53 mg/L at the Hassayampa River.

There are no designated-use water-quality standards for phosphorus; however, there are stream-reach specific water-quality standards for the Salt and Verde Rivers and their tributaries (State of Arizona, 1996). The standards require that the annual mean concentration, the 90th-percentile concentration from all samples, and single sample maximum concentrations be less than an assigned value for specific reaches (table 5). The standards for annual mean total phosphorus concentration in most years were met at stations on the tributaries of the Salt and Verde Rivers, whereas stations on the main stems of the Salt and Verde Rivers tended to exceed these standards in several years (table 5). All stations met the standard for the 90th-percentile concentration for all samples (0.30 mg/L) except the Verde River near Cornville, which had a 90th-percentile concentration of 0.35 mg/L. Most stations met the standards for the single sample maximum concentration of total phosphorus. Six stations had one or more samples exceed these standards; however, the exceedences represented less than 5 percent of the total samples collected at each station.

Concentrations of total nitrogen ranged from less than 0.10 mg/L at several stations to 120 mg/L at 27th Avenue at Salt River (fig. 6 and appendix 1). Concentrations of nitrate, ammonia, total ammonia plus organic nitrogen, and total nitrogen tended to be lower and less variable at stations in the Central Highlands than at stations in the Basin and Range Lowlands. Distributions of nitrate and ammonia concentrations can be used to estimate the predominant nitrogen species. Nitrate and ammonia concentrations typically are much lower than total nitrogen concentrations at unregulated perennial, unregulated intermittent, and regulated stations. This difference indicates that most of the total nitrogen occurs as organic nitrogen at these stations (fig. 6 and appendix 1). In contrast, nitrate and (or) ammonia make up a significant portion of the total nitrogen at stations on unregulated urban ephemeral and effluent-dependent reaches (fig. 6 and appendix 1). For example, most of the total nitrogen occurs as ammonia at the Santa Cruz River at Cortaro. At the 91st Avenue Wastewater-Treatment Plant outfall and at Indian Bend Wash, nitrate, ammonia, and organic nitrogen make up a significant portion of the total nitrogen.

The State of Arizona has two designated-use water-quality standards for nitrogen species and three stream-reach specific standards for total nitrogen in the Salt and Verde Rivers (State of Arizona, 1996). The standard for nitrate in streams designated as a domestic water source is 10 mg/L as nitrogen, which was not exceeded at the 11 stations on reaches having this designated use (table 4). The standard for ammonia applies to streams with aquatic and wildlife warm water and cold water fisheries designated uses and varies by stream temperature and pH. No samples from stations on stream reaches having these designated uses exceeded the ammonia standard (table 4). Stream-reach specific standards for total nitrogen in the Salt and Verde Rivers and their tributaries are similar to those for phosphorus and consist of the annual mean concentration, the 90th-percentile concentration from all samples, and single sample maximum concentration (table 5). The standard for the annual mean total nitrogen concentration was exceeded frequently at the Salt River near Roosevelt and the Salt River below Stewart Mountain Dam, but was exceeded infrequently at stations on the Verde River and its tributaries (table 5). Although total nitrogen concentrations from stations on the Salt River and its tributaries do not appear much different from those of the Verde River (fig. 6), the standard was exceeded more often in the Salt River and its tributaries than in the Verde River and its tributaries. This difference results from the standard being set at a higher concentration for reaches on the Verde River and its tributaries (1.0 mg/L) than for reaches on the Salt River and its tributaries (0.50–0.60 mg/L). The standard for the 90th-percentile concentration of total nitrogen for all samples was not exceeded at any of the stations sampled. Most stations met the standards for the single sample maximum concentration of total nitrogen. Six stations had one or more samples exceed these standards; however, the exceedences represented less than 5 percent of the total samples collected at each station.

RELATION OF STREAM PROPERTIES AND WATER-CHEMISTRY CONSTITUENT CONCENTRATIONS TO NATURAL AND HUMAN FACTORS

Stream properties and water-chemistry constituent concentrations were found to be related to streamflow, season, water management, stream permanence, land use, and water use. An understanding of how natural and human factors affect water-quality can be used to build a regional conceptual model of the water quality of streams and reservoirs in the CAZB study area. In addition, an understanding of how these natural and human factors affect water-quality is needed for design and evaluation of data from water-quality monitoring networks. For instance, if concentrations of a given constituent are related to streamflow, then the sample collection design should take into account variations in streamflow, and streamflow at the time of sampling should be considered when evaluating the water-quality data.

Streamflow and Season

Seasonal variation in the relative contribution of streamflow from different sources and seasonal variation in physical or biological processes in the stream cause seasonal variation in stream properties and water-chemistry constituent concentrations. For instance, precipitation (fig. 7) that becomes runoff and enters a stream can dilute or concentrate water-chemistry constituent concentration in the stream. Similar dilution or concentration processes can occur during periods of low flow as a result of changes in the relative contribution to flow to a stream from springs and ground-water sources that have different constituent concentrations. The relative contribution to the total streamflow from different sources typically is seasonal, and as a result, the concentrations of some constituents in streams vary seasonally. In addition, seasonal variation of concentrations also may result from seasonal variations in natural or human activities, such as microbiological consumption or production of constituents, or application of fertilizers during certain seasons.

The relation of the stream properties and water-chemistry constituent concentrations to streamflow at the 41 stations was determined by statistical correlations and also by graphical analysis for 6 stations. The strength and direction of the correlation between streamflow and the stream properties and water-chemistry constituent concentrations was determined for all stations using computer software (SPSS Inc., 1997) to perform the Kendall's tau test (Kendall, 1938). Kendall's tau is a rank-based, nonparametric test that determines the monotonic relation between two variables and is suitable for data that are skewed, include censored data, and (or) include outliers (Helsel and Hirsch, 1992). If the relation is nonmonotonic, results indicate the predominant monotonic relation exhibited by the samples. The seasonal variations and relations to streamflow for stream properties and water-chemistry constituent concentrations were illustrated graphically by using data from six stations collected during water years 1996–98 to contrast how they vary for stations affected by different natural and human factors. In a few cases a relation is apparent in the graphs but was not detected by the Kendall's tau test. This discrepancy occurred because the graphs are for 1996–98, whereas the Kendall's tau test was performed on all historic data inclusive of 1998.

Unregulated Perennial and Intermittent Reaches

Correlations of the stream properties and water-chemistry constituent concentrations with streamflow were common and generally consistent in sign (positive or negative) at stations on unregulated perennial and intermittent reaches (table 7; San Pedro River at Charleston and Verde River below Tangle Creek in figure 8). Correlations between streamflow and stream temperature, streamflow and pH, streamflow and dissolved-oxygen saturation, and streamflow and dissolved-solids concentration were generally either negative or not significant. In contrast, correlations between streamflow and concentrations of dissolved oxygen, suspended sediment, and nutrients were generally either positive or not significant.

Stream temperature was negatively correlated with streamflow because the samples from higher streamflows generally were collected during the winter or spring when stream temperatures were low as a result of lower air temperatures and (or) snowmelt runoff. In addition, the coinciding cold stream temperatures and high stream discharges also resulted in a positive correlation between dissolved-oxygen concentration and streamflow because the saturation equilibrium concentration for dissolved oxygen is higher for colder stream temperatures. The negative correlation between dissolved-oxygen percent saturation and streamflow at stations draining the Central Highlands resulted from streams being in equilibrium with atmospheric oxygen when storm runoff contributed flow and from streams being slightly oversaturated, probably because of increased algal production of oxygen, during periods of low flow. Dissolved-solids concentrations and pH were negatively correlated with streamflow because base flow in streams is diluted by runoff from precipitation that has a lower pH and lower dissolved-solids concentration (fig. 7; National Atmospheric Deposition Program, 1998a, 1998b).

Concentrations of suspended sediment and nutrients were positively correlated with streamflow as a result of several runoff processes. Concentrations of nitrate were generally higher in precipitation (fig. 7; National Atmospheric Deposition Program, 1998a, 1998b) than in streams during periods of low flow (San Pedro River at Charleston and Verde River below Tangle Creek in figure 8). Therefore, as precipitation runoff entered the streams and increased the discharge, the nitrate concentration also increased. Concentrations of ammonia also were generally higher in precipitation than in streamflow during periods of low flow; however, there was generally no relation between concentration of ammonia and streamflow. As precipitation runoff flows over the land surface and through soils, soluble nutrients are dissolved into the runoff and particulate nutrients and sediment are entrained in the overland runoff and transported to the stream. These processes likely increased the concentrations of nutrients and suspended sediment in the stream. In addition, the increase in streamflow that results from runoff also entrains sediment and organic matter from the stream channel into suspension, thereby increasing the concentrations of suspended sediment and nutrients.

Table 7. Correlation of stream properties and water-chemistry constituent concentrations with streamflow at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998

[Correlations between streamflow and concentration were determined using the Kendall's tau test and are reported as follows: +++, a strong positive correlation (p<0.01); ++, a positive correlation (p<0.05); +, a marginally positive correlation (p<0.10); 0, no significant correlation (p>0.10); -, a marginally negative correlation (p<0.10); --, a negative correlation (p<0.05); ---, a strong negative correlation (p<0.01); n, not determined. The colors of the table cells indicate the type of streamflow at the station; blue, unregulated perennial; green, unregulated intermittent; yellow, unregulated urban ephemeral; magenta, regulated; orange, effluent dependent]

Station	Temperature	pH	Dissolved-oxygen concentration	Dissolved oxygen, percent saturation	Dissolved-solids concentration	Suspended-sediment concentration	Dissolved-orthophosphorus concentration	Total phosphorus concentration	Nitrate concentration	Ammonia concentration	Total ammonia and organic nitrogen concentration	Total nitrogen concentration
Central Highlands												
Black River	--	---	0	n	---	++	+	+++	+++	n	0	0
White River	0	---	0	n	---	+++	0	++	+++	n	0	0
Pinal Creek	---	0	+++	0	---	+++	0	+++	+++	+	++	+++
Salt River near Roosevelt	---	---	+++	0	---	+++	+++	+++	0	0	++	++
Tonto Creek	---	---	+	--	---	0	0	+	+++	n	0	0
Salt River below Stewart Mountain Dam	0	0	0	++	--	0	+	+++	0	0	0	0
Verde River near Clarkdale	---	0	+++	---	---	++	+++	+++	+++	0	+++	+++
Verde River near Cornville	---	0	++	n	---	n	0	0	+	n	0	0
Oak Creek near Sedona	---	0	+++	n	---	0	0	+++	0	n	0	0
Oak Creek at Red Rock Crossing	---	---	+++	--	---	+	+++	+++	+	0	0	++
Oak Creek near Cornville	---	-	++	n	---	n	0	0	--	n	0	-
Verde River above West Clear Creek	---	0	0	---	---	++	0	++	0	0	+++	0
West Clear Creek	---	---	+++	---	---	0	+++	+++	0	0	++	++
Verde River near Camp Verde	---	0	+++	---	---	+++	0	+++	+++	0	0	0
East Verde River	--	+++	0	0	---	0	n	+	0	0	0	0
Wet Bottom Creek	---	0	+++	0	---	+++	---	+++	0	++	0	0
Verde River below Tangle Creek	---	0	+++	---	---	+++	+++	+++	++	+	+++	+++
Verde River below Bartlett Dam	0	--	0	0	---	0	0	0	0	0	--	-
Turkey Creek	---	0	0	0	---	++	n	+++	0	0	0	0
Agua Fria River near Rock Springs	---	+	+++	0	---	0	+++	+++	+++	0	0	+++
Agua Fria River below Waddell Dam	--	--	0	0	0	0	+++	++	++	0	0	0

Table 7. Correlation of stream properties and water-chemistry constituent concentrations with streamflow at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998—Continued

Station	Temperature	pH	Dissolved-oxygen concentration	Dissolved oxygen, percent saturation	Dissolved-solids concentration	Suspended-sediment concentration	Dissolved-orthophosphorus concentration	Total phosphorus concentration	Nitrate concentration	Ammonia concentration	Total ammonia and organic nitrogen concentration	Total nitrogen concentration
Basin and Range Lowlands												
Central Arizona Project near Parker	0	0	0	0	++	n	0	--	0	0	-	0
Central Arizona Project at Phoenix	++	0	---	0	+++	0	+++	++	0	0	---	---
Gila River at Winkelman	0	0	--	---	---	+++	0	+++	--	0	+	++
San Pedro River at Charleston	---	0	+	-	+++	+++	0	0	0	0	0	+++
San Pedro River below Aravaipa	--	0	0	0	---	+++	0	+++	+++	0	+++	+++
San Pedro River at Winkelman	0	0	0	n	---	++	0	+++	++	++	++	++
Gila River at Kelvin	0	-	0	0	---	+++	++	+++	++	++	+++	+++
Santa Cruz River at Rio Rico	0	0	0	n	---	0	---	---	+	0	---	---
Santa Cruz River at Tubac	--	0	0	--	---	+++	0	+++	+	+++	+++	+++
Santa Cruz River at Cortaro	0	0	0	0	0	0	0	0	+	0	+	+
Santa Cruz River at Laveen	0	0	0	n	0	+++	n	0	0	0	0	0
Indian Bend Wash at Curry Road	0	0	0	++	0	n	n	0	0	0	0	0
Box Culvert at 48th Street Drain	++	0	0	+	0	n	n	+	0	+++	0	+
27th Avenue at Salt River	0	0	0	0	0	n	n	0	0	+	0	0
43rd Avenue and Peoria Avenue	0	0	0	0	0	n	n	0	0	0	-	0
Olive Avenue and 67th Avenue	0	0	0	0	0	n	n	++	0	0	0	0
91st Avenue Wastewater-Treatment Plant outfall	0	0	0	--	--	0	0	0	0	0	0	++
Gila River at Buckeye Canal	++	0	0	0	0	0	0	0	0	0	+	0
Hassayampa River	--	---	--	---	---	+++	0	+++	---	0	+++	---
Gila River at Gillespie Dam	--	---	0	0	---	0	++	+++	---	+++	0	---

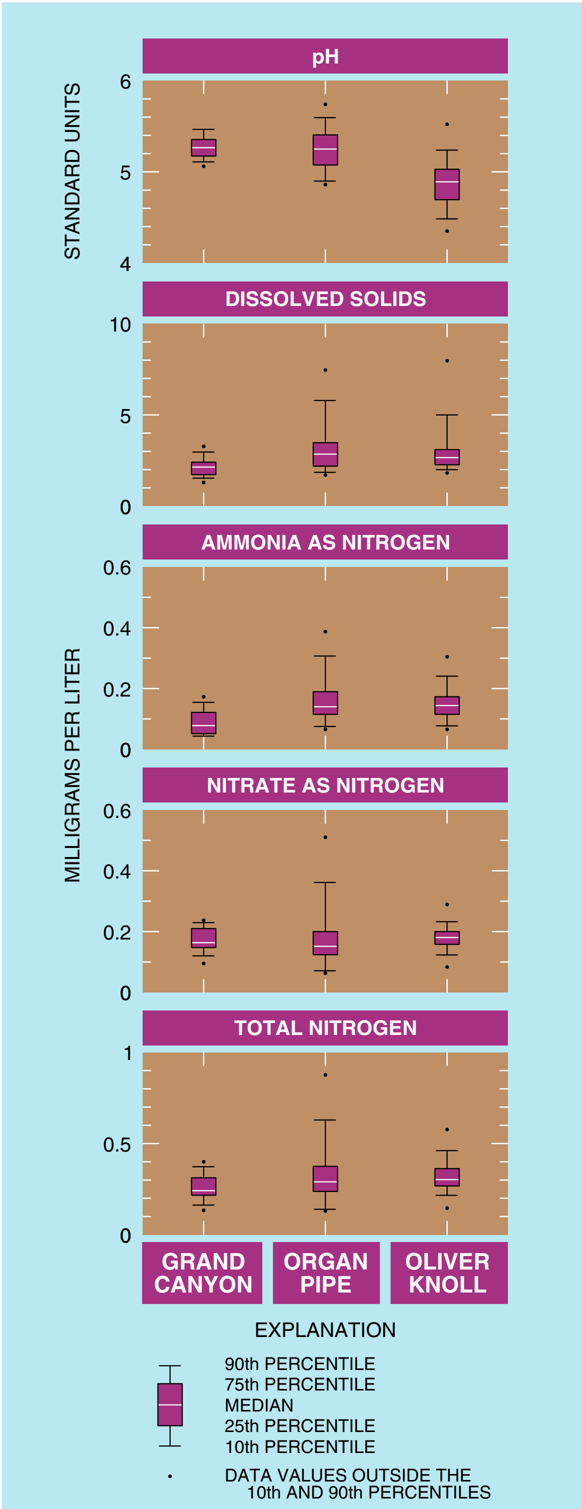


Figure 7. Distributions of precipitation-volume weighted annual average pH, dissolved solids, ammonia, nitrate, and total nitrogen concentrations in precipitation at three National Atmospheric Deposition Program monitoring stations in Arizona, 1980–96. The number of observations for each station are: Grand Canyon, 16; Organ Pipe, 17; and Oliver Knoll, 16.

Unregulated perennial and intermittent streams typically received direct runoff during the summer from thunderstorms and during the winter from frontal storms. The monthly streamflow volumes, however, had a unimodal distribution because the volume of direct runoff usually was much larger for one season than the other (table 1). For streams in the Central Highlands, the mode of the streamflow volume distribution was centered between February and April, depending on the altitude of the basin, as a result of runoff from winter precipitation and spring snowmelt. In contrast, for streams in the southeastern part of the Basin and Range Lowlands, such as the San Pedro River, the mode of the monthly streamflow volume distribution was centered in August as a result of direct runoff predominately being generated by summer thunderstorms.

Seasonal patterns of the stream properties and water-chemistry constituent concentrations in unregulated perennial and intermittent streams generally resulted from seasonal patterns in climate because the stream properties and water-chemistry constituent concentrations were correlated with streamflow (San Pedro River at Charleston and Verde River below Tangle Creek in figure 8). In general, stream temperature, pH, dissolved-oxygen percent saturation, and concentrations of dissolved solids were low during seasons that had substantial direct runoff (winter and summer) as compared to seasons that had long periods of low flow (spring and fall). In contrast, concentrations of suspended sediment and of nutrients generally were high during seasons that had substantial direct runoff (winter and summer). As previously discussed, seasonal patterns in dissolved-oxygen concentrations at some stations were related to the coincident seasonal patterns in stream temperature and streamflow. Seasonal patterns of stream properties and water-chemistry constituent concentrations that are correlated with streamflow are much less pronounced during drought years (such as 1996) than during wet years (such as 1998). For instance, concentrations of dissolved solids, suspended sediment, total phosphorus and total nitrogen at the Verde River below Tangle Creek were much less variable during 1996 than during 1998 (fig. 8)

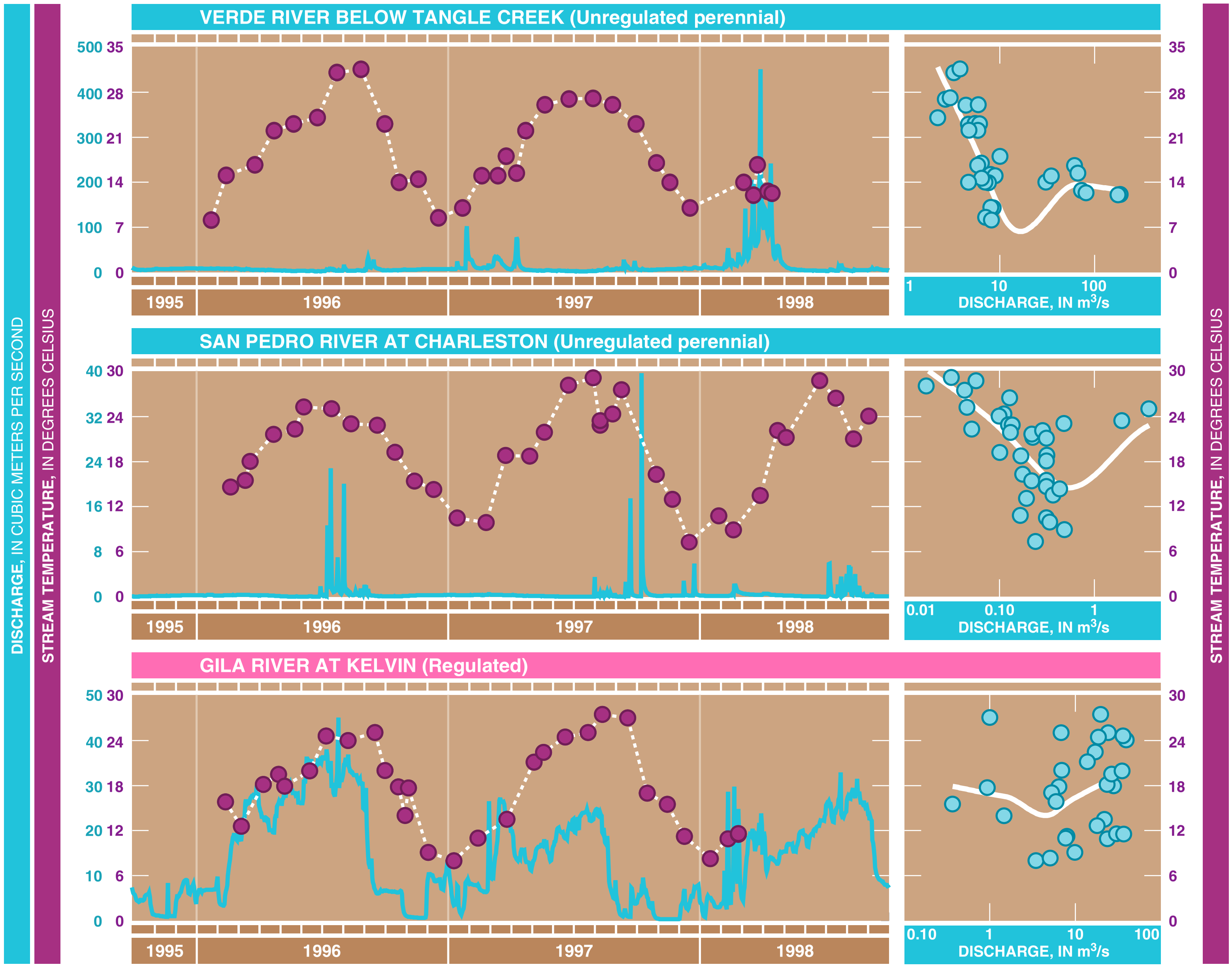


Figure 8. Relation of stream properties and water-chemistry constituent concentrations to season and stream discharge, at selected surface-water quality monitoring stations in the Central Arizona Basins study area, October 1995 through September 1998. Solid white line is a locally weighted scatter plot smooth (Cleveland, 1979). m^3/s, cubic meters per second.

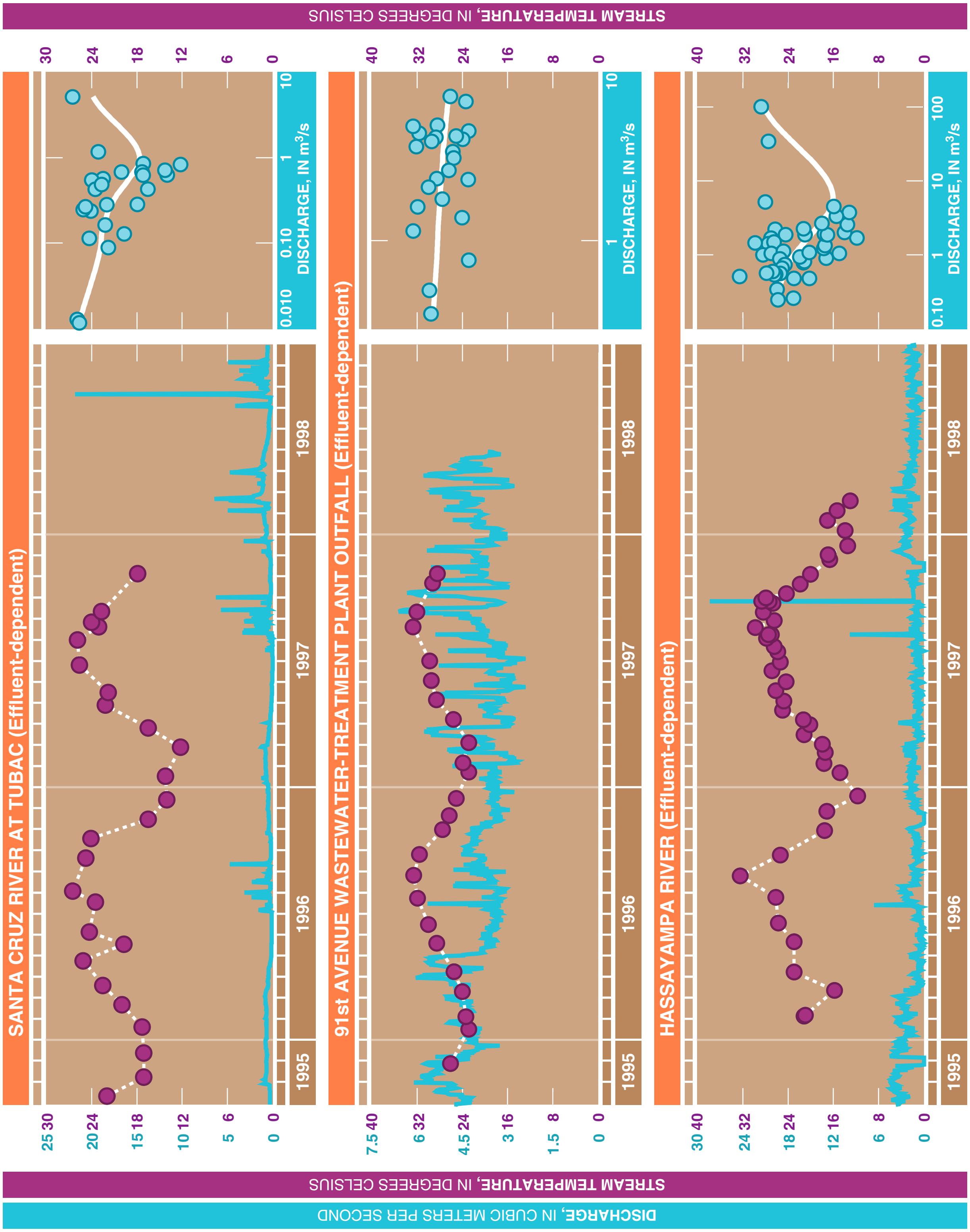


Figure 8. Continued. m^3/s, cubic meters per second.

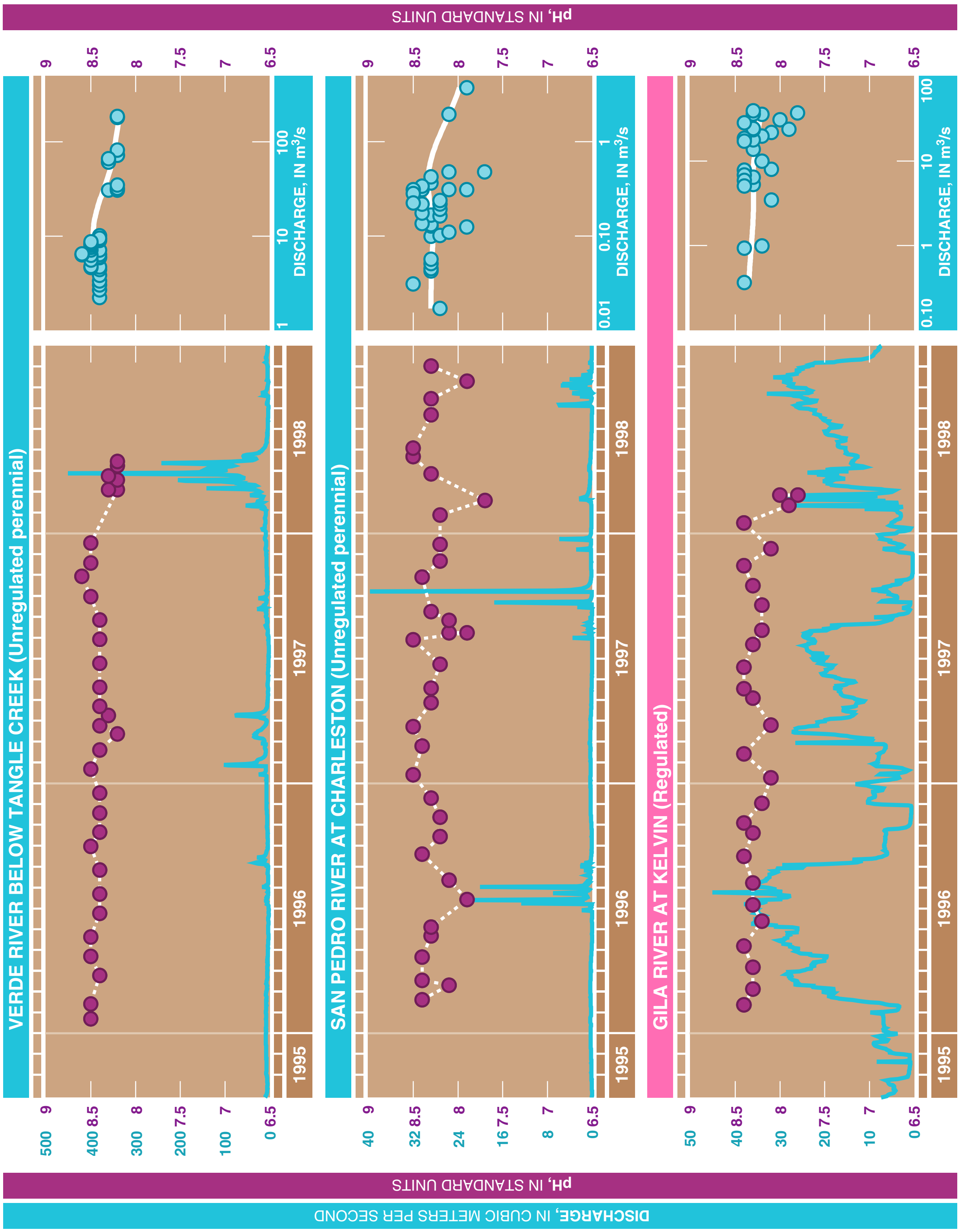


Figure 8. Continued. m^3/s, cubic meters per second.

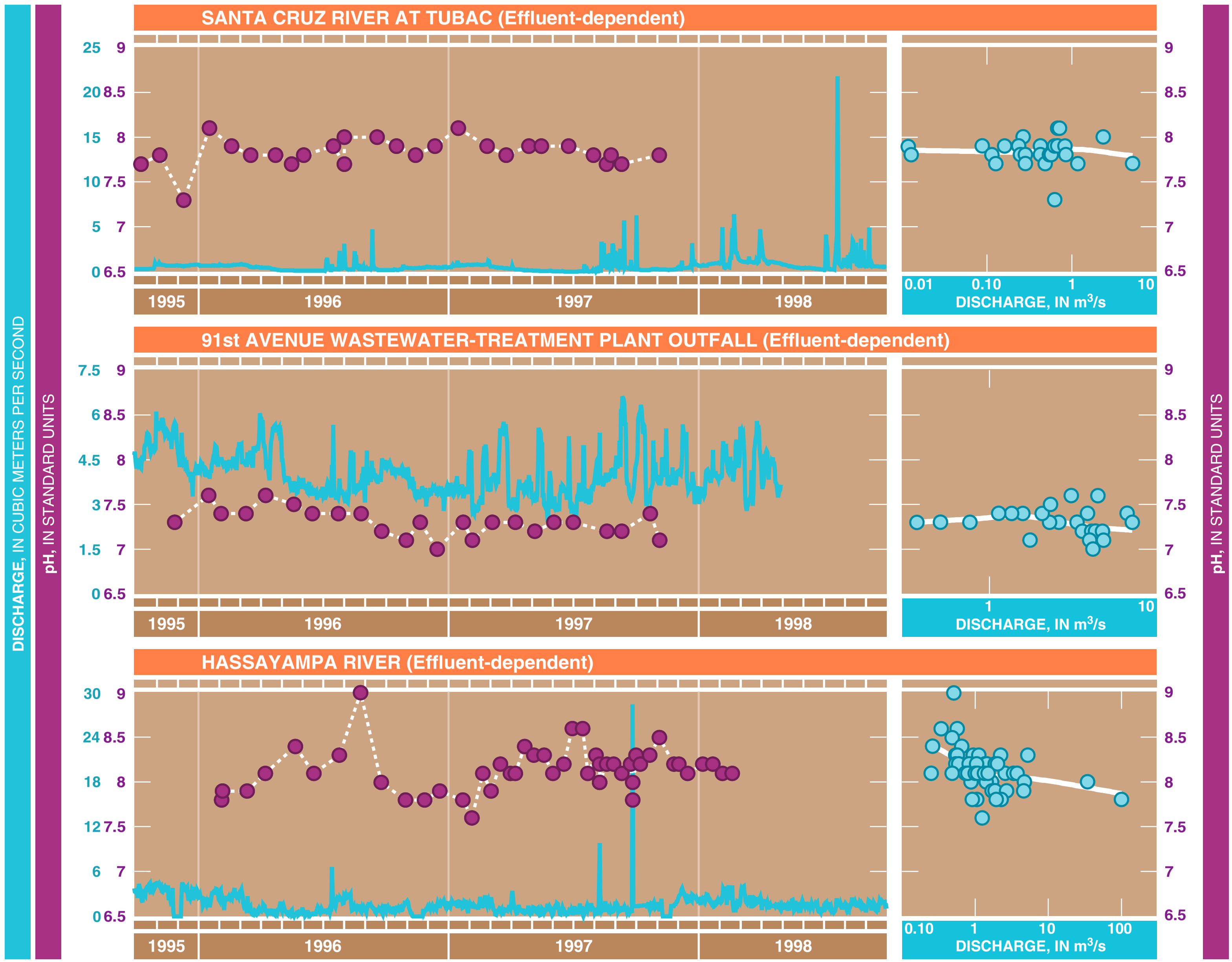


Figure 8. Continued. m^3/s, cubic meters per second.

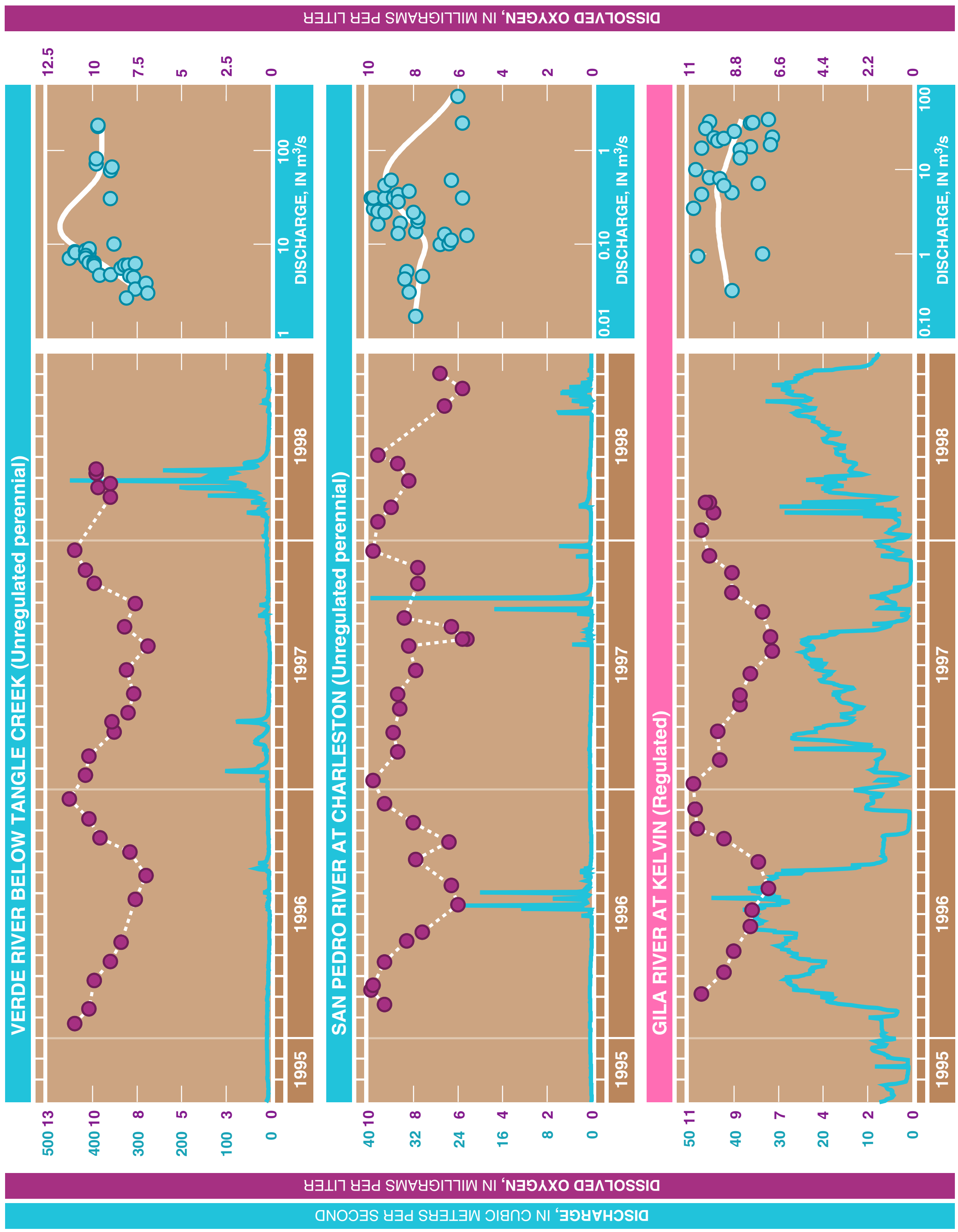


Figure 8. Continued. m^3/s, cubic meters per second.

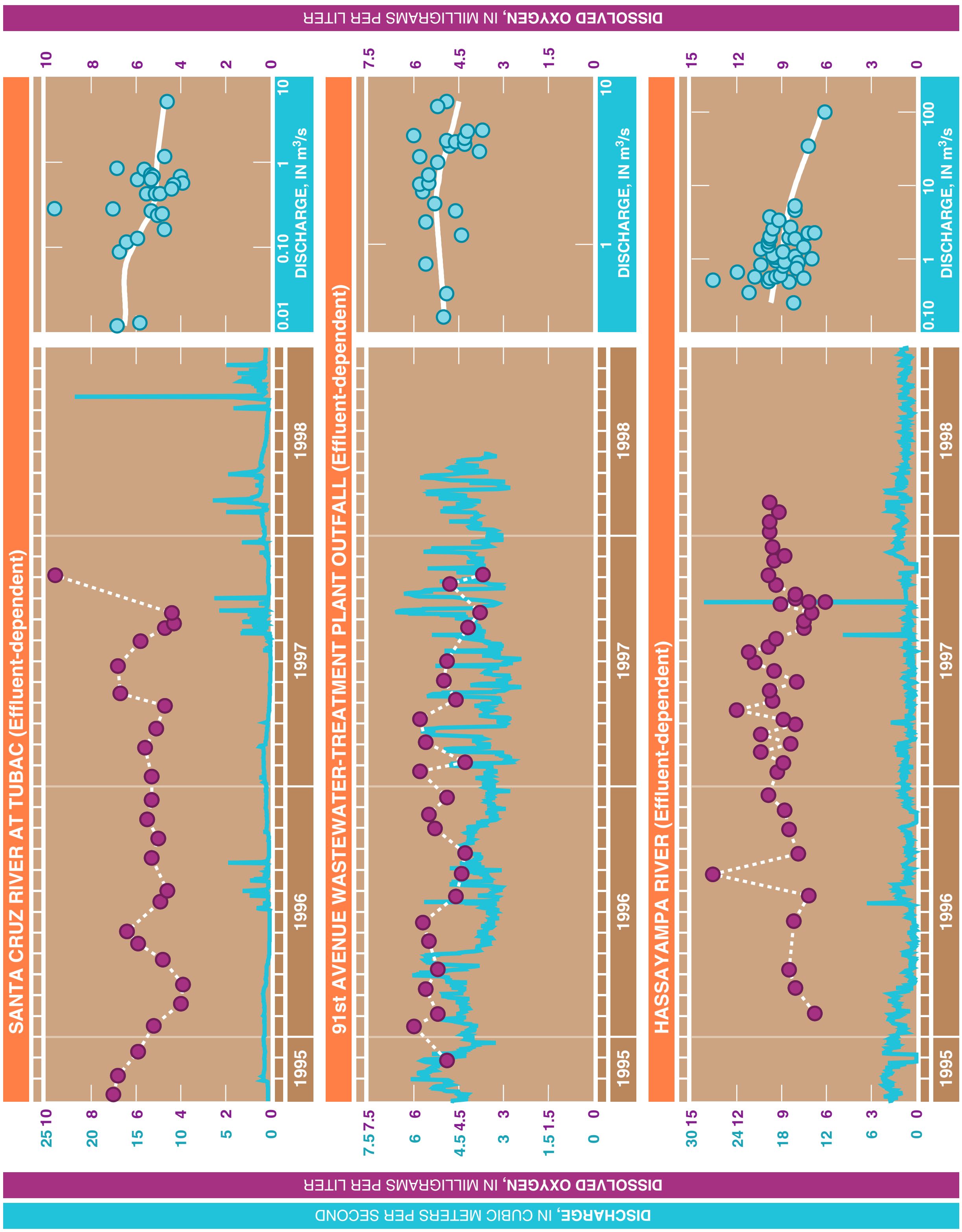


Figure 8. Continued. m^3/s, cubic meters per second.

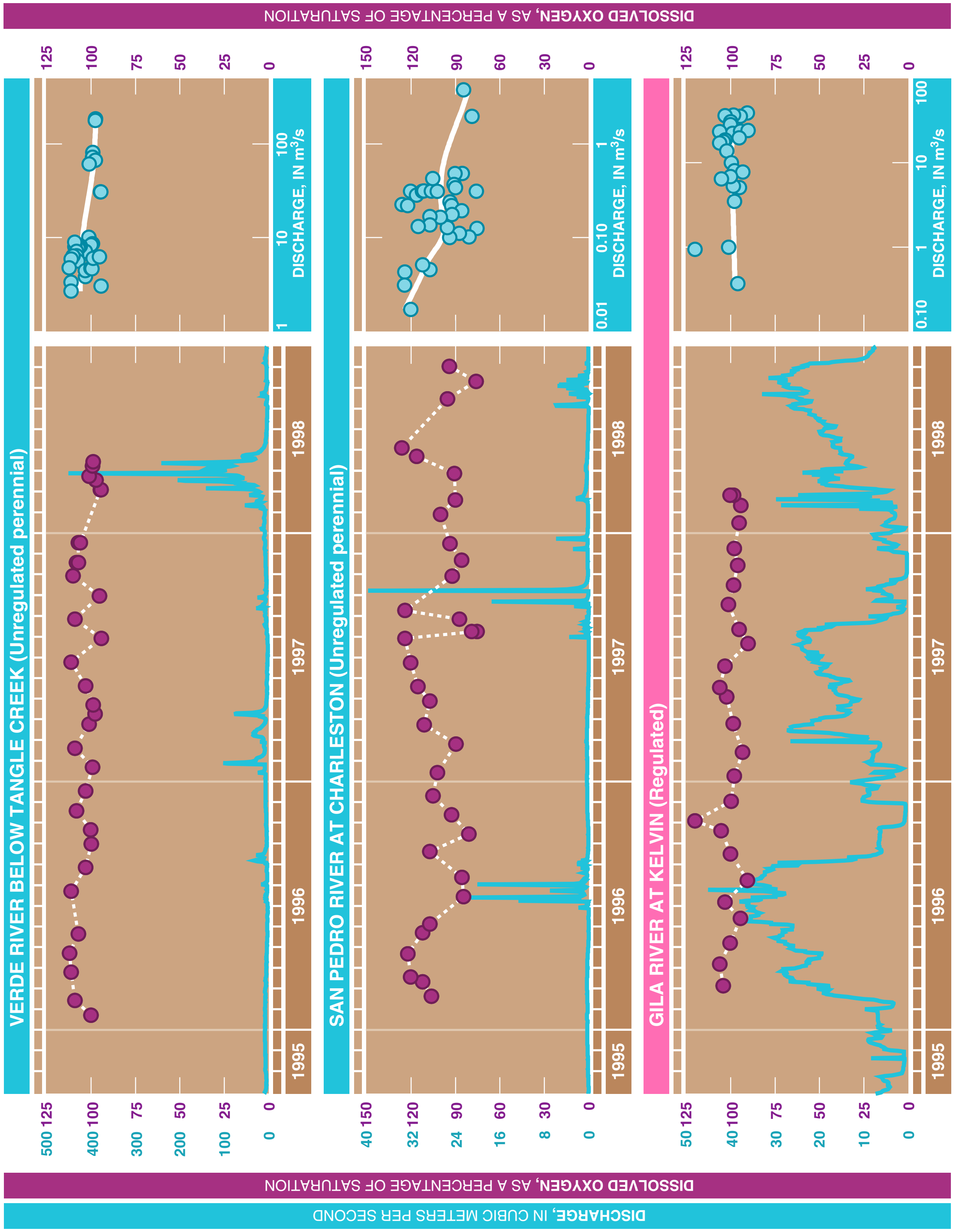


Figure 8. Continued. m^3/s, cubic meters per second.

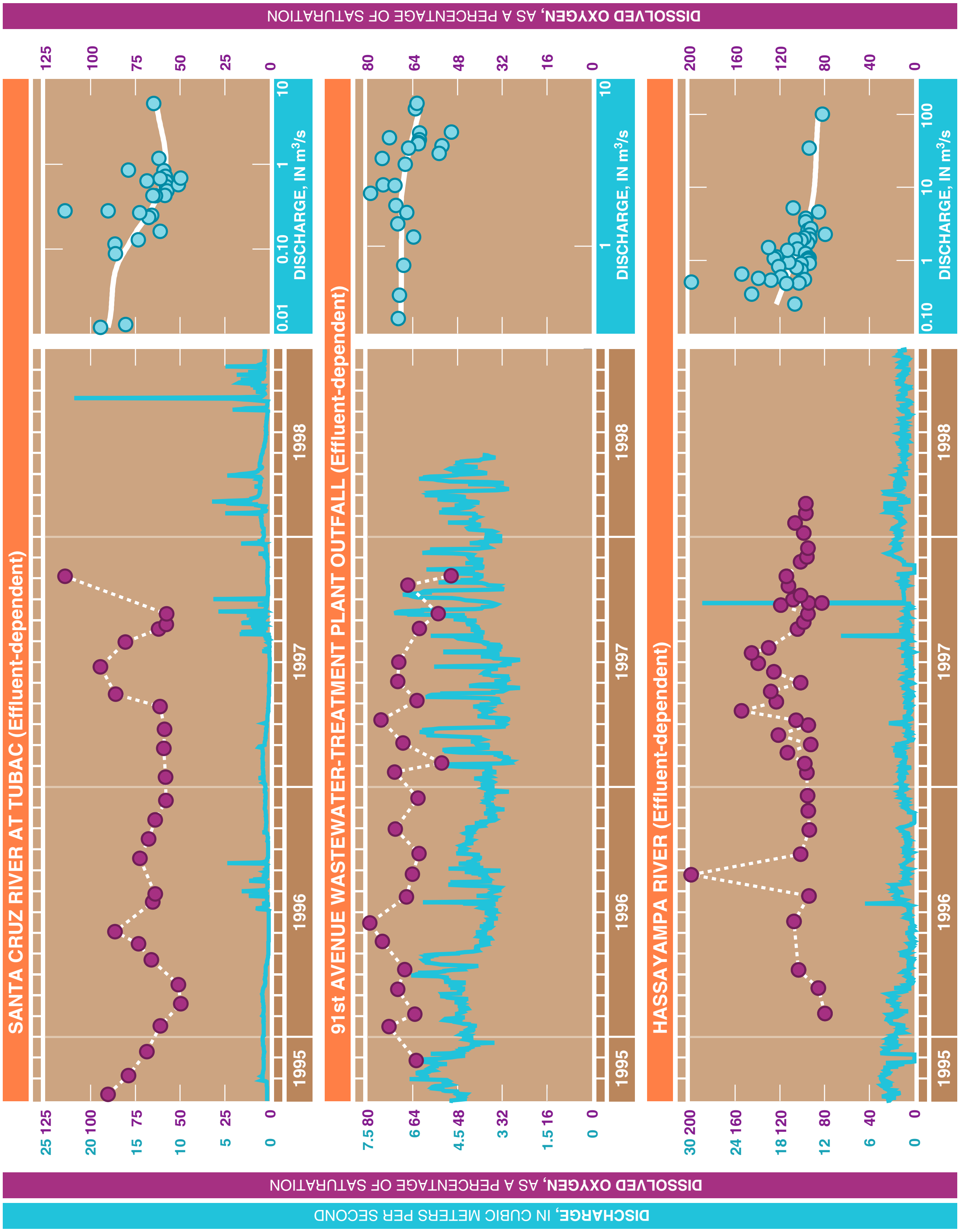


Figure 8. Continued. m^3/s, cubic meters per second.

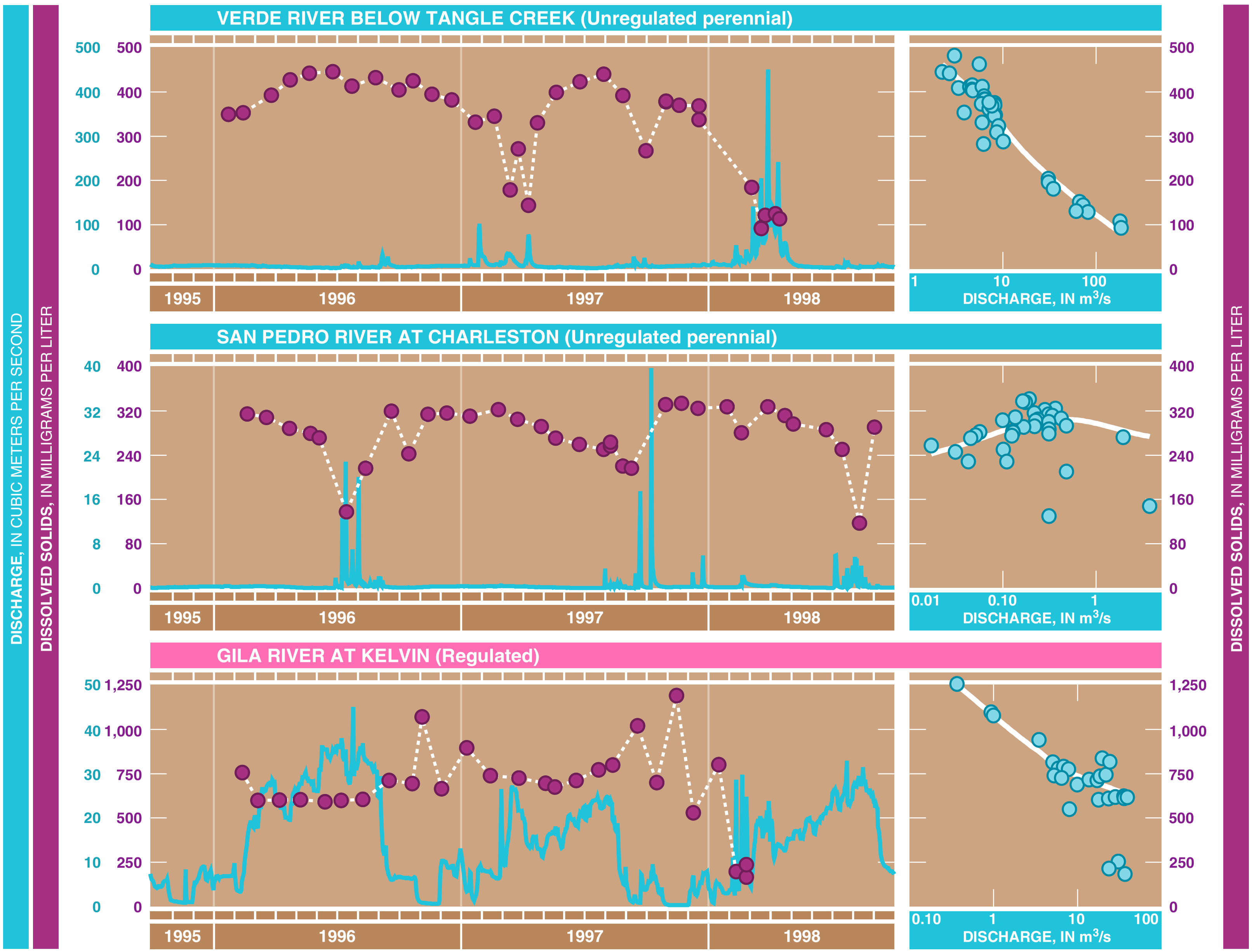


Figure 8. Continued. m^3/s, cubic meters per second.

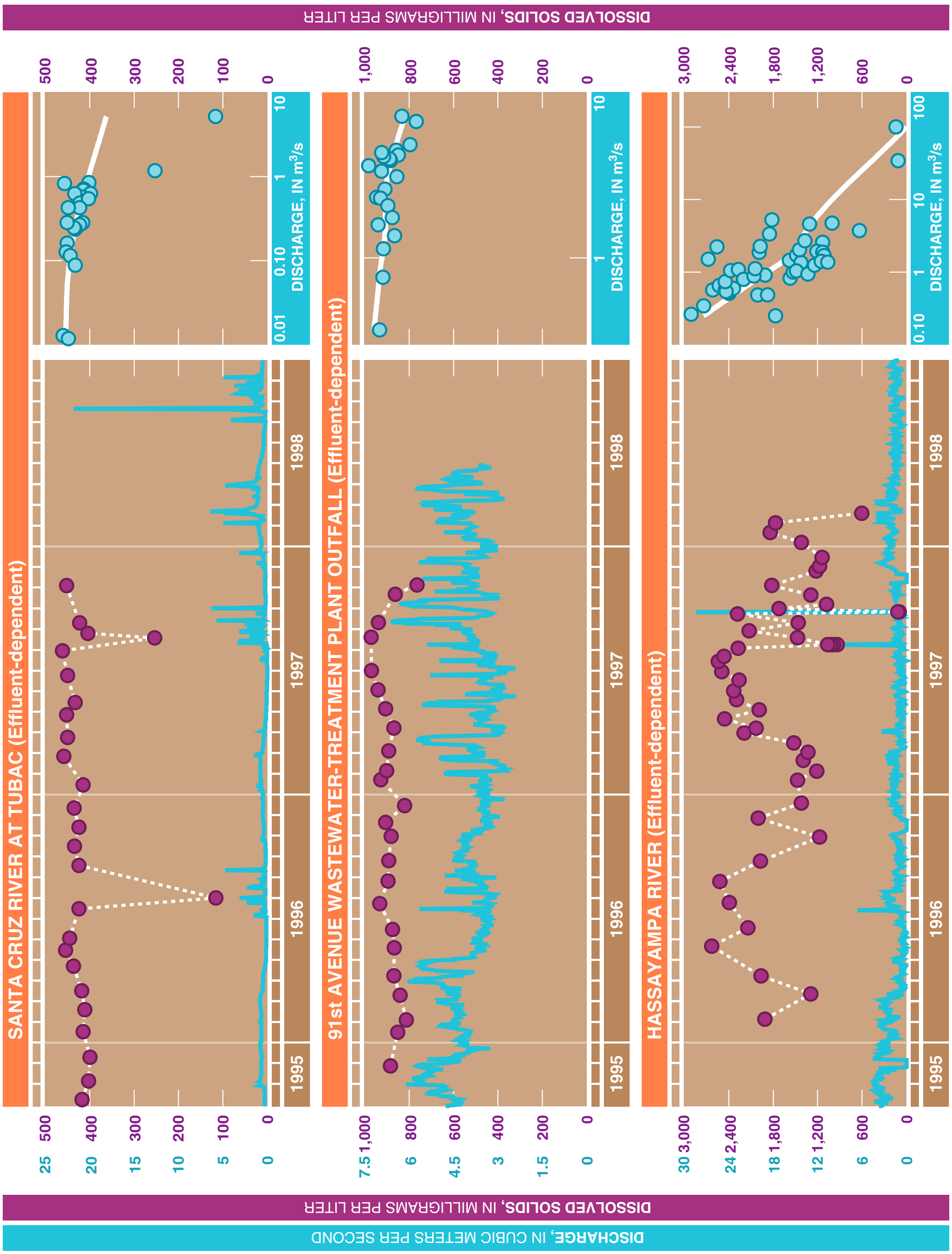


Figure 8. Continued. m^3/s, cubic meters per second.

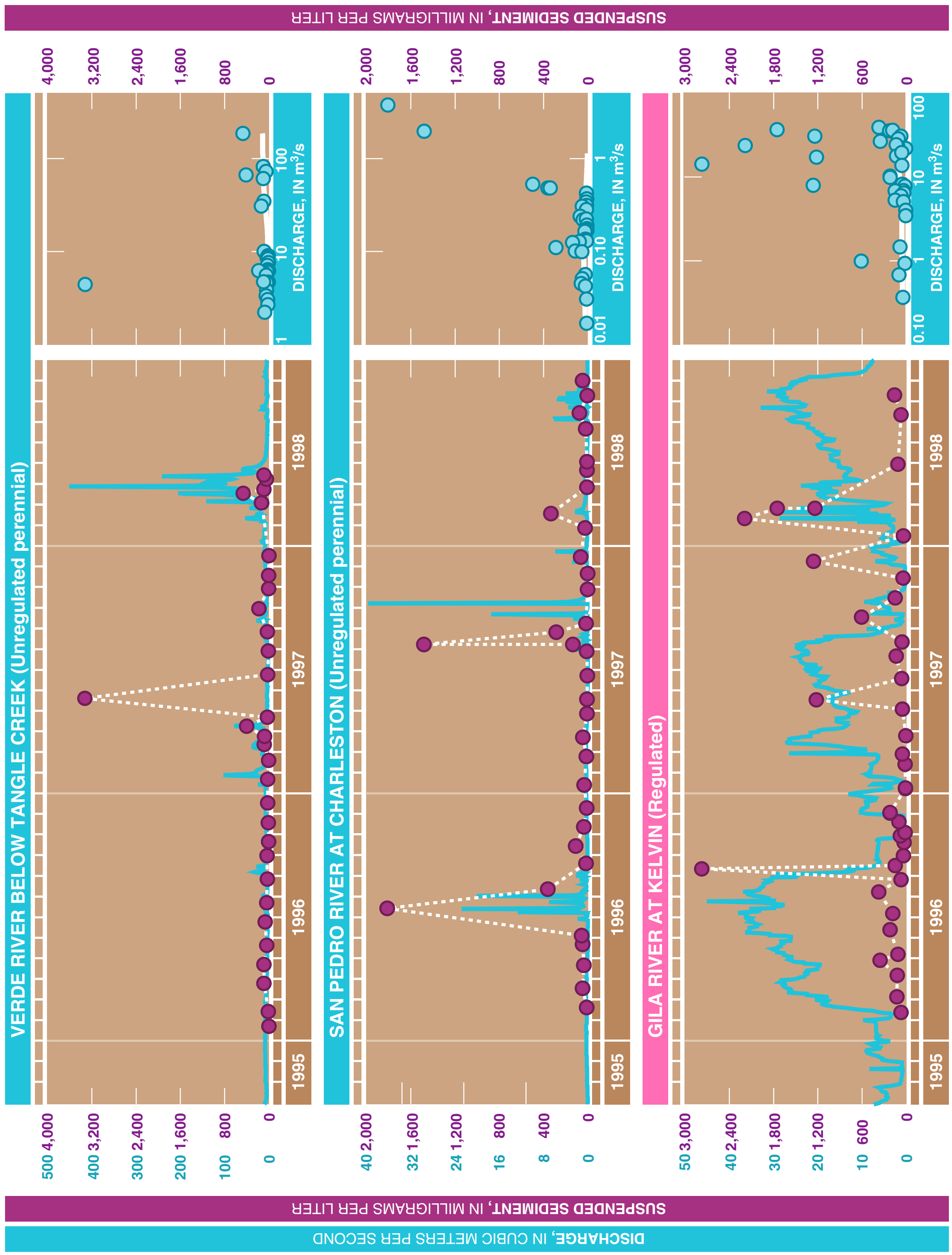


Figure 8. Continued. m^3/s, cubic meters per second.

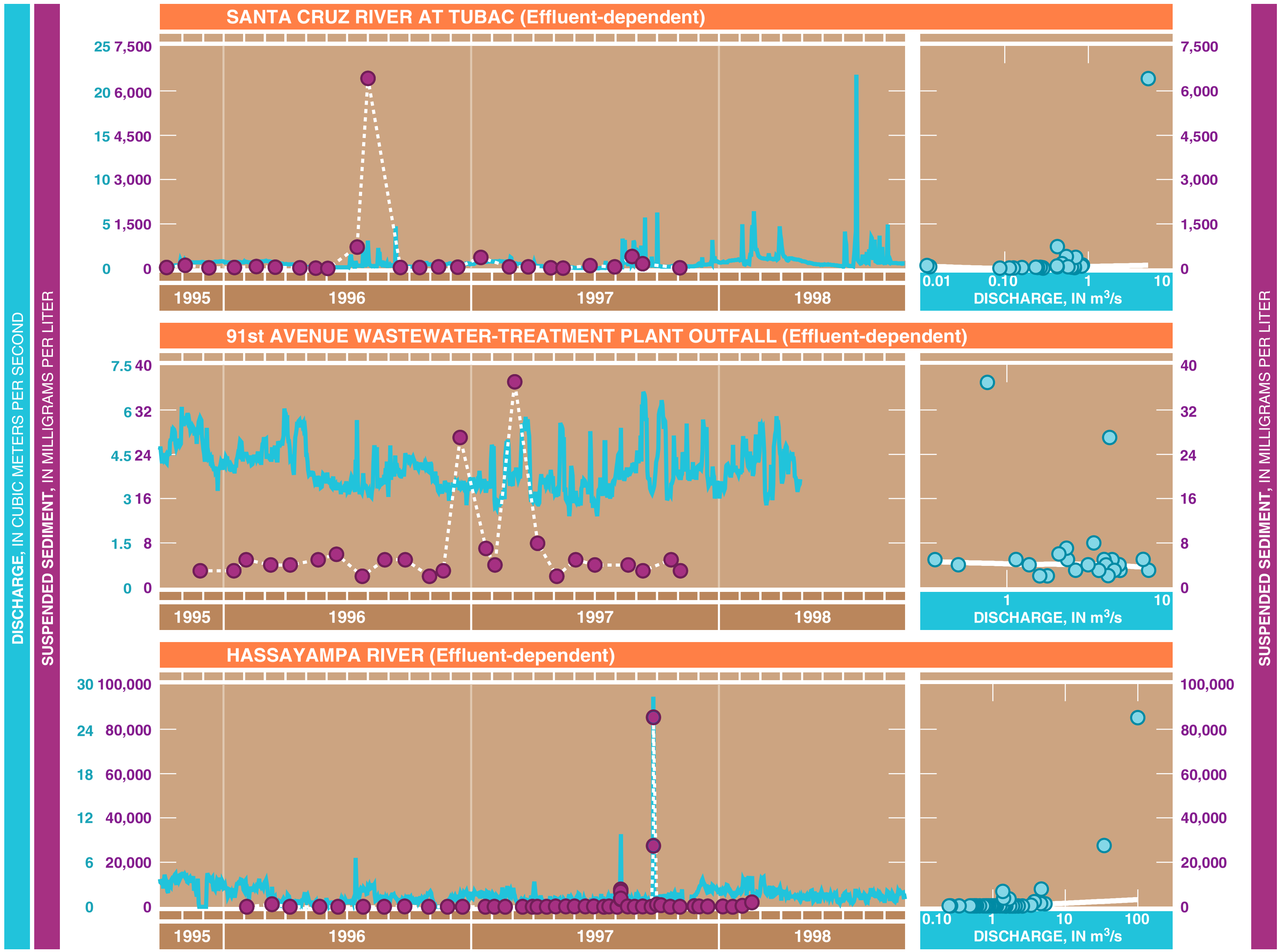


Figure 8. Continued. m^3/s, cubic meters per second.

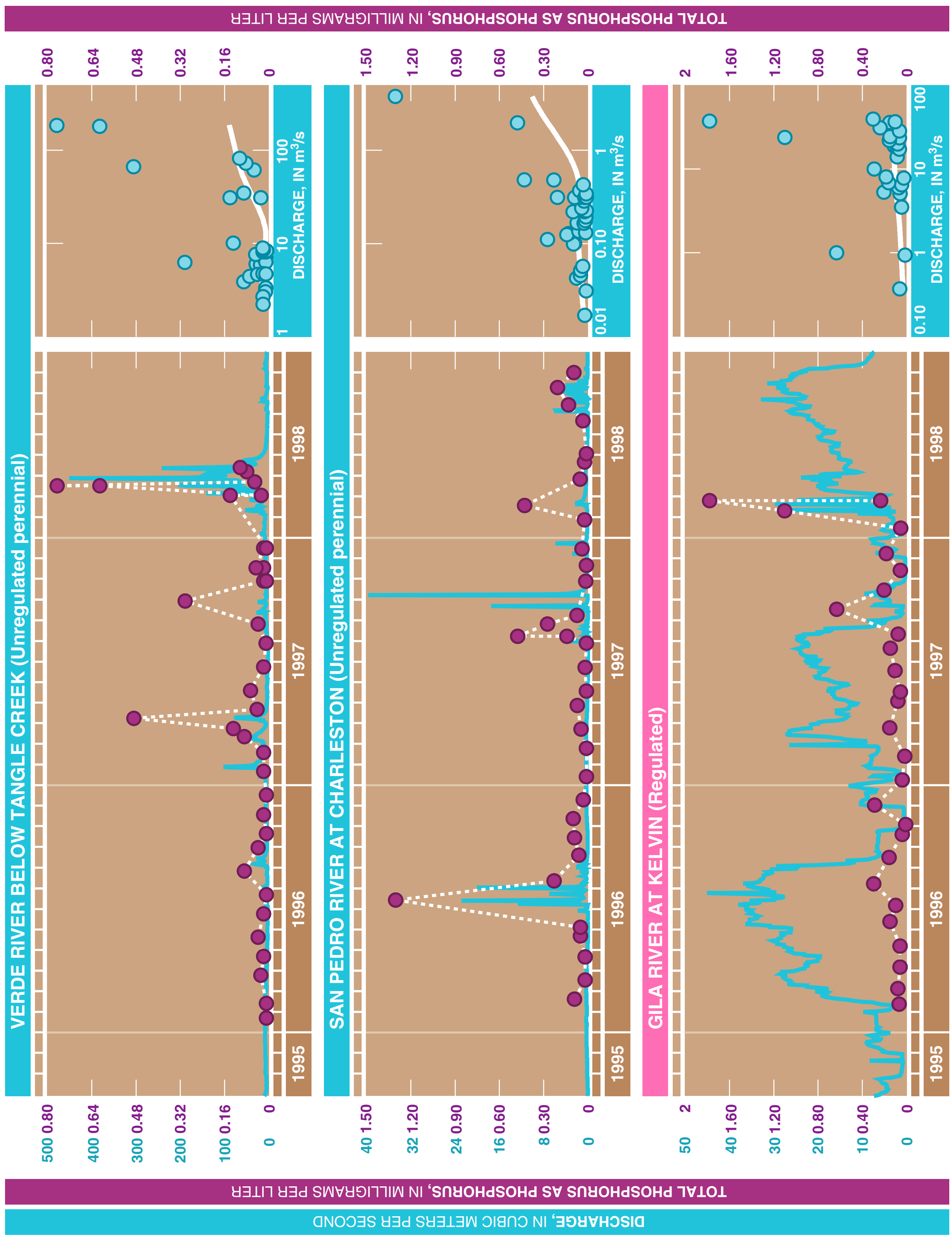


Figure 8. Continued. m^3/s, cubic meters per second.

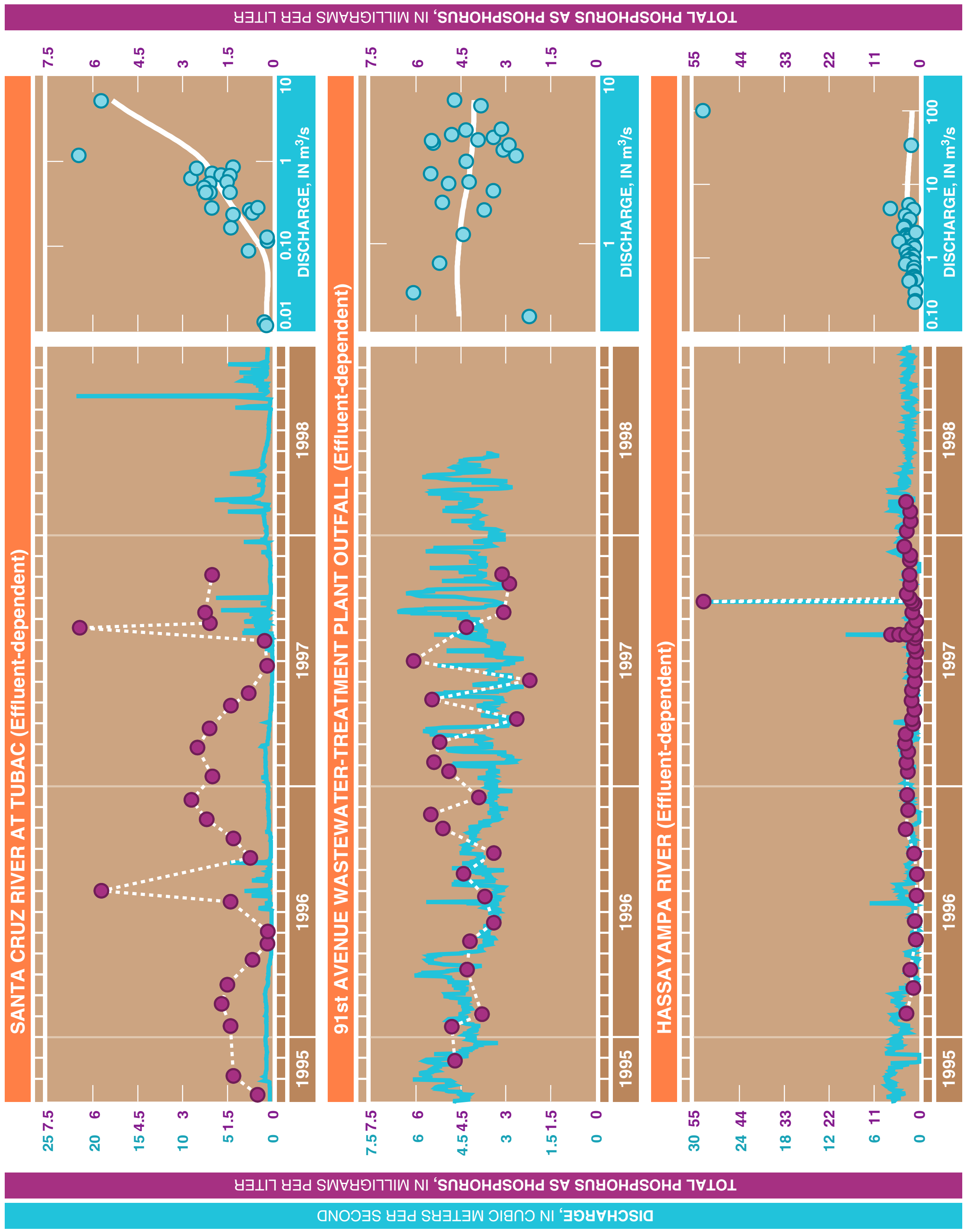


Figure 8. Continued. m^3/s, cubic meters per second.

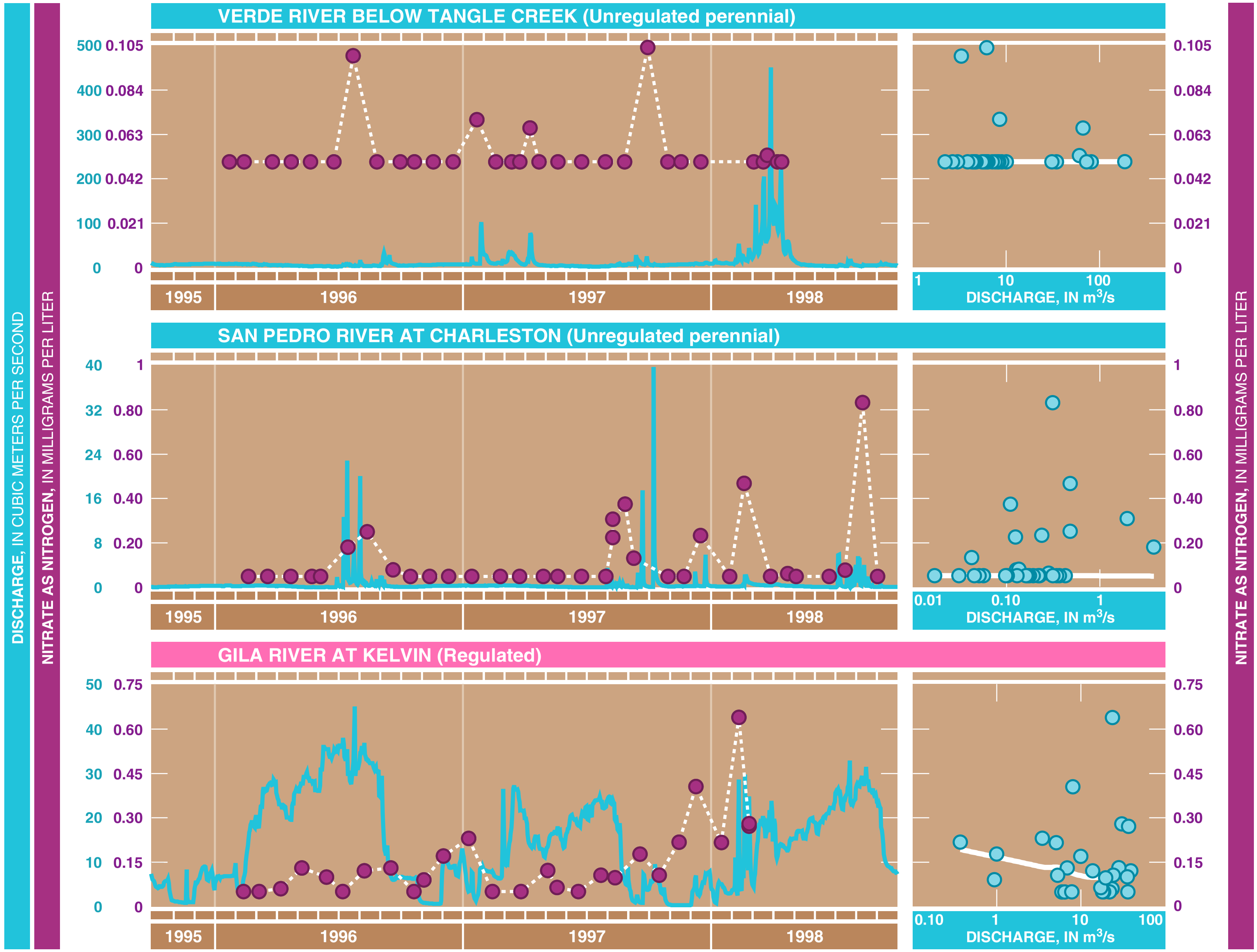


Figure 8. Continued. m^3/s, cubic meters per second.

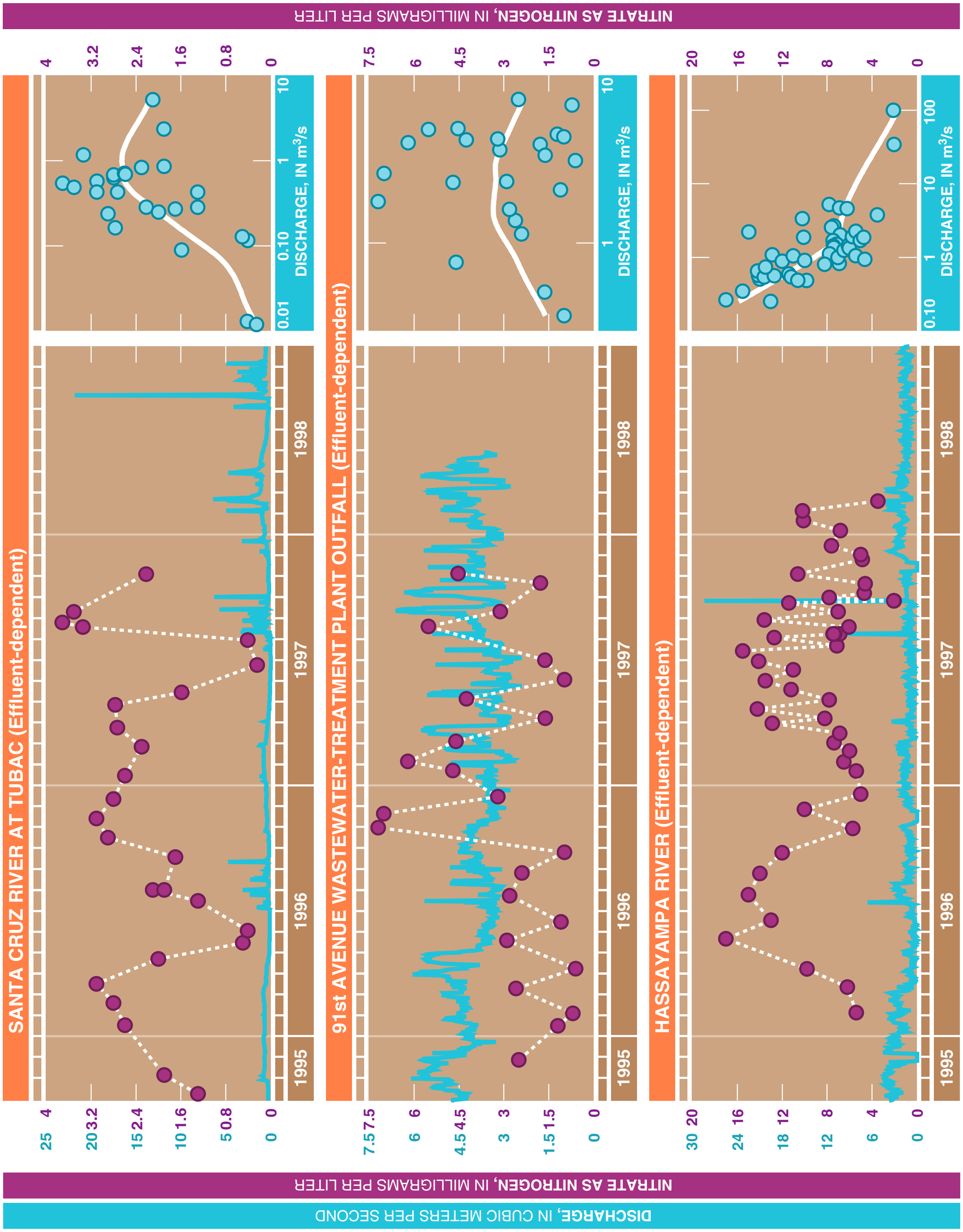


Figure 8. Continued. m^3/s, cubic meters per second.

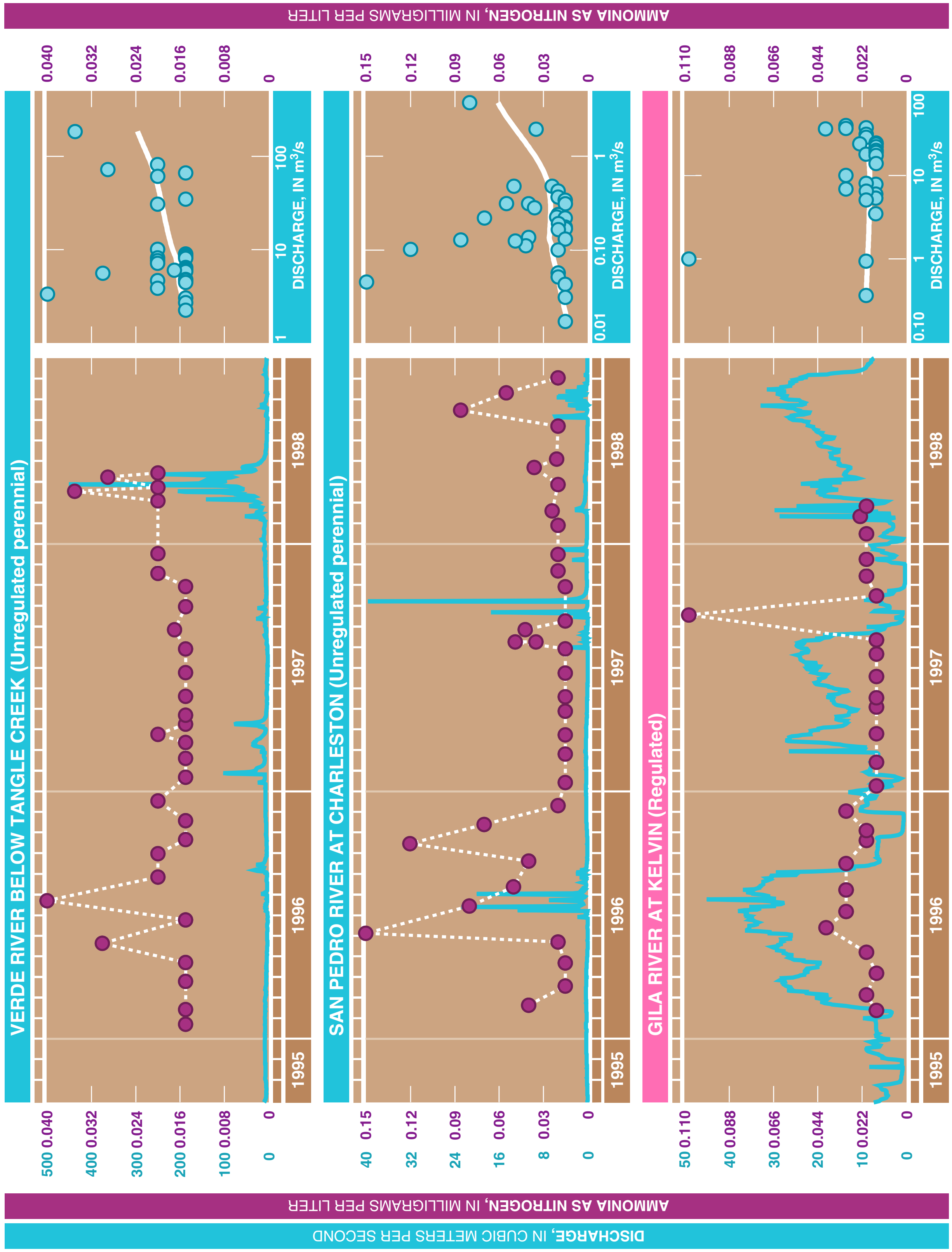


Figure 8. Continued. m^3/s, cubic meters per second.

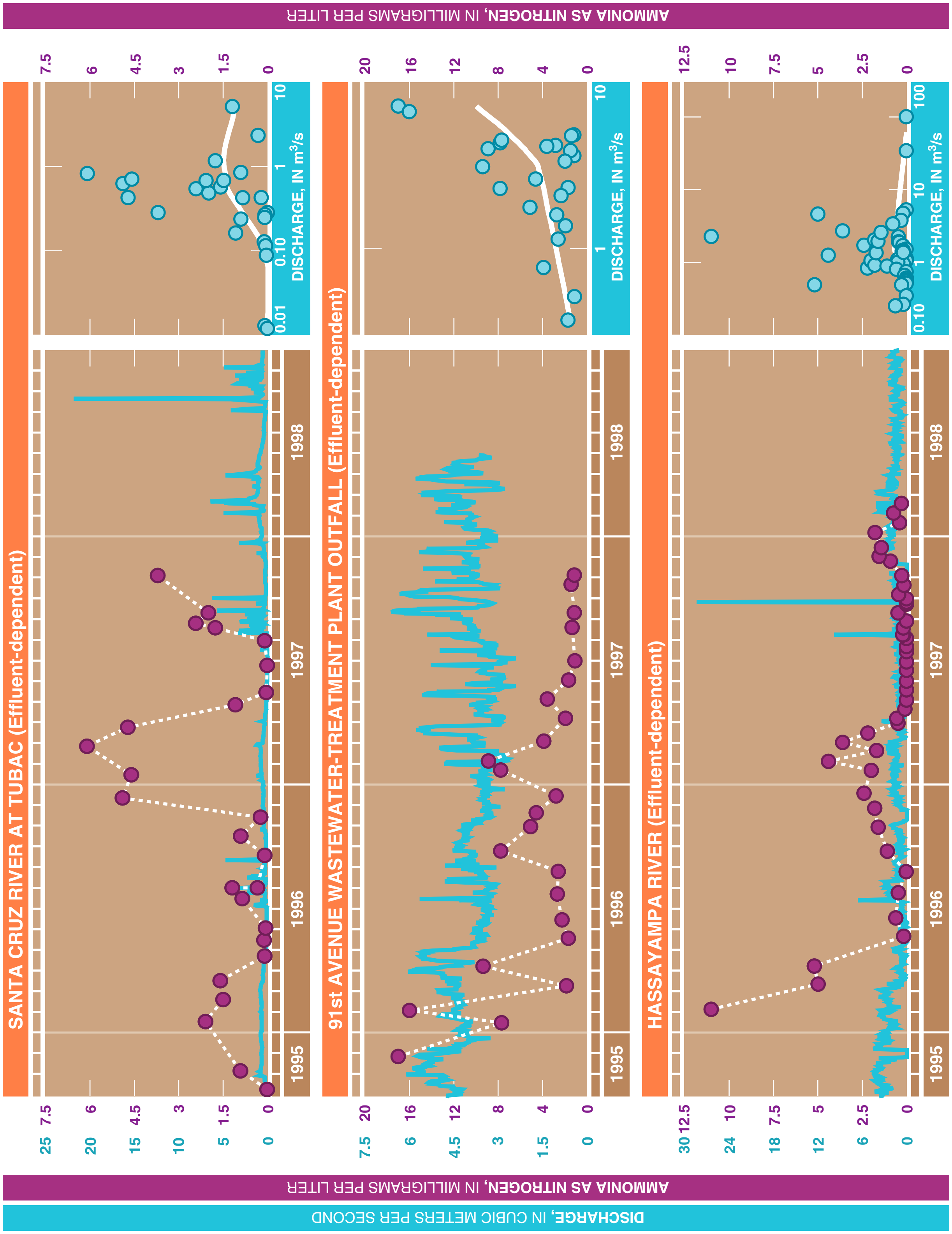


Figure 8. Continued. m^3/s, cubic meters per second.

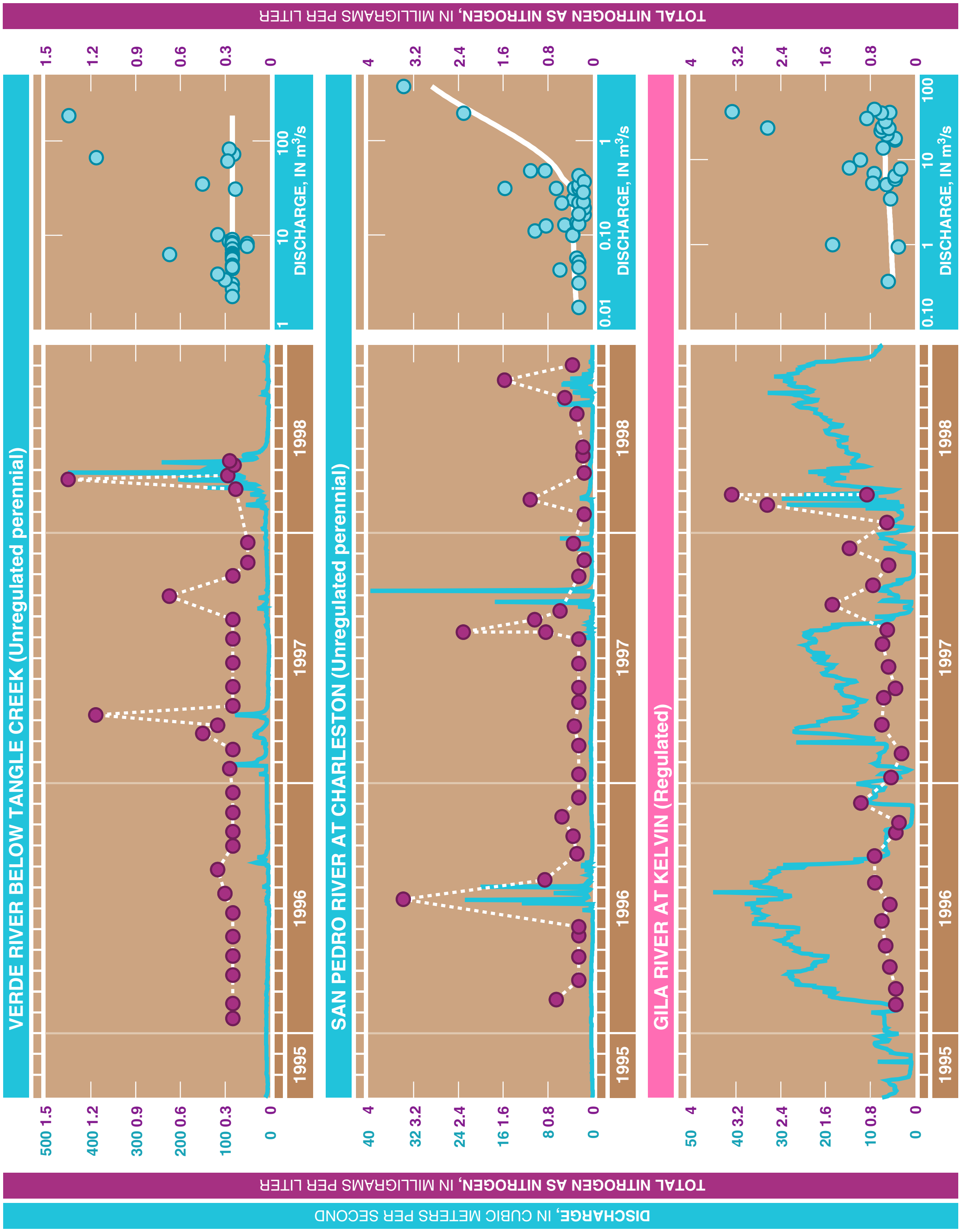


Figure 8. Continued. m^3/s, cubic meters per second.

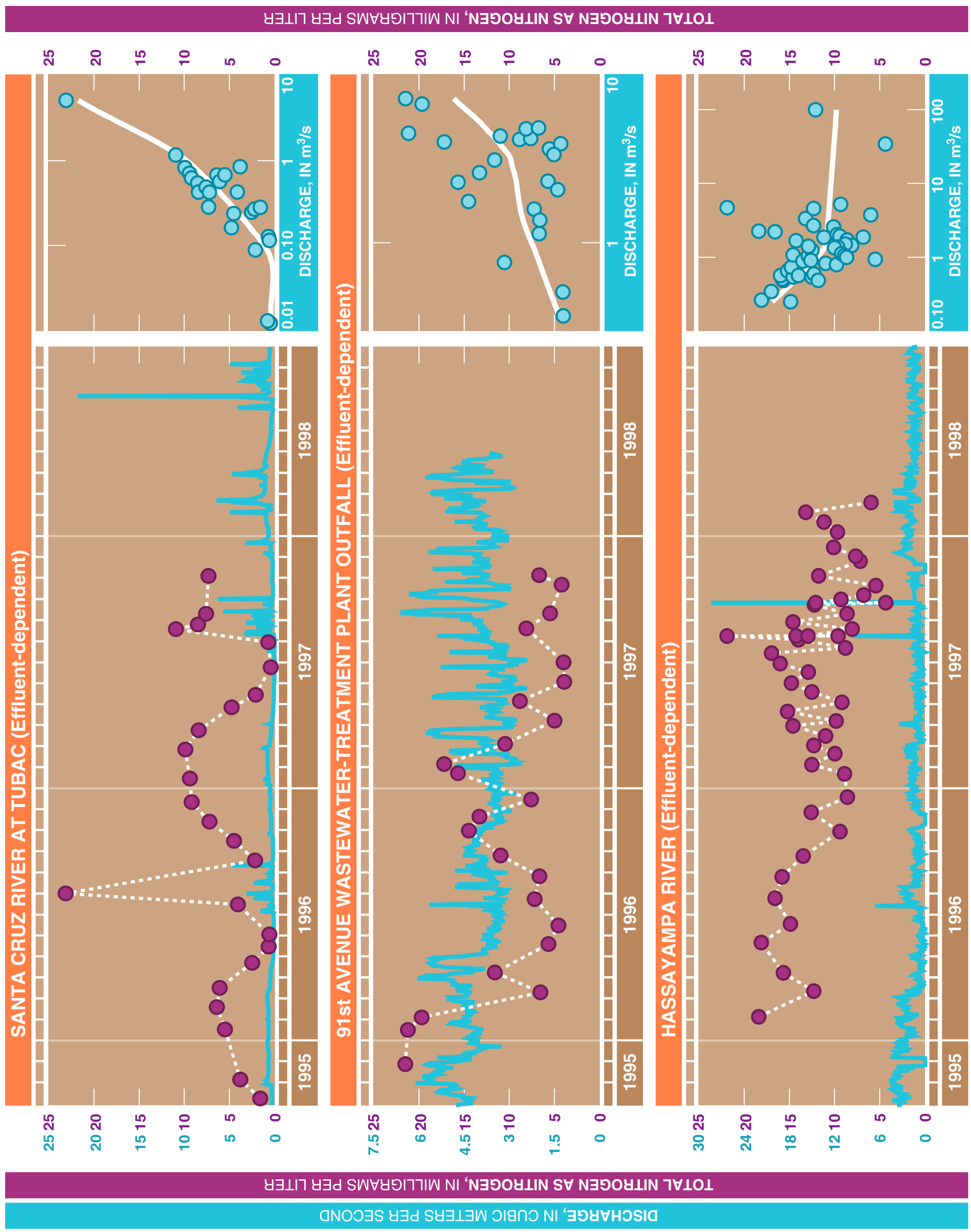


Figure 8. Continued. m^3/s, cubic meters per second.

Unregulated Urban Ephemeral Reaches

There were almost no significant correlations of stream properties and water-chemistry constituent concentrations with streamflow at stations on unregulated urban ephemeral reaches (table 7). This lack of correlation reflects the high variability of the stream properties and water-chemistry constituent concentrations that occur in direct runoff. Ephemeral streamflow at these stations was seasonal; streamflow only occurred in response to precipitation from regional winter storms and summer thunderstorms.

Regulated Reaches

The correlations of stream properties and water-chemistry constituent concentrations with streamflow at stations on regulated reaches generally were less significant than at stations on unregulated reaches, and the sign of the correlations was not as consistent (table 7; Gila River at Kelvin, figure 8). The number of cases of significant correlations of stream properties and water-chemistry constituent concentrations with streamflow was greater at stations several kilometers downstream from dams than at stations that were only a few kilometers downstream from dams. This was expected because the quality of the water released from the reservoir at any particular time should remain more or less constant, regardless of the discharge at which it is released. Any effects on water quality by streamflow would be dependent upon the conditions between the point of release and the point of sampling. Stations on regulated sections of the Agua Fria, Salt, and Verde Rivers are only a few kilometers downstream from the dams and have only four stream properties and water-chemistry constituent concentrations that are significantly correlated with streamflow. The Gila River at Winkelman and the Gila River at Kelvin, however, are several kilometers downstream from Coolidge Dam and have eight and nine stream properties and water-chemistry constituent concentrations, respectively, that are significantly correlated with streamflow.

Streamflow in regulated reaches was seasonal. The distribution of monthly streamflow volumes was unimodal; the center of the modes were in February for the Verde River, May for the Agua Fria River, and July for the Gila and Salt Rivers (table 1). Comparison of the seasonality of streamflow upstream and downstream from large reservoirs indicates that the storage of water on some rivers has greatly altered the seasonal patterns of flow. On the Agua Fria River, the center of the mode of monthly streamflow volumes shifts from February, for the reach above the reservoir near Rock Springs, to May, for the reach below Waddell Dam (table 1). On the Gila River at Kelvin, the monthly streamflow volumes changed from a bimodal distribution, with modes centered in January and August before regulation by Coolidge Dam, to a unimodal distribution with the mode centered in July (table 1). On the Salt River, the center of the mode of monthly streamflow volumes shifts from March, above the reservoir system near Roosevelt, to July, for the reach below Stewart Mountain Dam (table 1).

The seasonal variability of stream properties and water-chemistry constituent concentrations generally was not as well defined for regulated reaches as it was for unregulated reaches. At the Gila River at Kelvin, discharge was generally higher from February through September as a result of releases from Coolidge Dam, with the exception of two high flows during February of 1998 that resulted from runoff in the basin downstream from Coolidge dam (fig. 8). Stream temperature was warmer from early spring to early fall as a result of warmer air temperatures. Dissolved-oxygen percent saturation was fairly stable at about 100 percent through all seasons. As a result, dissolved-oxygen concentration was lower from late spring to early fall because of warmer stream temperatures during this period and because the 100-percent saturation concentration decreases with an increase in stream temperature. Concentrations of dissolved solids were also lower from early spring through early fall; however, this was a result of the higher discharges from Coolidge Dam during these seasons. The pH and the concentrations of suspended sediment, total phosphorus, ammonia, nitrate, and total nitrogen at the Gila River at Kelvin exhibited either a weak seasonality or an inconsistent seasonality from year to year. The largest variations in these stream properties and water-chemistry constituent concentrations occurred in the three samples collected from the runoff of February 1998; the pH decreased, and the concentrations of suspended sediment and the nutrients, except for ammonia, generally increased. This lack of variation, except during periods of runoff, indicates that seasonality has diminished for some stream properties and water-chemistry constituent concentrations in regulated stream reaches as a result of impounding runoff. There could also be a shift in the seasonal patterns of stream properties and water-chemistry constituent concentrations as a result of a shift in the seasonal pattern of streamflow. For example, concentrations of dissolved solids decrease as streamflow increases at the Gila River at Kelvin (fig. 8), so changes in the seasonality of streamflow at the Gila River at Kelvin probably have changed the seasonality of dissolved-solids concentrations. Before San Carlos Reservoir was in operation, concentrations of dissolved solids probably were high from April through June when streamflow typically was low, whereas concentrations are low during this period now as a result of reservoir releases.

Concentrations of dissolved solids in the Salt River below Stewart Mountain Dam (fig. 9) were not markedly seasonal; however, they did have a sinusoidal trend with a period of about 7 years. The troughs in the concentration data clearly were a function of the volume of water entering the reservoir system in past years. Because dissolved-solids concentrations were lower in the storm runoff and snowmelt entering the reservoir system than in the base flow entering the reservoir system, concentrations in reservoir releases decreased during or slightly after a year in which the inflow volume was large, and slowly increased until the next year in which the inflow volume was large. Dissolved solids in the reservoir systems of the Gila and Verde Rivers also followed this pattern; however, the behavior was not as clear, perhaps because their reservoir capacities were smaller (Cordy and others, 1998, table 2). Patterns for other stream properties and water-chemistry constituent concentrations in the Salt River below Stewart Mountain Dam may be present, but are not as clearly defined. The response of dissolved solids in regulated streams to large inflows to upstream reservoirs is significant. For the reservoir system on the Salt River, large volume inflows are needed to lower the concentration of dissolved solids below the SMCL for drinking water (500 mg/L) in reservoir releases.

Effluent-Dependent Reaches

Water chemistry in effluent-dependent reaches can vary in time as a result of seasonally variable biological and chemical reaction rates, and also as a result of seasonally variable surface- and ground-water inflows. Water chemistry can vary downstream from the original discharge point of the effluent as a result of biological and chemical reactions that occur as the effluent flows downstream, and also as a result of mixing with surface- and ground-water inflows to the stream. The strength and sign of correlations of the stream properties and water-chemistry constituent concentrations with streamflow at stations on effluent-dependent reaches varied by station (table 7 and fig. 8) and were related to the source of the effluent, the down-stream distance from the source, and the season at the time of sampling.

Samples collected from the Santa Cruz River at Cortaro (secondary treatment) and from the 91st Avenue Wastewater-Treatment Plant outfall (secondary treatment with nitrification/denitrification) represent water-quality conditions at the upstream end of effluent-dependent stream reaches during non-runoff conditions. Stream properties and water-chemistry constituent concentrations were not significantly correlated with streamflow at these stations, with the exception of dissolved-oxygen percent saturation and concentrations of dissolved solids and total nitrogen at the 91st Avenue Wastewater-Treatment Plant outfall and concentrations of nitrate, total ammonia and organic nitrogen, and total nitrogen at the Santa Cruz River at Cortaro (table 7). This general lack of correlation indicates that water quality is not necessarily related to release rates at the treatment plants, perhaps with the exception of total nitrogen. Stream properties and water-chemistry constituent concentrations for the 91st Avenue Wastewater-Treatment Plant generally were seasonal; stream temperature, pH, and dissolved-oxygen percent saturation generally were highest and concentrations of nutrients were generally lowest from early spring to early fall (fig. 8). The seasonality in water quality could result from the higher rates of biological respiration and nutrient consumption during the warmer months of the year.

Data for the Santa Cruz River at Rio Rico are more representative of actual water-quality conditions in an effluent-dependent reach immediately downstream from a wastewater-treatment plant than are data for the Santa Cruz River at Cortaro or 91st Avenue Wastewater-Treatment Plant because samples at Rio Rico were collected during periods of runoff as well as during effluent-only conditions. Concentrations of dissolved solids and most nutrient species were negatively correlated with streamflow (table 7). The negative correlation for nutrients indicates that concentrations of these constituents are diluted by direct runoff. This process is in contrast to the increase in nutrient concentrations that runoff causes in unregulated streams.

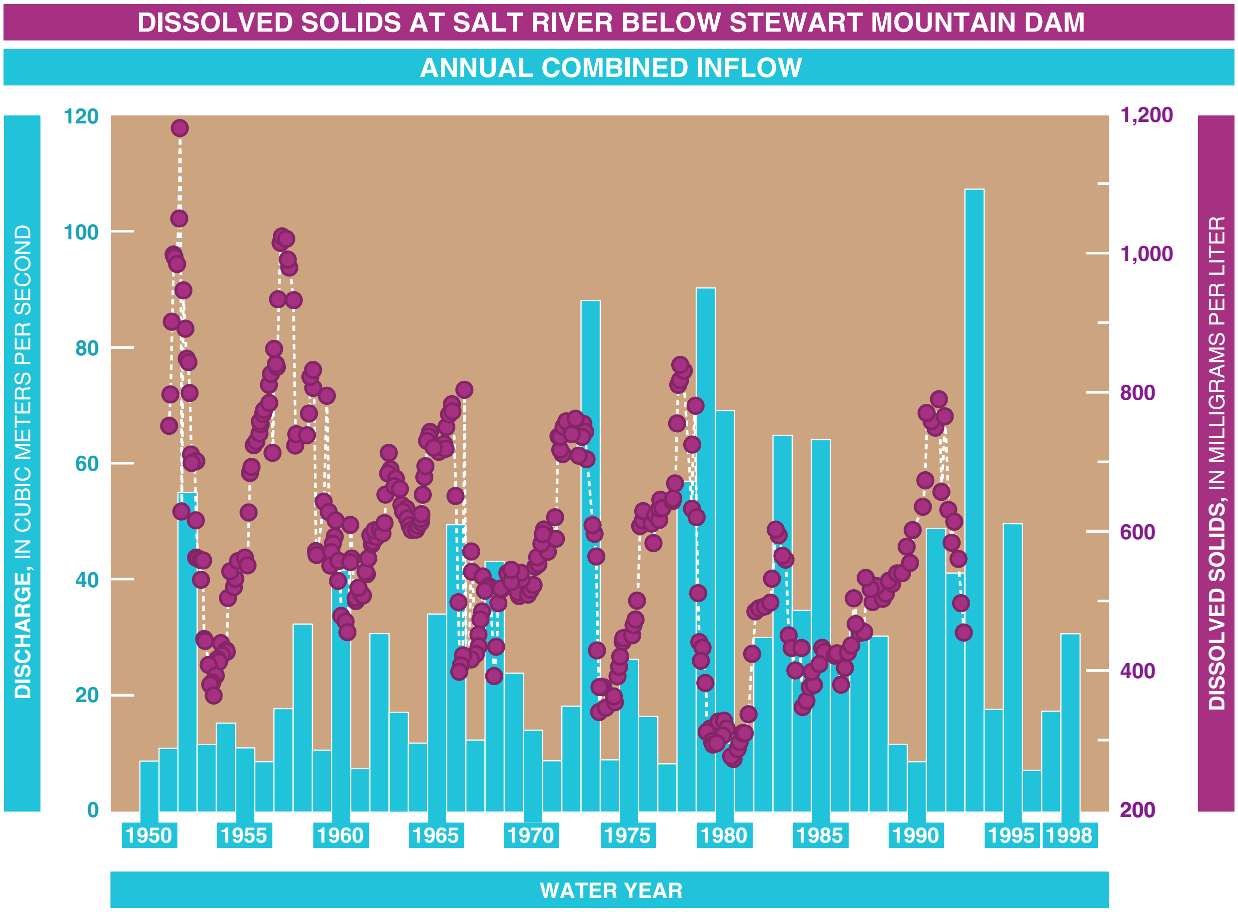


Figure 9. Dissolved-solids concentrations at the Salt River below Stewart Mountain Dam and the annual combined inflow from the Salt River and Tonto Creek to the reservoirs upstream from this station, 1950–98.

The Santa Cruz River at Tubac is about 25 km downstream from the station at Rio Rico and is representative of an effluent-dependent stream reach distant to the wastewater-treatment plant. Concentrations of suspended sediment and nutrients are positively correlated with streamflow and were generally lowest from early spring to early fall, except when summer thunderstorm runoff contributed to flow (table 7 and fig. 8). In contrast, stream temperature, disolved-oxygen percent saturation, and dissolved-solids concentration are negatively correlated with streamflow and were generally highest from early spring to early fall, except when summer thunderstorm runoff contributed to flow. This decrease in nutrients and increase in dissolved-oxygen percent saturation during the warmer months probably resulted from the growth of algae and aquatic plants in the upstream reach.

The Hassayampa River is representative of stream reaches having base flow sustained predominantly by agricultural effluent from fields that are irrigated with a combination of ground water and treated effluent from the 91st Avenue Wastewater-Treatment Plant. When there was little irrigation from early fall to early spring, stream properties and water-chemistry constituent concentrations, except suspended sediment concentrations, at this station were similar to those at the 91st Avenue Wastewater-Treatment Plant outfall and at the Gila River at Buckeye Canal (fig. 8, 91st Avenue Wastewater-Treatment Plant outfall and Hassayampa River). Conversely, during the irrigation season from early spring to early fall, stream properties and water-chemistry constituent concentrations, except for stream temperature and ammonia concentrations, at this station were dissimilar to those at the 91st Avenue Wastewater-Treatment Plant outfall and at the Gila River at Buckeye Canal. In the Hassayampa River, the stream temperature, pH, dissolved-oxygen percent saturation, and concentrations of dissolved oxygen, dissolved solids, nitrate, and total nitrogen increased during the irrigation season and were negatively correlated with streamflow (table 7 and fig. 8). In contrast, concentrations of total phosphorus and ammonia decreased during the irrigation season, and concentrations of suspended sediment, total phosphorus, and total ammonia plus organic nitrogen were positively correlated with streamflow (table 7, fig. 8). Concentrations of dissolved solids, nitrate, and total nitrogen probably increased as a result of an increase in the amount of irrigation wastewater that was returned to the Buckeye Canal and eventually flowed into the Hassayampa River. The decrease in ammonia and total phosphorus concentrations and increase in dissolved-oxygen concentrations during the warmer months probably resulted from the growth of algae and aquatic plants in the upstream reach.

Upstream Conditions

The relation of stream properties and water-chemistry constituent concentrations to upstream conditions, such as stream regulation, municipal and agricultural wastewater disposal, stream permanence, and land and water use, was determined by comparing amongst data from stations with various upstream conditions. The effects of impounding water in large reservoirs for future use and returning treated wastewater to streams after municipal or agricultural use were determined by comparing amongst data from stations on unregulated, regulated, and effluent-dependent reaches. The relation of water quality to stream permanence reflects upstream climate and hydrogeologic conditions and also was determined by comparing amongst data from stations on unregulated perennial, intermittent, and urban ephemeral reaches.

Sixteen stations representing various upstream conditions in the study area were selected for data comparison. Of the 16 stations, 4 were on unregulated perennial reaches, 4 were on unregulated intermittent or urban ephemeral reaches, 4 were on regulated reaches, and 4 were on effluent-dependent reaches. In most cases the 4 stations within each of the 4 groups of stations represented different upstream conditions within that group (table 8). Samples from each station were selected using specific criteria to remove temporal or streamflow biases in the water-quality data. For each station, only the 3 most recent samples for each of the 10 deciles of streamflow were selected. A variation of this sample selection procedure was made for unregulated intermittent and urban ephemeral stations that lack flow in the lower deciles of streamflow; for these stations, an equal number (4–7) of the most recent samples were selected from each non-zero decile of streamflow. In some cases where there were an inadequate number of samples for a certain decile of streamflow, a sample from an adjacent decile of streamflow was used. Seasonal effects were assumed to be accounted for by this selection method because, as was shown in the previous section of this report, most of the seasonal trends in the stream properties and water-chemistry constituent concentrations were related to streamflow. The selection procedures resulted in about 30 samples for each station that were representative of recent conditions and were unbiased with respect to streamflow conditions for the station.

Differences in the stream properties and water-chemistry constituent concentrations at the 16 stations were determined with the rank-sum test (Wilcoxon, 1945) and the Tukey-Kramer honest significance difference (HSD; Kramer, 1956) tests using computer software (SPSS, Inc., 1997). Data for all stations were ranked to reduce the departure from a normal distribution, which is an assumption of the tests. The rank-sum test was performed to detect differences in the means of the data for two stations, for each stream property and water-chemistry constituent, for all possible pairs of stations. The Tukey-Kramer HSD test was performed to determine which stations had similar means of ranked data (Helsel and Hirsch, 1992) in the context of all other stations. The Tukey-Kramer HSD test requires that results from an analysis of variance test on data for all 16 stations indicate there is at least one station with a mean that is significantly different ($p<0.05$) from the rest; this requirement was met for every stream property and water-chemistry constituent. The rank-sum and Tukey-Kramer HSD tests are seemingly very similar, but an important distinction must be made about the two tests. The rank-sum test determines that the mean of data for one station is different from the mean for another station if the two means differ by a certain amount; this amount is based on data for only those two stations. The Tukey-Kramer HSD test also determines that the means of data for two stations are different on the basis of the means differing by a certain amount; however, this amount is based on data for all 16 stations, not just the 2 being compared. The rank-sum test is more sensitive than the Tukey-Kramer HSD test to differences in data between two stations; however, the rank-sum test does not determine this difference in the context of the distribution of data from all other stations.

Table 8. Selected upstream conditions that could affect surface-water quality at selected monitoring stations in the Central Arizona Basins study area

Station	Land uses
Unregulated perennial reaches	
Salt River near Roosevelt	Rangeland
West Clear Creek	Minimally developed
Verde River below Tangle Creek	Mostly rangeland, small amounts of urban land use and irrigation several kilometers upstream
San Pedro River at Charleston	Mostly rangeland, small amounts of urban land use and irrigation
Unregulated intermittent or urban ephemeral reaches	
Station	**Land uses**
Wet Bottom Creek	Rangeland
Turkey Creek	Rangeland
San Pedro River at Winkelman	Rangeland, and small amounts of urban land use and irrigation
Indian Bend Wash	Municipal
Regulated reaches	
Station	**Distance downstream from regulating structure, in kilometers**
Salt River below Stewart Mountain Dam	6
Verde River below Bartlett Dam	3
Central Arizona Project Canal near Parker	13
Gila River at Kelvin	80
Effluent-dependent reaches	
Station	**Source of wastewater**
Santa Cruz River at Tubac	Municipal wastewater treatment plant, secondary treatment
Santa Cruz River at Cortaro	Municipal wastewater treatment plant, secondary treatment
91st Avenue Wastewater-Treatment Plant outfall	Municipal wastewater treatment plant, secondary treatment with nitrification/denitrification
Hassayampa River	Treated municipal wastewater applied to agricultural fields and returned to the stream

Results from the Tukey-Kramer HSD test indicate that for pH, dissolved-oxygen percent saturation, and nutrients, stations on reaches with similar stream regulation, stream permanence, and disposal of waste-water conditions tend to group together; that is, the mean ranks generally were not significantly different at the $p<0.05$ level (table 9). This suggests that stream regulation, stream permanence, and wastewater disposal upstream from the station are important conditions that affect these stream properties and water-chemistry constituents.

Stations on unregulated perennial reaches and regulated reaches generally had higher pH values than stations on unregulated intermittent and urban ephemeral, and effluent-dependent reaches. Dissolved-oxygen percent saturation generally was not significantly different among stations. The three stations on reaches that receive only municipal effluent, however, had significantly lower values than the other stations. Dissolved oxygen at these stations probably is low because of the high biological and chemical oxygen demand of the treated wastewater.

Table 9. Paired-station and multiple-station comparisons of stream properties and water-chemistry constituent concentrations at selected surface-water quality monitoring stations in the Central Arizona Basins study area

[The three most recent samples, as of 1998, for each decile of streamflow were used in this analysis. Stations are ordered by the mean rank for the constituent from highest to lowest. **I**, results from the rank-sum test indicate the mean constituent level is not significantly different ($p<0.05$) from that for the station with an **X**. Colored cells, results from the Tukey-Kramer honest significant difference test on ranked data indicate mean constituent levels at the stations within a given column or row are not significantly different ($p<0.05$) from that for the station with an **X**. Colors indicate type of streamflow at station: blue, unregulated perennial; green, unregulated intermittent; yellow, unregulated urban ephemeral; magenta, regulated; orange, effluent dependent. For some constituents, stations were excluded because of an insufficient number of samples]

Station	Station																
	X	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
pH																	
Verde River below Tangle Creek	1	X	I														
West Clear Creek	2	I	X	I													
Verde River below Bartlett Dam	3		I	X													
Salt River below Stewart Mountain Dam	4				X	I	I	I									
Gila River near Kelvin	5				I	X	I	I									
Salt River near Roosevelt	6				I	I	X	I									
San Pedro River at Charleston	7				I	I	I	X	I								
Central Arizona Project Canal near Parker	8							I	X	I	I						
Hassayampa River	9								I	X	I						
San Pedro River at Winkelman	10								I	I	X	I					
Wet Bottom Creek	11										I	X	I				
Indian Bend Wash	12											I	X	I	I	I	
Turkey Creek	13												I	X	I	I	
Santa Cruz River at Tubac	14												I	I	X		
Santa Cruz River at Cortaro	15												I	I		X	
91st Avenue Wastewater-Treatment Plant outfall	16																X
Dissolved oxygen, percent saturation																	
Verde River below Bartlett Dam	1	X	I	I	I	I	I	I									
West Clear Creek	2	I	X	I	I	I	I	I									
Verde River below Tangle Creek	3	I	I	X	I	I	I	I									
Central Arizona Project Canal near Parker	4	I	I	I	X	I	I	I	I	I							
Salt River near Roosevelt	5	I	I	I	I	X	I	I	I	I							
Salt River below Stewart Mountain Dam	6	I	I	I	I	I	X	I	I	I	I						
Hassayampa River	7	I	I	I	I	I	I	X	I	I	I	I					
Gila River at Kelvin	8				I	I	I	I	X	I	I	I					
San Pedro River at Charleston	9				I	I	I	I	I	X	I	I					
Wet Bottom Creek	10						I	I	I	I	X	I					
Indian Bend Wash	11							I	I	I	I	X					
Santa Cruz River at Tubac	12												X	I			
91st Avenue Wastewater-Treatment Plant outfall	13												I	X			
Santa Cruz River at Cortaro	14														X		

Table 9. Paired-station and multiple-station comparisons of stream properties and water-chemistry constituent concentrations at selected surface-water quality monitoring stations in the Central Arizona Basins study area—Continued

Station	X	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Dissolved solids																	
Hassayampa River	1	X															
91st Avenue Wastewater-Treatment Plant outfall	2		X	I	I	I											
Salt River near Roosevelt	3		I	X	I												
Gila River at Kelvin	4		I	I	X	I											
San Pedro River at Winkelman	5		I		I	X											
Central Arizona Project Canal near Parker	6						X	I	I								
Santa Cruz River at Cortaro	7						I	X	I								
Salt River below Stewart Mountain Dam	8						I	I	X								
Santa Cruz River at Tubac	9									X		I	I				
Verde River below Tangle Creek	10										X	I	I				
Turkey Creek	11									I	I	X	I	I	I	I	
Indian Bend Wash	12									I	I	I	X	I	I	I	
San Pedro River at Charleston	13											I	I	X	I		
Verde River below Bartlett Dam	14											I	I	I	X		
West Clear Creek	15											I	I			X	I
Wet Bottom Creek	16															I	X
Suspended sediment																	
San Pedro River at Winkelman	1	X															
Hassayampa River	2		X	I	I												
Gila River at Kelvin	3		I	X	I												
San Pedro River at Charleston	4		I	I	X	I	I	I	I								
Santa Cruz River at Tubac	5				I	X	I	I	I								
Santa Cruz River at Cortaro	6				I	I	X	I	I	I							
Verde River below Tangle Creek	7				I	I	I	X	I	I							
Salt River near Roosevelt	8				I	I	I	I	X	I							
Verde River below Bartlett Dam	9						I	I	I	X							
West Clear Creek	10										X	I					
91st Avenue Wastewater-Treatment Plant outfall	11										I	X	I				
Salt River below Stewart Mountain Dam	12											I	X				
Wet Bottom Creek	13													X			

Table 9. Paired-station and multiple-station comparisons of stream properties and water-chemistry constituent concentrations at selected surface-water quality monitoring stations in the Central Arizona Basins study area—Continued

Station		Station															
	X	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Total phosphorus																	
Santa Cruz River at Cortaro	1	X	I														
91st Avenue Wastewater-Treatment Plant outfall	2	I	X														
Hassayampa River	3			X	I												
Santa Cruz River at Tubac	4			I	X												
Turkey Creek	5					X	I	I									
Indian Bend Wash	6					I	X	I	I								
San Pedro River at Winkelman	7					I	I	X	I								
Gila River at Kelvin	8						I	I	X								
Verde River below Bartlett Dam	9									X	I						
San Pedro River at Charleston	10									I	X	I	I				
Verde River below Tangle Creek	11										I	X	I	I			
Salt River near Roosevelt	12										I	I	X	I	I	I	
Salt River below Stewart Mountain Dam	13											I	I	X			
West Clear Creek	14												I		X	I	I
Central Arizona Project Canal near Parker	15												I		I	X	I
Wet Bottom Creek	16														I	I	X
Nitrate																	
Hassayampa River near Arlington	1	X															
91st Avenue Wastewater-Treatment Plant outfall	2		X	I													
Santa Cruz River at Tubac	3		I	X													
Indian Bend Wash	4				X	I											
San Pedro River at Winkelman	5				I	X											
Turkey Creek	6						X										
Santa Cruz River at Cortaro	7							X	I								
Central Arizona Project Canal near Parker	8							I	X		I	I					
Verde River below Bartlett Dam	9									X	I	I	I				
Gila River at Kelvin	10								I	I	X	I	I				
San Pedro River at Charleston	11								I	I	I	X	I				
Salt River Below Stewart Mountain Dam	12									I	I	I	X				
Wet Bottom Creek	13													X	I		
West Clear Creek	14													I	X	I	
Salt River near Roosevelt	15														I	X	I
Verde River below Tangle Creek	16															I	X

Table 9. Paired-station and multiple-station comparisons of stream properties and water-chemistry constituent concentrations at selected surface-water quality monitoring stations in the Central Arizona Basins study area—Continued

Station	X	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Ammonia																	
Santa Cruz River at Cortaro	1	X															
91st Avenue Wastewater-Treatment Plant outfall	2		X														
Santa Cruz River at Tubac	3			X	I												
Hassayampa River	4			I	X												
Indian Bend Wash	5					X											
Turkey Creek	6						X										
Verde River below Bartlett Dam	7							X	I	I	I	I	I				
San Pedro River at Charleston	8							I	X	I	I	I	I	I			
Gila River at Kelvin	9							I	I	X	I	I	I	I			
Central Arizona Project Canal near Parker	10							I	I	I	X	I	I	I			
West Clear Creek	11							I	I	I	I	X	I	I			
Salt River below Stewart Mountain Dam	12							I	I	I	I	I	X	I	I	I	
Salt River near Roosevelt	13								I	I	I	I	I	X	I		
Verde River below Tangle Creek	14												I	I	X	I	
Wet Bottom Creek	15												I		I	X	
Total ammonia plus organic nitrogen																	
Santa Cruz River at Cortaro	1	X															
91st Avenue Wastewater-Treatment Plant outfall	2		X														
Hassayampa River	3			X	I	I											
Turkey Creek	4			I	X	I	I	I									
Santa Cruz River at Tubac	5			I	I	X	I	I									
Indian Bend Wash	6				I	I	X	I									
San Pedro River at Winkelman	7				I	I	I	X	I								
Gila River at Kelvin	8							I	X	I							
Verde River below Bartlett Dam	9								I	X							
Salt River below Stewart Mountain Dam	10										X	I	I				
Central Arizona Project Canal near Parker	11										I	X	I				
San Pedro River at Charleston	12										I	I	X	I	I	I	
Salt River near Roosevelt	13												I	X	I	I	
Wet Bottom Creek	14												I	I	X	I	
Verde River below Tangle Creek	15												I	I	I	X	I
West Clear Creek	16															I	X

Table 9. Paired-station and multiple-station comparisons of stream properties and water-chemistry constituent concentrations at selected surface-water quality monitoring stations in the Central Arizona Basins study area—Continued

Station	X	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Total nitrogen																	
Santa Cruz River at Cortaro	1	X															
Hassayampa River	2		X	I													
91st Avenue Wastewater-Treatment Plant outfall	3		I	X													
Santa Cruz River at Tubac	4				X			I									
Indian Bend Wash	5					X	I	I									
San Pedro River at Winkelman	6					I	X	I									
Turkey Creek	7				I	I	I	X									
Gila River at Kelvin	8								X	I	I						
Verde River below Bartlett	9								I	X	I		I				
Central Arizona Canal near Parker	10								I	I	X	I	I				
Salt River below Stewart Mountain Dam	11										I	X	I				
San Pedro River at Charleston	12									I	I	I	X	I	I		
Salt River near Roosevelt	13												I	X	I	I	I
Wet Bottom Creek	14												I	I	X	I	I
West Clear Creek	15													I	I	X	I
Verde River below Tangle Creek	16													I	I	I	X

Concentrations of nutrients generally were lowest at stations on perennial streams, somewhat higher at stations on regulated reaches, and highest at stations on effluent-dependent reaches (table 9). Nutrient concentrations at stations on unregulated intermittent and urban ephemeral reaches—Turkey Creek, the San Pedro River near Winkelman, and Indian Bend Wash—tended to group together or with concentrations at stations on effluent-dependent reaches. In contrast, nutrient concentrations for Wet Bottom Creek tended to group with those at stations on unregulated perennial reaches (table 9). Nutrient concentrations in regulated reaches could be different from those in unregulated perennial reaches because of physical processes or biological processes that occur in the reservoir, such as particle settling, nutrient consumption/production by aquatic life, or because reservoir outflow contains both base flow and runoff that were captured and mixed in the reservoir. Nutrient concentrations probably were higher at stations on unregulated intermittent and urban ephemeral reaches than at stations on unregulated perennial reaches because nutrient concentration tended to increase with streamflow (table 7), and the high-flow samples represented a larger percentage of the total samples for stations on unregulated intermittent and urban ephemeral reaches than for stations on unregulated perennial reaches. Nutrient concentrations were higher at stations on effluent-dependent reaches than at stations on unregulated reaches because the wastewater effluent has high concentrations of nutrients.

Results from the Tukey-Kramer HSD test indicate that dissolved-solids and suspended-sediment concentrations for stations with similar stream permanence, stream regulation, or return of wastewater did not group together. These results indicate that some other factor affecting water quality is more prevalent than these factors. Upstream basin geology and sediment supply are likely to be more prevalent factors; however, additional information concerning the upstream geology and abundance, availability, and size distribution of sediment is needed to substantiate this hypothesis.

The relation of surface-water quality to upstream conditions, such as stream regulation, municipal and agricultural wastewater disposal, stream permanence, and land and water use also was determined by performing the rank-sum test on data for two stations with different upstream conditions (table 9). Stream regulation was found to affect water quality as determined by comparison of data for stations immediately upstream and downstream from the large reservoirs on the Salt and Verde Rivers. Decreases in the dissolved solids in both rivers, and suspended sediment in the Salt River represent improvements in water quality for drinking-water purposes, whereas increases in nitrate, total ammonia plus organic nitrogen, and total nitrogen observed in both rivers represent water-quality degradation. Dissolved-oxygen percent saturation was not affected by stream regulation, as indicated by the lack of significantly different data for the stations upstream and downstream from the reservoirs on both the Salt and Verde Rivers.

Change in the quality of water from before use to after use reflects the effects of both land and water use. While the obvious effect of using stored water from the large reservoirs on the Agua Fria, Gila, Salt, and Verde Rivers for municipal and agricultural purposes was several kilometers of dry streambed downstream from the dams, there were also differences in the quality of the water that was returned to the stream. Water quality in the Salt River degraded as a result of municipal water use in the Phoenix metropolitan area as determined by comparing data from the Salt River below Stewart Mountain Dam and the Verde River below Bartlett Dam to data from the 91st Avenue Wastewater-Treatment Plant outfall, which constitutes nearly all the flow throughout most of the year at this point on the Salt River. The treated water returned after municipal use had lower values for dissolved-oxygen percent saturation and higher concentrations of nutrients than the water diverted from the streams.

Although results from the Tukey-Kramer HSD test indicate that data from stations on effluent-dependent reaches tended to group together and were significantly different from data from other stations, the rank-sum test indicates that there were also differences amongst data from stations on effluent-dependent reaches. These differences can be attributed to the source of the wastewater. Comparison of data from the Santa Cruz River at Cortaro with data from the 91st Avenue Wastewater-Treatment Plant outfall indicated that concentrations of ammonia, total ammonia plus organic nitrogen, and total nitrogen were higher in wastewater from facilities with secondary treatment than in wastewater from facilities with secondary treatment with nitrification/denitrification, whereas nitrate and dissolved-oxygen percent saturation were lower. Total phosphorus concentrations were not significantly different for the two types of wastewater treatment. Differences in water quality between the 91st Avenue Wastewater-Treatment Plant outfall and the Hassayampa River reflected the effects of irrigating fields with the treated municipal effluent and with ground water from wells along the Buckeye Canal. The pH, dissolved-oxygen percent saturation, and concentrations of dissolved solids, suspended sediment, and nitrate were higher at the Hassayampa River than at the 91st Avenue Wastewater-Treatment Plant outfall, whereas concentrations of ammonia and total ammonia plus organic nitrogen were lower. The increase in nitrate concentrations and decrease in ammonia and total ammonia plus organic nitrogen concentration are, in part, due to conversion of ammonia to nitrate and to the added nitrate from fertilizers in agricultural runoff.

Results from the rank-sum test on the stream properties and water-chemistry constituent concentrations at the four stations on perennial reaches and at the four stations on unregulated intermittent and ephemeral reaches indicate that land use of the upstream drainage basin has an affect on water quality. The pH and dissolved-oxygen percent saturation are higher and concentrations of dissolved solids, suspended sediment, total phosphorus, nitrate, ammonia and organic nitrogen, and total nitrogen are lower at West Clear Creek than at the San Pedro River near Charleston (table 9). The stream properties and water-chemistry constituent concentrations at the Verde River below Tangle Creek and the Salt River near Roosevelt typically have values equivalent to or between those of West Clear Creek and those of the San Pedro River near Charleston (table 9). The amount of municipal and agricultural development in the upstream drainage basin follows a similar pattern—it is lowest at West Clear Creek, highest at the San Pedro River near Charleston, and in between the lowest and highest at the Verde River below Tangle Creek and the Salt River near Roosevelt (table 8). This similarity in the rankings of stream properties and water-chemistry constituent concentrations suggests that upstream land use affects water quality[6]. The four stations on unregulated intermittent and ephemeral reaches also represented different amounts of municipal or agricultural development (table 8). On the basis of results from the rank-sum test on data from the four stations on unregulated intermittent and ephemeral reaches, concentrations of dissolved solids and most nutrients at Wet Bottom Creek were lower than those at Indian Bend Wash and the San Pedro River at Winkelman. This difference in water quality can also be attributed to differences in upstream land use because there is municipal land use or irrigation upstream from the San Pedro River at Winkelman and Indian Bend Wash, but not upstream from Wet Bottom Creek. It is not clear, however, why data for Turkey Creek were more similar to data for the San Pedro River at Winkelman and Indian Bend Wash than to data for Wet Bottom Creek, because land use upstream from Turkey Creek is most similar to that for Wet Bottom Creek (tables 8 and 9). This discrepancy could be a result of differences in upstream conditions that were not considered in this study.

Temporal Trends

An important aspect of monitoring surface-water resources is to detect changes in the quantity and quality of streamflow over time. An understanding of the temporal trends allows for evaluation of the effectiveness of past water-quality protection programs and for the determination of the need for existing or additional programs that will assure an adequate supply of good quality water in the future.

Eight stations were selected to represent the temporal trends in water quality in the study area. The Gila River at Kelvin, the Salt River below Stewart Mountain Dam, and the Verde River below Bartlett Dam were selected because these regulated reaches supply most of the surface water used in the study area (besides that imported into the study area from the Colorado River). The Salt River near Roosevelt and the Verde River below Tangle Creek were selected because trends in the water quality in reaches upstream from the reservoirs may not be apparent once streams enter the reservoirs. The Agua Fria River near Rock Springs was selected for additional spatial representation of the Central Highlands. Few human activities occur in the Wet Bottom Creek drainage basin, with the exception of livestock grazing, so it was selected as the best available reference station. The Gila River at Gillespie Dam was selected to show trends in stream-water quality at the downstream end of the study area. These same eight stations, along with the Verde River at Clarkdale, the San Pedro River at Charleston, and the Santa Cruz River at Cortaro Road, also were selected to demonstrate temporal trends in streamflow throughout the study area.

Streamflow

Temporal trends in streamflow were determined on the basis of monthly streamflow statistics. Trends in high flow are represented by trends in the monthly maximum daily streamflow. Trends in the overall volume of water transported in the stream are represented by trends in the monthly mean daily streamflow. Trends in streamflow during low-flow conditions are represented by trends in the monthly 3-day low flow, which is the lowest average flow for 3 consecutive days in a month. Trends in any of these monthly statistics of streamflow can result from natural causes such as climate or vegetation change, or from human causes such as stream regulation, upstream diversions, or ground-water pumping.

Seasonal and temporal trends in the monthly flow statistics were demonstrated graphically (fig. 10) for several stations. Monthly flow statistics for each station were standardized on the basis of the mean and standard deviation of logged-flow statistics data for the period 1970–98. Standardizing allowed for comparison of the seasonal and temporal variability between stations because the units are converted to standard

[6]There is a probability of less than 1 in 20 (or $p<0.05$) that the differences in a water-chemistry constituent for two stations as determined with rank-sum test (table 9) are due to statistical sampling error rather than being due to true differences in the data. For concluding that data for a water-chemistry constituent at one station is higher (or lower) than that for three other stations, the probability that the differences are due to statistical sampling error are higher, less than 1 in 7 ($p<(1-(1-0.05)^3)$), which is $p<0.14$).

deviations from the mean and the effects of record lengths are removed by standardizing to a common period. Years and seasons colored in blue are substantially above the average for 1970–98, and years that are red are substantially less than average for 1970–98. All stations except for the Santa Cruz River at Cortaro had fairly complete record for 1970–98; the small data gaps for this station were accommodated by the computer software (SPSS, Inc., 1997) graphing routine because it smoothed the data.

Seasonal variation was greater than the long-term variation in the monthly flow statistics for stations on unregulated reaches, with the exception of the 3-day low flow for the Verde River near Clarkdale (fig. 10). Low flow did not vary much at this station. This pattern suggests that, compared to other stations, this station monitors base flow that is maintained by a large body of ground water and (or) that seasonal and temporal trends in streamflow caused by evapotranspiration between the ground-water source and the station were small as compared to that for other stations. For other stations on unregulated perennial streams that drain the Central Highlands (Salt River near Roosevelt, Verde River below Bartlett Dam for years 1900–38, and Verde River below Tangle Creek for years 1946–98 in figure 10) the monthly 3-day low flow, monthly mean, and monthly maximum daily flow tended to be higher from 1900 through the 1930s, lower from the 1940s through the 1970s, and higher again after the 1970s. This pattern in streamflow follows that observed for the mean annual precipitation for the Southwestern United States (Trentberth, 1991) and indicates that for streams in the Central Highlands, long-term trends in streamflow were driven by long-term trends in climate.

For the San Pedro River at Charleston, which has unregulated perennial streamflow, seasonal variability in the monthly streamflow statistics was also generally greater than the long-term variability. In contrast to flows in unregulated reaches in the Central Highlands, the monthly mean daily flow and monthly maximum flows in the San Pedro River at Charleston are largest in the late summer rather than in the winter and early spring. Pool and Coes (1999) found that runoff, base flow, and drainage-basin precipitation declined for the San Pedro River at Charleston from 1936 through 1997 and that the decline in base flow had probable causes including declining runoff and recharge near the river during June through October and increased interception of ground-water flow to the river by wells and phreatophytes. These declining trends also are apparent for the 3-day low, monthly mean, and monthly maximum flows shown in figure 10.

Seasonal patterns in streamflow are changed as a result of stream regulation (fig. 10). For example, at the Salt River near Roosevelt, flow was typically high from March through May and low to medium from June through February. In contrast, downstream from the reservoir system at the Salt River below Stewart Mountain Dam, flow was medium to high from March through October and low to medium from November through February. Flow was typically medium to high from December through March at the Gila River at Kelvin and the Verde River below Bartlett Dam before the regulation of streamflow, and flow was typically medium to low from April through November under this condition. After streamflow was regulated, however, flow tended to be low from October through March and medium to high from April through September.

Long-term trends in the monthly streamflow statistics at stations on effluent-dependent reaches were more extreme than those for unregulated and regulated reaches; in fact, the long-term variation was greater than the seasonal variation in the streamflow for stations on effluent-dependent reaches (fig. 10, Santa Cruz River at Cortaro, Gila River at Gillespie Dam). The monthly 3-day low flow increased somewhat over the period of record at the Santa Cruz River at Cortaro as a result of population growth in the Tucson metropolitan area and the corresponding increase in the amount of wastewater returns. Streamflow in the Gila River at Gillespie Dam declined from the 1930s through the mid 1960s, probably as a result of a lowering of the ground-water table by pumpage. Streamflow has increased since the mid 1960s, probably as a result of population growth in the Phoenix metropolitan area and the corresponding increase in the amount of wastewater returns to the Salt River at the 91st Avenue Wastewater-Treatment Plant[7]. Streamflow could also be increasing as a result of a declining trend in groundwater pumpage since the 1960s (Anning and Duet, 1994).

---

[7]The 91st Avenue Wastewater-Treatment Plant came on line in 1958 (E.L. Montgomery and Associates, 1986).

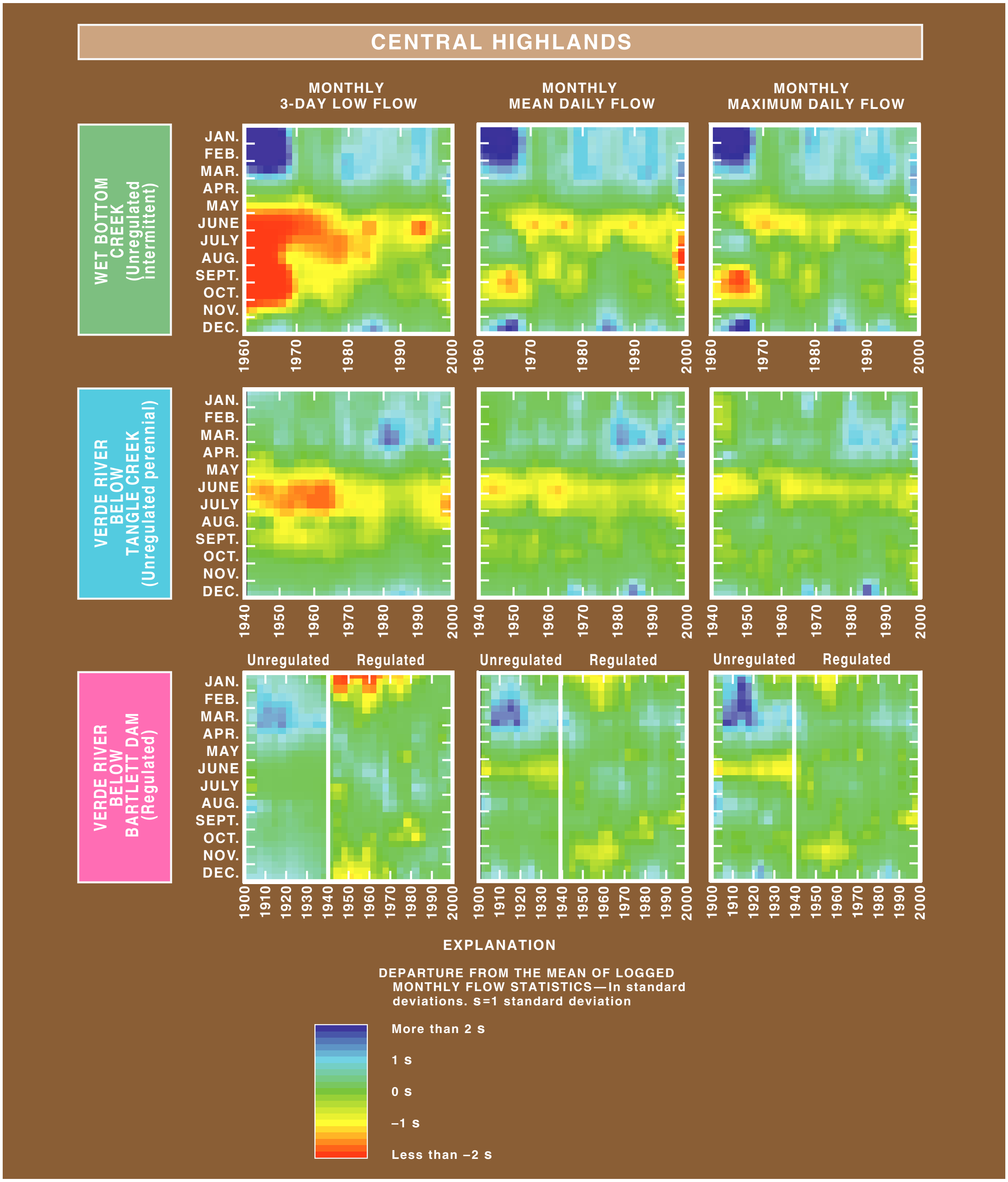


Figure 10. Seasonal and annual trends in logged monthly statistics of mean daily flow values at selected surface-water quality monitoring stations in the Central Arizona Basins study area.

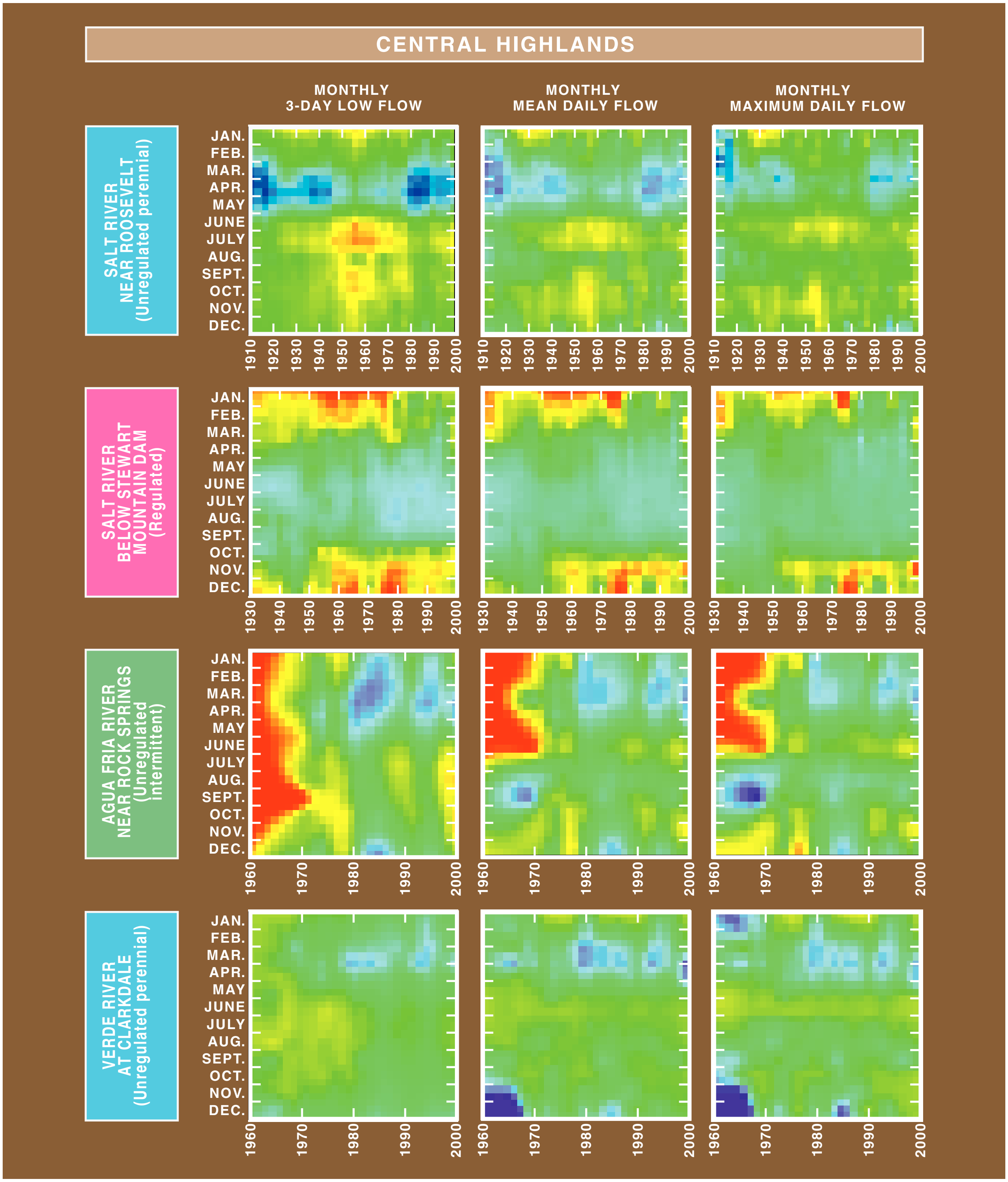


Figure 10. Continued.

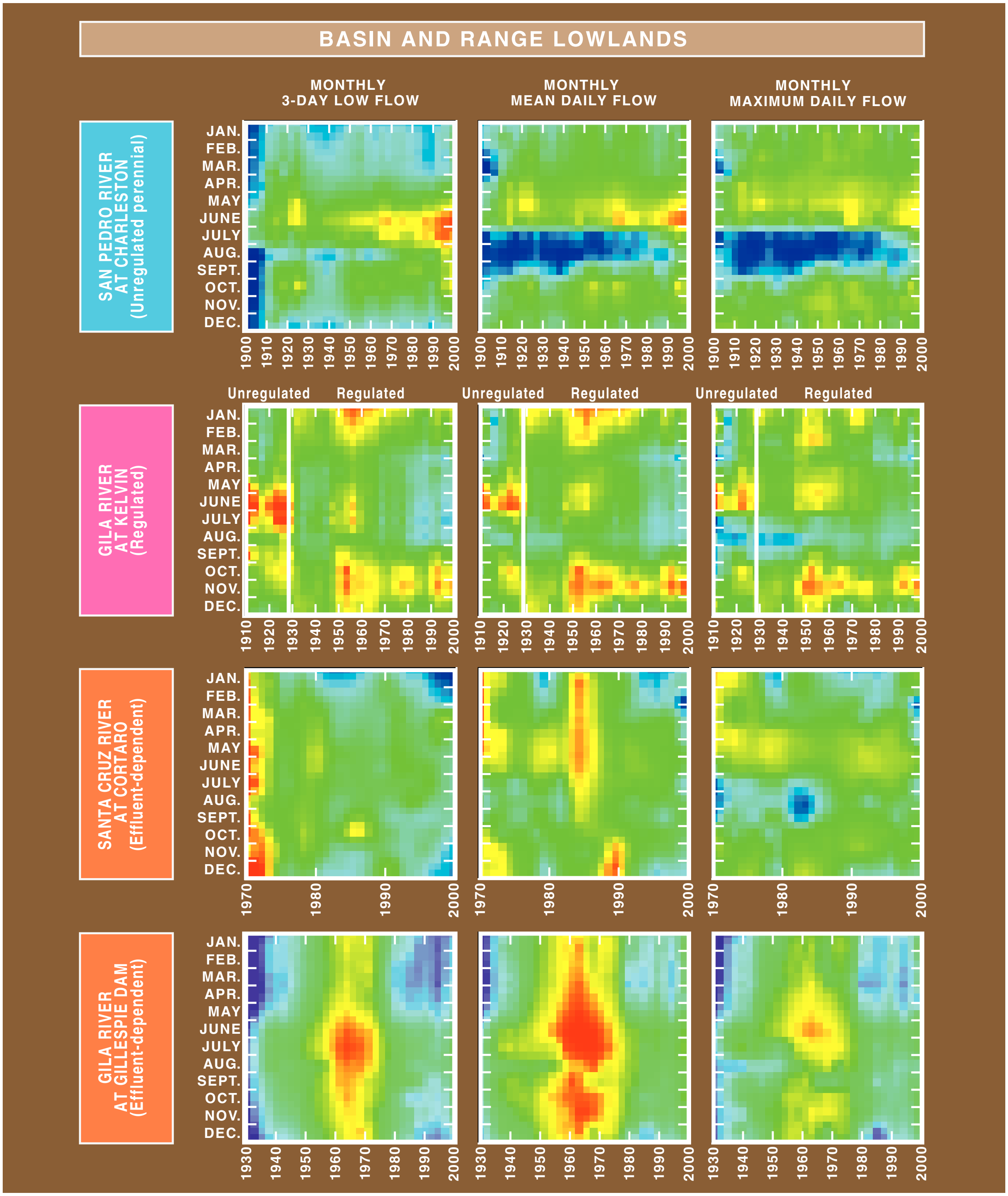


Figure 10. Continued.

Water Quality

Increases in water-chemistry constituent concentrations over time can indicate either that the mass load of that constituent delivered to the stream from natural or human sources has increased over time, or that losses of that constituent by physical or biological processes have decreased over time. Conversely, decreases in water-chemistry constituent concentration over time can indicate decreases in the mass load transported to the stream over time, or increases in the physical or biological processes removing the water-chemistry constituent over time.

Long-term trends in water-chemistry constituents were determined using the seasonal Kendall test for trends with corrections for serial dependence (Hirsch and others, 1982; Hirsch and Slack, 1984). This is a nonparametric method suitable for detection of trends in seasonal data that may have a nonnormal distribution, have missing values, have censored data, or have serial dependence. For stream properties and water-chemistry constituent concentrations that are correlated with discharge, trends in concentration can be confounded by trends in streamflow at the time of sampling. For instance, a decrease in dissolved solids over time can result from an increase in streamflow at the time of sampling during the period of record if the dissolved-solids concentration is negatively correlated with streamflow. For cases where stream properties and water-chemistry constituent concentrations were correlated with streamflow (table 7, those with $p<0.10$), trends in water quality were determined by using flow-adjusted concentrations (Hirsch and others, 1991) that were based on a LOWESS smooth (Cleveland, 1979) of concentration and discharge data. An increase in the flow-adjusted data indicates that, for a given streamflow, the concentrations of samples collected at the beginning of the period assessed are less than the concentrations of samples collected at the end of the period; the opposite is true for decreases in the flow-adjusted data. As an indication of the magnitude of the trend, the Sen slope (Helsel and Hirsch, 1992, p. 266), which is the median of all slopes drawn between the possible pairs of concentration-time data points, was determined.

The pH, dissolved-oxygen concentration, and dissolved-oxygen percent saturation of samples generally increased or had no trend over the period of sampling at the eight stations (table 10). Stream pH increased in the Salt River below Stewart Mountain Dam, the Verde River below Bartlett Dam, the Gila River at Kelvin, and the Gila River at Gillespie Dam, but had no trend at the Salt River near Roosevelt, Wet Bottom Creek, the Verde River below Tangle Creek, and the Agua Fria River near Rock Springs. Temporal trends in pH may cause trends in concentrations of some constituents such as arsenic or other trace elements that have solubilities related to pH. Concentrations of dissolved oxygen increased at the Salt River near Roosevelt, the Salt River below Stewart Mountain Dam, and the Verde River below Tangle Creek. Concentrations of dissolved oxygen had no trend at the other stations. The dissolved-oxygen percent saturation increased at the Verde River below Tangle Creek and the Gila River at Gillespie Dam.

Concentrations of dissolved solids decreased at the Salt River below Stewart Mountain Dam (fig. 9) and the Verde River below Bartlett Dam, increased at the Gila River at Kelvin, and had no trend at the other five stations (table 10). The decrease in dissolved-solids concentrations in the Salt and Verde Rivers is an important improvement in water quality because these rivers are used as a drinking-water source for the Phoenix metropolitan area and concentrations of dissolved solids in the Salt River are typically high (fig. 6), often exceeding the SMCL. The decreases in concentration could have resulted either from an increase in the volume of runoff entering the reservoirs or from a decrease in the load of dissolved solids being delivered to the river. The former explanation suggests that these trends were driven by changes in climate. This is the more likely explanation because the monthly mean daily streamflow increases over the period of sampling at these stations (fig. 10) and because the flow-adjusted concentrations do not change over the period of record in the Salt River near Roosevelt or in the Verde River below Tangle Creek. The increase in concentrations at the Gila River at Kelvin suggests that there is an increase in the load of dissolved solids delivered to the river from one or more natural or human sources.

Concentrations of suspended sediment at six of the stations had no trend, but at the Salt River below Stewart Mountain Dam and the Gila River at Gillespie Dam concentrations decreased over the period of sampling (table 10). Concentrations probably decreased at the Salt River below Stewart Mountain Dam as a result of impounding sediments in the series of four reservoirs upstream from the station. This is not the cause for the decrease observed in concentrations at the Gila River at Gillespie Dam, however, because this dam is a diversion dam with a low storage capacity.

Table 10. Monotonic trends in stream properties and water-chemistry constituent concentrations at selected surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998

[Data in each cell are beginning and ending year for analysis, Sen slope of the trend, and statistical significance that the slope is not equal to zero as determined by using the seasonal Kendall's test with correction for serial correlation (increasing tends: +++, p<0.01; ++, p<0.05; +, P<0.10; decreasing trends: ---, p<0.01; --, p<0.05; -, p<0.10; 0, trend is not significant). Purple shading, increasing trend; lavender shading, no trend; blue shading, decreasing trend. *, trend analysis performed on flow-adjusted concentrations]

		Dissolved-oxygen							
Station	pH	Concen-tration	Percent saturation	Dissolved solids	Suspended sediment	Total phosphorus	Nitrate	Ammonia	Total nitrogen
Central Highlands									
Salt River near Roosevelt (unregulated, perennial)	76-98 0.005* 0	82-98 0.041* ++	82-98 <0.0001 0	76-98 1.11* 0	78-98 1.10* 0	82-98 -0.0011* 0	76-98 <0.0001 0	84-98 <0.0001 0	82-98 -0.024* ---
Salt River below Stewart Mountain Dam (regulated)	50-96 0.015 +++	77-92 0.163 ++	82-92 -0.343* 0	50-92 -0.349* --	76-92 -0.57 --	74-92 -0.0007* -	70-92 <0.0001 0	77-92 -0.0019 --	74-92 -0.005 0
Wet Bottom Creek (unregulated, intermittent)	68-96 0.001 0	79-96 0.013* 0	82-96 -0.333 0	69-96 -0.396* 0	79-96 -0.04* 0	77-96 -0.0002* 0	71-96 <0.0001 0	80-96 -0.0019* --	80-96 -0.025 ---
Verde River below Tangle Creek (unregulated, perennial)	80-97 0.003 0	80-97 0.043* ++	82-97 0.207* ++	80-97 0.705* 0	81-97 0.10* 0	80-97 -0.0009* 0	80-97 -0.0020* --	84-97 -0.0012* ---	80-97 -0.021* ---
Verde River below Bartlett Dam (regulated)	50-92 0.011* +++	77-92 0.017 0	82-92 -0.0536 0	50-92 -2.35* ---	75-92 -0.14 0	74-92 <0.0001 0	70-92 <-0.0001 --	77-92 -0.0017* -	74-92 0.001* 0
Agua Fria River near Rock Springs (unregulated, intermittent)	82-95 -0.002* 0	82-95 -0.033* 0	82-95 -0.620 0	82-95 0.782* 0	82-95 -0.08 0	82-95 -0.0013* 0	82-95 -0.0029* 0	82-95 <0.0001 0	82-95 -0.020* --
Basin and Range Lowlands									
Gila River at Kelvin (regulated)	50-81 0.014* +++	Record not long enough for analysis	Record not long enough for analysis	50-77 11.4* +++	75-98 -19.7* 0	Record not long enough for analysis	70-77 -0.0355* 0	Record not long enough for analysis	Record not long enough for analysis
Gila River at Gillespie Dam (effluent-dependent)	59-98 0.006* +++	77-98 0.020 0	82-98 2.00 ++	59-98 -6.35* 0	75-98 -2.27 --	74-98 -0.0546* ---	74-98 -0.0550* --	77-98 -0.0490* --	78-98 -0.214* ---

Concentrations of nutrients at the eight stations either decreased over the period of sampling or had no trend (table 10). Concentrations of total phosphorus decreased over the period of sampling at the Salt River below Stewart Mountain Dam and the Gila River at Gillespie Dam. The decrease in total phosphorus at the Gila River at Gillespie Dam could have resulted from the decrease in suspended sediment because phosphorus sorbs to sediment. Concentrations of nitrate decreased at the Verde River below Tangle Creek, the Verde River below Bartlett Dam, and the Gila River at Gillespie Dam; concentrations of ammonia decreased at these same stations and also at the Salt River below Stewart Mountain Dam and Wet Bottom Creek. Concentrations of total nitrogen decreased over the period of sampling at the Salt River near Roosevelt, Wet Bottom Creek, the Verde River below Tangle Creek, the Agua Fria River near Rock Springs, and the Gila River at Gillespie Dam. The decreases in concentrations of nutrients were largest at the Gila River at Gillespie Dam, as indicated by the Sen slope (table 10), and indicate considerable improvement in water quality, not only because there is more water in the stream (fig. 10), but because loads of nitrogen to the stream from natural and human sources also have decreased and (or) nutrient uptake by aquatic biota and riparian vegetation has increased.

On the basis of results from the stations used in this study, temporal trends in streamflow and in stream properties and water-chemistry constituent concentrations commonly occur over the period of a decade or longer in streams in the study area. Temporal trends in streamflow and concentrations of dissolved solids at stations on unregulated and regulated reaches in the Central Highlands appear to be caused by trends in climate. In contrast, temporal trends in water management and in climate probably have caused the temporal trends in streamflow at stations on effluent-dependent reaches in the Basin and Range Lowlands and trends in concentrations of dissolved solids or nutrients in the Gila River at Gillespie Dam. Concentrations of dissolved solids or nutrients generally have decreased over time at most stations. In some cases the decrease has been quite substantial. Dissolved oxygen and pH generally have remained the same or increased. Temporal trends in pH may cause trends in concentrations of some constituents such as arsenic or other trace elements that have solubilities related to pH.

RELATION OF STREAM LOADS TO UPSTREAM CONDITIONS

A comparison of stream loads of water-chemistry constituents at different locations along the stream and a comparison of the stream loads to upstream inputs of the constituent from natural and anthropogenic sources can provide information about the relative importance of different sources and also can provide insight to the fate of the water-chemistry constituent (Likens and Bormann, 1995). To gain this information and insight, stream loads and upstream inputs of dissolved solids, nitrogen, and phosphorous were estimated at several surface-water quality monitoring stations in the study area. The methods used in this study provide quantities of mass input and output from a basin; however, the input and output values have a large amount of uncertainty, and therefore, the results of this analysis should be considered qualitative and exploratory.

Transport of water-chemistry constituents out of a basin in streamflow is controlled partly by the portion of the precipitation that runs off as streamflow. The percentage of the annual precipitation volume that runs off as streamflow is low for stations in the study area and ranges from 1 to 15 percent (table 11); the percentage is larger for stations in the Central Highlands than for stations in the Basin and Range Lowlands. Annual streamflow in 1996 and 1997 was less than average at most stations because of drought conditions (Baynham and Phillips, 1996). Annual streamflow in 1996 at the Hassayampa River, however, was about average, and streamflow in 1996 at the Gila River at Kelvin was above average. Annual streamflow in 1998 was less than average at the Agua Fria River near Rock Springs, the San Pedro River near Charleston, and the Gila River at Gillespie Dam; about average at the Salt River near Roosevelt, the Gila River at Kelvin, and the Hassayampa River; and above average at West Clear Creek and the Verde River below Tangle Creek.

Annual stream loads of dissolved solids, total phosphorus, nitrate, total ammonia plus organic nitrogen, and total nitrogen were estimated for selected sites for the 1996–98 water years (table 12). The stream loads were estimated using multiple regression; details of the estimation methods are explained in appendix 2. The annual load of total nitrogen was estimated as the sum of the annual loads of nitrate and total ammonia plus organic nitrogen. For the Santa Cruz River at Cortaro and the 91st Avenue Wastewater-Treatment Plant outfall, annual loads were estimated only for years when water-quality samples were collected and exclude loads carried in storm runoff. For the few days with direct runoff, the mean daily flow was replaced with the median of the mean daily flows for that month. Annual yields of the water-chemistry constituents facilitate comparison of loads amongst basins and were calculated as the annual load divided by the basin area. Annual yields were not calculated for canals or effluent-dependent reaches.

Dissolved Solids

Estimates of annual stream loads of dissolved solids at stations in the study area from 1996–98 ranged from 1.9 million kilograms per year at the Agua Fria River near Rock Springs in 1996 to 980 million kilograms per year at the Central Arizona Project Canal near Parker in 1998 (table 12). Estimates of annual stream loads of dissolved solids are relatively precise compared to annual stream loads of nutrients and have a range in standard error of prediction from 1 to 9 percent (table 12).

Table 11. Annual streamflow for water years 1996–98 and mean annual streamflow for the period of record at selected surface-water quality monitoring stations in the Central Arizona Basins study area

[---, not computed]

Station name	Annual streamflow, in cubic meters per second (annual streamflow as a percentage of the mean for the period of record[1]) 1996	1997	1998	Mean annual streamflow for the period of record, as a percentage of average annual precipitation volume[1]
Central Highlands				
Salt River near Roosevelt	6.68 (26)	15.5 (60)	26.1 (100)	13
West Clear Creek	.530 (28)	1.20 (63)	2.59 (136)	15
Verde River below Tangle Creek	6.40 (38)	9.32 (56)	21.6 (129)	7
Agua Fria River near Rock Springs	.173 (7)	.377 (14)	1.87 (70)	7
Basin and Range Lowlands				
Central Arizona Project Canal near Parker	30.5 (---)	44.3 (---)	53.1 (---)	---
Gila River at Kelvin[3]	18.0 (133)	11.8 (82)	13.0 (96)	2.1
San Pedro River at Charleston	.541 (41)	.311 (23)	.614 (46)	3.7
Santa Cruz River at Tubac	.493 (78)	.442 (70)	--- (--)	1.0
Santa Cruz River at Cortaro[2]	1.51 (---)	--- (---)	--- (---)	---
91st Avenue Wastewater-Treatment Plant outfall[2]	4.30 (---)	3.74 (---)	--- (---)	---
Gila River at Buckeye Canal	--- (---)	5.14 (---)	5.52 (---)	---
Hassayampa River	1.82 (101)	1.18 (65)	1.72 (95)	---
Gila River at Gillespie Dam[3]	4.19 (27)	4.45 (29)	6.31 (41)	1.1

[1]Mean annual streamflow from table 1; average annual precipitation volume estimated using drainage basin areas and mean annual precipitation data listed in Garrett and Gellenbeck, 1991.

[2]Streamflow excludes runoff.

[3]Includes drainage area above Coolidge Dam.

Table 12. Annual stream load and yield of selected water-chemistry constituents at selected surface-water quality monitoring stations in the Central Arizona Basins study area, water years 1996–98

[R^2, coefficient of determination for the concentration regression equation; ---, not computed]

Station name	Number of samples	R^2	Annual load, in millions of kilograms			Annual yield, in kilograms per square kilometer			Standard error of prediction, in percent		
			1996	1997	1998	1996	1997	1998	1996	1997	1998
Dissolved solids											
Central Highlands											
Salt River near Roosevelt	219	93	330	420	480	30,000	38,000	43,000	3	3	3
West Clear Creek	46	94	3.1	4.8	8.0	5,000	7,700	13,000	2	2	3
Verde River below Tangle Creek	159	92	71	85	125	4,700	5,600	8,000	1	2	2
Agua Fria River near Rock Springs	162	31	1.9	3.7	18	670	1,300	6,300	4	6	5
Basin and Range Lowlands											
Central Arizona Project Canal near Parker	41	([1])	970	820	980	([2])	([2])	([2])	4	4	4
Gila River at Kelvin	406	52	370	270	290	8,000	5,800	6,200	3	3	3
San Pedro River at Charleston	83	33	4.0	2.6	4.6	1,300	810	1,400	5	4	5
Santa Cruz River at Tubac	27	51	6.1	5.4	---	2,000	1,700	---	5	5	---
Santa Cruz River at Cortaro[3]	12	49	29	---	---	([2])	---	---	5	---	---
91st Avenue Wastewater-Treatment Plant outfall[3]	24	51	100	110	---	([2])	([2])	---	4	4	---
Gila River at Buckeye Canal	36	([1])	---	210	230	---	([2])	([2])	---	2	2
Hassayampa River	48	67	75	61	74	20,000	16,000	19,000	6	6	6
Gila River at Gillespie Dam	380	23	350	440	440	2,700	3,400	3,400	8	9	9
Total phosphorus											
Central Highlands											
Salt River near Roosevelt	260	33	.016	.027	.070	1.4	2.4	6.3	24	26	36
West Clear Creek	39	55	.001	[4].002	([4])	.41	[4]3.8	([4])	30	59	209
Verde River below Tangle Creek	197	31	.009	.025	.17	.62	1.7	11	13	23	35
Agua Fria River near Rock Springs	166	48	.002	.003	.010	.57	1.2	3.6	40	46	36

See footnotes at end of table.

Table 12. Annual stream load and yield of selected water-chemistry constituents at selected surface-water quality monitoring stations in the Central Arizona Basins study area, water years 1996–98—Continued

Station name	Number of samples	R^2	Annual load, in millions of kilograms			Annual yield, in kilograms per square kilometer			Standard error of prediction, in percent		
			1996	1997	1998	1996	1997	1998	1996	1997	1998
Total phosphorus—continued											
Basin and Range Lowlands											
Central Arizona Project Canal near Parker	41	([1])	.021	.018	.022	([2])	([2])	([2])	7	7	7
Gila River at Kelvin	92	31	.25	.12	.15	5.2	2.5	3.2	31	31	33
San Pedro River at Charleston	86	42	.006	[4].002	[4].005	1.7	[4].59	[4]1.6	47	56	52
Santa Cruz River at Tubac	26	87	.023	.058	---	7.4	18	---	12	15	---
Santa Cruz River at Cortaro[3]	12	47	.21	---	---	([2])	---	---	15	---	---
91st Avenue Wastewater-Treatment Plant outfall[3]	23	([1])	.55	.48	---	([2])	([2])	---	5	5	---
Gila River at Buckeye Canal	35	47	---	.45	.46	---	([2])	([2])	---	3	6
Hassayampa River	48	50	.19	.10	.14	50	26	38	12	14	11
Gila River at Gillespie Dam	250	29	.21	.28	.27	1.6	2.1	2.1	10	12	12
Total ammonia plus organic nitrogen											
Central Highlands											
Salt River near Roosevelt	260	33	.074	.11	.18	6.6	9.2	16	16	17	21
West Clear Creek	39	48	.002	.007	([4])	2.9	11	([4])	19	26	109
Verde River below Tangle Creek	197	46	.029	.040	([4])	1.9	2.6	([4])	12	15	70
Agua Fria River near Rock Springs	166	38	.001	.002	.011	.47	.77	3.8	37	55	36
Basin and Range Lowlands											
Central Arizona Project Canal near Parker	40	([1])	.47	.40	.47	([2])	([2])	([2])	23	23	23
Gila River at Kelvin	85	36	.60	.31	.38	13	6.6	8.2	21	21	23
San Pedro River at Charleston	86	24	([4])	([4])	([4])	([4])	([4])	([4])	165	178	245
Santa Cruz River at Tubac	26	88	.046	.18	---	15	57	---	22	27	---
Santa Cruz River at Cortaro[3]	12	49	1.4	---	---	([2])	---	---	4	---	---
91st Avenue Wastewater-Treatment Plant outfall[3]	24	68	1.4	.59	---	([2])	([2])	---	16	11	---
Gila River at Buckeye Canal	36	87	---	.61	.24	---	([2])	([2])	---	6	11
Hassayampa River	48	63	.43	.12	.11	110	32	28	21	11	13
Gila River at Gillespie Dam	244	6	.40	.60	.59	3.1	4.6	4.5	11	15	15
Nitrate											
Central Highlands											
Salt River near Roosevelt	230	17	.006	.010	.023	.53	.89	2.1	22	24	31
West Clear Creek	44	([1])	.001	.001	.003	.81	1.8	4.7	9	9	9
Verde River below Tangle Creek	85	([1])	.004	.006	.015	.29	.41	.96	8	8	8
Agua Fria River near Rock Springs	165	([1])	.001	.001	.002	.06	.13	.67	12	12	12

See footnotes at end of table.

Table 12. Annual stream load and yield of selected water-chemistry constituents at selected surface-water quality monitoring stations in the Central Arizona Basins study area, water years 1996–98—Continued

Station name	Number of samples	R^2	Annual load, in millions of kilograms			Annual yield, in kilograms per square kilometer			Standard error of prediction, in percent		
			1996	1997	1998	1996	1997	1998	1996	1997	1998
Nitrate—continued											
Basin and Range Lowlands											
Central Arizona Project Canal near Parker	40	([1])	.24	.20	.24	([2])	([2])	([2])	15	15	15
Gila River at Kelvin	194	28	.12	.057	.065	2.5	1.2	1.4	30	30	31
San Pedro River at Charleston	74	37	.004	[4].001	[4].004	1.4	[4].44	[4]1.2	48	55	51
Santa Cruz River at Tubac	27	73	.034	.055	---	11	18	---	12	13	---
Santa Cruz River at Cortaro[3]	12	34	.020	---	---	([2])	---	---	29	---	---
91st Avenue Wastewater-Treatment Plant outfall[3]	24	23	.35	.36	---	([2])	([2])	---	17	15	---
Gila River at Buckeye Canal	36	([1])	---	.70	.76	---	([2])	([2])	---	9	9
Hassayampa River	48	63	.40	.31	.40	100	81	100	5	5	5
Gila River at Gillespie Dam	190	33	1.3	1.4	1.4	9.8	11	11	16	16	16
Total nitrogen (estimated as the sum of total ammonia plus organic nitrogen and nitrate)											
Central Highlands											
Salt River near Roosevelt	---	---	.080	.12	.20	7.1	10	18	15	16	19
West Clear Creek	---	---	.002	.008	([4])	3.70	13	([4])	17	23	109
Verde River below Tangle Creek	---	---	.033	.046	[4].79	2.2	3.0	[4]52	12	14	69
Agua Fria River near Rock Springs	---	---	.002	.003	.013	.53	.89	4.5	34	49	32
Basin and Range Lowlands											
Central Arizona Project Canal near Parker	---	---	.71	.60	.71	([2])	([2])	([2])	20	20	20
Gila River at Kelvin	---	---	.72	.36	.45	15	7.8	9.6	23	22	24
San Pedro River at Charleston	---	---	([4])	([4])	([4])	([4])	([4])	([4])	160	170	244
Santa Cruz River at Tubac	---	---	.079	.23	---	25	75	---	17	23	---
Santa Cruz River at Cortaro	---	---	1.5	---	---	b	---	---	4	---	---
91st Avenue Wastewater-Treatment Plant outfall[3]	---	---	1.7	.96	---	([2])	([2])	---	16	12	---
Gila River at Buckeye Canal	---	---	---	1.3	1.0	---	([2])	([2])	---	7	9
Hassayampa River	---	---	.83	.43	.50	220	110	130	13	6	7
Gila River at Gillespie Dam	---	---	1.7	2.0	2.0	13	16	16	13	16	16

[1]Stream load and yield estimates are based on the mean concentration rather than on a regression equation.
[2]The annual yield was not estimated for stations on canals or on reaches in which the stream load excludes transport in runoff.
[3]Stream load and yield exclude transport in runoff.
[4]The 95-percent confidence interval for the stream load and yield is larger than the estimate of the stream load and yield. In cases where the 95-percent confidence interval is excessively large, the stream load and yield are not tabulated.

Dissolved solids in streamflow may originate from precipitation, geologic sources such as evaporite deposits and weathered rocks, or human activities such as the release of wastewater to land surfaces or water bodies, or the application of fertilizers to cultivated lands. Precipitation scavenges ions from the atmosphere as it falls and contains some dissolved solids (fig. 7), and the runoff flowing overland or through the subsurface can dissolve salts on its path to the stream. As a result, annual stream loads of dissolved solids are larger for wet years than for dry years. For stations draining the Central Highlands, the annual stream load of dissolved solids generally was higher in 1998, a wet year with a high annual streamflow, than in 1996, a dry year with a low mean annual streamflow (tables 11 and 12). The relative importance of precipitation as a source of dissolved solids can be assessed by comparing the annual input of dissolved solids from precipitation for a basin to the stream load of dissolved solids transported out of the basin; the remainder must come from other sources such as fertilizers, household cleansers, surface or subsurface geologic deposits, or other sources. The annual input of dissolved solids from precipitation typically represents less than half of the total stream load observed at the Salt River near Roosevelt, West Clear Creek, the Verde River below Tangle Creek, the Agua Fria River near Rock Springs, and the Gila River at Gillespie Dam (table 13). At these stations, other sources, such as geologic formations, must be more significant contributors to the annual stream load; in contrast, nearly all, 97 percent, of the stream load of dissolved solids could be attributed to precipitation at the San Pedro River near Charleston (table 13). In these comparisons of input mass to output mass, an important consideration is that the actual material input can be different from that in the stream load. For instance, most of the dissolved solids input to the basin for the San Pedro River at Charleston is from precipitation; however, the dissolved solids could remain in the basin near the land surface where the precipitation falls, and the mass of dissolved solids observed in the stream load could come mostly from other sources, such as subsurface geologic formations.

Table 13. Average annual input of dissolved solids from precipitation to drainage basins of selected surface-water quality monitoring stations in the Central Arizona Basins study area

Station	Annual input of dissolved solids from precipitation[1], 1980–96, in millions of kilograms per year	Annual input of dissolved solids from precipitation, 1980–96, as a percentage of the average annual stream load of dissolved solids for water years 1996–98
Central Highlands		
Salt River near Roosevelt	17	4.1
West Clear Creek	1.0	19
Verde River below Tangle Creek	19	20
Agua Fria River near Rock Springs	3.2	40
Basin and Range Lowlands		
San Pedro River at Charleston	3.6	97
Santa Cruz River at Tubac	3.8	66
Gila River at Gillespie Dam[2]	90	22

[1]The annual input of dissolved solids in precipitation is estimated on the basis of drainage area and mean annual precipitation (Garrett and Gellenbeck, 1991) and the mean concentration of dissolved solids in precipitation at the three atmospheric deposition stations for 1980–96 (fig. 7; National Atmospheric Deposition Program, 1998b).

[2]Includes drainage area above Coolidge Dam.

At the Gila River at Gillespie Dam, dissolved solids most likely originate from subsurface geologic sources and human sources. Stream loads of dissolved solids nearly doubled between the 91st Avenue Wastewater-Treatment Plant outfall and the Gila River at Buckeye Canal, and doubled again between the Gila River at Buckeye Canal and the Gila River at Gillespie Dam. This increase can be attributed to both saline ground-water inflow and irrigation return flows. The inflow of saline ground water to the Gila River is not well documented; however, it is inferred from several lines of evidence. The effluent-dependent reach on the Salt and Gila Rivers between the 91st Avenue Wastewater-Treatment Plant outfall and the Buckeye Canal gained streamflow. Some of this gain came from the Gila River upstream from the mouth of the Salt River. This reach of the Gila was sampled during low-flow conditions in March 1996 and had a dissolved-solids concentration of 7,210 mg/L at a streamflow of about 0.5 m^3/s (Tadayon and others, 1998, p. 342). In the area along the Gila River from the mouth of the Salt River to Gillespie Dam, ground water generally was shallow (Brown and Pool, 1989) and had a similar salinity to the stream sample just mentioned (Kister and Hardt, 1966; Kister, 1974; Brown and Pool, 1989). High salinity of the ground water upgradient from the confluence of the Gila and Salt Rivers is thought to be associated with subsurface evaporite deposits (Kister and Hardt, 1966); however, it also could have resulted, in part, from recharge of saline irrigation wastewater. Likewise, salinity in the Gila River could also result from surface return of irrigation wastewater. Although irrigation return flows are known to enter this reach of the Gila, the fact that the dissolved-solids concentrations and stream loads increased from the 91st Avenue Wastewater-Treatment Plant to the Gila River at Buckeye Canal and from the Gila River at Buckeye Canal to the Gila River at Gillespie Dam, during the non-irrigation season as well as during other times of the year, suggests that saline ground-water inflows were a major source of the dissolved solids.

Dissolved solids transported in streamflow from the Central Highlands and from the Central Arizona Project Canal were retained in the Basin and Range Lowlands. For example, during 1997 about 1,600 million kilograms of dissolved solids was transported into the Basin and Range Lowlands from the Gila, Salt, and Verde Rivers, and the Central Arizona Project Canal; however, only 440 million kilograms was transported out of the study area in the Gila River (fig. 11 and table 12). The difference, about 1,200 million kilograms of dissolved solids per year, was most likely stored in soils, unsaturated zones, and aquifers in agricultural and urban areas as a result of irrigating crops and urban vegetation. Much of the applied irrigation water is evapotranspired as pure water, and the remainder is a highly mineralized water that either becomes surface runoff or percolates through the soils and unsaturated zone and recharges the aquifer. As a result of the evaporation and because the dissolved solids generally remain in solution, the percolating water is much more concentrated than the original irrigation water, and the water in the soil, the unsaturated zone, and the aquifer becomes more saline. This process was evident in an agricultural area west of Phoenix, where high concentrations of dissolved solids in shallow ground water are believed to be the result of irrigation seepage (Edmonds and Gellenbeck, 2002).

Nutrients

Annual stream loads of total phosphorus, total ammonia plus organic nitrogen, nitrate, and total nitrogen were estimated for selected sites for water years 1996–98 (table 12 and fig. 12). The standard error of prediction of stream load estimates for the nutrients typically was high and ranged from 3 to 245 percent. For several cases, the standard error of prediction was much greater than 50 percent and precluded using results for certain years. The standard error of prediction was particularly high for nutrient stream loads for the San Pedro River at Charleston as a result of the large variability in concentration in higher streamflows and as a result of the small number of samples that were collected during high flows. Stream loads of total phosphorus, total ammonia plus organic nitrogen, nitrate, and total nitrogen generally were much greater in years with higher annual streamflow than in years with lower annual streamflow.

Along the lower Salt River and the Gila River west of Phoenix, stream loads of phosphorus tended to decrease downstream, whereas stream loads of nitrogen tended to increase (table 12 and fig. 12). For 1997, stream loads of nitrogen increased from 0.96 million kilograms per year at the 91st Avenue Wastewater-Treatment Plant outfall to 1.3 million kilograms per year at the Gila River at Buckeye Canal and to 2.0 million kilograms per year at the Gila River at Gillespie Dam. The increase probably resulted from additional inputs of fertilizer in downstream areas. For 1997, the stream load of phosphorus decreased from 0.48 million kilograms per year at the 91st Avenue Wastewater-Treatment Plant outfall to 0.45 million kilograms per year at the Gila River at Buckeye Canal and to 0.28 million kilograms per year at the Gila River at Gillespie Dam.

Figure 11. Annual stream loads of dissolved solids at selected surface-water quality monitoring stations in the Central Arizona Basins study area, water year 1997.

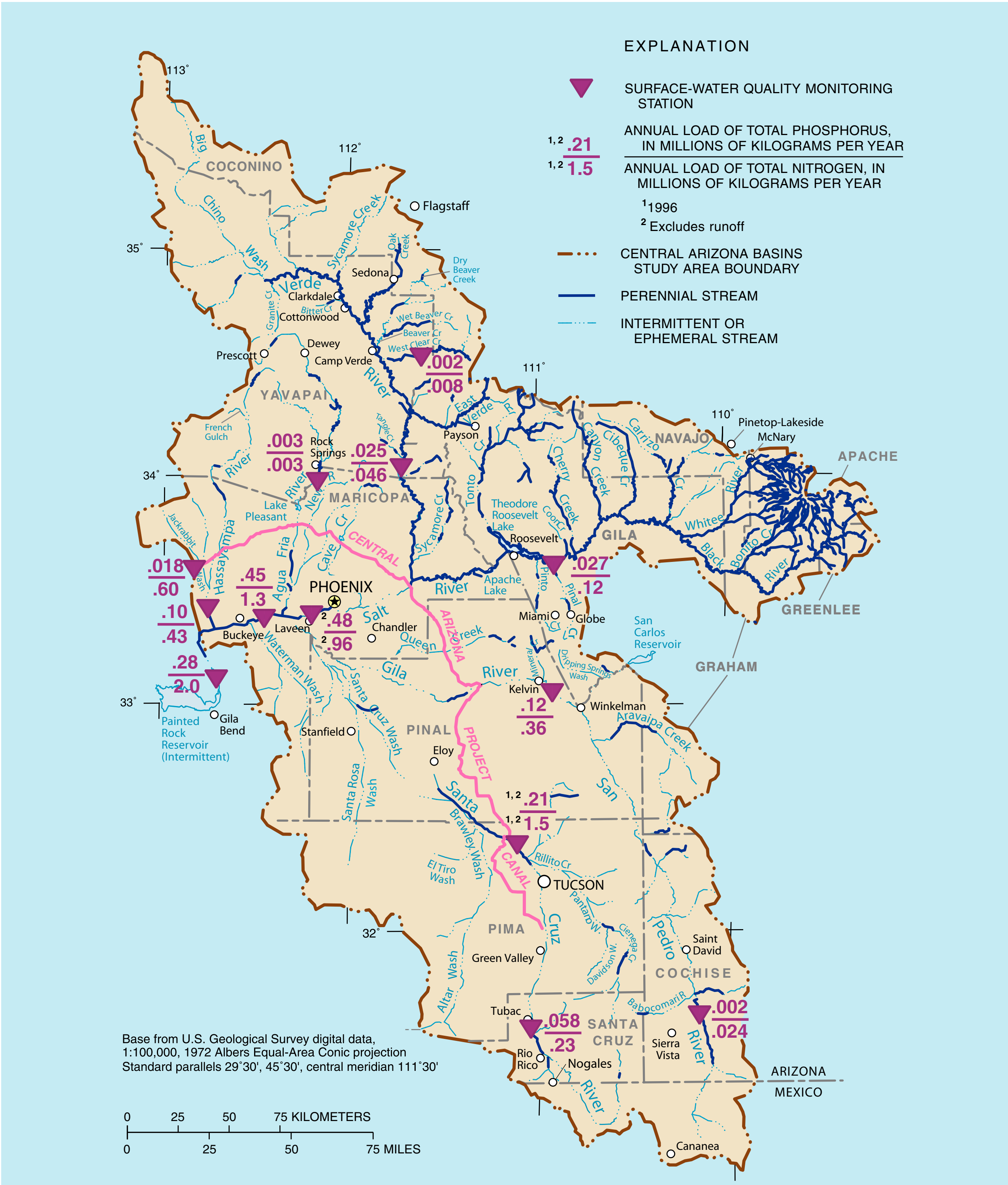


Figure 12. Annual stream loads of total nitrogen and total phosphorus at selected surface-water quality monitoring stations in the Central Arizona Basins study area, water year 1997.

The decrease in the stream load of phosphorus probably is a result of phosphorus adsorbing onto sediments in the streambed or in irrigated fields. If the phosphorus is being stored on the sediment, the phosphorus could accumulate in this reach during several consecutive dry years until high streamflow suspends and transports the sediment and phosphorus downstream.

Seasonal patterns in stream loads of nitrogen at stations on unregulated reaches are similar to seasonal patterns in streamflow (Salt River near Roosevelt, fig. 13); stream loads are much greater during high flow than during low flow. Stream loads of nitrogen at stations on effluent-dependent reaches also follow the seasonal patterns of flow (Hassayampa River, fig. 13); however, the seasonality is less amplified for effluent-dependent reaches than for unregulated reaches. The amplification is smaller because runoff tends to decrease concentrations of nitrogen in effluent-dependent reaches and increase concentrations of nitrogen in unregulated reaches (table 7). For the Salt River at Roosevelt, like other stations on unregulated perennial streams, more of the stream load of nitrogen occurs as ammonia and organic nitrogen than as nitrate (fig. 13). For the Hassayampa River, which receives agricultural effluent, the opposite is true—more of the stream load of nitrogen occurs as nitrate than as ammonia and organic nitrogen (fig. 13).

An analysis of the annual mass of nitrogen and phosphorus from major sources that are input to the land surface of a basin and of the mass that is transported out of the basin in the annual stream load provides information about the relative importance of each major source of the nutrients and the fate of the nutrients in that basin. The portion of the inputs that is not transported out of the basin in streamflow is either transported to the subsurface (soil, unsaturated zone, or aquifer), released to the atmosphere (such as volatilized ammonia), or incorporated into the biomass. An estimate of the annual inputs and outputs (stream loads) of nutrients for a basin, therefore, can be used to determine the percentage of the nutrients that is removed from the basin by surface-water processes and the percentage of the inputs that is either removed by other processes or stored in the basin.

Annual inputs to the land surface from the major sources were estimated for the drainage basins above six stations: West Clear Creek, the Salt River near Roosevelt (the upper Salt River Basin), the Verde River below Tangle Creek (the upper Verde River Basin), the San Pedro River at Charleston (the upper San Pedro River Basin), the Hassayampa River, and the Gila River at Buckeye Canal (the middle Gila River Basin). The middle Gila River Basin, for the purpose of this report, is defined as the area from Kelvin to the Buckeye Canal that drains to the Gila River. For the purpose of estimating inputs of nutrients, the drainage basin for the Hassayampa River includes the natural drainage basin plus an area of about 500 km^2 north of the Buckeye Canal between the Agua Fria and Hassayampa Rivers, because portions of this area drain into the Buckeye Canal and then into the Hassayampa River.

Each basin represents a different mix of land uses and land covers that are found throughout the study area (Cordy and others, 1998, figs. 9 and 10). The West Clear Creek Basin is small and has little municipal or agricultural development. The upper Salt River Basin is much larger than the West Clear Creek Basin and has a few small towns and irrigated fields. The upper Verde River Basin contains several minimally developed basins, such as the West Clear Creek Basin, but also has several small towns and irrigated agricultural land along the Verde River. The upper San Pedro River Basin has small cities, such as Sierra Vista, Arizona, and Cananea, Mexico, as well as irrigated agricultural land along the San Pedro River. The upper part of the Hassayampa River Basin is mostly undeveloped and comparable to the upper Salt River and upper Verde River Basins. The lower part of the Hassayampa River Basin, however, has towns and several thousand hectares of intensive agriculture. The middle Gila River Basin is a large basin and contains the Santa Cruz, Salt, Verde, and Agua Fria River Basins. The middle Gila River Basin generally reflects conditions of the whole study area and encompasses several large cities, such as Phoenix and Tucson, and several hundred thousand hectares of agricultural lands.

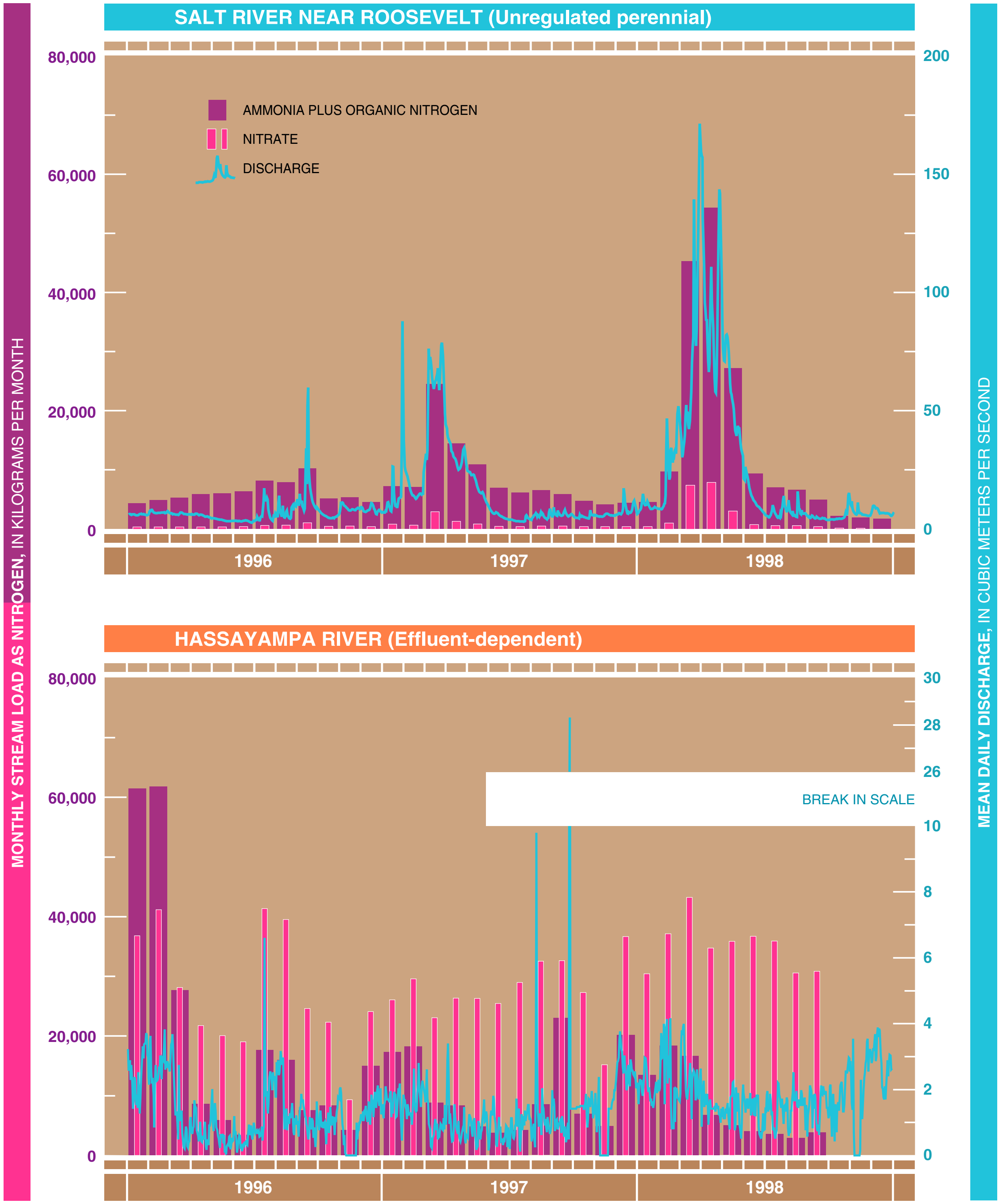


Figure 13. Mean daily discharge and monthly stream load of nitrate and ammonia plus organic nitrogen at the Salt River near Roosevelt and at the Hassayampa River, Central Arizona Basins study area, 1996–98.

Annual inputs to basins from the following major sources of nitrogen and phosphorus were estimated: atmospheric deposition, fertilizer, bodily waste from livestock on feed, bodily waste from humans, surface-water inflow, and toxic chemical releases. Estimates generally were determined by using empirical methods and existing data from other State and Federal agencies (appendix 2). The data used to estimate the annual inputs were not available for every year (1996, 1997, and 1998), and in some cases the data were only available for years before 1996. For this reason, the most recent data available were used to estimate the annual input for one year, and this estimate was considered to reflect typical current (1998) conditions. The uncertainty of the input estimates is high because the coefficients used in the empirical methods to estimate the nutrient inputs were not calibrated to local conditions. In addition, there are other possible sources of nitrogen and phosphorus, such as geological deposits, landfills, pets, and desert legumes; however, methods for estimating annual inputs from these sources without additional data collection were not available. Because the estimates may not include inputs from all sources, the annual input estimates should be considered as minimums, and the results of this study should be considered exploratory.

Total quantified annual inputs of nitrogen ranged from 0.15 million kilograms per year for the West Clear Creek Basin to 85 million kilograms per year for the middle Gila River Basin (table 14). Total quantified annual inputs of phosphorus ranged from 0.004 million kilograms per year for the West Clear Creek Basin to 23 million kilograms per year for the middle Gila River Basin (table 14).

Table 14. Estimated annual input of nitrogen and phosphorus from various sources to drainage basins of selected surface-water quality monitoring stations in the Central Arizona Basins study area

Source	Central Highlands			Basin and Range Lowlands		
	Upper Salt River Basin	West Clear Creek Basin	Upper Verde River Basin	Upper San Pedro River Basin	Hassayampa River Basin	Middle Gila River Basin
Phosphorus, in millions of kilograms per year						
Human waste						
Sewer	.032	0	.10	.13	.026	4.1
Septic	.029	.004	.10	.069	.027	.66
Livestock, nongrazing	.037	0	.04	.001	.13	5.5
Fertilizer	.053	0	.11	.028	.68	12.5
Industry	0	0	0	0	0	.34
Surface-water inflow	0	0	0	0	.46	.17
Unquantified	unknown	unknown	unknown	unknown	unknown	unknown
Total quantified						
Input	.15	.004	.36	.23	1.3	23
Flux[1]	14	6	24	72	330	320
Nitrogen, in millions of kilograms per year						
Precipitation	2.3	.14	2.6	.50	.50	11
Human waste						
Sewer	.089	0	.28	.37	.072	11
Septic	.082	.011	.30	.19	.077	1.9
Livestock, nongrazing	.13	0	.23	.004	.75	20
Fertilizer	.17	0	.35	.089	2.2	40
Industry	0	0	0	0	0	.14
Surface-water inflow	0	0	0	0	1.15	.51
Unquantified	unknown	unknown	unknown	unknown	unknown	unknown
Total quantified						
Input	2.7	.15	3.8	1.2	4.7	85
Flux[1]	250	240	250	360	1,200	1,200

[1]Units are in kilograms per square kilometer per year.

The variability in annual inputs for the basins is, in part, related to the basin size, and so the annual inputs are normalized to area and called annual input fluxes. Total quantified annual input fluxes of nitrogen and phosphorus were similar for the upper Salt River, West Clear Creek, and upper Verde River Basins—about 250 kg/km^2 for nitrogen and about 15 kg/km^2 for phosphorus (table 14). The similarity of the total quantified annual input fluxes of nitrogen and phosphorus for the upper Salt River and upper Verde River Basins to those of the minimally developed West Clear Creek Basin suggests that, at the basin scale, the small amount of municipal and agricultural development present in the upper Salt River and upper Verde River Basins does not greatly change the input flux. Total quantified annual input fluxes for the Hassayampa River and the middle Gila River Basins were also similar—about 1,200 kg/km^2 for nitrogen and 330 kg/km^2 for phosphorus. Total quantified annual input fluxes of nitrogen and phosphorus for the upper San Pedro River Basin were somewhat higher than those for the upper Salt River, West Clear Creek, and upper Verde River Basins, but were considerably lower than those for the Hassayampa River and middle Gila River Basins.

In the upper Salt River, West Clear Creek, upper Verde River, and upper San Pedro River Basins, precipitation was the largest quantified input of nitrogen, and fertilizers and bodily waste from humans were the largest quantified inputs of phosphorus (table 14). In the Hassayampa River and middle Gila River Basins, fertilizer was by far the largest quantified input of nitrogen and phosphorus. In the upper San Pedro River and middle Gila River Basins, more nutrient inputs from human bodily waste were treated by sewer systems than by septic tanks, whereas in the upper Salt River, West Clear Creek, upper Verde River, and Hassayampa River Basins, an approximately equal or larger amount of nutrient input from human bodily waste was treated by septic tanks than by sewer systems. The nutrients entering the middle Gila River in surface-water inflow were nearly negligible compared to the total quantified inputs. In contrast, nutrients from the 91st Avenue Wastewater-Treatment Plant releases and from agricultural return flows that are carried into the Hassayampa River Basin as surface-water inflow through the Buckeye Canal were a considerable part of the total quantified inputs. Release of nutrients by industry directly to the land surface of basins was low or nonexistent in all basins. Data from the toxic chemical release inventory (Arizona Department of Environmental Quality, 1997), however, indicate that the annual mass of nitrate and ammonia released to the atmosphere by industry is much greater than that released to the land surface. Some of these atmospheric releases could indirectly become basin inputs through atmospheric deposition.

Precipitation, fertilizer, and human bodily wastes that are treated by septic tanks are nonpoint sources of nutrients, whereas releases from industry, bodily wastes from livestock on feed, and human bodily wastes that are treated by sewer systems are point sources. With the exception of phosphorus inputs to the upper San Pedro River Basin, quantified inputs from nonpoint sources of nitrogen and phosphorus were greater than quantified inputs from point sources. This dominance of nonpoint sources indicates that strategies to protect water resources from nitrogen or phosphorus contamination should target inputs from both point and nonpoint sources.

Temporal trends in inputs from major sources of nitrogen and phosphorus to the State of Arizona can be used to approximate the temporal trends in the inputs to the middle Gila River Basin because much of the agricultural land and population of the State is in this basin. Inputs of nitrogen and phosphorus to Arizona were estimated using methods described in Appendix 2. Inputs of nitrogen and phosphorus to Arizona from fertilizer grew steadily from the time fertilizer was commercially introduced in the early 1940s until the 1970s and have been several times greater than inputs from bodily waste from humans, dairy cattle, or cattle on feed during this period (fig. 14). Inputs of nitrogen and phosphorus from bodily wastes from humans have steadily increased over time as a result of population growth. Inputs of nitrogen and phosphorus from beef cattle on feed have steadily declined since the 1970s.

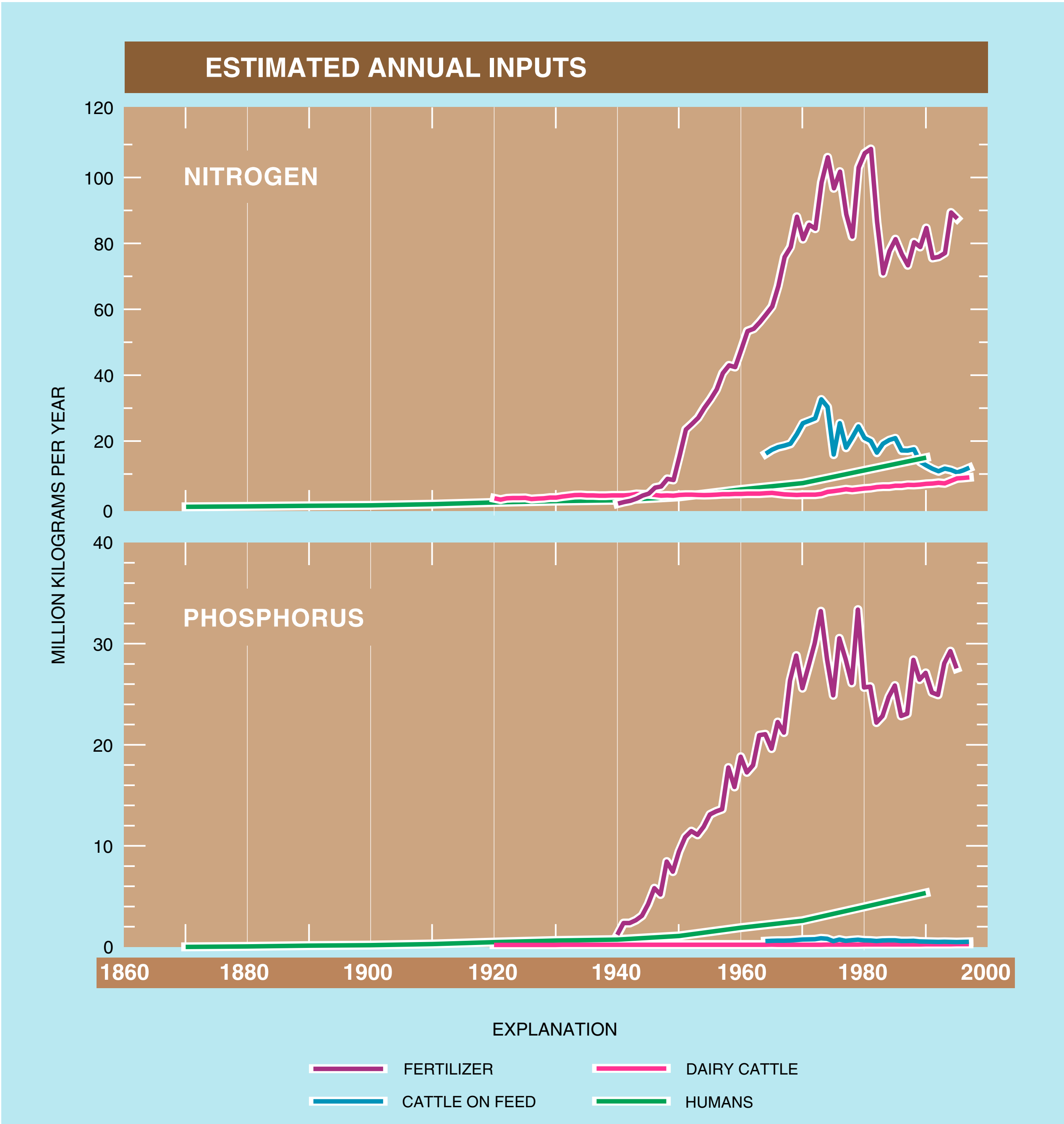


Figure 14. Temporal trends of estimated annual inputs of nitrogen and phosphorus to Arizona from fertilizer and from bodily waste from cattle on feed, dairy cattle, and humans.

The percentage of nitrogen input to basins that was transported out of the basins in streamflow in 1996–98 was low for all basins and ranged from 1 to 21 percent (table 15). The percentage of phosphorus input to basins that was transported out of the basins in streamflow in 1996–98 typically was higher than the percentage of nitrogen and ranged from 1 to 50 percent (table 15). The low percentages indicate that much of the nitrogen and phosphorus inputs are not being transported out of the basins in surface water. Much of the mass input to the basin, therefore, must be transported to the subsurface (soil, unsaturated zone, or aquifer), released to the atmosphere (such as volatilized ammonia), or incorporated into the biomass of the basin.

Table 15. Annual stream load of nutrients for 1996–98 as a percentage of the estimated annual inputs for selected basins in the Central Arizona Basins study area

[---, not computed]

Basin	Annual stream load of nutrients, as a percentage of the estimated annual inputs to the basin					
	Phosphorus			Nitrogen		
	1996	1997	1998	1996	1997	1998
Central Highlands						
Upper Salt River	10	17	45	3	4	7
West Clear Creek	25	50	---	1	5	---
Upper Verde River	3	7	47	1	1	21
Basin and Range Lowlands						
Upper San Pedro River	3	1	2	---	---	---
Hassayampa River	15	8	11	18	9	11
Middle Gila River	---	2	2	---	2	1

For the 3 years studied, 1996–98, the percentage of nutrient inputs that was transported out of the upper Salt River and upper Verde River Basins was greatest in 1998; this was mostly a result of the larger amount of streamflow that occurred during those years than during other years (table 11). This increase in the percentage suggests that nutrient inputs could accumulate and remain immobile in the basin for several years until they are transported out of the basin during infrequent but large flows.

During 1996–98, the percentage of nitrogen inputs that were transported out of the basin was on average the greatest for the Hassayampa River Basin; this could be because the Hassayampa River is an effluent-dependent stream. In contrast, the percentage of phosphorus inputs that was transported out of the Hassayampa River Basin was lower than those for the upper Salt River or West Clear Creek Basins during most years. This difference could indicate that there are substantial inputs of phosphorus from unquantified sources in the upper Salt River and West Clear Creek Basins, or that the physical, chemical, or biological processes of retaining phosphorus are more efficient in the Hassayampa River Basin than in the upper Salt River or West Clear Creek Basins.

SUMMARY AND CONCLUSIONS

A comparison of stream properties and water-chemistry constituent concentrations to water-quality standards, the relation of stream properties and water-chemistry constituent concentrations to natural and human factors, and water-chemistry constituent stream loads for the surface-water resources of the study area were analyzed using water-quality data collected by the NAWQA and other USGS programs. Stream temperature, pH, dissolved-oxygen, dissolved-solids, suspended-sediment, and nutrient data collected at 41 surface-water quality monitoring stations through water year 1998 were used in this analysis. Conclusions about the water quality of surface-water resources presented in this report were made in consideration of only the stream properties and water-chemistry constituents investigated; other water-chemistry constituents not considered in this study could be of more relevance to the water quality of a given stream reach.

Comparison of data to water-quality standards resulted in identification of several instances where stream properties or water-chemistry constituent concentrations exceeded Maximum Contaminant Levels. In a few samples from the White River, the Black River, and the Salt River below Stewart

Mountain Dam, pH was higher than allowed by the State of Arizona standard for reaches designated as domestic drinking water sources. State of Arizona standards for dissolved oxygen were typically met at most stations, with the exception of the Santa Cruz River at Cortaro, where half of the samples did not meet the standard. More than half of the samples from the Salt River below Stewart Mountain Dam and almost all of the samples from the stations on the Central Arizona Project Canal—two of the three most important surface-water sources used for drinking water—exceeded the USEPA drinking-water SMCL for dissolved solids. There were no exceedences at any stations where State of Arizona standards for nitrate were applicable, nor were there any exceedences of State of Arizona standards for ammonia in reaches designated for aquatic and wildlife warm water or cold water fisheries. Two reach-specific standards for nutrients established by the State of Arizona were exceeded: (1) the annual mean concentration of total phosphorus was exceeded in several years at stations on the main stems of the Salt and Verde Rivers, and (2) the annual mean concentration of total nitrogen was exceeded during several years at the Salt River near Roosevelt and the Salt River below Stewart Mountain Dam.

Stream properties and water-chemistry constituent concentrations were found to be related to streamflow, season, water management, stream permanence, and land and water use. At stations on unregulated perennial and intermittent reaches, correlations of stream properties and water-chemistry constituent concentrations with streamflow were common and generally were consistent in sign among stations for each constituent (positively or negatively correlated). Because streamflow in unregulated perennial reaches was seasonally variable and the stream properties and water-chemistry constituent concentrations were correlated with streamflow, the stream properties and water-chemistry constituent concentrations also were seasonally variable. For effluent-dependent reaches, the correlation of stream properties and water-chemistry constituent concentrations with streamflow was controlled by the source of the effluent, the distance from the source to the sampling station, and the season at the time of sampling. Correlations of stream properties and water-chemistry constituent concentrations with streamflow at stations on regulated reaches generally were weaker than those for stations on unregulated reaches, and the signs of the correlations were not as consistent. In cases where stream properties and water-chemistry constituent concentrations were correlated with streamflow, changes in the seasonality of streamflow caused by storing water in large reservoirs also changed the seasonality of the stream properties and water-chemistry constituent concentrations. Concentrations of dissolved solids in the Salt River below Stewart Mountain Dam had a 7-year sinusoidal pattern as a result of variability in flows entering the upstream reservoir. Because the concentrations of dissolved solids in storm runoff and snowmelt entering the reservoir system were lower than concentrations in base flow, the concentrations in water released from the reservoirs decreased during or slightly after a year in which there was a large inflow, and then slowly increased until another year of large inflow. For the reservoir system on the Salt River, only large-volume flows lowered the concentration of dissolved solids in reservoir releases below the USEPA SMCL (500 mg/L). Stream properties and water-chemistry constituent concentrations also were found to be related to upstream factors. The pH, dissolved-oxygen percent saturation, and nutrient concentrations were dependent on stream regulation, stream permanence, and upstream disposal of wastewater.

Storage of water in the reservoirs on the Salt and Verde Rivers resulted in a decrease in pH and decreases in concentrations of dissolved solids, suspended sediment, and total phosphorus. These decreases represented improvements in water quality for drinking-water purposes. In contrast, several species of nitrogen increased, which represents a degradation of water quality for drinking-water purposes. The diversion and use of surface water downstream from the reservoirs on the Agua Fria, Gila, Salt, and Verde Rivers for municipal and agricultural purposes resulted in several kilometers of dry streambeds, and the water returned from these uses was of poorer quality than water from upstream of the diversions. Change in the quality of water from before use to after use reflected the effects of both land and water use. Decreases in dissolved-oxygen percent saturation and increases in dissolved-solids and nutrient concentrations indicated that water quality in the Salt River degraded as a result of municipal water use in the Phoenix metropolitan area. Stream properties and water-chemistry constituent concentrations in effluent-dependent reaches were related to the source of the wastewater.

Concentrations of ammonia, total ammonia plus organic nitrogen, and total nitrogen were higher and concentrations of nitrate and dissolved oxygen were lower in wastewater from secondary treatment plants than in wastewater from secondary treatment plants with nitrification/denitrification. The pH, dissolved-oxygen percent saturation, and concentration of nitrate were higher in agricultural wastewater than in treated municipal wastewater. Comparison of data for West Clear Creek, a station in a minimally developed basin, with data for stations on unregulated perennial reaches in basins that had some rangeland, agricultural, and (or) municipal development, indicated that these land uses may increase the concentrations of dissolved solids, suspended sediment, total phosphorus, nitrate, ammonia and organic nitrogen, and total nitrogen.

Temporal trends in streamflow and in stream properties and water-chemistry constituent concentrations were common in the study area. Temporal trends of monthly 3-day low flow, monthly mean daily flow, and monthly maximum daily flow in unregulated perennial reaches draining the Central Highlands tended to be higher from 1900 through the 1930s, lower from the 1940s through the 1970s, and higher again after the 1970s. This pattern in streamflow follows that observed for the mean annual precipitation for the Southwestern United States and indicates that long-term trends in flow of streams draining the Central Highlands were driven by long-term trends in climate. For the San Pedro River at Charleston, which is in the Basin and Range Lowlands, results from this study corroborate the declining trend in streamflow found by Pool and Coes (1999), who stated that the decline could be a result of declining runoff and recharge near the river during June through October and increased interception of ground-water flow to the river by wells and phreatophytes. Stream-flow increased over the period of record at stations on effluent-dependent reaches as a result of the increase in the urban population and associated wastewater-treatment plant outflows to the Salt River and the Gila River in the Phoenix metropolitan area and to the Santa Cruz River in the Tucson metropolitan area.

Trends in stream properties and water-chemistry constituent concentrations were examined at eight water-quality monitoring stations in the study area and generally indicate that water quality has improved over time. Stream pH increased at the Salt River below Stewart Mountain Dam, the Verde River below Bartlett Dam, the Gila River at Kelvin, and the Gila River at Gillespie Dam, but had no trend at the Salt River near Roosevelt, Wet Bottom Creek, the Verde River below Tangle Creek, and the Agua Fria River near Rock Springs. Concentrations of dissolved oxygen increased at the Salt River near Roosevelt, the Salt River below Stewart Mountain Dam, and the Verde River below Tangle Creek. Concentrations of dissolved oxygen had no trend at the other stations. Concentrations of dissolved solids decreased in the Salt River below Stewart Mountain Dam and in the Verde River below Bartlett Dam. This decrease represents an improvement in these important drinking-water sources because concentrations in the Salt River typically are high and exceed the USEPA SMCL. This decreasing trend in concentrations most likely resulted from a concurrent increasing trend in the amount of runoff entering the reservoirs. Concentrations of nutrients generally have decreased over time at several stations. The decrease in concentrations of total phosphorus and total nitrogen over the period of sampling at the Gila River at Gillespie Dam resulted from an increase in streamflow and also from a decrease in the loads of these nutrients to the stream from natural and human sources and (or) an increase in nutrient uptake by aquatic biota and riparian vegetation.

Stream loads of water-chemistry constituents at different locations along the streams were compared amongst each other, and stream loads were compared with upstream inputs of the constituent from natural and anthropogenic sources to provide information about the relative importance of the different sources and about the fate of the water-chemistry constituent. Approximately 1.2 billion kilograms of dissolved solids per year that were transported into the Basin and Range Lowlands from the Central Arizona Project Canal and streams draining the Central Highlands accumulated in the soils, unsaturated zones, and aquifers in agricultural and urban areas of the Basin and Range Lowlands from irrigation of crops and urban vegetation. In streams that drain the Central Highlands, salt inputs from precipitation accounted for 4 to 40 percent of the annual stream loads of dissolved solids, and the annual stream load increased with annual streamflow because of increased inputs from precipitation. Stream loads of dissolved solids increased between the 91st Avenue Wastewater-Treatment Plant outfall and the Gila River at Gillespie Dam as a result of saline ground-water inflow and irrigation return flows.

The total annual input fluxes from quantifiable sources of nitrogen and phosphorus were considerably higher for developed basins than for minimally developed basins. These inputs exclude unquantifiable sources, such as geologic formations and soils. The total annual input fluxes for quantifiable sources of nitrogen and phosphorus for the upper Salt River and upper Verde River Basins were similar to those of the West Clear Creek Basin and suggested that, at the basin scale, the small amount of municipal or agricultural development present in the upper Salt and upper Verde River Basins did not greatly change the total input flux to the basin. For minimally developed basins, precipitation was the largest quantifiable source of nitrogen, whereas inputs from human bodily waste and from fertilizers was the largest quantifiable source of phosphorus. This was in contrast to developed basins, for which fertilizer was the largest source of both nutrients. For most basins examined, quantifiable inputs of nitrogen and phosphorus from nonpoint sources were greater than quantifiable inputs from point sources. This difference emphasizes the importance of land and water management policies that protect surface-water resources from nonpoint sources, as well as point sources, of nutrients. The amount of nitrogen and phosphorus transported out of the basins was much smaller than the amount of quantifiable inputs. This indicated that most of the nutrients input to basins were not transported out in surface water, but were transported to the subsurface (soil, unsaturated zone, or aquifer), released to the atmosphere (such as volatilized ammonia), or incorporated into the biomass.

REFERENCES CITED

Anderson, J.R., Hardy, E.E., Road, J.T., and Witmer, R.E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 28 p.

Anderson, T.W., Freethey, G.W., and Tucci, Patrick., 1992, Geohydrology and water resources of alluvial basins in south-central Arizona and parts of adjacent states: U.S. Geological Survey Professional Paper 1406–B, 67 p., 3 pls.

Anning, D.W., and Duet, N.R., 1994, Summary of ground-water conditions in Arizona, 1987–90: U.S. Geological Survey Open-File Report 94—476, 2 sheets.

Arizona Agricultural Statistics Service, 1996, 1995 Arizona agricultural statistics: Phoenix, Arizona Agricultural Statistics Service report, 109 p.

Arizona Agricultural Statistics Service, 1997, 1996 Arizona agricultural statistics: Phoenix, Arizona Agricultural Statistics Service report, 106 p.

Arizona Department of Environmental Quality, 1997, Arizona toxic chemical release inventory report summary—Data collected for reporting year 1995: Arizona Department of Environmental Quality report EQR 97–5, 88 p.

Arizona State Climatologist, 1975, Arizona precipitation: Tempe, Laboratory of Climatology, Arizona State University, Arizona Resources Information System Cooperative Publication no. 5, 1 sheet.

Arizona State Land Department, 1969, Annual report on ground water in Arizona, spring 1967 to spring 1968: Phoenix, Arizona State Land Department Water-Resources Report 38, 54 p.

Baynham, O.R., and Phillips, J.V., 1996, Precipitation and streamflow conditions in Arizona, winter and spring, 1996: U.S. Geological Survey Fact Sheet 223—96, 2 p.

Brown, D.E., Carmony, N.B., and Turner, R.M., compilers, 1981, Drainage map of Arizona showing perennial streams and some important wetlands: Phoenix, Arizona Game and Fish Department, scale 1:1,000,000.

Brown, J.G., and Pool, D.R., 1989, Hydrogeology of the western part of the Salt River Valley area, Maricopa County, Arizona: U.S. Geological Survey Water-Resources Investigations Report 88—4202, 5 sheets.

Cleveland, W.S., 1979, Robust locally weighted regression and smoothing scatterplots: Journal of the American Statistical Association, v. 74, p. 829–836.

Coordinacion General de los Servicios Nacionales de Estadistica, Geografia, E Informatica, 1981, Carta geologica—Nogales: Coordinacion General de los Servicios Nacionales de Estadistica, Geografia, E Informatica, Map H12–2, scale 1:250,000, 1 sheet.

____1983a, Carta geologicia—Nacozari: Coordinacion General de los Servicios Nacionales de Estadistica, Geografia, E Informatica, Map H12–6, scale 1:250,000, 1 sheet.

____1983b, Carta geologicia—Agua Prieta: Coordinacion General de los Servicios Nacionales de Estadistica, Geografia, E Informatica, Map H12–3, scale 1:250,000, 1 sheet.

Cohn, T.A., 1988, Adjusted maximum likelihood estimation of the moments of lognormal populations from type I censored samples: U.S. Geological Survey Open-File Report 88—350, 34 p.

Cohn, T.A., DeLong, L.L., Gilroy, E.J., Hirsh, R.M., and Wells, D.K., 1989, Estimating constituent loads: Water Resources Research, v. 25, no. 5, p. 937–942.

Cordy, G.E., Rees, J.A., Edmonds, R.J., Gebler, J.B., Wirt, Laurie, Gellenbeck, D.J., and Anning, D.W., 1998, Water-quality assessment of the Central Arizona Basins, Arizona and Northern Mexico—Environmental setting and overview of water quality: U.S. Geological Survey Water-Resources Investigations Report 98—4097, 72 p.

Edmonds, R.J., and Gellenbeck, D.J., 2002, Ground-water quality in the West Salt River Valley, Arizona, 1996–1998—Relations to hydrogeology, water use, and land use: U.S. Geological Survey Water-Resources Investigations Report 01—4126, 60 p.

E.L. Montgomery and Associates, 1986, Study of waterlogging problems in the West Salt River and Hassayampa sub-basins of the Phoenix Active Management Area: Arizona Department of Water Resources, v.p.

Fenneman, N.M., 1931, Physiography of western United States: New York, McGraw-Hill, 534 p.

Garrett, J.M., and Gellenbeck, D.J., 1991, Basin characteristics and streamflow statistics in Arizona as of 1989: U.S. Geological Survey Water-Resources Investigations Report 91—4041, 612 p.

Gebert, W.A., Graczyk, D.J., and Krug, W.R., 1987, Average annual runoff in the United States, 1951–80: U.S. Geological Survey Hydrologic Investigations Atlas HA—710, scale 1:7,500,000.

Gilliom, R.J., Alley, W.M., and Gurtz, M.E., 1995, Design of the National Water-Quality Assessment Program—Occurrence and distribution of water-quality conditions: U.S. Geological Survey Circular 1112, 33 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Amsterdam, The Netherlands, Elsevier Science Publishers, Studies in Environmental Sciences, v. 49, 522 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hirsch, R.M., Alexander, R.B., and Smith, R.A., 1991, Selection of methods for the detection and estimation of trends in water quality: Water Resources Research, v. 27, no. 5, p. 803–813.

Hirsch, R.M., and Slack, J.R., 1984, A nonparametric trend test for seasonal data with serial dependence: Water Resources Research, v. 20, no. 6, p. 727–732.

Hirsch, R.M., Slack, J.R., and Smith, R.A., 1982, Techniques of trend analysis for monthly water quality data: Water Resources Research, v. 18, no. 1, p. 107–121.

Hitt, K.J., 1994, Refining 1970's land-use data with 1990 population data to indicate new residential development: U.S. Geological Survey Water-Resources Investigations Report 94—4250, 15 p.

Kendall, M.G., 1938, A new measure of rank correlation: Biometrika, v. 30, p. 81–93.

Kister, L.R., 1974, Dissolved-solids content of ground water in the Phoenix area, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I–845–G.

Kister, L.R., and Hardt, W.F., 1966, Salinity of ground water in western Pinal County, Arizona: U.S. Geological Survey Water-Supply Paper 1819–E, 21 p., 2 pls.

Kramer, C.Y., 1956, Extension of multiple range tests to group means with unequal numbers of replications: Biometrics, v. 12, p. 309–310.

Likens, G.E., and Bormann, H.F., 1995, Biogeochemistry of a forested ecosystem, (2d ed.): New York, Springer-Verlag, 159 p.

Lopes, T.J., and Fossum, K.D., 1995, Selected chemical characteristics and acute toxicity of urban stormwater, streamflow, and bed material, Maricopa County, Arizona: U.S. Geological Survey Water-Resources Investigations Report 95—4047, 52 p.

Lorey, D.E., 1990, United States-Mexico border statistics since 1990: Los Angeles, University of California–Los Angeles, Latin American Center Publications, 475 p.

McKee, J.E., and Wolf, H.W., 1963, Water quality criteria: California State Water Quality Board Publication 3–A, 548 p.

Meinzer, O.E., 1923, Outline of ground-water hydrology: U.S. Geological Survey Water-Supply Paper 494, 71 p.

National Atmospheric Deposition Program, 1998a, NADP overview and history, accessed June 4, 1998, at URL http://nadp.sws.uiuc.edu/nadpoverview.asp.

____1998b, Precipitation chemistry data, accessed June 4, 1998, at URL http://nadp.sws.uiuc.edu/nadpdata.

Pool, D.R., and Coes, A.L., 1999, Hydrogeologic investigations of the Sierra Vista subwatershed of the Upper San Pedro Basin, Cochise County, Southeast Arizona: U.S. Geological Survey Water-Resources Investigations Report 99—4197, 41 p., 3 sheets.

Reynolds, S.J., 1988, Geologic map of Arizona: Tucson, Arizona Geological Survey Map, N–26, 1 sheet, scale, 1:1,000,000.

Robertson, F.N., 1991, Geochemistry of ground water in alluvial basins of Arizona and adjacent parts of Nevada, New Mexico, and California: U.S. Geological Survey Professional Paper 1406–C, 90 p.

Sellers, W.D., and Hill, R.H., eds., 1974, Arizona climate, 1931–72: Tucson, University of Arizona Press, 616 p.

Sisterson, D.L. 1990, Detailed SO_x-S and NO_x-N mass budgets for the United States and Canada, *in* National Acid Precipitation Assessment Program, Report 8, Acidic deposition—State of science and technology: National Acid Precipitation Program, Appendix A, 10 p.

SPSS, Inc., 1997, SYSTAT 7.0—Statistics: Chicago, Illinois, SPSS Inc., 751 p.

State of Arizona, 1996, Water quality standards: Phoenix, State of Arizona, Arizona Administrative Code, Title 18, Chap. 11, p. 1-60.

Tadayon, Saeid, Duet, N.R., Fisk, G.G., McCormack, H.F., Partin, C.K., Pope, G.L., and Rigas, P.D., 1999, Water resources data, Arizona, water year 1998: U.S. Geological Survey Water-Data Report AZ–98–1, 454 p.

Tadayon, Saeid, Duet, N.R., Fisk, G.G., McCormack, H.F., Pope, G.L., and Rigas, P.D., 1998, Water resources data, Arizona, water year 1997: U.S. Geological Survey Water-Data Report AZ–97–1, 416 p.

Trentberth, K.E., 1991, Climate change and climate variability: The climate record, *in* Managing water resources in the West under conditions of climate uncertainty: National Resources Council, Proceedings of the Colloquium, November 14–16, 1990, Scottsdale, Arizona, National Academy Press, Washington, D.C.

U.S. Department of Agriculture, 1992, National engineering handbook—Agricultural waste management field handbook, part 651: U.S. Department of Agriculture, Soil Conservation Service, v.p.

U.S. Department of Commerce, 1992, 1990 Census of population and housing—Summary social, economic, and housing characteristics– Arizona: U.S. Department of Commerce report 1990 CPH–5–4, v.p.

———1994, 1992 Census of agriculture, Volume 1 Geographic Area Series, Part 3 Arizona State and County Data: U.S Department of Commerce Report AC92–A–3, v.p.

U.S. Environmental Protection Agency, 1980, Design manual: On site wastewater treatment and disposal systems: U.S. Environmental Protection Agency, Office of Water Program Operations, Research and Development, Municipal Environmental Research Laboratory, 391 p.

____1996, Drinking water regulations and health advisories: U.S. Environmental Protection Agency, Office of Drinking Water, 11 p.

U.S. Federal Water Pollution Control Administration, 1968, Report of the committee on water-quality criteria: Washington, D.C., 234 p.

U.S. Public Health Service, 1962, Drinking water standards, 1962: U.S. Health Service Publication 956, 61 p.

Wilcoxon, F., 1945, Individual comparisons by ranking methods: Biometrics, v. 1, p. 80–83.

APPENDIX 1:
STATISTICAL SUMMARIES OF STREAM PROPERTIES AND WATER-CHEMISTRY CONSTITUENTS AT SURFACE-WATER QUALITY MONITORING STATIONS IN THE CENTRAL ARIZONA BASINS STUDY AREA, THROUGH 1998

Appendix 1. Statistical summaries of stream properties and water-chemistry constituents at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998

[mg/L, milligrams per liter; ---, not computed; <, value is less than the number listed; WWTP, wastewater treatment plant]

Station	Minimum	Percentile 25th	Percentile Median	Percentile 75th	Maximum	Mean	Standard deviation	Number of samples
Stream temperature, in degrees Celsius								
Central Highlands								
Black River	2	9	17	23	29	16	8	44
White River	2	5.5	13.5	20.5	27	14	8	45
Pinal Creek	10	17	22	26	34	22	6	160
Salt River near Roosevelt	4.5	10.5	17	24	30	17	7.5	265
Tonto Creek	2	11	19.5	26	31	18.5	8	55
Salt River below Stewart Mountain Dam	8.5	14	18	20.5	25.5	17.5	4	173
Verde River near Clarkdale	5	12	18	22	28.5	17	6	192
Verde River near Cornville	6	10	15	23	27	16	7	24
Oak Creek near Sedona	1	7	11	15	20	11	5	23
Oak Creek at Red Rock Crossing	3.5	8	14	21	28	14.5	7	147
Oak Creek near Cornville	6	12.5	20	23	29	18.5	7	34
Verde River above West Clear Creek	6.2	13.5	16.5	25	26.5	18	6.5	21
West Clear Creek	5.5	9	14	22	27	15	7	46
Verde River near Camp Verde	5	10	17	24	35	17	7.5	112
East Verde River	6	10	17	24	30	17.5	8	47
Wet Bottom Creek	5	11	16	22.5	32	16.5	7	181
Verde River below Tangle Creek	5	12.5	19	25.5	31.5	19	7	199
Verde River below Bartlett Dam	7	12	15	19	29	16	5	191
Turkey Creek	7	9	20.5	22.5	29	17.5	7.5	40
Agua Fria River near Rock Springs	3.5	13	20	25	33	19	6.5	167
Agua Fria River below Waddell Dam	10	14.5	16.5	19	29	17	3.5	75
Basin and Range Lowlands								
Central Arizona Project near Parker	11	15	20	25.5	30	20	6	41
Central Arizona Project at Phoenix	8.5	14	20	26	31	20	6.5	123
Gila River at Winkelman	6	12.5	16	19	32	16.5	5.5	86
San Pedro River at Charleston	2	16	21	24.5	32	20.5	6	176
San Pedro River below Aravaipa	7	18	22	26.5	33.5	22	5.5	115
San Pedro River at Winkelman	6	19	25	30.5	39	24.5	8	114
Gila River at Kelvin	7	13.5	19	24	32	19	6.5	305
Santa Cruz River at Rio Rico	13	21	23.5	26	29	23	4	26
Santa Cruz River at Tubac	12	17	22	24	26.5	21	4	27
Santa Cruz River at Cortaro	17.5	24	26	28	31	26	4	14
Santa Cruz River at Laveen	6	11	14.5	21	25	15.5	6.5	16
Indian Bend Wash at Curry Road	10	14	17	27	32	20	7	19
Box Culvert at 48th Street Drain	11.5	15.5	19	27.5	31.5	21	7	25
27th Avenue at Salt River	12.5	15	17	26.5	29	19.5	5.5	28
43rd Avenue and Peoria Avenue	11	14.5	18.5	27.5	30	20.5	7	25
Olive Avenue and 67th Avenue	11	13	17	27	28	19	7	18
91st Avenue WWTP outfall	23	25	28	30	33	27.5	3.5	24
Gila River at Buckeye Canal	15	19	21.5	26.5	31	22.5	4.5	40
Hassayampa River	12	17.5	23	26.5	32.5	22	5	48
Gila River at Gillespie Dam	8	14	20.5	26	34	20	6.5	280

Appendix 1. Statistical summaries of stream properties and water-chemistry constituents at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998—Continued

Station	Minimum	Percentile 25th	Percentile Median	Percentile 75th	Maximum	Mean	Standard deviation	Number of samples
Stream pH, in standard units								
Central Highlands								
Black River	6.9	7.4	7.9	8.3	9.6	8.0	0.6	41
White River	6.4	7.9	8.3	8.5	11.0	8.2	.7	44
Pinal Creek	5.7	7.7	7.9	8.0	8.4	7.8	.4	158
Salt River near Roosevelt	6.9	8.1	8.3	8.4	9.2	8.2	.3	264
Tonto Creek	7.2	8.0	8.2	8.4	8.9	8.2	.4	55
Salt River below Stewart Mountain Dam	4.5	7.6	7.8	8.0	9.1	7.8	.4	496
Verde River near Clarkdale	6.9	8.1	8.2	8.3	8.6	8.2	.2	188
Verde River near Cornville	7.7	8.1	8.2	8.3	8.6	8.2	.2	24
Oak Creek near Sedona	7.7	8.2	8.4	8.4	8.7	8.3	.2	20
Oak Creek at Red Rock Crossing	6.9	8.2	8.3	8.5	8.8	8.3	.3	141
Oak Creek near Cornville	7.1	8.0	8.1	8.3	8.7	8.1	.3	35
Verde River above West Clear Creek	7.9	8.3	8.3	8.4	8.7	8.3	.2	21
West Clear Creek	6.8	8.1	8.4	8.5	8.7	8.2	.5	47
Verde River near Camp Verde	6.4	8.2	8.3	8.4	9.2	8.3	.3	108
East Verde River	7.8	8.3	8.4	8.5	8.6	8.4	.2	46
Wet Bottom Creek	6.5	7.6	7.9	8.1	9.4	7.8	.4	169
Verde River below Tangle Creek	6.5	8.3	8.4	8.5	9.0	8.4	.3	198
Verde River below Bartlett Dam	6.8	7.9	8.1	8.2	8.9	8.1	.3	603
Turkey Creek	6.6	7.4	7.9	8.1	8.8	7.8	.5	37
Agua Fria River near Rock Springs	6.9	8.2	8.3	8.4	8.8	8.3	.3	166
Agua Fria River below Waddell Dam	7.1	8.1	8.2	8.4	8.9	8.2	.3	75
Basin and Range Lowlands								
Central Arizona Project near Parker	7.8	8.0	8.2	8.2	8.4	8.2	0.1	41
Central Arizona Project at Phoenix	7.8	8.3	8.4	8.4	8.9	8.4	.2	123
Gila River at Winkelman	7.3	8.0	8.2	8.4	8.8	8.2	.3	85
San Pedro River at Charleston	7.7	8.2	8.3	8.4	8.9	8.3	.2	87
San Pedro River below Aravaipa	7.8	8.1	8.3	8.5	8.9	8.3	.3	38
San Pedro River at Winkelman	7.6	8.0	8.1	8.2	8.6	8.1	.2	38
Gila River at Kelvin	3.2	7.6	7.8	8.0	8.6	7.8	.4	996
Santa Cruz River at Rio Rico	7.6	8.0	8.2	8.3	8.6	8.1	.2	26
Santa Cruz River at Tubac	7.3	7.8	7.8	7.9	8.1	7.8	.2	28
Santa Cruz River at Cortaro	7.4	7.6	7.7	7.8	8.1	7.7	.2	13
Santa Cruz River at Laveen	7.6	7.9	8.4	9.1	9.7	8.5	.7	15
Indian Bend Wash at Curry Road	6.7	7.4	7.8	8.0	8.5	7.8	.4	19
Box Culvert at 48th Street Drain	5.9	6.9	7.1	7.6	8.3	7.2	.6	26
27th Avenue at Salt River	6.9	7.6	8.0	8.4	9.3	8.0	.6	28
43rd Avenue and Peoria Avenue	5.7	6.4	6.7	6.9	8.1	6.7	.5	25
Olive Avenue and 67th Avenue	6.5	7.0	7.3	7.7	8.3	7.3	.5	19
91st Avenue WWTP outfall	7.0	7.2	7.3	7.4	7.6	7.3	.2	24
Gila River at Buckeye Canal	7.4	7.6	7.8	7.8	8.3	7.8	.2	40
Hassayampa River	7.6	8.0	8.1	8.2	9.0	8.1	.2	49
Gila River at Gillespie Dam	6.5	7.7	7.8	8.1	9.5	7.9	.3	646

Appendix 1. Statistical summaries of stream properties and water-chemistry constituents at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998—Continued

Station	Minimum	Percentile 25th	Percentile Median	Percentile 75th	Maximum	Mean	Standard deviation	Number of samples
Dissolved oxygen-concentration, in mg/L								
Central Highlands								
Black River	6.7	7.6	8.4	9.2	14.0	8.7	1.6	35
White River	6.9	7.6	8.7	9.6	12.2	9.0	1.6	37
Pinal Creek	5.8	7.1	7.8	8.5	14.1	7.9	1.2	154
Salt River near Roosevelt	5.8	8.0	9.1	10.4	15.9	9.2	1.7	240
Tonto Creek	5.8	8.0	9.2	10.4	17.2	9.5	2.3	40
Salt River below Stewart Mountain Dam	1.6	7.2	8.5	10.0	13.7	8.5	2.3	119
Verde River near Clarkdale	4.6	8.5	9.4	10.2	12.2	9.4	1.3	176
Verde River near Cornville	6.8	8.6	9.6	10.4	11.0	9.3	1.2	20
Oak Creek near Sedona	7.4	8.9	9.6	10.8	11.7	9.8	1.2	19
Oak Creek at Red Rock Crossing	7.2	8.1	9.4	10.5	12.8	9.4	1.4	138
Oak Creek near Cornville	6.4	7.9	8.9	9.7	11.0	8.9	1.4	24
Verde River above West Clear Creek	6.7	9.0	9.8	10.5	11.8	9.7	1.3	20
West Clear Creek	7.4	8.1	9.4	10.4	11.3	9.3	1.2	38
Verde River near Camp Verde	3.3	8.4	9.4	10.7	13.0	9.5	1.6	98
East Verde River	5.8	7.6	8.6	10.3	11.6	8.9	1.6	46
Wet Bottom Creek	5.4	7.6	8.4	10.0	12.2	8.7	1.5	117
Verde River below Tangle Creek	6.2	7.9	8.8	10.2	13.6	9.0	1.4	191
Verde River below Bartlett Dam	6.6	9.2	10.3	11.4	17.8	10.4	1.9	115
Turkey Creek	8.6	10.3	10.4	10.6	11.3	10.2	1.0	5
Agua Fria River near Rock Springs	3.6	8.1	8.9	10.0	16.2	9.0	1.9	163
Agua Fria River below Waddell Dam	6.7	8.8	9.9	11.0	13.6	9.9	1.5	73
Basin and Range Lowlands								
Central Arizona Project near Parker	7.6	8.6	9.2	9.9	16.2	9.4	1.5	41
Central Arizona Project at Phoenix	2.1	8.2	9.2	10.3	13.2	9.2	1.6	122
Gila River at Winkelman	4.1	8.4	9.4	10.6	13.2	9.4	1.6	77
San Pedro River at Charleston	5.6	7.3	8.6	9.6	13.5	8.6	1.7	85
San Pedro River below Aravaipa	4.2	7.2	8.2	8.8	11.6	8.1	1.5	37
San Pedro River at Winkelman	5.7	7.2	8.8	9.8	10.4	8.5	1.5	22
Gila River at Kelvin	5.4	8.0	9.0	10.1	11.3	9.0	1.4	68
Santa Cruz River at Rio Rico	5.0	6.7	7.2	7.6	10.3	7.3	1.3	20
Santa Cruz River at Tubac	3.6	4.7	5.3	5.9	9.6	5.4	1.2	27
Santa Cruz River at Cortaro	2.0	2.4	2.6	3.2	3.7	2.8	.6	12
Santa Cruz River at Laveen	4.3	7.0	9.1	10.0	12.1	8.6	2.2	14
Indian Bend Wash at Curry Road	4.8	7.8	8.6	9.1	11.2	8.2	1.9	12
Box Culvert at 48th Street Drain	3.8	6.6	7.3	8.3	11.6	7.5	1.7	19
27th Avenue at Salt River	5.2	5.8	7.6	8.7	10.2	7.5	1.6	19
43rd Avenue and Peoria Avenue	5.6	6.7	7.2	8.6	10.0	7.6	1.4	17
Olive Avenue and 67th Avenue	6.1	7.0	7.6	8.8	9.8	7.8	1.2	13
91st Avenue WWTP outfall	3.7	4.5	5.0	5.5	6.0	5.0	.6	24
Gila River at Buckeye Canal	2.9	4.7	5.6	6.5	10.9	5.8	1.7	40
Hassayampa River	6.1	8.1	9.1	9.8	13.6	9.0	1.4	43
Gila River at Gillespie Dam	3.5	6.7	8.4	9.7	17.1	8.5	2.6	222

Appendix 1. Statistical summaries of stream properties and water-chemistry constituents at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998—Continued

Station	Minimum	Percentile 25th	Percentile Median	Percentile 75th	Maximum	Mean	Standard deviation	Number of samples
Dissolved-oxygen percent saturation, in percent								
Central Highlands								
Black River	---	---	---	---	---	---	---	0
White River	---	---	---	---	---	---	---	0
Pinal Creek	84	95	98	102	157	100	8	120
Salt River near Roosevelt	83	98	101	105	139	102	8	181
Tonto Creek	81	98	100	107	132	102	13	12
Salt River below Stewart Mountain Dam	69	92	100	110	153	102	16	71
Verde River near Clarkdale	91	103	110	115	140	110	9	123
Verde River near Cornville	---	---	---	---	---	---	---	0
Oak Creek near Sedona	---	---	---	---	---	---	---	0
Oak Creek at Red Rock Crossing	95	100	102	105	124	103	5	98
Oak Creek near Cornville	---	---	---	---	---	---	---	0
Verde River above West Clear Creek	89	104	112	122	149	115	16	20
West Clear Creek	97	101	102	107	113	104	5	38
Verde River near Camp Verde	88	102	106	111	120	106	6	58
East Verde River	85	96	100	102	117	100	6	46
Wet Bottom Creek	75	98	100	104	126	101	9	52
Verde River below Tangle Creek	86	100	103	107	159	104	7	170
Verde River below Bartlett Dam	79	105	109	118	144	111	11	69
Turkey Creek	101	---	---	---	144	122	30	2
Agua Fria River near Rock Springs	47	93	100	108	235	103	22	155
Agua Fria River below Waddell Dam	81	98	105	115	155	108	15	66
Basin and Range Lowlands								
Central Arizona Project near Parker	89	97	103	110	210	107	19	41
Central Arizona Project at Phoenix	21	101	107	113	142	106	15	121
Gila River at Winkelman	85	95	99	104	129	100	10	23
San Pedro River at Charleston	75	94	106	116	162	107	16	83
San Pedro River below Aravaipa	87	94	96	100	108	97	6	17
San Pedro River at Winkelman	---	---	---	---	---	---	---	0
Gila River at Kelvin	90	96	99	103	120	100	6	27
Santa Cruz River at Rio Rico	---	---	---	---	---	---	---	0
Santa Cruz River at Tubac	48	58	65	76	114	69	15	27
Santa Cruz River at Cortaro	27	31	34	40	52	37	8	12
Santa Cruz River at Laveen	---	---	---	---	---	---	---	0
Indian Bend Wash at Curry Road	63	80	94	102	115	91	17	12
Box Culvert at 48th Street Drain	44	82	88	94	123	88	15	19
27th Avenue at Salt River	54	76	89	93	104	85	13	19
43rd Avenue and Peoria Avenue	61	86	90	95	106	89	12	17
Olive Avenue and 67th Avenue	70	84	91	98	107	90	10	13
91st Avenue WWTP outfall	50	62	66	70	79	66	7	23
Gila River at Buckeye Canal	34	58	66	76	147	71	24	39
Hassayampa River	79	95	101	114	199	108	22	42
Gila River at Gillespie Dam	47	73	92	103	209	93	28	158

Appendix 1. Statistical summaries of stream properties and water-chemistry constituents at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998—Continued

Station	Minimum	Percentile 25th	Percentile Median	Percentile 75th	Maximum	Mean	Standard deviation	Number of samples
Dissolved-solids concentration, in mg/L								
Central Highlands								
Black River	51	78	92	99	124	88	16	44
White River	66	156	205	244	293	195	63	44
Pinal Creek	247	2,510	2,740	2,920	3,370	2,700	445	152
Salt River near Roosevelt	105	542	1,100	1,670	3,110	1,150	663	220
Tonto Creek	91	188	245	285	354	239	63	54
Salt River below Stewart Mountain Dam	275	435	540	696	1,270	571	176	389
Verde River near Clarkdale	59	268	280	288	310	258	58	167
Verde River near Cornville	158	348	356	364	404	340	59	23
Oak Creek near Sedona	56	113	166	172	192	143	43	23
Oak Creek at Red Rock Crossing	53	150	163	168	202	149	35	116
Oak Creek near Cornville	71	201	210	222	301	192	60	34
Verde River above West Clear Creek	134	380	420	507	667	425	124	21
West Clear Creek	51	95	190	202	215	160	59	46
Verde River near Camp Verde	73	351	429	499	651	398	156	81
East Verde River	90	187	215	242	377	221	56	47
Wet Bottom Creek	40	97	182	232	375	167	76	172
Verde River below Tangle Creek	86	332	365	392	481	340	87	159
Verde River below Bartlett Dam	102	211	305	372	604	294	88	429
Turkey Creek	91	118	177	374	1,320	300	276	25
Agua Fria River near Rock Springs	111	357	399	426	525	385	76	162
Agua Fria River below Waddell Dam	209	250	298	339	595	328	107	75
Basin and Range Lowlands								
Central Arizona Project near Parker	356	529	593	660	693	592	77	41
Central Arizona Project at Phoenix	206	528	577	645	700	575	90	123
Gila River at Winkelman	242	497	773	953	2,870	822	468	50
San Pedro River at Charleston	117	270	296	316	379	286	48	83
San Pedro River below Aravaipa	310	743	835	883	1,010	760	202	37
San Pedro River at Winkelman	232	606	925	1,060	1,240	820	310	40
Gila River at Kelvin	167	572	784	1,140	2,980	926	472	406
Santa Cruz River at Rio Rico	263	387	460	496	555	443	73	26
Santa Cruz River at Tubac	116	414	423	448	460	412	71	27
Santa Cruz River at Cortaro	314	573	585	592	610	560	78	13
Santa Cruz River at Laveen	167	258	346	459	1,060	404	223	15
Indian Bend Wash at Curry Road	75	175	283	466	610	312	180	19
Box Culvert at 48th Street Drain	35	51	92	110	257	94	53	23
27th Avenue at Salt River	92	124	154	175	444	174	80	26
43rd Avenue and Peoria Avenue	18	25	40	58	183	53	41	24
Olive Avenue and 67th Avenue	26	34	47	56	90	48	17	19
91st Avenue WWTP outfall	765	866	888	912	971	886	49	24
Gila River at Buckeye Canal	1,010	1,230	1,350	1,380	1,640	1,330	128	40
Hassayampa River	98	1,220	1,740	2,210	2,630	1,670	622	48
Gila River at Gillespie Dam	144	2,080	2,740	3,810	7,230	2,940	1,440	384

Appendix 1. Statistical summaries of stream properties and water-chemistry constituents at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998—Continued

Station	Minimum	Percentile 25th	Percentile Median	Percentile 75th	Maximum	Mean	Standard deviation	Number of samples
Suspended-sediment concentration, in mg/L								
Central Highlands								
Black River	1	3	6	7	57	15	21	9
White River	3	7	11	30	217	36	63	11
Pinal Creek	.2	7	35	169	25,560	334	2,220	133
Salt River near Roosevelt	1	11	30	151	11,690	307	1,110	208
Tonto Creek	1	5	9	17	2,190	106	445	24
Salt River below Stewart Mountain Dam	1	3	5	8	259	12	33	85
Verde River near Clarkdale	3	16	27	49	2,760	84	274	136
Verde River near Cornville	---	---	---	---	---	---	---	0
Oak Creek near Sedona	1	4	7	24	377	35	84	20
Oak Creek at Red Rock Crossing	1	4	7	12	2,400	34	217	127
Oak Creek near Cornville	---	---	---	---	---	---	---	0
Verde River above West Clear Creek	11	30	50	86	374	72	77	21
West Clear Creek	2	3	6	18	2,720	97	454	36
Verde River near Camp Verde	6	22	36	74	2,700	126	367	70
East Verde River	.1	1	4	10	177	12	29	44
Wet Bottom Creek	.3	1	3	6	110	7	15	118
Verde River below Tangle Creek	.3	7	15	48	3,320	77	273	176
Verde River below Bartlett Dam	1	8	12	23	8,560	98	747	136
Turkey Creek	3	165	836	1,750	24,300	2,480	4,800	42
Agua Fria River near Rock Springs	.2	3	6	20	29,400	439	2,580	163
Agua Fria River below Waddell Dam	2	6	8	16	151	15	23	75
Basin and Range Lowlands								
Central Arizona Project near Parker	---	---	---	---	---	---	---	0
Central Arizona Project at Phoenix	.2	2	4	8	478	13	50	116
Gila River at Winkelman	5	60	120	183	12,100	341	1,600	56
San Pedro River at Charleston	2	29	322	19,020	142,000	11,200	19,840	152
San Pedro River below Aravaipa	2	43	108	460	71,700	3,130	10,860	132
San Pedro River at Winkelman	47	6,340	45,700	90,500	208,000	54,840	50,030	102
Gila River at Kelvin	5	150	487	7,740	200,000	11,570	25,240	313
Santa Cruz River at Rio Rico	76	93	319	367	2,100	591	854	5
Santa Cruz River at Tubac	1	18	30	61	6,410	370	1,330	23
Santa Cruz River at Cortaro	10	18	26	66	33,600	2,440	8,970	14
Santa Cruz River at Laveen	44	2,660	5,060	6,720	15,100	5,280	3,830	14
Indian Bend Wash at Curry Road	---	---	---	---	---	---	---	0
Box Culvert at 48th Street Drain	---	---	---	---	---	---	---	0
27th Avenue at Salt River	---	---	---	---	---	---	---	0
43rd Avenue and Peoria Avenue	---	---	---	---	---	---	---	0
Olive Avenue and 67th Avenue	---	---	---	---	---	---	---	0
91st Avenue WWTP outfall	2	3	5	5	37	7	9	20
Gila River at Buckeye Canal	2	18	33	65	111	44	31	31
Hassayampa River	14	37	76	342	36,500	1,720	6,060	38
Gila River at Gillespie Dam	3	52	93	176	15,010	278	1,060	250

Appendix 1. Statistical summaries of stream properties and water-chemistry constituents at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998—Continued

Station	Minimum	Percentile 25th	Percentile Median	Percentile 75th	Maximum	Mean	Standard deviation	Number of samples
Dissolved-orthophosphorus concentration, in mg/L as phosphorus								
Central Highlands								
Black River	<0.01	0.02	0.03	0.05	13	---	---	37
White River	<.01	<.01	.02	.04	17	---	---	37
Pinal Creek	<.01	.02	.03	.04	.2	---	---	63
Salt River near Roosevelt	<.01	<.01	.02	.03	.11	---	---	143
Tonto Creek	<.01	<.01	<.01	.02	.07	---	---	49
Salt River below Stewart Mountain Dam	<.01	<.01	.02	.03	.06	---	---	72
Verde River near Clarkdale	<.01	<.01	<.01	.03	.09	---	---	51
Verde River near Cornville	<.01	<.01	.02	.03	.07	---	---	23
Oak Creek near Sedona	<.01	<.01	<.01	.02	.07	---	---	18
Oak Creek at Red Rock Crossing	<.01	<.01	.02	.02	.05	---	---	29
Oak Creek near Cornville	<.01	<.01	<.01	.02	.05	---	---	31
Verde River above West Clear Creek	<.01	<.01	<.01	<.01	.04	---	---	14
West Clear Creek	<.01	<.01	<.01	.03	.79	---	---	44
Verde River near Camp Verde	<.01	<.01	.02	.03	.06	---	---	38
East Verde River	---	---	---	---	---	---	---	0
Wet Bottom Creek	<.01	<.01	<.01	.02	.07	---	---	107
Verde River below Tangle Creek	<.01	<.01	<.01	.02	.05	---	---	86
Verde River below Bartlett Dam	<.01	.02	.02	.04	.09	---	---	87
Turkey Creek	---	---	---	---	---	---	---	0
Agua Fria River near Rock Springs	<.01	.03	.04	.05	.18	---	---	165
Agua Fria River below Waddell Dam	<.01	.02	.03	.04	.09	---	---	75
Basin and Range Lowlands								
Central Arizona Project near Parker	<0.01	<0.01	<0.01	<0.01	0.09	---	---	39
Central Arizona Project at Phoenix	<.01	<.01	<.01	<.01	.05	---	---	123
Gila River at Winkelman	<.01	.03	.07	.09	.15	---	---	40
San Pedro River at Charleston	<.01	<.01	<.01	.02	.10	---	---	74
San Pedro River below Aravaipa	<.01	.02	.03	.05	.13	---	---	31
San Pedro River at Winkelman	<.01	.02	.03	.05	.20	---	---	30
Gila River at Kelvin	<.01	.03	.05	.08	.25	---	---	182
Santa Cruz River at Rio Rico	.13	1.8	3.7	4.6	7.5	3.5	2.1	21
Santa Cruz River at Tubac	.12	.42	.89	1.4	3.0	1.0	.72	27
Santa Cruz River at Cortaro	.15	3.3	3.7	4.0	4.1	3.2	1.3	12
Santa Cruz River at Laveen	---	---	.06	---	---	---	---	1
Indian Bend Wash at Curry Road	---	---	---	---	---	---	---	0
Box Culvert at 48th Street Drain	---	---	---	---	---	---	---	0
27th Avenue at Salt River	---	---	---	---	---	---	---	0
43rd Avenue and Peoria Avenue	---	---	---	---	---	---	---	0
Olive Avenue and 67th Avenue	---	---	---	---	---	---	---	0
91st Avenue WWTP outfall	1.0	2.8	3.6	4.6	5.1	3.5	1.2	24
Gila River at Buckeye Canal	1.0	2.0	2.4	2.8	3.5	2.4	.61	40
Hassayampa River	<.01	.52	1.1	2.0	3.2	1.3	.88	48
Gila River at Gillespie Dam	<.01	.35	.70	1.8	3.4	1.1	.92	168

Appendix 1. Statistical summaries of stream properties and water-chemistry constituents at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998—Continued

Station	Minimum	Percentile 25th	Percentile Median	Percentile 75th	Maximum	Mean	Standard deviation	Number of samples
Total phosphorus concentration, in mg/L as phosphorus								
Central Highlands								
Black River	<0.01	0.04	0.05	0.09	0.27	---	---	43
White River	.02	.04	.06	.09	.48	---	---	43
Pinal Creek	<.01	.03	.05	.11	10	---	---	143
Salt River near Roosevelt	<.01	.02	.04	.11	4.0	---	---	260
Tonto Creek	<.01	<.01	.02	.04	.19	---	---	54
Salt River below Stewart Mountain Dam	<.01	.02	.03	.04	8.3	---	---	145
Verde River near Clarkdale	<.01	.02	.03	.07	3.4	---	---	188
Verde River near Cornville	<.01	.05	.07	.14	.76	---	---	23
Oak Creek near Sedona	<.01	<.01	.02	.06	.23	---	---	22
Oak Creek at Red Rock Crossing	<.01	<.01	.02	.04	.70	---	---	141
Oak Creek near Cornville	<.01	.02	.04	.07	.31	---	---	30
Verde River above West Clear Creek	<.01	.02	.02	.08	.32	---	---	20
West Clear Creek	<.01	<.01	<.01	.04	.60	---	---	39
Verde River near Camp Verde	<.01	.02	.04	.08	3.0	---	---	104
East Verde River	<.01	.02	.02	.03	.16	---	---	47
Wet Bottom Creek	<.01	<.01	<.01	.02	.50	---	---	100
Verde River below Tangle Creek	<.01	.02	.03	.05	.97	---	---	197
Verde River below Bartlett Dam	<.01	.03	.05	.07	7.3	---	---	147
Turkey Creek	<.01	.14	.55	2.4	11	---	---	43
Agua Fria River near Rock Springs	<.01	.04	.05	.07	39	---	---	166
Agua Fria River below Waddell Dam	<.01	.04	.06	.09	.19	---	---	75
Basin and Range Lowlands								
Central Arizona Project near Parker	<0.01	<0.01	<0.01	0.02	0.15	---	---	41
Central Arizona Project at Phoenix	<.01	<.01	<.01	.02	.25	---	---	123
Gila River at Winkelman	<.01	.09	.16	.22	7.3	---	---	86
San Pedro River at Charleston	<.01	.02	.04	.06	1.3	---	---	86
San Pedro River below Aravaipa	.02	.04	.08	.29	40	---	---	37
San Pedro River at Winkelman	.02	.05	.10	1.4	14	---	---	40
Gila River at Kelvin	<.01	.08	.15	.32	13	---	---	92
Santa Cruz River at Rio Rico	1.1	3.4	6.1	6.9	11	5.5	2.6	26
Santa Cruz River at Tubac	.15	.75	1.4	2.2	6.4	1.8	1.5	26
Santa Cruz River at Cortaro	3.4	3.9	4.1	4.4	5.2	4.2	.5	12
Santa Cruz River at Laveen	.16	4.2	6.0	6.8	13	5.7	3.3	15
Indian Bend Wash at Curry Road	.05	.09	.16	.33	.52	.21	.15	19
Box Culvert at 48th Street Drain	.15	.33	.94	1.5	2.5	1.0	.73	23
27th Avenue at Salt River	.51	.81	1.2	1.7	7.9	1.6	1.5	26
43rd Avenue and Peoria Avenue	.16	.34	.49	.75	2.0	.58	.38	25
Olive Avenue and 67th Avenue	.14	.38	.49	.54	1.2	.53	.28	19
91st Avenue WWTP outfall	2.2	3.4	4.3	5.0	6.1	4.2	1.0	23
Gila River at Buckeye Canal	1.6	2.5	2.9	3.2	4.0	2.9	.54	39
Hassayampa River	.59	1.1	2.0	3.0	53	3.2	7.4	48
Gila River at Gillespie Dam	.10	.93	1.6	2.6	9.4	1.8	1.2	250

Appendix 1. Statistical summaries of stream properties and water-chemistry constituents at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998—Continued

Station	Minimum	Percentile 25th	Percentile Median	Percentile 75th	Maximum	Mean	Standard deviation	Number of samples
Nitrate concentration, in mg/L as nitrogen								
Central Highlands								
Black River	<0.01	<0.01	0.02	0.05	0.42	---	---	44
White River	<.01	<.01	.02	.08	.49	---	---	44
Pinal Creek	<.02	.09	.10	.13	1.3	---	---	150
Salt River near Roosevelt	<.01	.05	.10	.10	1.3	---	---	254
Tonto Creek	<.01	<.01	.09	.10	.29	---	---	54
Salt River below Stewart Mountain Dam	<.01	.06	.10	.10	.59	---	---	163
Verde River near Clarkdale	<.01	.07	.10	.20	.60	---	---	179
Verde River near Cornville	<.01	.07	.13	.25	.72	---	---	23
Oak Creek near Sedona	<.01	.03	.05	.07	.08	---	---	21
Oak Creek at Red Rock Crossing	<.01	.05	.10	.10	.18	---	---	127
Oak Creek near Cornville	<.01	.04	.06	.09	.34	---	---	32
Verde River above West Clear Creek	<.02	.06	.09	.11	.23	---	---	20
West Clear Creek	<.01	<.05	<.05	<.05	.60	---	---	44
Verde River near Camp Verde	<.01	<.05	.10	.10	1.3	---	---	95
East Verde River	<.02	<.02	.02	.05	.15	---	---	42
Wet Bottom Creek	<.01	.03	.05	.10	.70	---	---	142
Verde River below Tangle Creek	<.01	<.05	.10	.10	.42	---	---	188
Verde River below Bartlett Dam	<.01	.10	.10	.17	.81	---	---	185
Turkey Creek	.10	.21	.27	.55	1.2	.40	.30	25
Agua Fria River near Rock Springs	<.05	.10	.10	.10	.80	---	---	166
Agua Fria River below Waddell Dam	<.05	.10	.10	.11	.46	---	---	75
Basin and Range Lowlands								
Central Arizona Project near Parker	<0.05	0.10	0.17	0.20	0.36	---	---	40
Central Arizona Project at Phoenix	<.05	.07	.10	.10	.39	---	---	123
Gila River at Winkelman	<.01	.14	.26	.35	15	---	---	82
San Pedro River at Charleston	<.05	<.05	.09	.15	.83	---	---	82
San Pedro River below Aravaipa	.30	.53	.65	.80	1.8	.70	.27	37
San Pedro River at Winkelman	.18	.48	.75	.98	4.0	.85	.64	37
Gila River at Kelvin	<.01	.12	.29	.62	2.7	---	---	200
Santa Cruz River at Rio Rico	<.02	.36	.59	2.7	3.9	---	---	25
Santa Cruz River at Tubac	.25	1.6	2.3	2.8	4.7	2.2	1.1	27
Santa Cruz River at Cortaro	.06	.13	.33	.46	1.5	.43	.44	12
Santa Cruz River at Laveen	.28	1.0	1.2	1.7	4.1	1.6	1.1	15
Indian Bend Wash at Curry Road	.29	.52	.75	1.2	3.6	1.1	.90	19
Box Culvert at 48th Street Drain	.63	.79	1.2	1.6	2.3	1.2	.49	23
27th Avenue at Salt River	.48	1.9	2.6	3.3	4.7	2.6	1.0	26
43rd Avenue and Peoria Avenue	.35	.59	.95	1.5	3.9	1.3	1.0	25
Olive Avenue and 67th Avenue	.57	.96	1.1	1.3	2.2	1.2	.39	19
91st Avenue WWTP outfall	.61	1.5	2.7	4.6	7.2	3.1	2.0	24
Gila River at Buckeye Canal	2.2	3.4	4.3	5.1	6.9	4.3	1.2	40
Hassayampa River	2.0	6.0	7.5	12	17	8.8	3.7	48
Gila River at Gillespie Dam	.10	6.6	8.6	11	25	8.6	4.4	293

Appendix 1. Statistical summaries of stream properties and water-chemistry constituents at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998—Continued

Station	Minimum	Percentile 25th	Percentile Median	Percentile 75th	Maximum	Mean	Standard deviation	Number of samples
Ammonia concentration, in mg/L as nitrogen								
Central Highlands								
Black River	---	---	---	---	---	---	---	0
White River	---	---	---	---	---	---	---	0
Pinal Creek	<.02	.05	.13	.21	.41	---	---	91
Salt River near Roosevelt	<.01	<.01	.02	.04	.16	---	---	156
Tonto Creek	---	---	---	---	---	---	---	0
Salt River below Stewart Mountain Dam	<.01	<.01	.03	.05	.68	---	---	117
Verde River near Clarkdale	<.01	<.01	<.01	.02	.10	---	---	105
Verde River near Cornville	---	---	---	---	---	---	---	0
Oak Creek near Sedona	---	---	---	---	---	---	---	0
Oak Creek at Red Rock Crossing	<.01	<.01	<.01	.02	.05	---	---	77
Oak Creek near Cornville	---	---	---	---	---	---	---	0
Verde River above West Clear Creek	<.01	<.01	.02	.02	.04	---	---	20
West Clear Creek	<.01	<.01	.02	.02	.19	---	---	39
Verde River near Camp Verde	<.01	<.01	.02	.03	.10	---	---	26
East Verde River	<.01	<.01	<.01	.02	.19	---	---	42
Wet Bottom Creek	<.01	<.01	.02	.06	.16	---	---	76
Verde River below Tangle Creek	<.01	<.01	.02	.02	.26	---	---	147
Verde River below Bartlett Dam	<.01	.02	.04	.07	.47	---	---	115
Turkey Creek	<.01	.05	.10	.14	.69	---	---	25
Agua Fria River near Rock Springs	<.01	<.01	.02	.02	.09	---	---	63
Agua Fria River below Waddell Dam	<.01	.02	.03	.05	.24	---	---	35
Basin and Range Lowlands								
Central Arizona Project near Parker	<0.01	<0.01	0.02	0.03	0.08	---	---	39
Central Arizona Project at Phoenix	<.01	<.01	.02	.02	1.4	---	---	81
Gila River at Winkelman	<.01	<.01	.02	.09	.11	---	---	8
San Pedro River at Charleston	<.01	<.01	.02	.03	.15	---	---	83
San Pedro River below Aravaipa	<.01	.06	.10	.13	.40	---	---	35
San Pedro River at Winkelman	<.01	<.01	.04	.06	.63	---	---	16
Gila River at Kelvin	<.01	.02	.02	.05	.13	---	---	51
Santa Cruz River at Rio Rico	.04	---	---	---	2.8	---	---	4
Santa Cruz River at Tubac	.02	.12	1.1	2.3	6.1	1.7	1.9	27
Santa Cruz River at Cortaro	1.0	19	26	27	34	22	9.3	12
Santa Cruz River at Laveen	.05	.08	.24	.46	1.4	.37	.40	14
Indian Bend Wash at Curry Road	.02	.1	.23	.34	.92	---	---	19
Box Culvert at 48th Street Drain	.22	.76	1.1	1.5	2.4	1.1	.57	23
27th Avenue at Salt River	.03	.33	.61	1.2	64	3.4	12	26
43rd Avenue and Peoria Avenue	.68	1.2	1.7	2.4	7.8	2.2	1.6	25
Olive Avenue and 67th Avenue	.19	.75	.97	1.4	3.4	1.1	.74	19
91st Avenue WWTP outfall	1.1	1.7	2.8	7.7	17	4.8	4.5	24
Gila River at Buckeye Canal	.04	.82	1.7	4.0	15	3.1	3.7	40
Hassayampa River	<.01	.02	.36	1.6	11	1.1	2.0	48
Gila River at Gillespie Dam	<.01	.16	.89	3.2	11	2.1	2.6	203

Appendix 1. Statistical summaries of stream properties and water-chemistry constituents at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998—Continued

Station	Minimum	Percentile 25th	Percentile Median	Percentile 75th	Maximum	Mean	Standard deviation	Number of samples
Ammonia and organic nitrogen concentration, in mg/L as nitrogen								
Central Highlands								
Black River	0.04	0.15	0.19	0.34	1.5	0.28	0.25	43
White River	.04	.16	.25	.55	4.7	.47	.72	43
Pinal Creek	.12	.20	.40	.70	8.6	.54	.76	142
Salt River near Roosevelt	<.01	.20	.30	.60	5.0	.51	.59	260
Tonto Creek	.03	.11	.20	.60	4.8	.40	.66	53
Salt River below Stewart Mountain Dam	.03	.27	.38	.60	2.9	.48	.40	145
Verde River near Clarkdale	.03	.20	.20	.41	4.9	.40	.52	187
Verde River near Cornville	.03	.15	.36	.44	.79	.33	.21	23
Oak Creek near Sedona	.03	.16	.28	.43	2.3	.38	.47	22
Oak Creek at Red Rock Crossing	<.02	.20	.30	.42	2.9	.41	.41	141
Oak Creek near Cornville	<.01	.16	.22	.39	.67	.26	.18	29
Verde River above West Clear Creek	.20	.20	.20	.28	.70	.29	.17	20
West Clear Creek	.09	.17	.20	.20	1.5	.23	.22	39
Verde River near Camp Verde	.12	.20	.40	.60	2.0	.47	.33	105
East Verde River	.20	.20	.20	.20	.80	.24	.10	47
Wet Bottom Creek	.20	.20	.32	.49	2.5	.41	.32	76
Verde River below Tangle Creek	.10	.20	.30	.45	5.2	.43	.50	197
Verde River below Bartlett Dam	.10	.28	.40	.60	11	.53	.92	144
Turkey Creek	.32	.72	2.0	4.4	16	3.8	4.5	25
Agua Fria River near Rock Springs	.20	.20	.20	.50	6.2	.52	.86	166
Agua Fria River below Waddell Dam	.20	.40	.50	.60	1.4	.53	.25	75
Basin and Range Lowlands								
Central Arizona Project near Parker	0.20	0.20	0.30	0.33	0.90	0.33	0.17	40
Central Arizona Project at Phoenix	.20	.20	.30	.50	3.7	.44	.44	123
Gila River at Winkelman	.10	.63	.85	1.1	11	1.3	1.7	81
San Pedro River at Charleston	.10	.20	.20	.40	3.2	.35	.40	86
San Pedro River below Aravaipa	.30	.49	.80	1.2	47	4.8	12	37
San Pedro River at Winkelman	.10	.36	.64	2.8	81	6.2	15	34
Gila River at Kelvin	.06	.42	.73	1.1	23	1.7	3.5	85
Santa Cruz River at Rio Rico	3.9	9.8	17	26	40	19	11	23
Santa Cruz River at Tubac	.20	.51	3.0	5.5	21	3.9	4.3	26
Santa Cruz River at Cortaro	22	28	30	32	38	30	4.9	12
Santa Cruz River at Laveen	.91	2.7	4.3	6.7	10	4.9	3.1	12
Indian Bend Wash at Curry Road	.40	.91	1.2	1.8	2.5	1.3	.62	19
Box Culvert at 48th Street Drain	.60	2.6	5.6	7.0	16	5.7	4.3	23
27th Avenue at Salt River	1.0	2.8	4.4	7.1	120	9.3	23	26
43rd Avenue and Peoria Avenue	1.3	3.1	3.9	5.3	12	4.7	2.9	25
Olive Avenue and 67th Avenue	.90	2.6	3.4	4.1	11	3.7	2.3	18
91st Avenue WWTP outfall	2.2	3.0	4.4	10	20	7	5.6	24
Gila River at Buckeye Canal	.84	2.0	3.0	6.0	18	4.8	4.3	40
Hassayampa River	.84	1.5	2.0	3.6	15	3.2	3.0	48
Gila River at Gillespie Dam	.20	2.0	3.2	5.2	17	4	2.8	244

Appendix 1. Statistical summaries of stream properties and water-chemistry constituents at surface-water quality monitoring stations in the Central Arizona Basins study area, through 1998—Continued

Station	Minimum	Percentile 25th	Percentile Median	Percentile 75th	Maximum	Mean	Standard deviation	Number of samples
Total nitrogen concentration, in mg/L as nitrogen								
Central Highlands								
Black River	0.01	0.17	0.22	0.36	1.9	0.31	0.30	43
White River	.01	.18	.27	.57	4.7	.50	.74	43
Pinal Creek	.11	.27	.50	.83	2.9	.66	.48	138
Salt River near Roosevelt	.02	.28	.40	.70	4.0	.58	.56	256
Tonto Creek	.01	.16	.33	.68	5.0	.47	.68	54
Salt River below Stewart Mountain Dam	.05	.33	.46	.63	3.0	.55	.39	144
Verde River near Clarkdale	.09	.29	.40	.60	5.4	.54	.56	178
Verde River near Cornville	.09	.28	.42	.67	1.5	.51	.31	23
Oak Creek near Sedona	.05	.18	.32	.49	2.4	.43	.48	22
Oak Creek at Red Rock Crossing	.04	.30	.40	.56	3.0	.50	.42	131
Oak Creek near Cornville	.04	.20	.29	.50	.76	.35	.22	29
Verde River above West Clear Creek	.25	.28	.31	.42	.83	.39	.17	20
West Clear Creek	.13	.22	.25	.29	1.5	.30	.23	39
Verde River near Camp Verde	.15	.30	.50	.79	2.3	.59	.39	95
East Verde River	.22	.22	.22	.30	.85	.28	.12	42
Wet Bottom Creek	.25	.30	.40	.56	2.6	.49	.32	76
Verde River below Tangle Creek	.12	.27	.40	.55	5.3	.52	.52	191
Verde River below Bartlett Dam	.11	.38	.50	.71	11	.64	.91	144
Turkey Creek	.50	.99	2.2	4.7	17	4.2	4.6	25
Agua Fria River near Rock Springs	.25	.30	.40	.60	6.9	.66	.96	166
Agua Fria River below Waddell Dam	.30	.46	.60	.72	1.5	.65	.26	75
Basin and Range Lowlands								
Central Arizona Project near Parker	0.29	0.39	0.44	0.53	1.2	0.50	0.21	39
Central Arizona Project at Phoenix	.25	.34	.40	.60	3.8	.54	.45	123
Gila River at Winkelman	.12	.85	1.1	1.6	16	1.8	2.4	81
San Pedro River at Charleston	.15	.25	.33	.55	3.4	.49	.46	81
San Pedro River below Aravaipa	.81	1.2	1.4	1.8	48	5.5	12	37
San Pedro River at Winkelman	.39	.91	1.5	3.0	85	7.0	16	34
Gila River at Kelvin	.16	.51	.89	1.5	88	3.0	9.9	87
Santa Cruz River at Rio Rico	6.2	11	18	26	40	20	10	23
Santa Cruz River at Tubac	.45	2.3	5.8	8.5	23	6.1	4.9	26
Santa Cruz River at Cortaro	23	28	30	33	39	30	4.7	12
Santa Cruz River at Laveen	2.0	4.4	5.8	8.3	12	6.4	3.1	12
Indian Bend Wash at Curry Road	.75	1.8	2.3	2.4	5.6	2.4	1.2	19
Box Culvert at 48th Street Drain	1.7	3.4	6.5	8.3	18	7.0	4.6	23
27th Avenue at Salt River	1.9	5.4	7.2	9.7	120	12	22	26
43rd Avenue and Peoria Avenue	1.7	3.6	4.8	6.6	16	6.0	3.8	25
Olive Avenue and 67th Avenue	1.5	3.5	4.5	5.5	12	4.9	2.4	18
91st Avenue WWTP outfall	4.0	5.6	7.9	14	22	10	5.7	24
Gila River at Buckeye Canal	5.3	6.6	7.9	11	20	9.2	3.8	40
Hassayampa River	4.3	9.3	12	15	22	12	3.7	48
Gila River at Gillespie Dam	.30	9.3	12	15	35	12	5.0	284

APPENDIX 2:
METHODS OF ESTIMATING STREAM LOADS AND BASIN INPUTS OF NUTRIENTS

Stream loads of dissolved solids and nutrients were estimated using the computer program ESTIMATOR (version 94.06). ESTIMATOR implements the minimum variance unbiased estimator described by Cohn and others (1989) and the adjusted maximum likelihood estimator described by Cohn (1988). The minimum variance unbiased estimator is superior to other methods, such as the traditional rating-curve method, because it does not produce bias that can be introduced when retransforming data from "log space," where regression estimates are derived, to "real space," where loads are calculated. The ESTIMATOR program calibrates a multiple linear regression model in the form of:

$$\ln(C) = \beta_0 + \beta_1 \ln\left(\frac{Q}{\bar{Q}}\right) + \beta_2 \ln\left(\frac{Q^2}{\bar{Q}^2}\right) + \beta_3 Q^{0.5} + \beta_4 \sin(2\pi T) + \beta_5 \cos(2\pi T) + \beta_6 (T - \bar{T}) + e \, ,$$

where

ln	=	the natural logarithm function;
C	=	the water-chemistry constituent concentration;
$\beta_0 ... \beta_6$	=	the slope coefficients of the explanatory variables;
Q	=	the mean daily discharge for the day the sample was collected;
$\bar{Q}$	=	the centered mean daily discharge;
T	=	time, in years, converted to decimal form;
$\bar{T}$	=	the centered time, in years, converted to decimal form; and
e	=	the independent random error.

The explanatory variables allow for some of the variability of water-chemistry constituent concentrations to be accounted for as a result of the variability in streamflow, $\ln(Q/\bar{Q})$, $\ln(Q^2/\bar{Q}^2)$, and $Q^{0.5}$; season, $\sin(2\pi T)$ and $\cos(2\pi T)$; and long-term trends, T-$\bar{T}$. Model diagnostics were used to select the explanatory variables significant to the regression model. Graphical diagnostics included normal probability plots of residuals and plots of residuals versus month, predicted values, flow, and time. P-values for beta coefficients, coefficient of determination (R^2), and serial correlation coefficient also were provided. Explanatory variables with beta coefficients of p-values less than 0.10 were deemed significant and included in the model. Graphical diagnostics were then examined to ensure that there were no patterns in the relation between the residuals and flow, the residuals and predicted values, the residuals and season, and the residuals and time.
The coefficient of determination (R^2) for each water-chemistry constituent regression model represents the fraction of the variance in the water-chemistry constituent concentration that is explained by the regression model. For some of the water-chemistry constituents at some of the stations there were no significant regressors in the regression model except for the constant (β_0); for these cases the R^2 value is not reported. Daily stream loads were estimated by multiplying the mean daily streamflow for the day by the concentration estimated from the regression model. Daily stream loads then were aggregated into monthly and annual loads.

The program ESTIMATOR provided estimates of the standard error of prediction (SEP) for the daily, monthly, and annual stream loads. The SEP is a measure of the precision of the stream load estimate and is useful when expressed as a percentage of the stream load estimate. Using the SEP, an approximate 95-percent confidence interval for the stream load estimate is:

$$L \pm \left(1.96 \times \frac{SEP}{100} \times L\right) ,$$

where L is the annual load. In several cases the SEP was greater than 50 percent, which results in a 95-percent confidence interval for the stream load that is equal to or greater than the estimate for the annual stream load. In these cases the uncertainty of the estimate was deemed too large to report annual stream load.

Estimates of inputs to basins from total (wet plus dry) annual atmospheric deposition of nitrogen (ammonia and nitrate) were determined using precipitation-chemistry data from the National Atmospheric Deposition Program (NADP; National Atmospheric Deposition Program, 1998b). Data were collected in accordance with strict clean-handling procedures and sent to a central laboratory for analyses (National Atmospheric Deposition Program, 1998a). Precipitation-chemistry data for phosphorus were unavailable; therefore, estimates of phosphorus deposition were not made. Annual wet deposition inputs of ammonia and of nitrate for each basin were estimated as the mean of the concentrations from the three NADP precipitation chemistry sites in Arizona (figs. 3 and 7) for the period 1981–96, multiplied by the mean annual basin precipitation volume for the period 1931–60 (estimated from basin-precipitation data by Garrett and Gellenbeck, 1991). No attempt was made to correct the annual mean input for the proximity of the NADP sites to the basins because data were available only from three NADP sites in Arizona, and these were about 80 kilometers outside of the study area (fig. 3). Estimates of dry deposition of nitrate were determined on the basis of wet deposition estimates of nitrate, and both wet and dry deposition estimates were adjusted for urban perturbations (Sisterson, 1990).

Estimates of nutrient inputs to selected basins from fertilizer were determined using statewide sales data for 1995 (Arizona Agricultural Statistics Service, 1996). State fertilizer sales (by mass) were assumed to equal State fertilizer use and were disaggregated into county fertilizer use on the basis of the number of farmland acres that fertilizer was applied to in each county (U.S. Department of Commerce, 1994). County fertilizer sales were apportioned to each basin on the basis of county agricultural land use (digital data modified from Anderson and others, 1976; unpublished digital data from Maricopa County Association of Governments, Pima County, and the University of Arizona).

Estimates of nutrient inputs to selected basins from bodily waste from humans were determined on the basis of human populations (data for locations in Arizona from Hitt, 1994; data for locations in Mexico, from Lorey, 1990) and a per capita nutrient coefficient (U.S. Environmental Protection Agency, 1980). Human populations within each basin were estimated by aggregating populations within census tracts for those areas in the United States, and adding in populations by city for those locations in Mexico. Nutrient inputs from bodily waste from humans were subcategorized as that to be treated by a wastewater-treatment plant, or that to be treated by a septic system, on the basis of plumbing characteristics data (available with precision to the Census Designated Place; U.S. Department of Commerce, 1992). Septic tanks were considered nonpoint sources of pollution, whereas wastewater-treatment plants were considered point sources.

Estimates of nutrient inputs to selected basins were determined for bodily waste from livestock on feed (dairy cows, beef cattle, hogs, and horses). Nutrient inputs from grazing livestock were not estimated in this study because these nutrients were considered to be a conversion of one form to another with no net gain of nutrients to the basin; in contrast, fed livestock consume nutrients in their food, which is either imported to the basin or is generated specifically for livestock consumption, and thus results in a net increase in nutrients. Nutrient inputs for bodily waste from livestock on feed were estimated for each county on the basis of county livestock populations (Arizona Agricultural Statistics Service, 1997; U.S. Department of Commerce, 1994) and nutrient coefficients (U.S. Department of Agriculture, 1992). The nutrient inputs for each county were then apportioned to each basin on the basis of county agricultural land use (digital data modified from Anderson and others, 1976; unpublished digital data from Maricopa County Association of Governments, Pima County, and the University of Arizona).

In the case of the middle Gila River Basin and the Hassayampa River Basin, some nutrients are transported into the basin by surface water. For the middle Gila River Basin, nutrients enter the upstream end of the basin through the Gila River at Kelvin and also in the western side of the basin through the Central Arizona Project Canal. For the Hassayampa River Basin, nutrients enter through the Buckeye Canal in the lower part of the basin. The stream loads of nutrients carried by the streams and canals entering these basins are used as the estimates for the basin inputs from surface-water flow.

Estimates of nutrient inputs to selected basins from industrial sources were determined using data from the toxic chemical release inventory (Arizona Department of Environmental Quality, 1997). Nutrient inputs only include those releases that are toxic and are required to be reported by the U.S. Environmental Protection Agency, and thus are likely to be underestimated. Estimates from site-specific data were aggregated into basin estimates.

Anning—ASSESSMENT OF SELECTED INORGANIC CONSTITUENTS IN STREAMS IN THE CENTRAL ARIZONA BASINS STUDY AREA, ARIZONA AND NORTHERN MEXICO, THROUGH 1998—U.S. Geological Survey Water-Resources Investigations Report 03—4063

Printed on recycled paper