Synthesis of Upper Verde River Research and Monitoring

1993-2008

United States Department of Agriculture / Forest Service

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Abstract

This volume is a state-of-knowledge synthesis of monitoring and research conducted on the Upper Verde River (UVR) of Arizona. It contains information on the history, hydrology, soils, geomorphology, vegetation, and fish fauna of the area that can help land managers and other scientists in successfully conducting ecosystem management and future monitoring and research in this important Southwest river ecosystem. Chapter 1 provides an introduction to the UVR's location, vegetation, climate, soils, and watersheds. A historical and pictorial perspective of the UVR is presented in Chapter 2. The hydrology of the watershed and its current physical condition are covered in Chapters 3 and 4. Geomorphic relationships of the UVR channels are described in Chapter 5. The woody and herbaceous vegetation of the UVR are presented in Chapters 6 and 7. Water quality status and issues of the river are discussed in Chapter 8. The status of the fish fauna and other aquatic organisms are described in Chapter 9. Chapters 10 through 12 present summaries of information resources, research recommendations, a summary of this volume, and conclusions.

Keywords: fluvial ecosystem, history, climate, soils, vegetation, geomorphology, watersheds, water quality, fish fauna, Upper Verde River

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Preface

In 1993, the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station (now Rocky Mountain Research Station [RMRS]) Project RM-4302 was invited by the Prescott National Forest to conduct monitoring and research on the Upper Verde River (UVR) after a large flood event. A number of resource management issues were coming to the forefront on the Forest related to threatened and endangered species and livestock grazing, thereby prompting the invitation. Of particular interest was the spikedace (*Meda fulgida*) because of its limited range and the variety of biological, physical, and chemical impacts on riparian and fluvial ecosystems in the Southwest. It was widely recognized that there was a paucity of good data on the native fish fauna of the river as well as biological, chemical, and physical processes that were impacting the UVR ecosystem.

A large flood in 1993 provided a re-set of many ecological processes on the UVR, and created an unusual opportunity to gather information on the ecological processes of the Verde River affecting threatened and endangered species. This volume captures the knowledge of a number of RMRS scientists who are retired, about to retire, or deceased. Other scientists from the Station and other agencies have already added to the UVR knowledge base or will do so in the future.

As conceptual background, this volume provides technical support to District, Forest, and Regional resource managers for carrying out interdisciplinary planning, which is essential to managing Southwest wildlands in an ecosystem context. Planners and managers will find this useful in many aspects of ecosystem-based management, but they will also have the responsibility to seek out and synthesize the detailed information needed to resolve specific management questions. A number of recommendations for future research are made at the end of the report . This research will need to be addressed by the Station; Region 3; the U.S. Fish and Wildlife Service; university cooperators; state agencies like the Arizona Game and Fish Department; and other organizations like The Nature Conservancy, the Verde River Association, Arizona Cattle Growers, and the U.S. Geological Survey.

Acknowledgments

We dedicate this particular volume to three colleagues who although no longer with us, provided inspiration for the Report. The late Dr. Malchus B. Baker, Jr., a former USDA Forest Service, RMRS Research Hydrologist, nourished a career-long commitment to research on the hydrology and watershed management of Southwest forests and woodlands. The late Mr. Tom Moody's passion for the Verde River, understanding of the rivers of Arizona, and dedication to stream restoration was always with us. The late Dr. Benee F. Swindel, a former U.S. Forest Service, Southern Research Station Research Forester and Project Leader, provided inspiration through his timeless counseling in the art of perseverance.

Several present and past staff members of the Prescott National Forest deserve recognition: Dr. Robert M. Leonard, who has been a trusted friend, and who is largely responsible for instituting long-term monitoring studies for the purpose of increasing our objective knowledge base for the UVR; Mr. Ron Stein (Forest Soil Scientist), who, together with Hydrologist Jack Turner, was instrumental in initiating studies to characterize the long-term attributes of the riparian vegetation and hydrology; Chino Valley District Rangers Mark L. Johnson and Linda Jackson, who have supported the monitoring studies and greatly facilitated getting field work done; and Forest Supervisors Mike King, Alan Quan, and Betty Matthews who provided long-term support, patience, and feedback for the RMRS efforts on the Verde River. The authors also thank Thomas Potter, GIS Coordinator for the Prescott National Forest for providing GIS coverage used in analyses in this document.

The authors also thank members of the former UVR Adaptive Management Partnership for their commitment to conservation of the Verde River, patient support of the research, hosting of many visits to the river, and willingness to talk to people interested in the river. Specifically we recognize Dr. George Yard and Mrs. Sharon Yard of the Y-D Ranch, and Mr. David Gipe, Mrs. Jo Ann Gipe, Mr. Donny Vernor, and Mrs. Anne Vernor of the Verde River Ranch for their wisdom, dedication to the Verde River, and enormous patience and perseverance.

Many dedicated students and technicians labored merrily in the pursuit of field data and great fellowships. Specifically, we thank Jackson Leonard, Larry Telles, Tyler Johnson, Wesley Sprinkle, Paola Gutierrez, Brian Deason, Pam Sponholtz, Andrea Neary Dutoit, and Jerry Stefferud for their efforts.

The authors wish to thank the unknown and unnamed reviewers that participated in the blind review of this document for their insightful and helpful reviews, suggestions, information, and assistance that led to substantial technical and editorial improvements in the manuscript. We also specially thank Dr. Frank McCormick, Program Manager, Air, Water, and Aquatic Environments Program, RMRS, for his work in consolidating the reviews and for his patience with the process.

Summary

The Verde River is a unique hydrological resource in Arizona because it has perennial flow over a large portion of its reach. This is unusual for all but the largest rivers in the desert Southwest (e.g., Colorado River, Rio Grande, and San Juan Rivers). Verde River flows are sustained by groundwater discharge and winter snowmelt and rainfall. The river, and its riparian zone, provides important refugia for both aquatic and terrestrial species. Perhaps 80% of the terrestrial species depend on riparian zones for their life cycles and food and water needs. Human uses of the river for irrigation, municipal water supplies, and recreation are growing and can adversely affect the River and its associated resources.

The perennial reach of the Verde River is divided into Upper, Middle, and Lower reaches that have unique characteristics, flows, land use patterns, and ownership. The authors focused on the Upper Verde River (UVR) because: (1) much of this reach is within the Prescott National Forest, (2) it is the least impacted of the three Verde River reaches, and (3) it supports key threatened, endangered, and sensitive (TES) species populations. The UVR has been a source of land management controversy in recent years because of the resident TES species, a long history of legacy cattle grazing, and looming impacts on the quantity of river flow due to rapidly expanding human populations in the Chino, Prescott, and Prescott Valley areas.

This report summarizes 15 years of monitoring and research conducted first by the Rocky Mountain Research Station Project RMRS-3402, and now by the Southwest Watershed Science Team, Air, Water, and Aquatic Environments Science Program. This report is divided into 12 chapters that cover introductory, technical, and summary material. It has been written as an information source for personnel involved in fluvial and riparian ecosystem management; planners; decision-makers; public land managers; grazing allotment permittees; public relations personnel; interested public; non-Government organizations and Associations; and local, county, State, and Federal politicians.

Because of widespread international interest in this volume and topic, the International System of Units (SI), informally called the metric system, is used along with English units throughout the volume. In some instances only one system or the other is used where conversions would be awkward or where space does not allow presentation of both units.

Contents

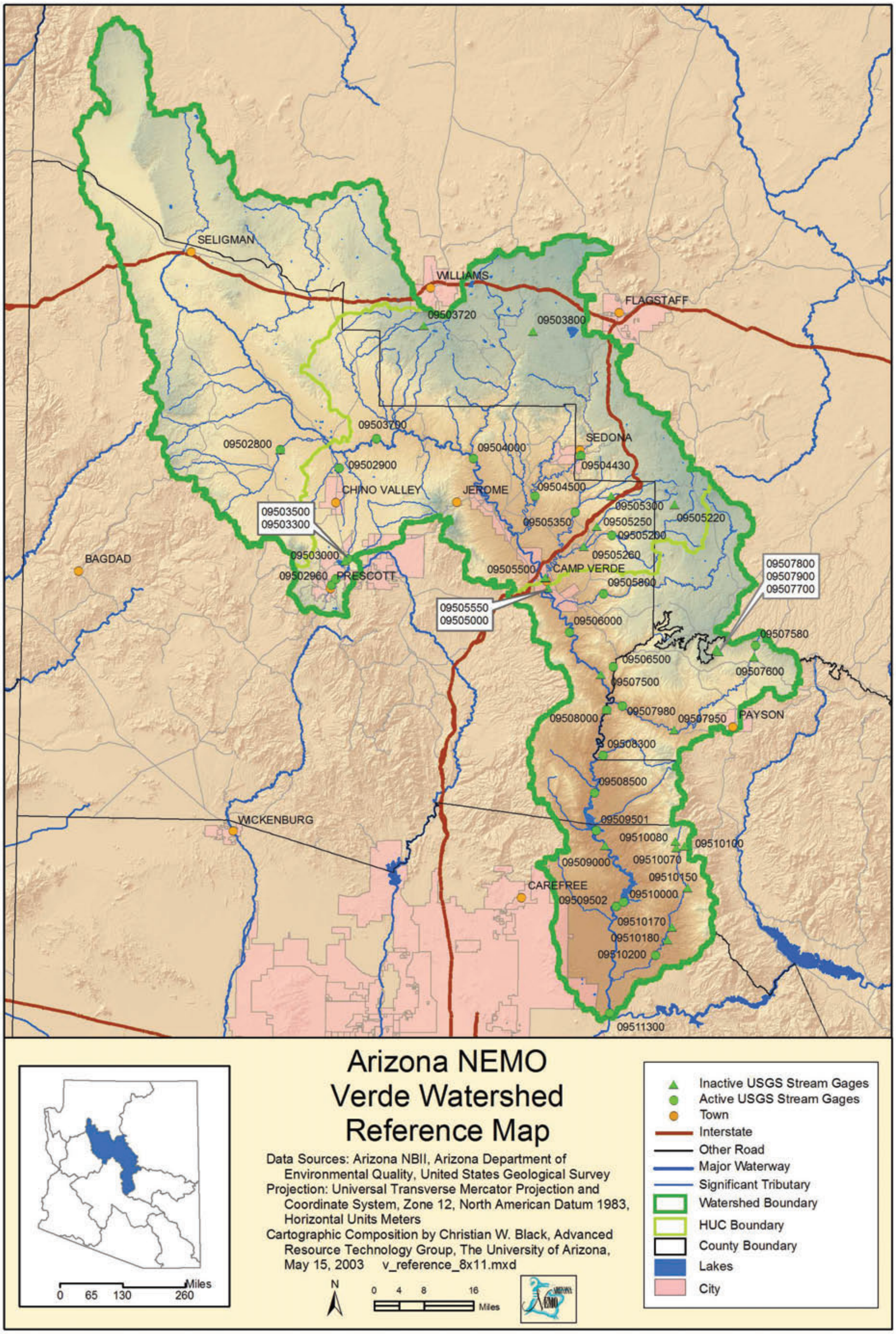


Figure 1.1—The Verde River Watershed, north of Seligman, Arizona, to the Salt River. (Map courtesy of the USDA Natural Resources Conservation Service.)

Chapter 1

Introduction

Daniel G. Neary, John N. Rinne, Alvin L. Medina, Malchus B. Baker, Jr.

Location

The UVR area of north-central Arizona overlaps the Central Highlands and the Plateau Uplands biogeographic provinces. The UVR area occupies about 6,700 km^2 (2,600 mi^2) of Yavapai and Coconino Counties (fig. 1.1), and its watershed encompasses the northern valley of the Verde River bounded by the escarpment of the Mogollon Rim to the north and northeast and by the Black Hills to the southwest. The Mogollon Rim escarpment is the boundary between the Plateau uplands province and the Central highlands province. It is a steeply sloping cliff that rises 310 to 610 m (1,000 to 2,000 ft) from the Verde Valley floor to elevations of 1,680 to 2,290 m (5,500 to 7,500 ft). The Rim is dissected by deeply incised canyons. South of the Rim, the landscape is characterized by many buttes and mesas.

The Verde River is the major stream that drains the study area. The UVR watershed begins 120 km (75 mi) to the northwest of the study area near Frazier Wells, but streamflow is only intermittent in that portion. Perennial flow begins in Section 15, Township 17 N., Range 1 W. The river flows along the foot of the Black Hills eastward to Perkinsville, then southeastward where it leaves the study area at Tapco, just upstream of Clarkdale and below its confluence with Sycamore Creek. For the purposes of this synthesis and the monitoring and research that has been conducted by RMRS, the UVR consists of the perennial flow reach from the dam at Sullivan Lake downstream to the boundary of the Prescott National Forest at Tapco (fig. 1.1). This includes a portion of what is labeled in fig. 1.1 as the Middle Verde River. The UVR coincides with the U.S. Geological Survey Hydrologic Unit Code (HUC) Watershed 15060202, Lower Colorado Region, Verde River Basin, UVR (fig. 1.2; http://water.usgs.gov/GIS/huc_name.html#Region15).

Elevations along the Verde River range from about 1,290 m (4,200 ft) where the perennial flow begins to about 1,040 m (3,400 ft) at Tapco. Perennial flow in the Verde River and its major tributaries is maintained by groundwater discharge.

The majority of the UVR watershed where flow is perennial is within the boundaries of, and managed by, the Prescott National Forest. Smaller areas in the upper elevations to the north, northeast, and east are managed by the Kaibab and Coconino National Forests. The western portion of the UVR, at the beginning of perennial flow and upstream in the ephemeral flow reaches of the Chino Valley, is mainly private and State of Arizona-owned lands.

Watershed Descriptions

The watershed of the UVR encompasses an area of diverse topography and lithology since it traverses the Transition Zone from highlands on the southwestern edge of the Colorado Plateau into a large basin that is more typical of the desert

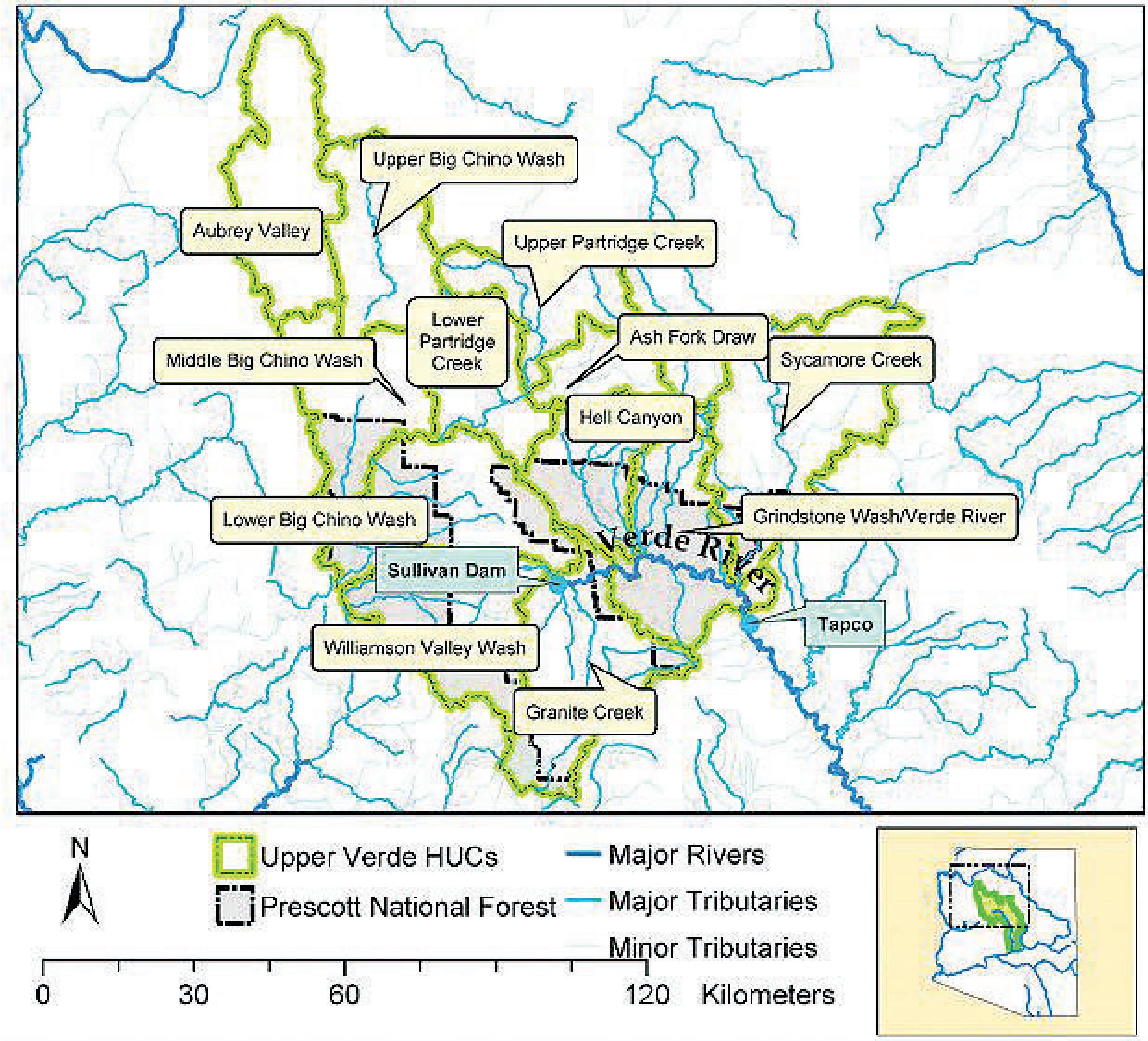


Figure 1.2—Sub-watersheds within the UVR, Prescott National Forest, Arizona. The UVR study area is in the easternmost portion of the Forest's lands shown in this figure. (Map courtesy of the Prescott National Forest.)

Southwest. This Report is limited to lands within the Prescott National Forest (fig. 1.2) since those are the areas for which the most data are available and for which the Prescott National Forest makes management decisions. The Tapco site is used as the lower boundary of the analysis in this report, just upstream of Clarkdale and below its confluence with Sycamore Creek. This area coincides with the first of three reaches included in the biological evaluation by the Prescott National Forest (2001).

The UVR Watershed encompasses twelve "5th code" HUCs (fig. 1.2) from the Big Chino Wash downstream to Tapco. Seven are within the U.S. Geological Survey's "4th code" HUC Watershed 15060202, UVR (fig. 1.3). The HUCs refer to the two digit sequences of nested watersheds that go from the Lower Colorado Region (#15), to the Salt River Subregion (#1506), to the Verde River Basin Accounting Unit (150602), to the UVR Cataloguing Unit (#15060202). For more details see the U.S. Geological Survey website http://water.usgs.gov/GIS/huc_name.html#Region15. The Williamson Valley Wash (HUC #1506020107), Hell Canyon (HUC #1506020202), and Sycamore Creek (HUC #1506020203) hydrologic units

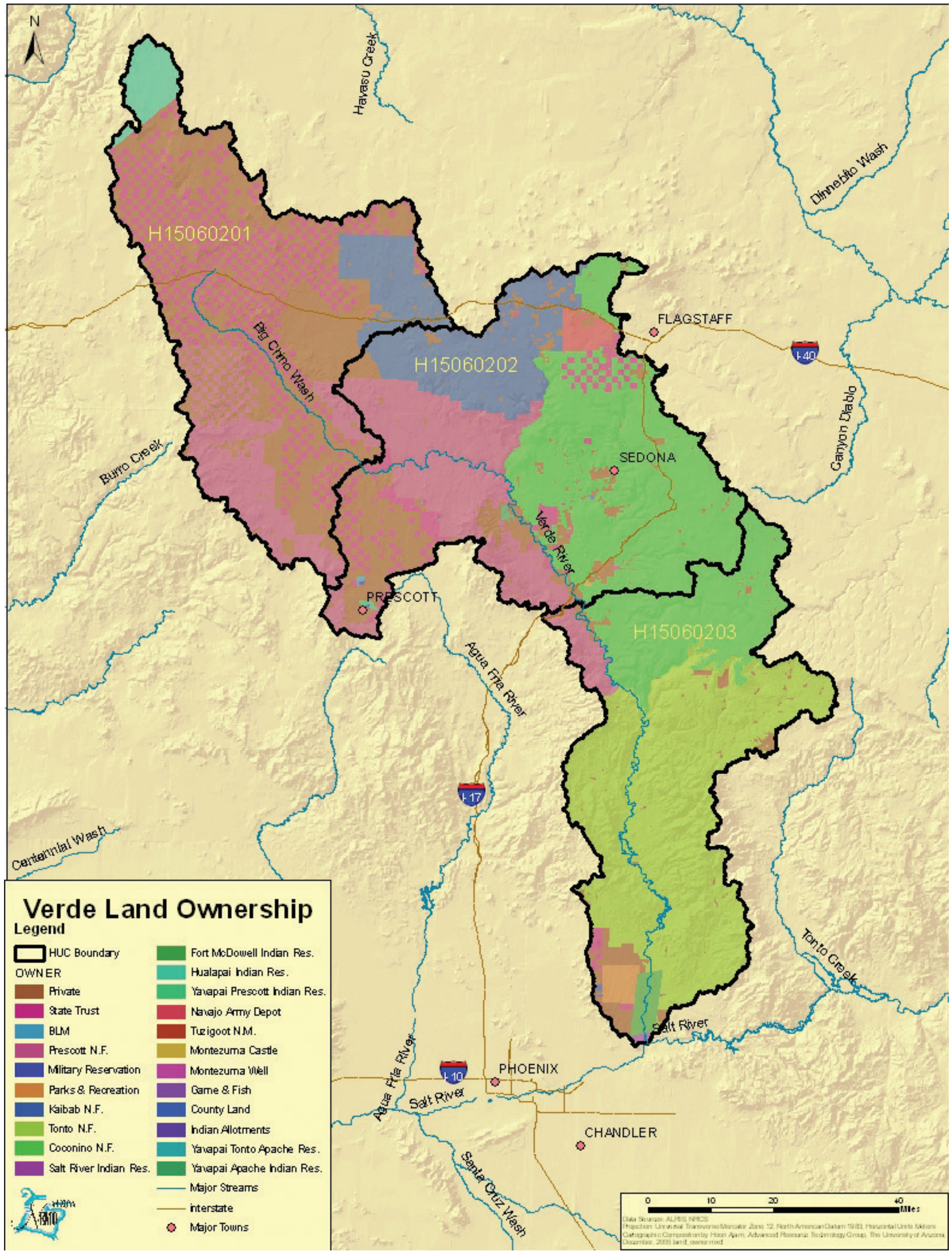


Figure 1.3—Land ownership within the U.S. Geological Survey Hydrologic Unit 4th Code watersheds for the Verde River, Arizona: Big Chino Wash (H15060201), Upper Verde River (H15060202) and Lower Verde River (H15060203). (Arisona NEMO 2012).

are true watersheds, but the Middle Big Chino Wash (HUC #1506020106), Lower Big Chino Wash (HUC #1506020108), Granite Creek/upper Verde River (HUC #1506020201), and Grindstone Wash/UVR (HUC #1506020204) hydrologic units are not, because parts of their watersheds are contained by other HUC watersheds. A major disadvantage of using HUCs that are not true watersheds is that their boundaries are arbitrary. Consequently, boundaries of some of the HUCs reported here do not coincide precisely with those used in Prescott National Forest's biological and National Environmental Protection Act evaluations.

The general condition of the UVR consists of a plateau with pinyon-juniper dissected by the entrenched Verde River (fig. 1.4). Some sections open out wider (e.g., Perkinsville and Burnt Ranch) before returning to the mostly canyon-bound condition.

Figure 1.4—Typical UVR landscape, Prescott National Forest, Arizona. (Photo by Daniel G. Neary.)

Figure 1.5—Land use patterns and major cultural and hydrologic features, Verde River, Arizona (From Blasch and others 2006).

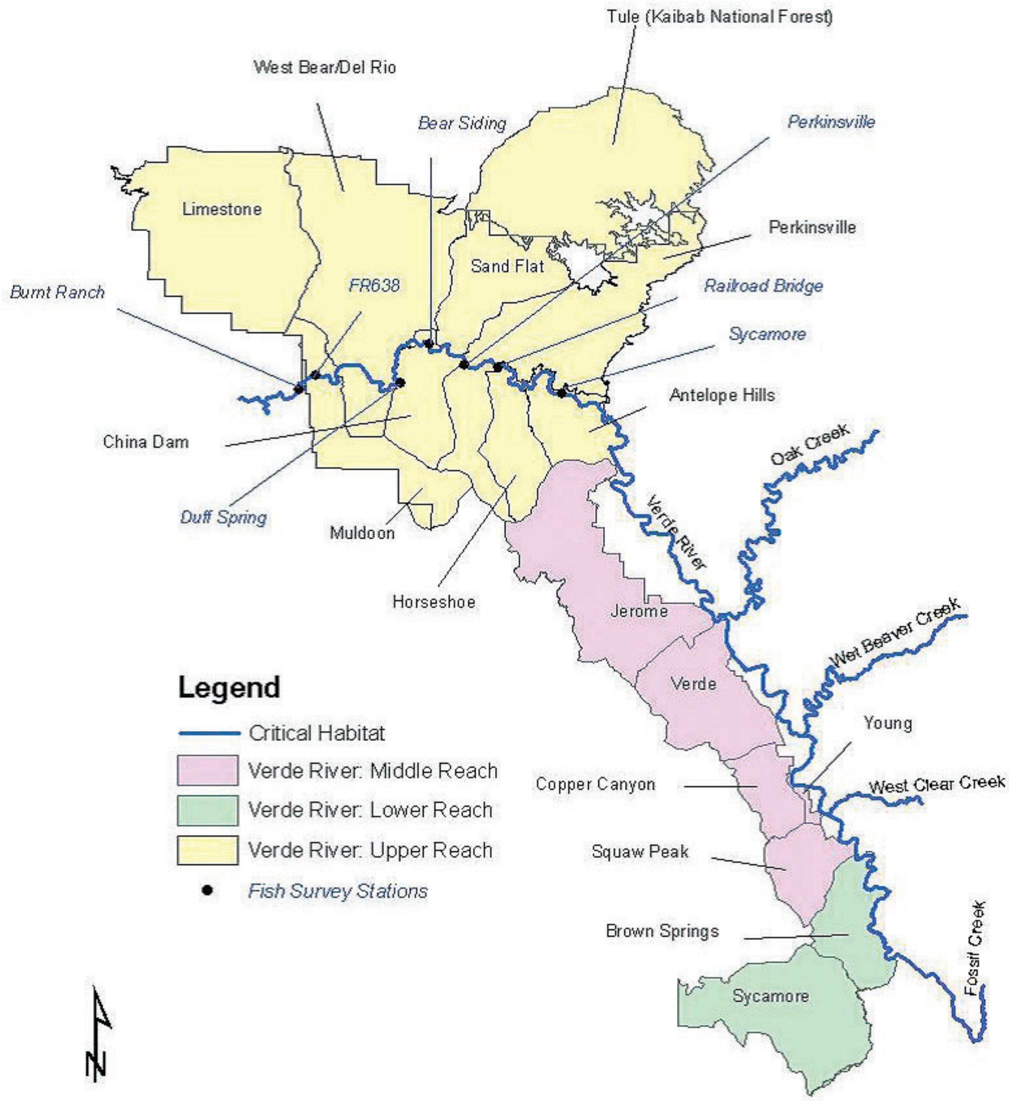


Figure 1.6—Prescott National Forest UVR grazing allotments.

Land Use and Tenure

Within Yavapai County, Arizona, 38% of the UVR watershed is managed by the USDA Forest Service. The State of Arizona manages 24.5%, and the Bureau of Land Management is responsible for another 11.5%. Private holdings account for 25%, and a mixture of public agencies and Indian Nations manage the remainder (Blasch and others 2006). The majority of the land within the UVR study area considered for this report is managed by the Prescott National Forest (fig. 1.5). Private in-holdings occur mainly at Perkinsville, the Verde River Ranch, and the higher reaches of the UVR where Arizona Game and Fish Department and other private land ownerships occur.

Most of the UVR lands within the Prescott National Forest are managed under grazing allotments. Nine grazing allotments border a total of about 60 km (38 mi) of the UVR (fig. 1.6, table 1.1). The allotments cover an altitude range of 1,280 m (4,200 ft). Two allotments—Limestone and Tule—do not border the main stem of the UVR but are within the watershed. Permitted maximum stocking levels range from 428 to 10,200 AUMs per allotment (animal unit months; Scarnecchia 1985)

Table 1.1—Grazing allotments of the UVR, Prescott National Forest (from King 2002).

Allotment	AUMs[1]	Area ha	Area ac	River length km	River length mi
Limestone	428	23,321	57,627	0.0	0.0
West Bear/Del Rio	10,200	29,265	72,315	15.5	9.7
Muldoon	2,340	9,710	23,995	5.8	3.6
China Dam	1,260	6,454	15,947	4.8	3.0
Sand Flat	1,500	9,353	23,111	2.7	1.7
Tule	2,250	24,406	60,309	0.0	0.0
Perkinsville	3,192	20,919	51,692	2.6	1.6
Antelope Hills	936	5,826	14,397	23.4	14.6
Horseshoe	2,700	5,927	14,646	5.4	3.4
TOTAL	24,806	135,181	334039	60.2	37.6

[1]AUMs = animal unit months (Scarnecchia 1985)

but are often well below these levels due to climate conditions and forage production (table 1.1).

Recreation is another important land use but its frequency is low, concentrated mainly at several limited access points. The Verde River Railroad runs up the river as far as Perkinsville before moving out of the river valley. Mining of flagstones is becoming a larger land use in the Grindstone Wash portion of the watershed. Above the UVR study area, the Big Chino Wash is becoming urbanized.

Water consumption in the UVR area is mainly through groundwater use. Annual withdrawals in the Big Chino and Little Chino sub-basins that provide much of the source flow for the UVR average 6.1 to 9.8 x 10^6 m^3 (about 4,900 to 7,900 ac-ft), respectively. Residential water usage from domestic wells and commercial water suppliers adds another 0.6 and 9.8 x 10^6 m^3 (500 to 7,900 ac-ft), respectively (Blasch and others 2006).

Climate

The climate of the UVR is governed by the climate of the Southwest United States in that it is characterized by a cyclic climatic regime of winter precipitation, spring drought, summer precipitation, and fall drought (Ffolliott and Davis 2008; Hendricks 1985). Precipitation usually comes from the northwest in the winter and from the southeast in the summer. It is bi-modally distributed with more precipitation occurring in the winter season (October through April) than during the summer season. Winter precipitation, often snow at higher elevations, is associated with frontal storms moving into the region from the Pacific Ocean. Surface thermal heating in the winter is less pronounced than in the summer; upslope air movement is relatively slow; cloudiness is common; and precipitation is usually widespread and relatively low in intensity.

The major source of moisture for summer rains is the Gulf of Mexico. This moisture moves into Arizona from the southeast, passes over highly heated and mountainous terrain, rises rapidly, cools, and condenses. Summer storms, primarily convectional, are often intense and local rather than widespread. Summer rains typically begin in early July, breaking the prolonged spring drought and providing relief to the hot weather of June and July.

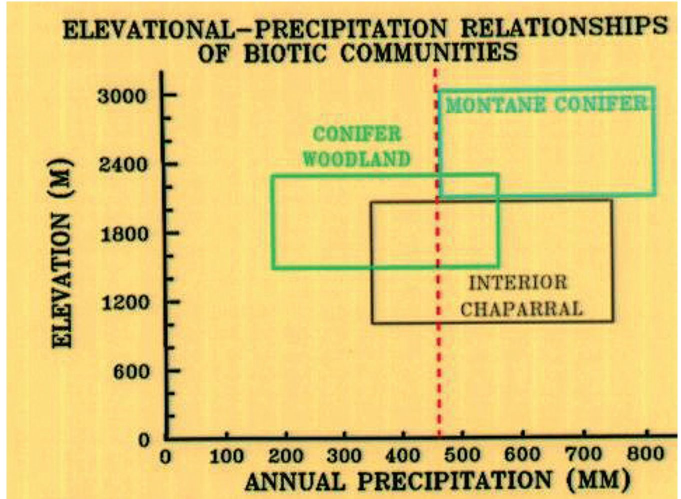


Figure 1.7—Central Arizona Highlands vegetation versus altitude relationships of biotic Communities (Baker 1982).

Winter precipitation is more variable than summer precipitation in both amount and time of occurrence from year to year. However, yearly variations in precipitation generally decrease with increase in elevation. Winter precipitation is generally less intense than summer precipitation so it has less energy to detach and transport sediment. Spring drought is often more detrimental to most plants and animals in the region than fall drought due to the higher temperatures and wind conditions during the beginning of the active growing season. Total precipitation increases with altitude and has a strong influence on both the types and productivities of vegetation communities (fig. 1.7).

Average annual precipitation in the central highlands ranges from 250 mm (10.0 in) in the lower desert shrub types to 760 mm (30.0 in) and 1,140 mm (45.0 in) in the highest mixed conifer forest areas (Baker 1982; fig. 1.7). The majority (80 to 95%) of the resulting streamflow occurs during the winter period either from melting snow or rainfall of moderate to low intensity (Baker 1982, 1999; Baker and others 2003). Little runoff is produced in the desert shrub types. Summer runoff is the product of intense, convective cells that cover relatively small areas (about 2.5 km^2 or 1 mi^2). These storm events may result in "flash floods," which are capable of producing localized flooding, significant erosion and sedimentation, property damage, and loss of life.

Vegetation

Vegetation types in the Central Arizona Highlands include mixed conifer forests, ponderosa pine forests, mountain grasslands, pinyon-juniper woodlands, chaparral shrublands, and desert shrub ecosystems (Baker 1999; Baker and others 2003). The mixed conifer forests, ponderosa pine forests, and mountain grasslands that make up the montane conifer biotic community are located above the elevations of the UVR study area except for small portions of the Tule Allotment (fig. 1.6). The desert shrub community is confined to the Lower Verde River and is not represented in the UVR. The elevation and precipitation limits for the conifer woodland and interior chaparral vegetation types are illustrated in fig. 1.7. These biotic communities provide a range of ecosystem services, including water, wood, forage, recreation opportunities, and wildlife habitats for a variety of big and small game animals, rodents, and game and non-game birds. A diversity of riparian ecosystems occur in, or adjacent to, stream systems and their floodplains that cut across both the conifer woodland and interior chaparral communities.

Figure 1.8—Pinyon-Juniper woodlands of the UVR region, Prescott National Forest. (Photo by Daniel G. Neary.)

The evolution of the American Southwest plant communities during the past 100 million years derived from major Tertiary geofloras that resided over a much greater subcontinental area than exists today (Brown 1982). The native vegetation of North America was composed of three great geofloras: (a) a mesophytic, broad-leafed evergreen Neotropical-Tertiary geoflora in the south half of the continent; (b) a temperate conifer and mixed-deciduous Arcto-Tertiary geoflora in the north; and between them, (c) an emerging sclerophyllous and microphyllous Madro-Tertiary geoflora that appearing on drier sites within and bordering the Neotropical Tertiary geoflora. Even the most pristine conditions within the derivative biomes are, for the most part, remnants of once-greater biotic communities of a greatly expanded geographic Southwest. The Southwest forests of relict conifers, montane conifers, subalpine conifers, and riparian deciduous trees are now relatively simplistic and depauperate modern derivatives of the more generalized and diverse temperate Arcto-Tertiary geoflora.

Conifer Woodlands—Woodlands containing pinyon pine and juniper species constitute the majority of the vegetation of the UVR area (figs. 1.4 and 1.8). They are below the signature ponderosa pine forests, at elevations of 1,370 to 2,290 m (4,500 to 7,500 ft), and constitute the largest forest type in the Southwest (fig. 1.8). Colorado pinyon (*Pinus edulis*) is found throughout, with singleleaf pinyon (*Pinus monophylla*) occurring on limited areas (Baker 1999). North of the Mogollon Rim, Utah juniper (*Juniperus osteosperma*), Rocky Mountain juniper (*J. scopulorum*), and one-seed juniper (*J. monosperma*) are intermixed with pinyon, while alligator juniper (*J. deppeana*) and Utah juniper are found south of the Mogollon Rim. Annual and perennial grasses and grass-like plants, forbs, half-shrubs, and shrubs abound beneath the woodland overstories when the tree cover is not overly dense or when grazing intensity is moderate to low. Recreation, a resource in these woodland areas, is limited by summer temperature and the relative lack of water. These woodlands are also an important source of firewood. Livestock, which spend

Figure 1.9—Chaparal shrublands of the UVR region, Prescott National Forest. (Photo by Malchus B. Baker, Jr.).

summers at higher elevations, graze in the woodlands in winter. These woodlands are also seasonal and yearlong habitats for many wildlife species.

There are wide fluctuations in weather patterns throughout the pinyon-juniper woodlands. Annual precipitation varies from 310 to 610 mm (12.0 to 24.0 in) (Baker 1999). Winter precipitation is usually rain with occasional snow. Evapotranspiration rates are relatively high in the growing season. Only during the coldest months of December through February is precipitation greater than the evapotranspiration rates. About 80 to 85% of the runoff produced in these woodlands occurs during the winter period (Clary and others 1974).

Soils are derived from basalt (Typic Chromusterts Vertisols–Springerville series), limestone, and sandstone parent material (Hendricks 1985). Pinyon-juniper woodlands generally occupy extensive areas of gently rolling topography. With the exception of steep canyon walls, few slopes exceed 20 to 25%. All aspects are well represented.

Chaparral Shrublands—Chaparral shrublands occur on rough, discontinuous, mountainous, terrain south of the Mogollon Rim (fig. 1.9; Baker 1999). Chaparral stands consist of a heterogeneous species mix in many locations, but often only one or two species dominate. Shrub live oak (Quercus turbinella) is the most prevalent species, while true (*Cercocarpus montanus*) and birchleaf mountain mahogany (*Cercocarpus betuloides*), Pringle (*Arctostaphylos pringlei*) and pointleaf (*A. pungens*) manzanita, yellowleaf (*Garrya flavescens*), hollyleaf buckthorn (*Rhamnus crocea*), desert ceanothus (*Ceanothus greggii*), and other shrub species can be included in the chaparral mixture of shrubs (Baker 1999). Annual and perennial grasses, forbs, and half-shrubs are present, particularly where the overstory canopy is open or only moderately dense. Although the recreational value (hiking, camping, and hunting) of chaparral is less than the higher-elevation vegetation types, its close proximity to major population centers gives it the advantage of providing a much larger recreation resource. Research has also determined that chaparral areas are marginal and intermittent sources of water supply for municipalities if vegetation control is employed to reduce tree densities (Baker 1984; Poff and Neary 2008). Chaparral rangelands are often grazed year-long by livestock and wildlife because evergreen plants common to the shrublands provide a continuous forage supply. A variety of wildlife species are found in chaparral shrublands, with comparatively high populations often concentrated in ecotones between chaparral and ponderosa pine forests at higher altitudes and grasslands at lower altitudes.

Average annual precipitation varies from about 380 mm (15.0 in) at the lower limits of the chaparral shrublands (910 m or 3,000 ft) to over 640 mm (just over 25.0 in) at the higher elevations (1,830 m or 6,000 ft) (Baker 1999). Approximately 60% of the annual precipitation occurs as rain or snow between November and April. The summer rains fall in July and August, which are the wettest months of the year. Annual potential evapotranspiration rates can approach 890 mm (35.0 in) (Hibbert 1979). Eighty-five percent of the annual runoff occurs

during the dormant season (November through April). Streams originating in the chaparral zone are ephemeral.

Chaparral soils are typically coarse-textured, deep, and poorly developed (loamy-skeletal, mixed, nonacidic, mesic Lithic Ustorthent). The term *soil* as used here includes all porous material (regolith) in which weathering and roots are active (Hibbert and others 1974). The distinction between soil depth and solum depth (A and B horizons) is critical since most of the soil supporting chaparral is in the C horizon. Usually, the A horizon is only a few centimeters thick and the B horizon is absent. The C horizon, which can be as much as 9 to 12 m (30 to 40 ft) deep, is hydrologically important, even though total porosity may only be 20 to 25%. Because of deep weathering, this zone is able to store much of the winter rain, which the deep-rooted shrubs use during dry periods Soil texture in the chaparral type varies from cobbly and gravelly loamy sand to gravelly loam. Slopes of 60 to 70% are common, and all aspects are represented.

Riparian—Chapters 6 and 7 contain more extensive discussions of woody and herbaceous riparian vegetation. This section is intended to be a brief overview since riparian vegetation is part of, and reflects the condition of, the upland portions of the watersheds. Three riparian ecosystems, delineated by elevation, are recognized in the Central Arizona Highlands. Riparian vegetation that occurs along the flood plain of stream channels is typically composed of herbaceous species of sedges (*Carex* spp.), spikerushes (*Eleocharis* spp.), rushes (*Juncus* spp.), and bulrushes (*Scirpus* spp.) (Baker 1999). These species produce the characteristic dark green edge found along channel systems. Woody plants, including saltcedar (*Tamarix* spp.), sycamore (*Platanus wrightii*), and cottonwood (*Populus fremontii*), that are often associated with riparian ecosystems are typically found higher up on the terraces adjacent to the flood plains.

In riparian ecosystems below 1,070 m (3,500 ft), many of the ephemeral streams have broad alluvial floodplains that can potentially support herbaceous plants and terraced bottoms that often support high densities of deep-rooted trees including saltcedar, sycamore, cottonwood, palo verdes (*Cercidium* spp.), and other species. Riparian ecosystems between 1,070 and 2,130 m (3,500 and 7,000 ft) contain the greatest number of plant species and the greatest canopy cover (fig. 1.7; DeBano and Schmidt 1989). Besides the characteristic herbaceous plants along the flood plain, cottonwood, willow (*Salix* spp.), sycamore, ash (*Fraxinus velutina*), and walnut (*Juglans major*) are typically found on the terraces, with three or four species often occurring together.

Above 2,130 m (about 7,000 ft), herbaceous species of sedges, spikerushes, rushes, and bulrushes predominate along the edge of the stream channels. Willow, chokecherry (*Prunus virens*), boxelder (*Acer negundo*), Rocky Mountain maple (*Acer glabrum*), and various coniferous tree species occupy the higher terraces.

Because of the abundance of water, plants, and animals, riparian areas provide valuable recreation opportunities as well as forage for livestock and wildlife in an

(A)

(B)

Figure 1.10—Riparian vegetation typical of the UVR region, Prescott National Forest: (a) Canyon-bound reach below Perkinsville, and (b) sedge-lined E-channel below the Verde River Ranch. (Photo by Alvin L.Medina.)

otherwise arid environment (fig. 1.10). Riparian ecosystems are "prime" habitats for many game and non-game species of wildlife and fishes.

Collectively, climatic characteristics of riparian ecosystems exhibit a wide range of conditions due to the large elevational differences and distributions of associated mountain ranges and highlands. The key characteristic of the riparian system is the availability of water throughout the year or at least during the growing season, which makes these ecosytems so highly productive.

Soils in riparian ecosystems at the higher elevations generally consist of consolidated or unconsolidated alluvial sediments derived from parent materials of the surrounding uplands. Depths vary depending upon the stream gradient, topographic setting, and parent materials. Soils on the flood plains at lower elevations consist of recent depositions, tend to be uniform within horizontal strata, and exhibit little development. The alluvial soils in all of these ecosystems are subject to frequent flooding and, as a consequence, are characterized by a range of textures. However, they are often very fertile. Riparian ecosystems in the UVR vary from narrow, deep, steep-walled canyon bottoms, to intermediately exposed sites with at least one terrace or bench, to exposed, wide valleys with meandering streams.

Riparian Ecosystems

Riparian Health

Southwestern riparian areas, where water is present a majority of the time, are fairly resilient to the multiple natural and anthropogenic disturbances that commonly occur in these ecosystems. The term "riparian health" refers to the stage of vegetative, edaphic, geomorphic, and hydrologic development, along with the degree of structural integrity, exhibited by a riparian area (DeBano and Schmidt 1989). A healthy riparian system is one that maintains a dynamic equilibrium between streamflow forces acting to produce change and vegetative, geomorphic, and structural resistance to change. Dynamic equilibrium results from the internal adjustment among factors operating simultaneously in the riparian system (e.g., climate, geology, vegetation, hydrology, and stream morphology) to increased flow or sediment movement (Heede 1980). Excessive short-term runoff from the upland watershed can increase channel flow volume and velocity, which can cause channel erosion and deposition in the riparian communities. However, when the riparian areas are healthy, flows in excess of channel capacity frequently overflow onto floodplains where riparian vegetation and associated debris provide substantial resistance to flow and act as filters, or traps, for sediment (Medina 1996). During these bank overflows, opportunities are available for germination and establishment of a wide assortment of phreatophyte and riparian plant species, ranging from herbaceous (e.g., species of sedges and rushes) to tree species (ash, cottonwood, willow, and alder; Brady and others 1985).

A healthy riparian area reflects a dynamic equilibrium between channel erosion (degradation) and sediment deposition (aggradation) processes (Heede 1980). A riparian area in a healthy state maintains a dynamic equilibrium between streamflow forces acting to produce change and vegetative, geomorphic, and structural resistance to these changes (Lane 1955; Heede 1980; Rosgen 1980; DeBano and Schmidt 1989).

When a "natural" or functional riparian system is in dynamic equilibrium, it is sufficiently stable so that internal adjustments can occur without producing changes in the system that overwhelm this equilibrium. This resistance to rapid change results from several factors acting together in the riparian area and throughout the watershed. Excess runoff reaching the channel increases flow volume and velocity, and this short-term increase in flow causes an oscillation in the equilibrium between erosion and deposition in the riparian area. While the balance tips back and forth, it is quickly dampened by the channel characteristics and results in no major change in the central tendency toward maintaining a dynamic equilibrium. When the resilience, or elasticity, of the system is not violated, a different dynamic equilibrium condition can be quickly reestablished. Most important of these factors is the native riparian vegetation (Medina 1996). Native riparian species (i.e., sedges, rushes, and other aquatic plants) have long, thick, fibrous root systems that can resist flood flows and hold the soil. They also have flexible stems that can fall over in flood conditions and protect the soil surface. The healthy riparian area is also characterized by a shallow water table, which is necessary to sustain healthy riparian plant communities on nearby floodplains (fig. 1.10).

Many phreatophyte species (e.g., cottonwood, willows, alders, and saltcedar) not only can shade out the herbaceous, aquatic species, but they can also affect erosion of the channel banks and terraces. Woody species generally have ridged stems that often result in increased turbulence in streamflow and, consequently, increased erosion around these stems and exposed root systems during flood flows if the soil surface is not sufficiently protected by herbaceous, riparian plants.

When sufficiently large changes in erosion and depositional processes occur, riparian areas can be thrown out of equilibrium, or, in extreme cases, may be permanently altered because they are no longer able to quickly adjust to change. Riparian health can be thrown out of equilibrium faster and more permanently during channel degradation processes than during stream aggradation phases. Excessive channel incision can intercept and drain existing water tables, which are close to the surface and support healthy riparian ecosystems. Loss of the water table, in turn, can rapidly desiccate the site, destroy the riparian ecosystem, alter plant composition, reduce plant diversity, and create an unhealthy or dysfunctional riparian system. On the other extreme, when excessive deposition occurs, channels become braided and are so shallow that they easily shift locations with resulting bank and channel erosion (Cooperrider and Hendricks 1937; Heede 1980). Once the disturbance factor is eliminated, it is easier for the aggraded system to "flush out" the excess sediment than for the degraded system to reestablish its original channel level.

The interrelationship between watershed condition and riparian health is well substantiated by historical accounts of many riparian areas in the Southwest that were portrayed as stable, aggrading stream networks containing substantial amounts of organic debris and supporting large beaver populations (Cooperrider and Hendricks 1937; Leopold 1951; Minckley and Rinne 1985). Under these conditions, forested headwater tributaries provided a continual supply of small and large organic debris that formed log steps in smaller streams and large accumulations of logs and other organic debris along higher-order, low-elevation mainstreams. Naturally occurring floodplain and channel structures, along with living, aquatic plants, dissipated energy, controlled sediment movement and deposition, and thereby tended to regulate and sustain flow that provided an environment sufficiently stable for maintaining and perpetuating healthy riparian ecosystems (fig. 1.10). Energy dissipation decreased flow velocities in stream channels and on floodplains, resulting in improved percolation of water into subsurface storage. This delaying effect was likely enhanced because many stream channels were above fault-fracture zones that lead to underground aquifers. Water stored in high-elevation aquifers was available and, when slowly released, supported late-season flows in downstream riparian areas.

This discussion might lead to the impression that conditions are either all "good" or all "poor." In reality, riparian ecosystems in the Southwest, as in general, are quite varied. With any reference to a given condition, one must realize that there is a continuum in all landscapes. In Cooperrider and Hendrick's (1937) evaluation of the Upper Rio Grande Watershed in New Mexico and Colorado, areas of the watershed were grouped by degrees of soil erosion potential (normal, moderate, advanced, and excessive). Normal erosion was assumed to take place under the cover of "natural" vegetation. Only 25% of the land analyzed by Cooperrider and Hendricks (1937) had sufficient plant cover to control erosion within normal and moderate limits in 1937. Soil erosion was in the advanced stage on about 35% of the area, and rapid land destruction was in progress on 40% of the Upper Rio Grande Watershed. Forage production had also been reduced 50%, principally as a result of overgrazing and accelerated erosion.

Leopold (1941, 1951) stated that the idea of verdant vegetation cover everywhere in the Southwest that deteriorated as a result of man's activities led to excessive optimism concerning the possible recovery of riparian ecosystems from the effects of grazing. Recovery of vegetation density in 1951 on depleted ranges, even after protection for years, was spotty and in many places, disappointing. At that time, the roles and interactions of drought, fire, and natural grazing in controlling vegetation productivity were not well understood. Many people, even today, still hope to restore large areas to levels of vegetation density that were originally attained only in selected localities.

Riparian Soils

The soils of the riparian area described by Stein (2001) include Typic Ustifluvents, Typic Fluaquents, Oxyaquic Ustifluvents, Aquic Ustochrepts, and Oxyaquic Haplustalfs. Typic Ustifluvents are the dominant streambank soil type in the uppermost reaches while Typic Fluaquents are more common in the lower reaches of the Verde River. The soils typically support dominant bulrushes (*Schoenoplectus americanus* and *S. pungens*) but also are noted for dense stands of sedges (*Carex praegracilis*, *C. pellita*, *C. simulata*, and *C. Nebraskensis*) and rushes (*Juncus articus*, *J. mexicanus*, and *J. tenuis*).

Oxyaquic Ustifluvents are found on some streambanks and may be indicative of an underlying aquic soil. Their droughty and sandy character limits perennial graminoid establishment on floodplain locations; but near water, these soils are readily inhabited by bulrushes and assorted annuals, e.g., beardless rabbitfoot grass (*Polypogon viridis*).

Aquic Ustochrepts are a minor inclusion on the river, but they exhibit strong soil development with stable non-eroding fluvial conditions. These soils are associated stable sinuous channels typical of the "E-type" (Rosgen 1994) and wetland sites with dense stands of sedges and rushes. These habitats were evident prior to recent floods and establishment of woody vegetation. Remnant habitats exist only in localized areas with gaining reaches, e.g., Verde Ranch and Duff Springs (fig. 1.10).

Oxyaquic Haplustalfs occur in association with other colluvial upland soils. These soils are very close to the older Paleustalf classification and are indicative of relatively old soils that have also been largely undisturbed during the last 100 years (Stein 2001).

Watershed Condition

Watershed condition can be defined as the physical and biological "state" of a watershed (DeBano and Schmidt 1989; Lafayette and DeBano 1990; Reynolds and others 2000). It involves such factors as vegetation cover, flow regime, sediment and nutrient output, and site productivity on the watershed. Climate, geology, soils, and native vegetation can exert varying degrees of natural control on watershed condition, and human activities can have strong negative and positive influences on watershed condition.

A watershed in "good" or proper functioning condition absorbs rainfall energies, maintains high infiltration rates of water into the soil, has a large temporary water storage capacity, and releases storm water slowly into the channels (Barrett and others 1993; Horton 1937). It also has a minimal channel density necessary for conveying runoff from the watershed. These factors combine to provide desirable base flows while minimizing peak flows.

A watershed in "poor" or dysfunctional condition has an expanded channel (or gully) network (Barrett and others 1993) that produces greater amounts of sediment-laden runoff water because a sparse vegetation cover permits detachment of soil particles, sealing of soil pores, and increases in runoff and erosion. The resulting base flows are reduced while peakflows increase in magnitude and volume.

The balance between watershed condition and riparian health can be defined in terms of four combinations: (1) good watershed condition-healthy riparian, (2) good watershed condition-unhealthy riparian, (3) poor watershed condition-healthy riparian, and (4) poor watershed condition-unhealthy riparian (DeBano and Schmidt 1989). Some of these combinations are more likely to occur than others. Over long periods of time, misuse of riparian areas can lead to channel incision and the extension of a gully network throughout the surrounding watershed. It is least likely that a healthy riparian area is present when the surrounding watershed is in poor condition, but installing structures and excluding grazing may temporarily improve riparian areas on these watersheds (Heede 1986).

Historical misuse of both watersheds and associated riparian areas throughout the West shifted the balance between watershed condition and riparian health (Cooperrider and Hendricks 1937; Leopold 1951). A common scenario leading to degradation of these riparian ecosystems was as follows:

- Overgrazing or improper timber harvesting practices led to a loss of protective plant cover and increased soil compaction throughout the watershed, including the riparian areas.
- Where plant removal and soil compaction was severe, infiltration was reduced and overland flow was increased.
- Excessive overland flow from upland hillslopes delivered more water to the channels, increased flood flows, exceeded channel capacity, and resulted in channel enlargement and downcutting. This is a natural process of channel incision that has been aggravated by many human activities on the landscapes of the Southwest.

The downcutting of drainages and natural gullies have often been used as a diagnostic feature of watershed condition deterioration. Downcutting of gullies can proceed to and through the local water table, resulting in lowering of the water table, drying or dewatering of the riparian system, loss of riparian plant species, and replacement of hydric with mesic species

A number of land management activities have resulted in expanded drainage networks that maintained undesirable flashy runoff and increased available sediment. Wildfire and episodic storm events had a role in natural watershed condition degradation, and intensive grazing brought additional stresses on watershed condition. Overland flow was further concentrated when roads and trails were developed as part of various landscape uses, which further increased water delivery to the channels. Incising channels intercepted and drained existing water tables, many of which were close to the surface and supported healthy riparian ecosystems. Lowering water tables led to dewatering, alteration and destruction of riparian ecosystems, and an overall reduction in site productivity (Cox and others 1984). Meanwhile, on lower-elevation main streams, logging, agricultural development, urbanization, and more subtle impacts of desiccation from stream incision, impoundment, and channelization, along with over-pumping of regional groundwater aquifers, were responsible for the widespread destruction of riparian areas (Cooke and Reeves 1976; Bahre and Hutchinson 1985; Minckley and Rinne 1985).

The condition of a watershed is important because it influences the quality, abundance, and stability of downstream riparian resources and habitats. This influence results from controlled sediment and nutrient production, influencing streamflow, and modified distribution of nutrients throughout the environment. It should be remembered, of course, that not all areas have the same vegetation potential and productivity. Climate, geology, and soils will always limit vegetation potential, productivity, and cover, and sparseness of vegetation is not always an indicator of poor watershed condition.

The following chapters discuss and summarize available information concerning the current watershed conditions within the UVR and potential restoration conditions that are believed to be possible for these areas. Information derived from 30 years of research on the Beaver Creek Watersheds in the Middle Verde River and on other sites in the Central Arizona Highlands, such as Workman Creek at Sierra Ancha, was used to support this analysis (Baker 1999). A more complete discussion of watershed condition in the UVR can be found in Chapter 4.

Watershed Management Issues

The research and monitoring documented in this Report were conducted on behalf of the Prescott National Forest to assess the impacts of grazing on the watershed condition of the uplands and on the channels of riparian corridor of the UVR. This has been the primary land use issue on Forest lands as expressed by Prescott National Forest staff over a number of years (Rinne 1999b; Fleischner 2002; King 2002). Of particular concern to the Prescott National Forest is the impact of land management activities on the spikedace (*Meda fulgida*)—a small fish species that is part of the native fish fauna of the UVR (see Chapter 9; Rinne 1999a). The spikedace is a Federally listed threatened species that occurs in only four isolated stream and river systems in Arizona (Douglas and others 1994; Rinne 2005). It was once widespread and locally abundant in streams and rivers of the Gila River Basin. Rinne (1991a, 1991b, 1996, 2005) and Rinne and Stefferud (1995) noted the important role of large predatory nonnative fish species (e.g., smallmouth bass, catfish, common carp, and green sunfish) and smaller nonnative fish, such as the red shiner and fathead minnow, in producing adverse effects on the spikedace. Despite lacking definitive evidence of direct links between current grazing activities and stocking levels and declines of spikedace populations (Rinne 1999b), the focus of regulatory and environmental concern has continued to be the extrinsic (out-of-channel) factor of grazing and its potential impacts on watershed condition (table 1.2). Thus, one focus of the monitoring and research reported in this publication is watershed condition and immediate channel impacts.

The ecosystem factors that might produce potential impacts on the spikedace fall into categories of intrinsic, extrinsic-natural, and extrinsic-human related,

Table 1.2—Factors potentially influencing the spikedace and other fishes in the UVR watershed.

Uplands Extrinsic–natural	Ecosystem influences River Intrinsic	Uplands Extrinsic–human related
1. Climate	1. Nonnative fish	1. Grazing
2. Geology	2. Other nonnative fauna	2. Mining
3. Soils	3. Streamflow	3. Roads
4. Vegetation	4. Water quality	4. Forestry
5. Groundwater	5. Geomorphology	5. Urban development
6. Runoff	6. Sediment regime	6. Agriculture
7. Natural Sediment	7. Macroinvertebrates	7. Recreation
8. Wildlife	8. Riparian vegetation	8. Water engineering

relative to the river (table 1.2). Intrinsic factors are operative within or immediately adjacent to the aquatic environment of the river channel. Extrinsic factors operate in the terrestrial uplands of the watershed. Watershed condition integrates the extrinsic-natural factors and reflects the extrinsic-human impacts. The extrinsic (human-related) influence that is the most controversial management issue is grazing. However, urban development has the potential to be a much greater issue and of far greater impact due to its potential to de-water a substantial portion of the UVR. Chapter 9 discusses and highlights the research that demonstrates that the major threats to the spikedace and associated native fishes are intrinsic (in-channel) factors.

Objectives

The objectives of this volume are two-fold. The first is to summarize 15 years of research and monitoring on the UVR conducted by Rocky Mountain Research Station staff in Project RMRS-4302, Watersheds and Riparian Ecosystems of Forests and Woodlands in the Semi-Arid West (now the Southwest Science Team; Air, Water, and Aquatic Environments Science Program). The research and monitoring began after floods that occurred in early 1993 and re-set the UVR in a 75-year flood event. The second objective is to make recommendations to the Rocky Mountain Research Station, the Prescott National Forest, and the Southwest Region of the USDA Forest Service on future research and monitoring on the UVR. Although a lot of knowledge has been gained over the past 15 years, much work remains to be accomplished. The information presented here will help focus future efforts.

Chapter 2

Historical and Pictorial Perspective of the Upper Verde River

Alvin L. Medina, Daniel G. Neary

Introduction

The UVR corridor is a diverse riverine ecosystem in central Arizona (see Chapter 1). Since European settlement, it has witnessed many events such as droughts, floods, construction of Sullivan Dam, groundwater withdrawals, cattle grazing, mining, nonnative fish introductions, native fish extinctions, and urbanization that are not fully understood. Geologically, the UVR displays a wide array of formations of spectacular color and variety; the landscapes vary from open valleys to narrow and deep canyons. Several publications have described the Verde River (Wirt and Hjalmarson 2000; Blasch and others 2006), yet few provide pictorial descriptions of historical and existing conditions. Oral accounts offer different glimpses of purported historic conditions (Byrkit 1978). For the most part, descriptions of the Verde River are largely limited to the Middle Verde River and the Lower Verde River. The UVR is distinct from the former sections due to the smaller character of the landscapes, yet it is unique in many attributes.

In this chapter, repeat photography is used to display the vivid texture of the river vegetation, channel, and valley landscapes and to contrast the historic with current conditions. These contrasts are interpreted within the context of plant ecology and hydrogeomorphology to provide a comprehensive understanding of the changes that have occurred in the past century. In some cases, additional photographs provide a larger perspective of the area and its habitats. A principal objective is to provide a broad understanding of historic influences that is necessary to comprehend the physical and biological processes that govern present-day conditions on the UVR. Climate and land uses undoubtedly have affected the flow and sediment regimes, which, in turn, have influenced such factors as riparian vegetation and aquatic life. Paleo-reconstruction studies of historic environmental conditions are utilized to put forward alternative descriptions of the Verde River for the period of record (1890 to present). These paleoecological data are useful for discriminating between natural and cultural influences on observed environmental changes (Swetnam and others 1999). The most significant period regarding vegetation and hydrologic changes may be the last 400 to 500 years (the time of European influence in the area. The introduction of livestock circa 1890 is an important event that is often cited as crucially influential on present-day conditions. However, many past descriptions of the UVR that have been extrapolated from general sources do not recognize climatic conditions during this period. These changes in climate may have misunderstood and long-lasting consequences on the future evolution of riparian and aquatic habitats.

Credits

Several people and organizations contributed photographs to this effort. Mr. James Cowlin (Cowlin 2008) is a freelance photographer who captured many views of the UVR in 1979. Some photographs are courtesy of and used with permission from Sharlot Hall Museum, Prescott, Arizona. Many photographs are courtesy of Mr. Thomas Perkins, a descendant of the original settlers on the UVR. Mr. Perkins shared photographs that are now archived at Sharlot Hall Museum. Dr. and Mrs. George and Sharon Yard of the Y-D Ranch in Perkinsville provided photographs of their private lands and the Horseshoe Allotment. Mr. and Mrs. David and JoAnn Gipe of the Verde River Ranch provided historical photos of ranching activities. Some photographs of the 1920s were taken by Mr. Matt Cully while working for Southwestern Forest and Range Experiment Station on the Santa Rita Experimental Range in southern Arizona. A special thanks is extended to Mr. James Steed who assisted in the collection and archival of repeat photographs. Photographs are also provided from the author's private collections.

Methods

Layout

A spatial sequence is used to reference locations of historic photos, starting at the headwaters on the west of the UVR and proceeding easterly downstream. Photographs were selected that depict significant changes in the vegetation and channel conditions for the period of record. Repeat photographs were utilized to provide a temporal aspect and spatial contrast through the riverine corridor, as well as extended areas above the headwaters. Relative changes that are observed in the photographs are described and discussed in order to provide differing perspectives of riparian conditions using background studies of the hydrology and vegetation of the UVR.

The Verde River and its watershed have been studied extensively since the early Twentieth Century. More than 2000 science and popular articles have been written on diverse aspects of the river, including many on historical, ecological, and socio-economic issues. It was impractical to review all of the collective works, so only those with original context relevant to the objectives of this Report were selected. Considerable works on watershed management of all of the principal vegetation types of the Southwest, compiled by Dr. Malchus B. Baker, Jr. are available online (http://ag.arizona.edu/OALS/watershed/). In addition, selected scientific works on the UVR are available at the RMRS, Flagstaff, Arizona web site: http://www.rmrs.nau.edu/lab/4302/4302VerdeRiverBibliography.htm.

Terminology

The following definitions are provided to assist the reader. The UVR study area is defined as the section of river starting at the Prescott National Forest boundary to the east near Tapco, Arizona, to the headwaters at Sullivan Dam to the west (fig. 1.1). This designation is consistent with the Arizona Department of Water Resources watershed area, which drains to the Clarkdale USDI Geological Survey gauge (#0904000). The Middle Verde River study area is defined as the section of river starting at the Prescott National Forest boundary to the west near Tapco, inclusive of the Verde Valley, to the eastern boundary of the Prescott National Forest. This Report deals only with the UVR, but references to or examples from the Middle Verde River (Camp Verde area) are utilized. The Lower Verde River extends from the Middle Verde River section south to the river's confluence with the Salt River.

The Verde River was historically referred to as "El Rio de Los Reyes" by Antonio de Espejo in 1583, "Sacramento River" and "El Rio Azul" in Seventeenth and Eighteenth Century Spanish maps, and "San Francisco River" and "Granite Creek" by Nineteenth Century Anglo-American pioneers (Byrkit 2001). In this chapter, the term "historical" refers to time of recorded history since Antonio de Espejo's travel in the Southwest. The word "paleo" refers to time before recorded history. The Pecos Classification refers to a period sequence used to describe paleo and historic settlements of Southwestern Native Americans (Morrow and Price 1997). The classification is as follows:

Paleo-Indian (unknown dates to 8500 before present [B.P.])

Basketmaker I (6700 B.P. to A.D. 1) (Archaic)

Basketmaker II (A.D. 1 to 500)

Basketmaker III (A.D. 500 to 700)

Pueblo I (A.D. 700 to 900)

Pueblo II (A.D. 900 to 1100)

Pueblo III (A.D. 1100 to 1300)

Pueblo IV (A.D. 1300 to 1600)

Pueblo V (A.D. 1600 to 2000)

Common geomorphic and hydrologic terms used in this Report can be found in the Glossary (Appendix 1). "Floodplain" refers to "the area along the river that has been subject to erosion and deposition by the Verde River in the past few thousand years" (Pearthree 1996). This geomorphic feature and the river itself are the foci of this report, but the surrounding landscape is considered in this and other chapters.

Study Area

The Verde River is centrally located within Arizona, flowing about 350 km (220 mi) southward to its confluence with the Salt River (fig. 1.1). The watershed area, elevations, and other features are discussed in Chapter 1. Landownership is mostly public lands, with private ownerships centered about the river and transportation corridors (fig. 1.5).

Major vegetation types of the Verde Valley range from mixed conifer on peaks of the Mogollon Rim to Sonoran Desert Scrub at the confluence with the Salt River. (see Chapter 1). Original riparian woody vegetation was largely coincident with valley form, with large cottonwoods scattered in the wide open valleys, and Arizona ash on terrace slopes of canyon bound reaches. Since 1993, an expansion of many obligate species has occurred owing to such factors as floods, land use changes, and general climate changes. Invasive plants such as saltcedar have been a developing component since about the 1950s (see Chapter 6).

Several scientists have recently provided characterizations of the geohydrology of the UVR (Wirt and Hjalmarson 2000; Blasch and others 2006), owing to public demand for estimates of the water resources and locations. Perennial flow in the UVR watershed is limited from the confluence of Granite Creek easterly. The Del

Rio Springs in the Chino Valley supplied perennial flow above the Granite Creek confluence prior to the construction of Sullivan Dam in 1938. Principal intermittent and ephemeral streams above Sullivan Dam are Big Chino Wash, Little Chino Wash, Williamson Valley Wash, Walnut Creek, Granite Creek, Pine Creek, and Partridge Creek (Blasch and others 2006). Other major tributaries that contribute significant flow and bedload from the Rim to the north include Hells Canyon, Grindstone Wash, MC Canyon, Bear Canyon, Government Canyon, Railroad Wash, and Sycamore Creek. The southern tributaries from the south are Muldoon Canyon, Bull Basin, Wildcat Draw, Munds Draw, Orchard Draw, and SOB Canyon.

Paleo-Historic Description

Many authors have provided insight into paleoecological conditions of local and regional riverine and upland environments of the UVR (Gladwin and Gladwin 1930; Fish 1967, 1974; Hevly 1974; Fish and Fish 1977; Hevly and others 1979; Smith and Stockton 1981; Ely and Baker 1985; Hevly 1985; Anderson 1993; Pearthree 1993, 1996; Ely and others 1993; Ely 1997; House and Hirschboeck 1997; Allen and others 1998; Swetnam and Betancourt 1998; Blasch and others 2006). This analysis mainly addresses scholarly works that pertain to the river within the context of human influences and land uses, vegetation changes, and hydrology and geomorphology, but it also includes relevant works of upland influences. There are many descriptions of the Verde River with often conflicting accounts of historic and current conditions. The purpose of this analysis is to establish an understanding of paleohistoric conditions using reconstruction studies from the Verde River and the region. The paleohistoric events, especially climate (Ni and others 2002), and human influences, of the late Nineteenth Century have had strong influences on the current and potential ecological states of the habitats of the UVR.

Geologic History

The Verde River and the Mogollon Rim are believed to have established during the Oligocene epoch of the Paleogene period, 27.4 to 37.2 million years ago (Ma) (Pierce and others 1979). During the following Miocene epoch (7.4 to 27.4 Ma), the Verde River was interrupted by tectonic and volcanic events in the Hackberry Mountain–Thirteen-Mile Rock volcanic center a few miles southeast of Fort Verde (Elston and others 1974; McKee and Elston 1980; Menges and Pearthree 1989; Nealy and Sheridan 1989; Elston and Young 1991). This resulted in a closed basin, during which Miocene volcaniclastic, clastic, and evaporite sedimentation occurred to form the Verde Formation (Nations and others 1981). Between the Miocene and Pliocene, extensive sedimentation occurred within the Verde Basin until the breaching of the volcanic-tectonic dam during the Quaternary period (<3.6 Ma), which eroded much of the Verde Formation (Nations and others 1981). The depth of the Verde Formation is unknown but is estimated near 960 m (3,150 ft) or roughly a top elevation near 2,000 m (6,560 ft) (Nations and others 1981).

The UVR is largely situated within the Chino Basin and the Verde Basin (fig. 2.1). One can surmise that the extensive sedimentation that occurred during the Miocene epoch within the Verde Basin likely reached elevations upstream to include the Chino Basin. Sullivan Dam lies within the Chino Basin at an elevation of about 1,325 m (4,350 ft). Some sediments reside as terraces or mesas (see

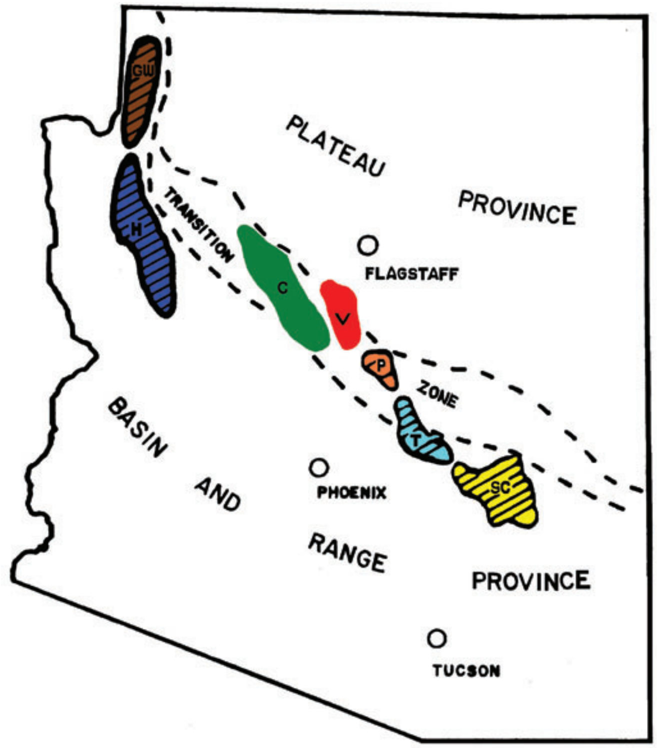


Figure 2.1—The Cenozoic basins of the Transition Zone between the Colorado Plateau province and the Basin and Range province. The basins are identified by color and letters: brown (GW) = Grand Wash Basin, dark blue (H) = Hualapai Basin, green (C) = Chino Basin, red (V) = Verde Basin, orange (P) = Payson Basin, light blue (T) = Tonto Basin, and yellow (SC) = San Carlos Basin (adapted from Nations and others 1981).

Chapters 3 and 4). Hence, the paleogeology of the UVR suggests that the basin sediments are different from those of the Middle or Lower reaches of the Verde River, as well as from other streams and rivers of Arizona.

The paleogeology and local physiography have influenced the current character of the Verde River (Twenter and Metzger 1963; House and Pearthree 1993). The depositional history is important for understanding the current and changing conditions of the watershed and riparian corridor. Hydrologic processes, such as flooding and channel incision, have been occurring over several million years and are witnessed by the 90 to 150 m (300 to 500 ft) of incised tributaries and the Verde River canyon below Perkinsville. Pleistocene floodplain terraces are evident at various locations about 45 m (150 ft) above the present-day valley floor. Open valley forms account for about 75% of the landscape types, with the remaining 25% classified as confined reaches with high canyon walls and limited floodplain.

Climate, Floods, and Drought

The climate in central Arizona is undoubtedly influenced by the varied mountainous topography and the formidable Mogollon Rim. Precipitation in the region is bimodal, with intense monsoonal storms in the summer that are linked to tropical Pacific events and cooler winter storms linked to northern Pacific Ocean events (Philander 1990; see Chapters 1 and 3). The climate varied substantially during the Twentieth Century (Hereford and others 2002), but more so during the paleo period (Swetnam and Betancourt 1998).

Grissino-Mayer (1996) reconstructed more than 2,100 years of precipitation in the Southwest from tree-ring records (fig. 2.2). His climate reconstruction is well corroborated with other studies (Swetnam and Betancourt 1990, 1998) that link the three- to five-year Southern Oscillation to the regional climate (Philander 1990). Essentially, greater rainfall occurs during El Niño years, with somewhat lesser rainfall in summer, and La Niña years produce an opposite consequence. These

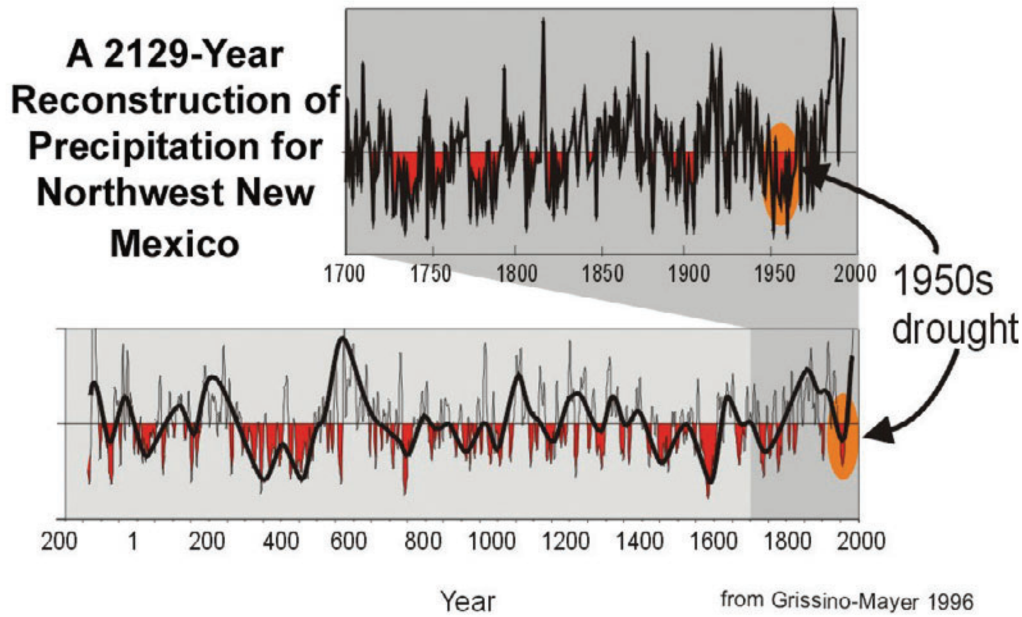


Figure 2.2—This graph is a reconstruction of precipitation for northwestern New Mexico. The units are of standard deviation, with red color indicating drought periods. This graph was developed by the National Oceanographic and Atmospheric Administration's Paleoclimatology Center (http://www.ncdc.noaa.gov/paleo/drought/drght_grissno.html; adapted from Grissino-Mayer 1996).

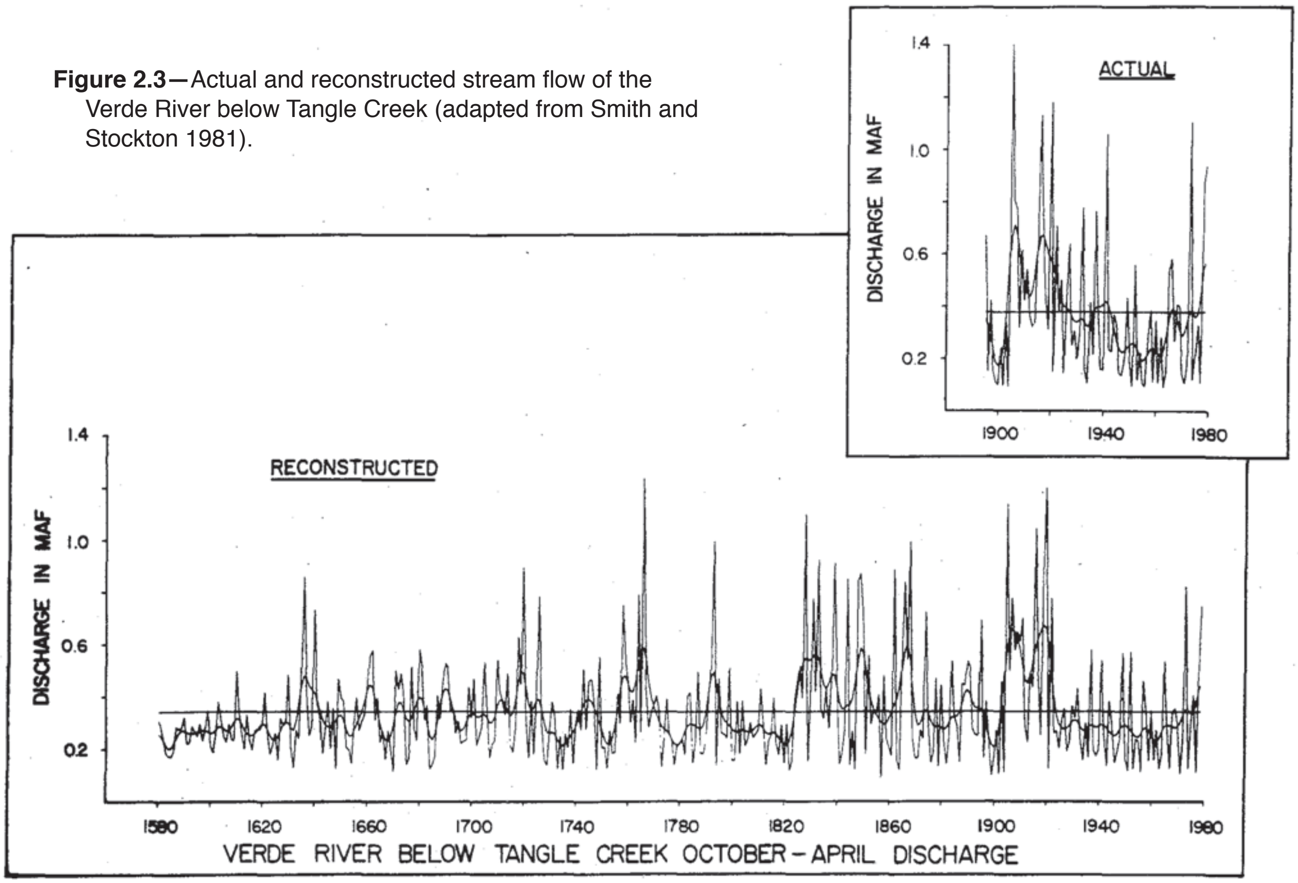
fluctuations are linked to floods (Webb and Betancourt 1992; Ely 1997), drought cycles (Grissino-Mayer 1996), fire frequencies (Swetnam and Betancourt 1990; Grissino-Mayer and Swetnam 2000; Gray and others 2003), and periods of high reproduction of woody plants (Swetnam and Betancourt 1998).

Ely and Baker (1985) performed the first paleoflood reconstruction study on the Verde River and provided an in-depth inventory of paleoflood frequencies and magnitudes. By 1997, Ely and other scientists (Smith and Stockton 1981; Ely and others 1993; O'Connor and others 1994; House and others 1995; Ely 1997) produced a 5,000-year paleoflood chronology linking the occurrence of similar floods in other regional river systems of the Southwest in a pattern similar to the Verde River.

Ely (1997) noted three types of storms that generated large floods: North Pacific winter frontal storms, late summer and fall storms, and convective summer thunderstorms. The largest historic floods have been from winter storms (Smith and Stockton 1981; Ely 1997). High- magnitude floods coincided with periods of cool, wet climate such as those witnessed in the last 200 years (fig. 2.3). Ely (1997) further noted the occurrence of 15 large-magnitude floods on the Verde River within the past 200 years. This is a frequency much greater than that reported in the historic record, and it ranks third highest of 19 Southwestern rivers. Evidence from tree-ring records (Webb 1985; Ely 1992; Grissino-Mayer 1996) corroborate that the historical period between 1905 and 1941 (early 1900s) and in the latter half of the Nineteenth Century experienced a high frequency of high-magnitude floods (Ely and others 1993; Ely 1997). Ely (1997) and Baldys (1990) noted that the largest historic flood peakflow of 4,248 m^3 s^{-1} (150,017 ft^3 s^{-1}) at the Tangle Creek Gauge (#09508500) on the Verde River that occurred February 24, 1891 (fig. 2.4). This flood was slightly larger than the January 8, 1993, flood peakflow of 4,106 m^3 s^{-1} (145,002 ft^3 s^{-1}) at the same site. This would explain the scoured and eroded conditions seen in photographs from the early 1900s on the Verde and other regional rivers (e.g., Little Colorado, Salt, Bill Williams, and Agua Fria).

Examination of reconstructed paleoflood studies (Smith and Stockton 1981; Ely and Baker 1985; Ely and others 1993; Ely 1997; Klawon 1998; House and others 2001) and paleoclimate studies (Grissino-Mayer 1996) reveals high agreement (Figures 2.2, 2.3, and 2.4). There is also high agreement between historical floods

Figure 2.3—Actual and reconstructed stream flow of the Verde River below Tangle Creek (adapted from Smith and Stockton 1981).



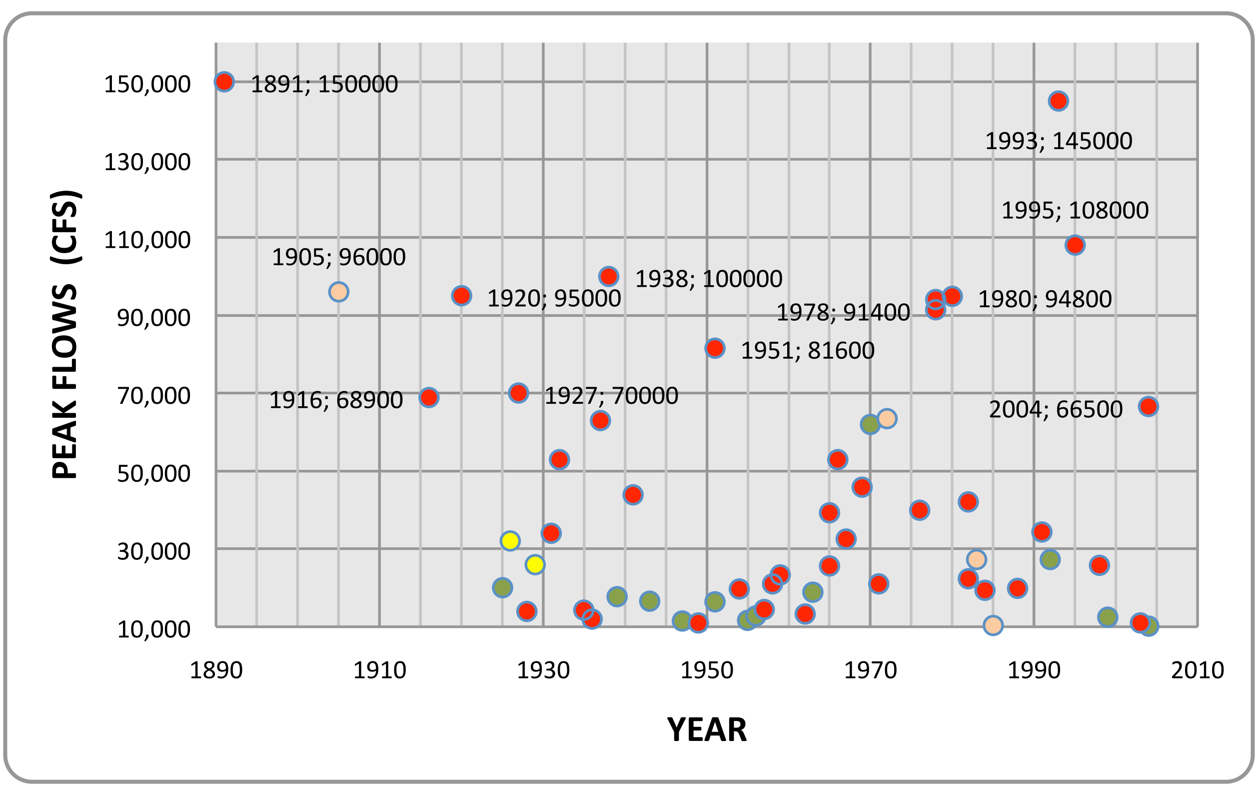


Figure 2.4—Peak flow events greater than 10,000 ft^3 s^{-1} (283 m^3) at Verde River-Tangle Creek Gauge #09508500. Winter storms are depicted in red, spring in yellow, summer in green, and fall in orange. Data points between 1891 and 1932 are estimates (USDI Geological Survey 2005).

(Smith and Stockton 1981) and the regional climate (Blasch and others 2006) for the Twentieth Century. In addition, the paleoflood history of the Verde River is coincident with the other western streams of Arizona, (e.g., Bill Willams Basin; Enzel and others 1993; House and Baker 2001). This provides greater assurance that early photographs depicting highly eroded and barren conditions were likely due to floods and drought episodes.

Aside from winter floods, summer monsoon storms are an important source of moisture in the Southwest (Poore and others 2005), and they promote a unique climatic regime where summer floods are annual occurrences. Tropical-derived thunderstorms of the monsoon, as well as decaying tropical storms and hurricanes, may be intense enough to cause widespread flooding and erosion in desert rivers (House and Hirschboeck 1997). As with many Southwest rivers and streams, flow varies considerably from season to season, year to year, decade to decade, and century to century.

Robert Webb and colleagues also published studies of paleofloods on other Southwest rivers (Webb 1985; Webb and others 1988, 1991; Webb and Betancourt 1992). The paleo studies by Webb and his colleagues provided the best explanation to date about likely evolutionary conditions of Southwestern rivers and associated vegetation in the late Holocene (Webb and others 2007). More important, Webb and others (2007) provided a rationale for understanding long-term relationships among climate, hydrology, and riparian vegetation. Their extensive treatise renewed debate about the role of riparian gallery forests in Southwestern rivers.

Examination of paleodroughts (figs. 2.2 and 2.3) revealed that droughts within the Twentieth Century were relatively mild compared to droughts within the two millennia of paleoprecipitation described by Grissino-Mayer (1996). The 1950s drought, noted as the most severe within the region in modern time, was mild compared to droughts dating back to 2148 years B.P. In contrast, the duration of paleodroughts was several decades compared to one decade now, and their magnitude in terms of reduced precipitation and streamflow was two to three times that experienced in 1950 (figs. 2.2 and 2.3). The significance of the 1950s drought on the Verde River cannot be quantified in terms of biological changes, but the resulting intermittent flows in the headwater sections of the Verde River in 1954 certainly would have influenced riparian conditions (Wagner 1954). The period from the early 1960s to early 1990s is noted with significant departure from normal in winter flows and the recent wetter period from 1993 to present (see fig. 3.5). Smith and Stockton (1981) remarked that several periods of extended low flow have occurred during the past 400 years and appeared to have a recurrence interval of 22 years (fig. 2.3). The current floodplain and terrace vegetation community of the UVR is comprised of many mesic species (e.g., juniper, oaks, acacias, and other upland plants) indicative of prolonged dry periods and comparatively mild floods witnessed during this century as the plants are age-correct for the time period (see Chapter 6).

Concomitant with drought and flood studies are investigations that address the period of arroyo cutting in the Southwest. The arroyo development periods are important because many past and present-day environmental assessments have used channel erosion as a determinant of historic land degradation by humans in the Verde River watershed. Many assessments attributed overgrazing by cattle and other human activities to arroyo cutting (Antevs 1952; Cooke and Reeves 1976; Graf 1983; Bull 1997). However, recent examination of Quaternary geologic records by Waters and Haynes (2001) linked arroyo formation to the Holocene epoch of the late Quaternary (<11,700 years B.P.) and to changing post-glacial climate, vegetation, groundwater conditions, and human land use. Specifically, the authors identified arroyo-forming episodes around 8,000 and 4,000 years B.P. Waters and Haynes (2001) further noted that arroyo formation appears to be linked to repeated wet-dry cycles, similar to other studies linked to the Southern Oscillation (El Niño-La Niña). The authors described the processes as dropping of water tables and reduced vegetation cover during dry periods (fig. 2.2), making sites susceptible to erosion. Subsequent wet periods induced flooding and initiated arroyo formation. Mann and Meltzer (2007) noted that incision occurred early in the Medieval Warm Period (1000 to 1300 A.D.) and aggradation ensued during the Little Ice Age (1350 to 1900 A.D.), followed by another incision cycle during this past century. Hereford (1993) also suggested that arroyo formation was related to periods of large floods. In the early Twentieth Century, Dellenbaugh (1912) cautioned that grazing wasn't the only probable cause of arroyo formation, but his interpretation was not widely accepted.

Today, the physical evidence identifying climate change as the principal factor inducing channel erosion is revealed in the works of several scientists (Webb and others 1991; Hereford 2002; Reheis and others 2005; Mann and Meltzer 2007; Chapin 2008) and are consistent with paleoclimate interpretations of pollen and packrat middens of the region (Reheis and others 2005). These processes have likely been operative on the Verde River Watershed and would explain historic sediment pulses from tributaries into the main channel, as well as recent erosion of terraces. In short, these sediment-channel dynamics are linked to the paleohydrology of the watershed, as previously discussed. Further examination of climate-sediment relationships could explain some residual effects on flora and fauna changes that have occurred on the UVR.

Vegetation

The biota of the Colorado Plateau during the middle (50,000 to 27,500 years B.P.) and late (27,500 to 14,000 years B.P.) Wisconsin time periods were very different from present day. Anderson (1993) attributes the differences to major climate changes associated with the last major glacial period. Areas once dominated by mixed conifers (late Wisconsin period 21,000 to 10,400 B.P.) are largely occupied today by ponderosa pine (*Pinus ponderosa*), a newcomer (<10,000 years B.P.). As the cold climate of the last glaciations ended, there was a shift toward warmer and wetter conditions (3550 to 2480 years B.P.), resulting in major shifts in vegetation upslope. Mixed conifer species and all lower-elevation woodlands and scrublands similarly retreated upslope to present-day elevations.

Oral accounts of UVR vegetation available from Nineteenth Century pioneers and settlers are insightful but not completely reliable. Brykit (1978, 2001) cites Spanish accounts that the Verde River was more "marsh-cienega"-like than typical stream conditions. Trees were scant and grass-like vegetation prevailed. Such references are most likely of the Middle Verde Valley where the landscape was most suitable for wetland conditions. Perkinsville, Bear Siding, Duff Springs, Bull Basin, Verde River Ranch, and a few other open valley areas upstream are sites that could have retained substantial wetlands. The presence of wetland vegetation and soil conditions at Duff Springs, Verde River Ranch, Al's Spring, and the Prescott National Forest "wetland" (fig. 2.5) have been verified by on-the-ground examinations.

Early accounts of Espejo's visit in 1583 to the mines at present-day Jerome noted the presence of "great groves of walnut trees" along the banks of the Verde River and most likely the confluence of either Sycamore Creek or Oak Creek (Farish 1915). Whipple and others (1856) quoted Antoine Leroux's description of

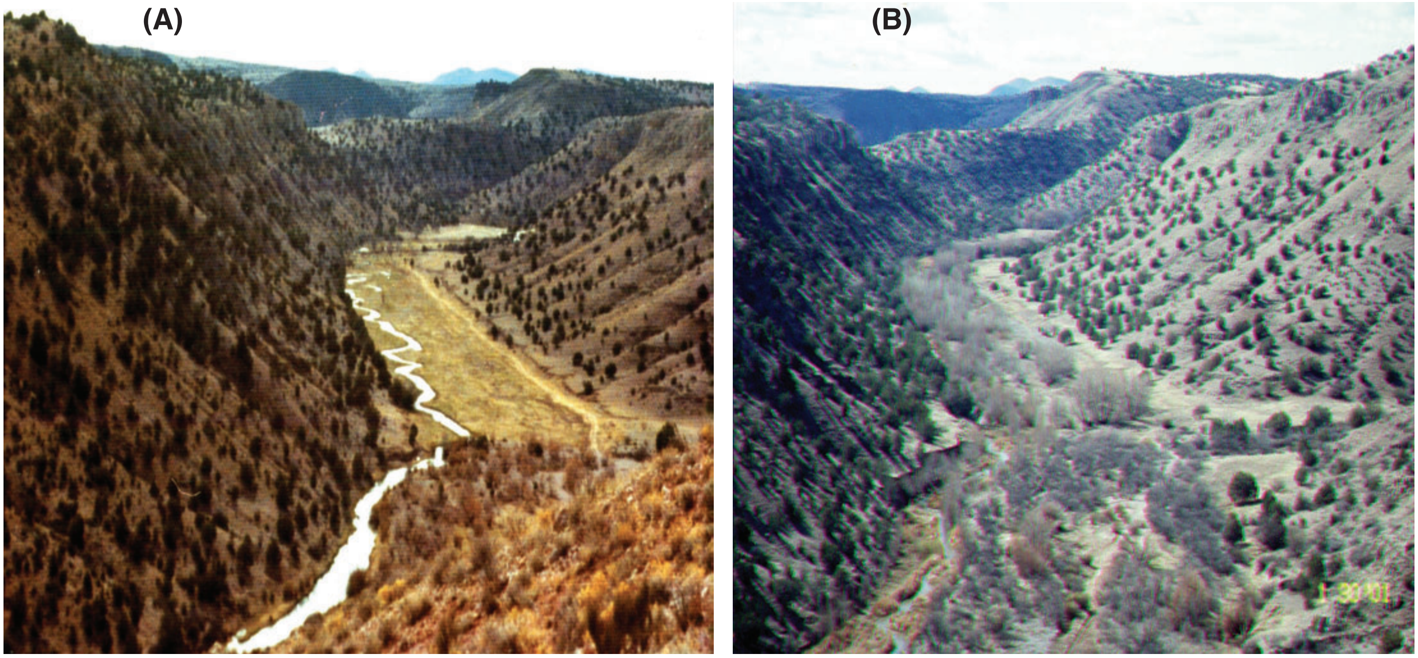


Figure 2.5—The 1979 photo (A) shows a stable wetland sedge meadow, while the 2001 photo (B) shows an invasion of woody species, e.g., tamarisk, and deeply incised channel. Woody vegetation on the floodplain is dated to 1993 flood. (Photo A by Prescott National Forest staff; Photo B by Alvin L. Medina.)

the Verde Valley accordingly: "The river banks were covered with ruins of stone houses and regular fortifications; which, he [Leroux] says, appeared to have been the work of civilized men, but had not been occupied for centuries. They were built upon the most fertile tracts of the valley, where there were signs of acequias and of cultivation." Accounts of cottonwoods and willows occur in archeological studies (Fewkes 1896, 1898, 1912; Mindeleff 1896) and in Hinton's (1878) travelogue. These accounts are limited to the Middle Verde and the tree stands are described as "scattered" and "confined to the immediate vicinity of the river" (Mindeleff 1896). This is surprising, considering the Verde Valley is several miles wide, and one would expect evidence of old groves around old channels. No mention of cottonwoods and other groves of riparian trees were found in historical records beyond Perkinsville. Walnut groves are likely, since they are facultative species that can occupy mesic habitats away from the river's edge. Photographic evidence from the turn of the century in the Perkinsville valley shows an absence of cottonwoods and other obligate riparian woody plants (figs. 2.6, 2.7, and 2.8). These photos show the presence of a few and scattered large cottonwoods perched on the first terrace. Most cottonwoods evident today established along irrigation ditches on the south side of the river (fig. 2.8). The floodplain was devoid of obligate woody plants, except for a few facultative species (e.g., mesquite). These same photos illustrate the eroded channel conditions and terraces likely caused by the 1891 paleoflood noted by Ely (1992, 1997) and Ely and others (1993). It is implausible that livestock ate, or otherwise affected mature stands of cottonwoods and willows between the period 1890 to 1925, since no evidence of stands of trees was found in any historical photos for of the Perkinsville area or other locations. The small grove of cottonwoods in Perkinsville appear to be remnant survivors of floods, with an approximate age greater than 40 to 50 years based on their girth and height (fig. 2.7). Hence, the presence of extensive riparian gallery habitats or stands of cottonwoods, willows or other obligate trees is highly questionable over the last century for the UVR. This situation has been suggested for several Southwestern

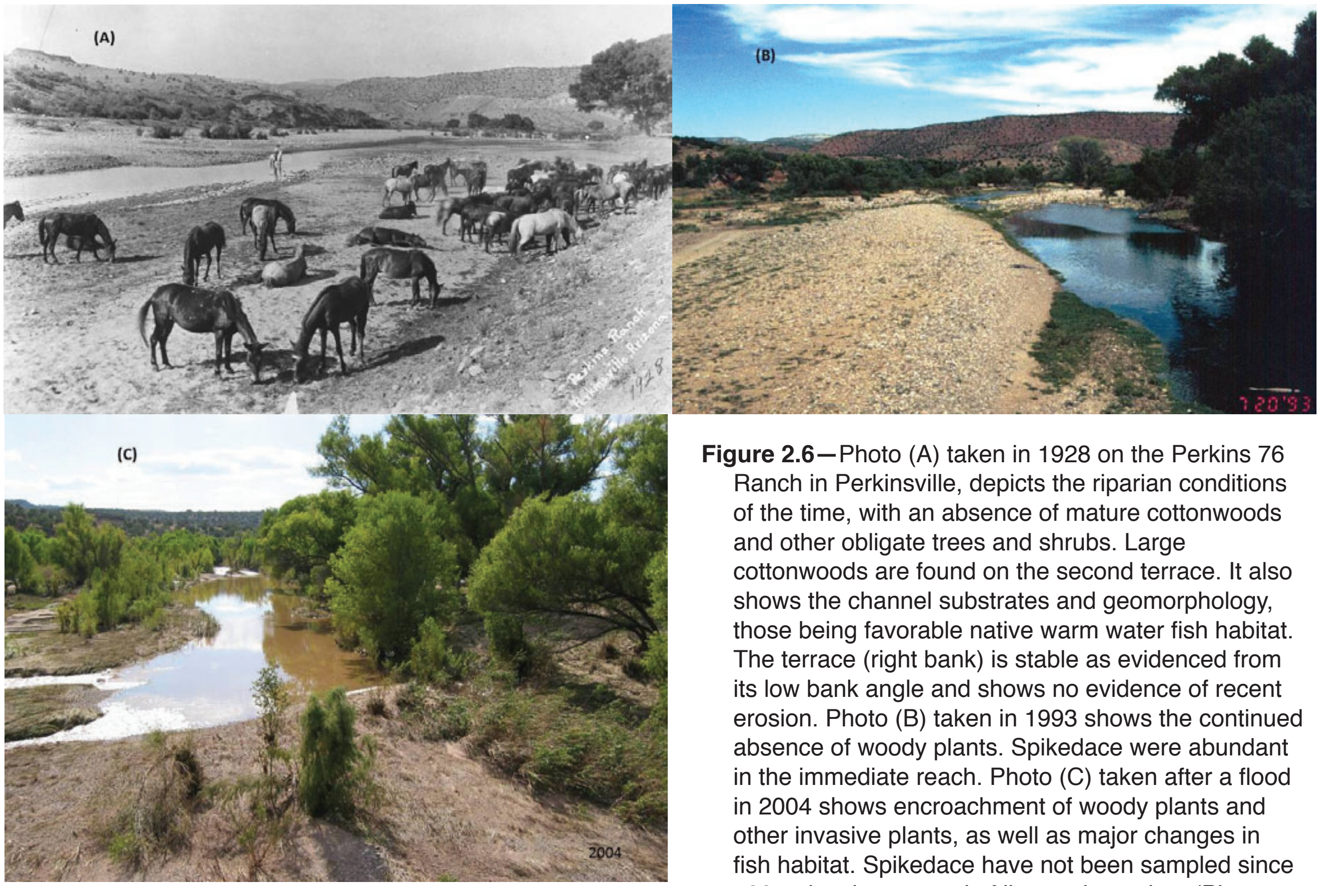


Figure 2.6—Photo (A) taken in 1928 on the Perkins 76 Ranch in Perkinsville, depicts the riparian conditions of the time, with an absence of mature cottonwoods and other obligate trees and shrubs. Large cottonwoods are found on the second terrace. It also shows the channel substrates and geomorphology, those being favorable native warm water fish habitat. The terrace (right bank) is stable as evidenced from its low bank angle and shows no evidence of recent erosion. Photo (B) taken in 1993 shows the continued absence of woody plants. Spikedace were abundant in the immediate reach. Photo (C) taken after a flood in 2004 shows encroachment of woody plants and other invasive plants, as well as major changes in fish habitat. Spikedace have not been sampled since 1997, despite removal of livestock grazing. (Photo A courtesy of the Sharlot Hall Museum, Prescott, Arizona; Photos B and C by Alvin L. Medina.)

rivers (Webb and others 2007), and in recent quantitative descriptions of riparian vegetation by Medina (see Chapter 6). This is not to say that cottonwoods (*Populus*), willows (*Salix*), and other obligate riparian woody species were absent from the basins. Pollen studies by Nations and others (1981) noted the presence of various genera from Miocene to Pleistocene. The most likely explanation for the general absence of gallery vegetation in the UVR prior to recorded history is severe paleoflooding and drought as evidenced by the paleoflood records and climate over the past 2,500 to 5,000 years (Smith and Stockton 1981; Ely and Baker 1985; Webb 1985; O'Connor and others 1986; Ely 1992, 1997; Ely and others 1993; O'Connor and others 1994; House and others 1995; Grissino-Mayer 1996).

In summary, major climatic changes are attributed to the last major glacial period (Anderson 1993). The paleoclimate before 8,000 B.P. was relatively cold and moderately wet with mixed conifer species dominant on present-day ponderosa pine areas. Climatic shifts also produced high variability in drought and flood frequencies and in magnitude. The period of early European occupation and settlement (1600s to 1900 A.D.) of the Southwest was marked with droughts and floods of high magnitudes. Essentially, conditions were harsh and chaotic. The largest recorded flood on the Verde River occurred in 1891 A.D., though many more paleofloods are apt to be discerned using modern technology (e.g., Lidar and HEC-RAS). Regionally, many rivers were subject to the same extremes, thereby setting the stage for a new climatically and hydrologically quasi-stable era where the growth of woody plants was favored across many rivers of the Southwest. Riparian vegetation as evidenced today was largely absent in the late 1800s and early 1900s on the UVR and attributable to large floods.

Figure 2.7—Photo looking south across the Perkinsville valley depicting the condition of the UVR circa 1920s. The river runs amidst a valley devoid woody plants and irrigated bottomland (ditches in foreground) where horses are seen grazing. Streamside vegetation was largely herbaceous and lacking woody plants. The floodplain morphology is a gentle "C" type channel with ample freeboard for flood waters to spread. A small grove of cottonwoods resided atop an older terrace. (Photo A courtesy of the Sharlot Hall Museum, Prescott, Arizona.)

Figure 2.8—This photo was taken from the Perkinsville Road looking east and shows the homestead on the south side of the river. A stand of young cottonwoods, likely less than 10 years old, can be seen growing along the irrigation ditch. These same cottonwoods are seen in figs. 2.36 to 2.42. (Photo A courtesy of the Sharlot Hall Museum, Prescott, Arizona.)

Human Influences

Paleo-Indians—The UVR watershed and riparian corridor have been influenced by man for centuries. Archeological studies (Pilles 1981; Elias 1997) suggest the Colorado plateau and the Verde River Valley were likely occupied by paleo-Indians since around 14,000 B.P. Archeological studies of the Perkinsville sites confirm the UVR was occupied by paleo-Indians from Pueblo I thru Pueblo IV periods (Fish 1967, Fish and Fish 1977). The influence of hunter-gather nomadic groups was likely small. On the other hand, paleo-Indians of the Pueblo periods inhabited the river valleys (e.g., Verde Valley and Perkinsville Valley), building abodes, harvesting fish and game, and farming using extensive irrigation canals (Kayser and Whiffen 1966; Minckley and Alger 1968). Gladwin and Gladwin (1930) suggested that various paleo-Indians from the south and east (Salado), north (Tusayan and Hopi), and west (Havasupai, Yavapai, and Hualapai) also visited and inhabited the UVR valleys, as evidenced by lithic materials. The valleys of the Lower Verde River experienced agriculture as early as 750 A.D. and probably remained until 1450 A.D. (Van West and Altschul 1997). Pierson (1957) concluded that the Hohokam settled the southern reaches of Verde Valley prior to 1100 A.D., but then the valley was resettled during the drought of 1276 to 1299 A.D. (fig. 2.2) by the Sinaguans, who built the elaborate structures known as Tuzigoot and Montezuma Castle (Wormington 1977). These settlers farmed the Middle Verde Valley using extensive irrigation canals. Likewise, the Perkinsville Valley was also farmed, and several irrigation canals have been discovered (Kayser and Whiffen 1966; Fish 1974). The Sinaguans abandoned the Verde Valley in the early 1400s for unknown reasons (Pierson 1957).

As Fewkes (1896, 1898) suggested, it is reasonable to expect that the valleys of the UVR were occupied and farmed by paleo-Indians. In 1896, Fewkes noted pueblo ruins in Sycamore Canyon, Perkinsville (Baker's Ranch House), Hell Canyon, Granite Creek confluence, and Del Rio Springs. Kayser and Whiffen (1966) confirmed farming and extensive irrigation canals in Perkinsville. Extensive pueblo ruins can be observed at Bear Siding, Duff Springs, Prospect Point area, Bull Basin, Verde River Ranch area, 638 Road areas, the Prescott National Forest wetland area, and the Arizona Game and Fish Department property. All of these areas have open valleys with moderate to extensive floodplain terraces that could have easily accommodated farming. In addition, Fewkes (1896, 1912) noted several defensive structures (i.e., forts) and many cave dwellings (fig. 2.9) throughout the UVR. Mearns (1890) noted locations of several habitations as far west as Sycamore Canyon and many throughout the Middle Verde River area, but he did

Figure 2.9—Cliff dwelling located about 61 m (200 ft) above the UVR overlooking the Duff Springs area to the east. (Photo by Alvin L. Medina.)

not visit the upper reaches. Hence, considerable evidence exists that the UVR was largely occupied by paleo-Indians. It is also reasonable to expect their agricultural activities would have affected riparian conditions, including the exploitation of fish and wildlife for domestic uses.

Europeans—The Spanish explorer Antonio de Espejo was the first European to visit the Camp Verde area of the Valley during an expedition in May 1583 (Hammond and Rey 1966; Mecham 1930). Espejo's visit was brief—he was in search of mineral wealth at the location where the mines were established near Jerome. In 1598 A.D., Don Juan de Oñate sent his lieutenant, Marcos Farfán de los Godos, to further investigate the ore mines at Jerome (Pierson 1957). Munson (1981) reported that "Oñate crossed the Verde River in 1604 en route to the Colorado." For about another 220 years, the Verde Valley remained unnoticed, except for the paleo-Indians of the area, until the arrival of French trappers to the Arizona Territory.

Historical accounts of European trappers in the Verde River are scant. Cleland (1963) noted that various trappers visited the Verde Valley, including Ewing Young, James Pattie, Pegleg Smith, George Yount, Milton Sublette, Kit Carson, Bill Williams, and Antoine Leroux. In 1826, Ewing Young was reported to have led a trapping expedition up the tributaries of the Salt River. Pattie encountered Young at the Salt River after coming down the Gila River and losing most of his party to Indian skirmishes. He joined Young on the Salt River while a separate party ascended the Verde River to its source (Pattie 1831; Cleland 1963; Hafen 1982, 1983). Three years later in 1829, Ewing Young and 40 men, including Kit Carson, ventured on another trapping expedition down the Salt River to the confluence with the Verde River, then up the Verde to the headwaters and onto the Colorado (Cleland 1963; Byrkit 1978). In 1854, Leroux is said to have discovered the paleo-Indian ruins of the Verde Valley in passing through the area but he made no mention of trapping (Fewkes 1898).

Considering the many miles of streams and rivers in Arizona that were supposedly traversed in search of beaver pelts, relatively small quantities of beaver pelts were reported in historical accounts (Hafen 1982, 1983; Despain 1997). Hamilton (1881) noted that beaver were found throughout the Sub-Mogollon region, including the Verde River and its tributaries. Coues (1867) reported that beaver were abundant in the Verde River, as well as in the many other waterways of Arizona. However, others (DeBuys 1985; Hoffmeister 1986) reported that streams were over-trapped from the headwaters to their confluences. Such exploitations led to trapping moratoriums in 1838 by Mexican authorities (DeBuys 1985) who detested trappers in Southwestern territories (Hafen 1983). Apparently, the Southwestern river otter (*Lontra canadensis sonora*) may have been similarly over-exploited (Huey 1956). The UVR, not unlike many other streams of the Southwest, was likely exploited for beaver from the mid-1820s through to settlement in mid-1860s (Pierson 1957). Leroux was part of other trapping expeditions in Arizona throughout the period from the mid-1820s through mid-1850s, when he visited Montezuma Castle. Likewise, Pauline Weaver, a noted mountain man, trapper, rancher, guide, prospector, and pioneer, was part of several expeditions in the Southwest (Pierson 1957). Weaver first visited the Verde Valley in 1829/1830 A.D. (Munson 1981), although others placed him in the Verde Valley in 1832 (Pierson 1957). He finally settled in the UVR valley, where he scouted at Fort Whipple in 1864. He was later assigned to Fort Lincoln where he died in 1867 (Despain 1997). Bill Williams was another trapper who lived in the area and was noted for his expeditions across the Southwest with other trappers (Favour 1962). Trapping by "foreigners" in Mexican Territory was eventually banned and limited to Mexican citizens. Thereafter, illegal trapping and defrauding was common by trappers who commonly had their pelts confiscated (Weber 1971). It's highly likely that beaver were trapped thereafter as part of settlement activities during the late 1800s (Pierson 1957) and early to mid-1900s, as trapping was a common secondary source of income. In short, trapping in the UVR appears to have been limited as reported, probably to the general absence of beaver. This is consistent with the general absence of woody vegetation noted in previous sections.

Sand and Gravel Mining—Undoubtedly, the period from the 1880s to the present marked a period on the Verde River where a variety of human influences consistent with settlement activities occurred. Extraction of river products, e.g., sand and gravel, for construction of towns and businesses was in place since the mining industry in Jerome began expansion in the late 1800s. Extensive gravel mining of Verde River reaches near Tapco, Cottonwood, and the Camp Verde area was reported as early as 1910 (Simons, Li, and Associates, Incorporated 1985). Similarly, sand and gravel mining occurred on private lands in Perkinsville from the 1960s to 1970s. Remnant piles of rock and boulders traceable to sand and gravel extraction still remain on the Y-D Ranch. By 1989, sand and gravel mining was curtailed under order from the Environmental Protection Agency for violations of the Clean Water Act (Arizona Floodplain Management Association 1989). These actions resulted in limiting sand and gravel extraction activities on the Verde River.

Diversions—The settlement period of the late 1800s to early 1900s also initiated new water diversions throughout the Verde Valley and Perkinsville (Turney 1901, 1929; Alam 1997; NRCD Verde 2000). These diversions were, and continue to be, used for agriculture (Owen-Joyce and Bell 1983). As noted before, these same areas were extensively farmed by paleo-Indians. Arizona Department of Water Resources (1994) estimated that about 90% of summer flow in the Middle Verde River between Clarkdale and Camp Verde was diverted at one time for agricultural use. Some of these diversions are still in place today. One of the most notable diversions was the Peck's Lake diversion in 1920, which created a barrier and tunnel to provide water from the Verde River to the estuary/marsh. The barrier of Peck's Lake diversion dam has functioned much like a fish barrier, limiting upstream movement of fish to the UVR study area for decades. Alam (1997) reported 11 other diversions in the Verde Valley. These diversions have been implicated as threats to native fish habitats and populations (Girmendonk and Young 1997; USDI Fish and Wildlife Service 2005, 2007a, 2009). However, no scientific evidence exists yet linking significant decreases in native fish or habitats to diversions or determing whether diversions affect stream flow or hydrologic conditions (Moyle and Israel 2005; Industrial Economics Incorporated 2006). Roy (1989) documented entrainment of fish in two irrigation ditches of the Verde Valley, noting that exotic species, i.e., red shiners (*Cyprinella lutrensis*), smallmouth bass (*Micropterus dolomieui*), and rainbow trout (*Oncorhynchus mykiss*), were the most abundant fish found in the diversions. However, Ziebell and Roy (1989) noted that some fish, like the roundtail chub (*Gila robusta*), rarely used irrigation diversions on the Verde River. Reliable estimates of entrainment losses are lacking, despite observations of entrainment. Studies of trout suggest entrainment rates are relatively small (0.4 to 3.3%) at the basin level and constitute a relatively small loss compared to the total annual mortality (Carlson and Rahel 2007). Nonetheless, some entrainment losses are apt to occur wherever irrigation diversions exist, but their extent is debatable.

Impoundments—The UVR ecosystem has been impacted by indirect and direct effects of impoundments. Two large reservoirs—Bartlett and Horseshoe—constructed in 1939 and 1949 (USDI Bureau of Reclamation 2009a, 2009b), respectively, have regulated flows and impeded aquatic wildlife (e.g., fish movements) from the Lower Verde River corridor to the UVR. In addition, these impoundments became regionally important for sport fishing, recreation, flood control, and water storage for agriculture and production of electricity for the Phoenix metropolitan areas (Arizona Department of Water Resources 2009). The impoundments have excluded fish movements across the Salt River and Gila River Basins.

On the UVR, King (2007b) reported that as early as 1884, a dam was built on Miller Creek to store water for the city of Prescott. Granite Dam was completed in 1899 on Granite Creek (King 2007b). Several other impoundments (e.g., Goldwater Lake, Lynx Lake, Watson Lake, and Willow Lake) were also constructed in headwater tributaries of the Prescott area. Other impoundments with 616,800 m^3 (500 ac-ft) capacity (e.g., Hell's Canyon Tank) are located on tributaries north of the Verde River. Arizona Department of Water Resources (2007) listed several registered impoundments, including six impoundments of greater than 20 ha (50 ac) in surface area. Another 27 impoundments have storage volumes of 18,500 m^3 (greater than 15 ac-ft). About 32 reservoirs have storage capacities rated between 2 and 20 ha (5 and 50 ac) of surface area, and another 2,328 stock ponds with up to 18,500 m^3 (15 ac-ft) capacity are scattered across the UVR landscape. It's reasonable to assume that these impoundments have altered flow and bedload contributions to the Verde River over their years of service. Sullivan Dam, constructed in 1939, has probably most directly affected the hydrology and overall ecology of the UVR. Originally intended as another regional recreational lake with inflows from the Del Rio Springs, it quickly filled up with alluvium within three to four years of construction and currently remains a largely seasonal water impoundment. Sullivan Dam cut off access to headwater flows, and blocked natural bedload movement to the UVR perennial flow riverine system. The effects of 70 years of bedload-sediment deprivation can be viewed in deeply incised channels and eroded terraces throughout the UVR corridor. The cumulative effects of the Sullivan Dam and other impoundments on the hydrology and native fishery have yet to be assessed, but there is considerable evidence that impoundment disturbances have altered the UVR ecosystem considerably. Other efforts to harness the tranquil baseflows near the headwaters are yet evident at the Verde River Ranch, where a dam was constructed across the river sometime in the 1960s, only to be washed away or demolished. Several authors have referred to the Verde River as "the last free-flowing river" in Arizona (Beyer 2006; Marder 2009). However, this limited definition applies only to the segment between the confluence of Granite Creek and Horseshoe Dam, an approximately 160-km (100-mi) segment of the river. The designation of "the last free-flowing river" applies only if the many smaller diversions noted above are discounted. Today, perennial flow starts at springs near the Granite Creek confluence, rather than from the historical Del Rio Springs a short distance upstream. In short, the Verde River is not free flowing but rather limited to only segments, owing to its variety of channel diversions and impoundments.

Ranching and Grazing—The first permanent settlers to the Verde Valley arrived in January 1865 (Pierson 1957; Munson 1981). This event marked the beginning of cattle ranching in the Verde Valley. Livestock were produced to meet local needs of Army personnel at Fort Lincoln (name changed in 1868 to Camp Verde and later in 1879 to Fort Verde) and the settlers. The valley floodplain and terraces were suited for agricultural production of foods and forage for settlers and Army personnel at Fort Whipple in Chino valley (Pierson 1957) despite very marshy conditions. Outbreaks of malaria were attributed to wet conditions, typical of wetland environments (Munson 1981).

Livestock grazing of the UVR area began after the establishment of Fort Whipple in 1864. Ludington (2002) provides a historical account of this period:

> "In 1864, President Abraham Lincoln sent an official party with military escort to establish the capital of the new Arizona Territory. Their first camp was at Del Rio Springs north of present site of the town of Chino Valley. A few months later the party moved to the forested area of present-day Prescott, where logs were readily available to build a fort, houses, and businesses. While at the original site, army doctor James Baker traded his horse and saddle to a squatter for his land claims along the Verde River. Baker and his partner James Campbell were soon running one of the largest cattle/horse operations in Arizona. They called it the Verde Ranch. The severe drought years of the 1890s, however, brought financial setbacks that forced the partners to sell."

Early attempts to establish cattle ranches in the Williamson Valley were made by Stevens in 1864 (40 head) and H.C. Hooker in 1868, but these efforts were unsuccessful owing to Indian conflicts (McClintock 1916). Sheep were introduced into the watershed in 1876 by John Clark on Bill Williams Mountain (McClintock 1916). Bronson (1978) provided cattle numbers for various ranches in the upper Chino Basin during the 1870s, further suggesting that large herds were being sent to Arizona. However, most of the livestock were used to meet local needs. The presence of Fort Whipple would have increased the chances of establishment, despite frequent raids by Native American tribes, but little evidence exists to infer that the range was heavily stocked at that time (Bronson 1978). Brown (2007a) reported from oral accounts that James Baker's 76 Ranch in Perkinsville was stocked with 10,000 head of cattle circa 1882, making the operation the largest cattle and horse operation in northern Arizona. This number of cattle was widely distributed in the watershed and not solely in Perkinsville, as range capacity was limited (see discussion below). However, troubled years lay ahead with prolonged droughts that saw many cattle perish, especially in 1891/1892, for lack of forage and water. Poor financial markets for livestock (1895), as well as personal problems left the 76 Ranch with relatively little stock, thereby forcing Baker to sell in 1898.

In 1900, Marion Perkins purchased the Verde Ranch from Baker and Campbell and arrived on the UVR at Perkinsville November 1, 1900, with his cattle herd (Ludington 2002). The expanse of the cattle operation was reported to extend from Granite Mountain to the west, to Ash Fork and Williams to the north, to Dugas to the east, and to Mayer to the south (Ludington 2002). This approximated about 91 km^2 (35 mi^2) of open rangeland, inclusive of summer and winter range. The number of livestock of this operation is unreported for this period, although numbers were probably relatively low owing to the scarcity of precipitation as well as the relative poor distribution of water throughout the area at the time.

Talbot (1919) noted that range examiners performed a range survey of the present-day Limestone and Del Rio Allotments on the UVR encompassing 34,978 ha (86,433 ac). These rangelands were part of the southern portion of what was then the Tusayan National Forest, which was established July 1, 1910. Encompassing just over 569,635 ha (1,407,600 ac), it was later transferred to the Prescott National Forest October 22, 1934 (Davis 1983). Approximately 16.4% (5,765 ha or 14,245 ac) were classified as forage acres, with an estimated carrying capacity for these lands based on year-long use of 3.2 ha cow^{-1} (8 ac cow^{-1}). Total annual carrying capacity for all Forest lands combined was estimated at about 12.6 ha (31.1 acres cow^{-1}). Non-forage acres were mixed pinyon-juniper woodland range with browse and annual forage. Cattle and sheep were grazed year-long on the UVR portion of the Prescott National Forest with an average stocking rate of 380 cattle and 1,730 sheep. These numbers were noted as being under the protective limits for the local District. Limiting factors to management included water, fencing, and range pests (e.g., prairie dogs). Most range improvements were constructed during the 1930s. Contrary to popular belief for the times, Talbot's (1919) assessment indicated that range conditions were relatively fair, despite the drought conditions and poor animal distribution. The examiners noted that trend conditions were declining, but estimates for stocking capacity suggested that range conditions were not "highly degraded or devastated," as is often advocated in some literature. Declining range conditions during this time (1900 to 1920) were exacerbated by severe droughts and floods, poor livestock management practices, and lack of range improvements. Cattle stocking was fueled by demands for meat products to meet the nation's World War I (1914 to 1918) needs, mining industry requirements throughout the West, and new human population center expansions.

Today, stocking of the same range that was examined by Talbot (1919) approximates a small fraction of the estimates of 1919. Miller (1921) attributed the conversion of 4,050 to 6,070 ha (10,000 to 15,000 ac) of tobosa grassland to Utah juniper (*Juniperus utahensis*) to sheep grazing. Miller (1921) further noted that the average age of 20% of Utah juniper stands was fewer than 35 years; the remaining 80% was 13 years or less. He also noted the same phenomena for one-seed juniper (*J. monosperma*), citing seed size and lessened herbivory.

Despite the lack of stocking data, the period of the late 1880s through the early 1940s was marked with severe droughts (Webb 1985; Ely 1992; Grissino-Mayer 1996) and very intense floods (Ely and others 1993; Ely 1997) that contributed to overuse of rangelands. These climatic events were coincident with the influx of cattle and sheep and establishment of the ranching industry in the region. Early range scientists recorded the general overgrazing that was obvious in the region (Griffiths 1901, 1904, 1910). These assessments brought about major changes in land management and the start of range research in the West. Also coincident with range overgrazing during the same period was the exploitation of neighboring forests and woodlands for development (King 2007a). Forest products were in demand for the mining industry, railroads, and settlements within the watershed. These activities undoubtedly worsened the deterioration of the rangelands, as noted by range examiners (Talbot 1919).

Indirectly, trends in range conditions could be partially explained by economic factors. During poor markets, livestock operators were more likely to retain annual crops, thereby placing additional stress on overstocked rangelands. Local livestock production during the period of 1890 to 1910 was initially determined by the ability to successfully stock the range and maintain numbers in the face of adversities (e.g., Native American skirmishes, livestock thefts and depredations, and droughts). Some stock was produced for local needs, such as military fort and mining camp meat supplies, but stock that was produced for regional and national markets became susceptible to national economic recessions. The link between stocking strategies, climatic conditions, and national markets remains today. Another factor that likely affected range trends between the turn of the century and circa 1950 was the national policy of Congress and land management agencies to encourage settlement and development of States with public land (Nielsen 1972). This policy made it more difficult for land managers to administer grazing lands in accordance with carrying capacity principles.

Grazing Litigation—Litigation over livestock grazing in riparian habitats and federally listed fish and wildlife species in Region 3 has played a major role in the management of the riparian habitats and listed fish species in the UVR. The results of litigation have great potential to affect ecosystems and their components long term. Although well intended and supposedly based on best science available, litigation may not always yield the best of intended results. Despite numerous appeals and lawsuits, native fish, such as the spikedace on the UVR, continue to disappear.

Livestock have grazed portions of the UVR since about the 1860s. Large numbers were introduced when cattle were imported from Texas to the Perkinsville area in 1895. Large-scale reductions in cattle numbers using the river occurred in the early 1900s (see previous discussion on ranching and grazing), and was accompanied by long-term monitoring of the uplands. Yearlong grazing use of the river continued until the 1980s. At that time the Prescott National Forest changed grazing use to seasonal or rotational, releasing yearlong grazing pressure on riparian plant communities in the river corridor. With the wholesale reduction in cattle numbers in the early 1900s, cattle numbers have declined considerably to the present (Rinne and Medina 2000).

In 1993, the Horseshoe Allotment (Y-D Ranch) voluntarily removed cattle from the river after a cooperative effort with Prescott National Forest to improve riparian conditions from the historic 1993 winter flood. Prescott National Forest surveys suggested that riparian conditions would likely improve within five years and the area could be restocked. Grazing on the Horseshoe Allotment had also been under contention by Forest Guardians for years prior to the voluntary temporary removal. Although National Environmental Policy Act (NEPA) analyses has since been completed for grazing on the allotment, grazing on the river was not considered at that time, and is not precluded pending approval of the NEPA analysis. In continuing efforts (1993 to 2010) to get research performed on grazing- fish relationships, Y-D Ranch and Verde River Ranch invited RMRS and Prescott National Forest to engaged in a collaborative group (UVR Adaptive Management Partnership [UVRAMP]), which became the conduit for communication and development of research plans. The hope was to provide management science-based guidelines for grazing the UVR. However, appeals to grazing riparian areas were impending and discouraged plan implementation.

In 1997, Forest Guardians (Forest Guardians v. U.S. Forest Service 1997) and the Center for Biological Diversity (Southwest Center for Biological Diversity v. U.S. Forest Service 1997) filed complaints against the U.S. Forest Service, Region 3, seeking an injunction and cessation of grazing on multiple allotments in Region 3, including four of the seven grazing allotments, Antelope Hills, Perkinsville, China Dam, and Sand Flat, in the UVR. Three grazing allotments, Horseshoe, West Bear-Del Rio, and Muldoon were not included in the litigation because the permittees had previously agreed with the Prescott National Forest to remove livestock from the river. Forest Guardians and the Center alleged failure by the U.S. Forest Service to comply with the Endangered Species Act (ESA) by failing to have completed ESA Sec. 7 consultation for livestock grazing effects on watersheds and riparian habitat affecting four listed species, loachminnow, spikedace, spotted owl, and southwestern willow flycatcher. These lawsuits placed livestock grazing of riparian areas in Region 3 at risk. Subsequently, the Arizona Cattle Growers Association (ACGA) and the New Mexico Cattle Growers Association (NMCGA) joined the lawsuit as interveners (CV-97-2562 PHX-SMM, CV-97-0666-TUC-IMR).

On April 16, 1998, Region 3 entered into a stipulated agreement with Forest Guardians and the Center (Southwest Center for Biological Diversity v. U.S. Forest Service, Forest Guardians v. U.S. Forest Service, ACGA, and NMCGA interveners 1998). The agreement required the U.S. Forest Service to exclude livestock from at least 99 percent of occupied, suitable but unoccupied, and potential habitat of the species identified in the Motion for Preliminary Injunction, "so long as the U.S. Forest Service complies with the terms of this stipulation for the duration of the ongoing grazing consultation." The ongoing grazing consultation was completed on February 2, 1999. The consultation period essentially avoided a region-wide injunction over livestock grazing and gave the U.S. Forest Service time to come into compliance with the requirements of the ESA Section 7. At the time of the stipulated agreement, the West Bear-Del Rio allotment was the only allotment of the seven that had completed a NEPA assessment and Sec. 7 ESA consultation. Since then the remaining six allotments have completed NEPA assessments and ESA Sec. 7 consultation. However, none of the assessments included grazing of the river, thus effectively limiting livestock grazing, but not precluding if supported by future NEPA analyses.

The USDI Fish and Wildlife Service proposed designation of critical habitat for the spikedace several times (Federal Register 2000, 2010). The first proposal was on March 8, 1994 (Federal Register 1994) which was set aside by court order for failure by USDI Fish and Wildlife Service to analyze the effects of critical habitat designation under NEPA (Catron County Board of Commissioners, New Mexico v. USDI Fish and Wildlife Service, CIV No. 93-730 HB DNM 1994). On September 20, 1999 the Southwest Center for Biological Diversity filed suit against the USDI Fish and Wildlife Service for failure to propose a rule (Southwest Center for Biological Diversity v. Clark, CIV 98-0769) and the court ordered USDI Fish and Wildlife Service to finalize designation of critical habitat. The proposed rule was promulgated December 10, 1999, and a final rule was submitted April 25, 2000 (Federal Register 2000). It was subsequently challenged in court (NMCGA and Coalition of Arizona/New Mexico Counties for Stable Economic Growth v. United States Fish and Wildlife Service, CIV 02-0199 JB/LCS–D.N.M.) because the USDI Fish and Wildlife Service used a method for economic analysis deemed invalid by the U.S. Tenth Circuit Court. The proposed rule was rescinded on August 31, 2004. The USDI Fish and Wildlife Service re-proposed rules December 20, 2005 (Federal Register 2005), again in 2006 (Federal Register 2006), and a Final rule in 2007 (Federal Register 2007). The 2007 final rule was challenged on the basis that USDI Fish and Wildlife Service designated critical habitat without adequate delineation or justification (Coalition of Arizona/New Mexico Counties for Stable Economic Growth, and others v. Salazar and others–D.N.M.). The proposal was voluntary remanded on May 4, 2009. Each proposal from 2000 to 2007 met and failed legal challenges, mostly on economic and science based issues. For example, the 2007 proposal excluded segments of the Verde River below the UVR study area "due to potential economic impacts," still noting grazing as a threat but recognized nonnative fish as a threat for the first time (Federal Register 2007).

The 2010 proposed rule (Federal Register 2010) takes into consideration new information on distribution, e.g., Mangas Creek in southern New Mexico, and addressed flaws in previous proposals. However, livestock grazing is still cited as a major threat (Federal Register 2010, p-66489) because of adverse effects that may occur from watershed alteration and "subsequent changes in the natural flow regime, sediment production, and stream channel morphology." This Report presents alternative views of watershed responses to other factors other than grazing, and that have similar consequences as those noted in the 2010 proposal.

Despite various litigation efforts on the UVR to protect listed fish, native fish populations continue to decline. Spikedace have not been found for over 10 years (see Chapter 9). Other minnows that were once common, such as speckled dace and longfin dace, also have become infrequent in fish surveys (see Chapter 9). Depressed populations of the latter are attributed to direct effects of nonnative fish (Desert Fishes Team 2004, 2006). The future of native fishes in the UVR and the Southwest has been well expounded by many fishery experts (Rinne and Minckley 1991; Rinne 1991a, 1999a, 2001a; Olden and Poff 2005; Rinne and others 2005a), all of which note that native fish populations are down trending despite various legal and resource protection measures, and pleas for exclusion of livestock grazing of riparian areas (Desert Fishes Team 2004). On the UVR, the threat of litigation looms even across research efforts to understand fish-grazing-riparian relationships. To date, there have been no studies that addressed direct effects of livestock grazing on native fishes despite the continued urgency to resolve the controversies. However, many have recognized that nonnative fish in the UVR are the principal cause of depressed native fish populations (see Chapter 9; Desert Fishes Team 2004, 2006). In addition, litigation may force managers to employ conservative protection measures, such as livestock exclusion, that could cause unforeseen changes to the aquatic and riparian habitats over time and ultimately further limit opportunities to manage the UVR habitats for listed species.

Railroads—In 1912, the Santa Fe Railroad brought a spur line through the Perkins family ranch, creating Perkinsville Station and a siding for loading cattle (fig. 2.7). The United Verde and Pacific Railway originated in 1894 when United Verde Copper Company owner, Senator William A. Clark, constructed a narrow-gauge railroad from Jerome to Jerome Junction, which became Chino Valley in 1920 when the railroad ended service (McClintock 1916). The spur line was later decommissioned and became a roadway from Jerome to Perkinsville and Chino Valley. Much wood product was reportedly harvested from the vicinity of the spur to meet mining and community needs.

Mining and Power Development—The first mining camps in the Verde Valley were established in 1876 and were greatly facilitated by the introduction of railroads into the territory in 1882. Railroads were used to import coal to the region from New Mexico, providing coke to the mines and exporting ore (Munson 1981). The United Verde Copper Company was founded in 1883 (Munson 1981) and so began the industrialization of the area. A smelter was built in Jerome to process ore, thus marking another landmark of what was to be a significant change to the local environment of the Valley. Another narrow gauge railroad between Ash Fork and Prescott, known as "United Verde and Pacific Railroad" was constructed in 1894. By 1900 Jerome had become the fifth largest city in Arizona (Munson 1981).

The mining boom during the early 1900s created additional needs for electricity to power equipment and the new settlements. Originally, an oil fired plant provided power to the mines; but by June 18, 1909, electricity that was generated at the Fossil Creek Power Plant was being used to power mining operations at the United Verde Mine in Clarkdale (Munson 1981). By 1917, the need for an additional smelter warranted construction of another steam powered plant, built on a terrace of the Verde River upstream from Clarkdale, to provide power to other mining customers (Munson 1981). The power plants supplied electricity to the surrounding towns of Prescott, Mayer, Poland Junction, and Crown King, and they met 70% of the Phoenix power needs (Munderloh 2007). Brown (2007b) reported that smoke from the smelters in Clarkdale clouded the Camp Verde Valley, resulting in a decline of range plants. As early as the 1920s and 1930s, Verde Valley farmers organized to protest, document, and seek compensation from the effects of smelter emissions on crops (Verde Valley Protective Association, no date). The sulfur dioxide rained on the valley for several years until the smelters shut down in the 1950s (Byrkit 2001). Smelter slag deposited on an 18-ha (45-ac) site amounted to 18.1 million Mg (20 million tons) from the years 1912 to 1950. The slag still resides adjacent to the Verde River, although efforts are underway to reclaim precious metals from the slag material (Searchlight Minerals Corp. 2008). The off-site atmospheric deposition of heavy metals and metallic oxides on watershed rangelands is another unknown variable that complicates our understanding of present-day environmental conditions for plants and animals. Byrkit (2001) noted that by 1910, Woodchute Mountain had been denuded by woodcutting and the effects of acidic sulfurous smelter smoke.

Fish Species History

Native Species Decline—The Verde River historically was home to many native fish species. Minckley and Alger (1968) identified paleo remains of five species of fishes on an archeological site in Perkinsville: *Pantosteus clarki* (Gila sucker), *Castostomus insignis* (Sonora sucker), *Gila robusta robusta* (roundtail chub), *Xyrauchen texanus* (humpback sucker), and *Ptychocheilus lucius* (squawfish). Some of these fish are present still, although in low numbers, while others were extirpated and some were repatriated (see table 2.1). Spikedace have not been confirmed on the Verde since 1997 (Rinne 1999a; see also Chapter 9). A single spikedace was reported in a 1999 fish survey but was unconfirmed and questionable. As of 2009/2010, no fish surveys have found spikedace, yet the species status is reported as extant (Robinson and Crowder 2009; Chmiel 2010a, 2010b, 2010c).

The native fish fauna (table 2.1) of the entire Verde River markedly changed with the introduction of 22 species of sport and forage fishes (Rinne 2005; Pringle 2009; see also Chapter 9). Stocking of Arizona's waterways began as early as 1880/1881 with the passage of an Act by the Arizona Legislature "for stocking the rivers and lakes of the Territory with carp and other varieties suited to the climate" (Hamilton 1881). The earliest recorded stocking of nonnative fish in the Verde River system occurred in 1938 (Pringle 2009). Upon the completion of Sullivan Dam at the headwaters, 10,000 blue gill (*Lepomis macrochirus*) were stocked in 1938 (Arizona Game and Fish Department 1938). An additional 2,500 bass (*Micropterus dolomieui* and *Micropterus salmoides*), 4,000 blue gill, and 15,500 channel catfish (*Ictalurus punctatus*) were stocked above Clarkdale and Peck's Lake. Rinne and others (1998) reported that more than a dozen nonnative species and more than 15 million individuals were stocked in virtually every tributary, stock tank, reservoir, and water body capable of sustaining fish on both public and non-public lands. From 1920 to 1995, nearly 560,000 nonnative fish comprising 14 species were planted in stock tanks within the Verde watershed (Pringle 2009). Sponholtz and others (1997) speculated that stock tanks might also contribute to introductions of nonnative fish during high rainfall events that cause overflow into the Verde River. Rinne (2005) further noted that by 1950, five records of nonnative fishes were noted for Oak Creek and Wet Beaver Creek (tributaries of the Middle Verde). By 1964, records doubled with 6 of 11 records from the main stem Verde and the number increased four-fold from 1965 to 1979. Since the 1970s, more intensive surveys revealed that the UVR was exceptional in retaining proportional abundance of native fishes compared with the Middle and Lower Verde River. The UVR harbored about a 4:1 ratio native to nonnative, while the lower reaches ranged from about 1:3 to 1:9 ratios (Rinne 2005; see also Chapter 9). Stocking of rainbow trout (*Oncorhynchus mykiss*) is a continued practice today in the middle Verde Valley in response to angler pressure (Pringle 1996). The Peck's Lake diversion barrier is an apparently effective obstruction to the upstream movement of trout, as trout were not found in the upper reaches.

Interest in the status of native fishes of the UVR did not peak until the early 1990s concomitant with regional implications of effects of livestock grazing and regional trends in native fish populations (Rinne 1999b, 2000, 2005). Land managers sought information about management of riparian areas and native fishes, while others (USDI Fish and Wildlife Service 1999) sought protection status citing grazing, introduced fishes, and water diversions. Long-term studies were

Table 2.1—List of native and introduced aquatic fauna on the Verde River over the last 75 years. Species identified with "*" are reintroduced and experimental. Spikedace were last evidenced in 1997 by Rinne (1999a). Speckled dace have become uncommon in recent years (Rinne and Miller 2006). Roundtail chub were proposed for review in 2009 (USDI Fish and Wildlife Service 2009). (Adapted from Rinne 2005.)

Status	Common name	Scientific name
Extirpated	Gila trout	*Oncorhynchus gilae*
Extirpated	Colorado Pikeminnow	*Ptychocheilus lucius**
Extirpated	Razorback sucker	*Xyrauchen texanus**
Extirpated	Flannelmouth sucker	*Catostomus latipinnis*
Extirpated	Loach minnow	*Rhinichtyhs cobitis*
Extirpated	Gila chub	*Gila intermedia*
Unknown	Spikedace	*Meda fulgida*
Present	Desert sucker	*Catostomus clarki*
Present	Sonora sucker	*Catostomus insignis*
Present	Roundtail chub	*Gila robusta*
Present	Speckled dace	*Rhinichthys osculus*
Present	Longfin dace	*Agosia chrysogaster*
Introduced	Rainbow trout	*Oncorhynchus mykiss*
Introduced	Brown trout	*Salmo trutta*
Introduced	Brook trout	*Salvelinus fontinalis*
Introduced	Goldfish	*Carassius auratus*
Introduced	Common carp	*Cyprinus carpio*
Introduced	Threadfin shad	*Dorosoma petenense*
Introduced	Fathead minnow	*Pimephales promelas*
Introduced	Red shiner	*Cyprinella lutrensis*
Introduced	Golden shiner	*Notemigonus crysoleucas*
Introduced	Tilapia	*Oreochromis mossambicus*
Introduced	Northern pike	*Esox lucius*
Introduced	Smallmouth bass	*Micropterus dolomieni*
Introduced	Striped bass	*Morone saxatilis*
Introduced	White crappie	*Pomoxis annularis*
Introduced	Black crappie	*Pomaxis nigromaculatus*
Introduced	Green sunfish	*Chaenobryttus cyanellus*
Introduced	Bluegill sunfish	*Lepomis macrachirus*
Introduced	Mosquitofish	*Gambusia affinis*
Introduced	Channel catfish	*Ictalurus punctatus*
Introduced	Flathead catfish	*Pilodictus olivaris*
Introduced	Yellow bullhead	*Ameiurus natalis*
Other introduced fauna	Otter	*Lontra canadensis*
Other introduced fauna	Bull frog	*Rana catesbeiana*
Other introduced fauna	Crayfish	*Procambarus clarkii*
Other introduced fauna	Asiatic clam	*Corbicula fluminea*

initiated by Rinne (2001a) and the Arizona Game and Fish Department (2000, 2002). Since 1994, fish surveys have been conducted on an annual basis jointly by the Prescott National Forest and RMRS, as well as Arizona Game and Fish Department. Specific surveys to locate spikedace were jointly performed in 2005 by USDI Fish and Wildlife Service, Arizona Game and Fish Department, and U.S. Forest Service (USDI Fish and Wildlife Service 2005), with no positive results of the presence of spikedace. Similar studies were performed in New Mexico, where spikedace were noted to decline over 18 years in the absence of livestock grazing on the Gila National Forest and Wilderness Area (Paroz and others 2006, Paroz and Probst 2007). These contradictive studies have not abated the controversy over grazing and native fishes.

The cumulative effects of nonnative fishes on native fish and ecosystem processes of the UVR are highly significant. Rinne (1999b, 2005; see also Chapter 9) documented the gradual disappearance of spikedace and present rarity (see Chapter 9) of native fishes on the UVR. A principal hypothesis that has been promoted universally in the Southwest is that livestock grazing is a major causative factor in the demise of native fishes and all fishes in general. However, Rinne (2005) and Rinne and Miller (2006) found no evidence to justify the hypothesis for the Verde River. Others have similarly tried to link grazing effects to native fish sustainability in Arizona and have obtained conflicting results (Robinson and others 2004). Rinne (1999b) examined the grazing-fish controversy and found little evidence in support of the hypothesis, noting that over 80% of the literature was not peer reviewed and the rest of the studies were fraught with design issues. The overwhelming evidence of 15 years of study on the UVR strongly suggests that other factors, such as predation by nonnative fish and other aquatic invasive species (e.g., bullfrogs and crayfish) and hydrogeomorphic changes in habitat conditions are operative in the decline (see Chapter 9). In addition, Rinne and Miller (2006) suggested that factors related to changes in hydrology and geomorphology in the UVR could be principal factors that caused habitat changes favoring nonnative fishes, thereby placing additional survival stress on native fish populations. Propst and others (2008) later identified similar factors for the Gila River watershed. Schade and Bonar (2004, 2005) noted that nonnative fishes have profound effects on native fish populations in the Southwest and note largemouth bass as the principal predator on the Verde River (Bonar and others 2004). Efforts to mechanically reduce populations of nonnative fishes have shown positive results (Rinne 2001b; see Chapter 9). However several other factors have to be addressed before any success can be declared (Rinne 2003a, 2003b; see also Chapter 9).

Repatriation of Native Fish—Various efforts to repatriate native fishes in Arizona have yielded poor results (Desert Fishes Team 2004) and have largely been a learning process, especially with razorback sucker and pikeminnow. Hendrickson (1993) reported that approximately 12 million fingerling razorback suckers (*Xyrauchen texanus*) were stocked into the Verde River between 1981 and 1991 with little or no success. Losses were assumed to be due to predation by nonnative fishes. Since 1991, 22,869 razorback suckers have been released into the Verde River by the USDI Fish and Wildlife Service (Hyatt 2004). In 1992, 11,231 Colorado pikeminnow (*Ptychcheilus lucius*) stocking-fry and fingerlings were stocked (table 2.2) in the UVR and Lower Verde River (Hendrickson 1993; Hyatt 2004). Hendrickson (1993) noted that after several years of failure to detect recruitment, stocking sites were relocated to sections of the UVR, including Perkinsville. These attempts were made to reduce predation on stocked fishes. Subsequent surveys failed to locate the stocked fish, which had likely moved or were transported downstream, where predation may have again become a factor

Table 2.2—Razorback sucker (XYTE: *Xyrauchen texanus*) and pikeminnow (PTLU: *Ptychocheilus lucius*) stocking from 1991 to 2003 by the USDI Fish and Wildlife Service on the Verde River. (Adapted from Hyatt 2004.)

Year	Species	Location	Number stocked	Mean total length mm
1991	XYTE	Upper Verde River	128	356
1992	PTLU, XYTE	Upper Verde River	222	330-406
1993	XYTE	Upper & Lower Verde River	1120	76-356
1994	XYTE	Lower Verde River	2204	324-386
1995	PTLU, XYTE	Lower Verde River	5837	305-432
1996	PTLU, XYTE	Lower Verde River	5961	254-362
1997	PTLU, XYTE	Lower Verde River	3818	287-477
1998	PTLU, XYTE	Lower Verde River	4036	305-330
1999	PTLU, XYTE	Lower Verde River	2364	381-406
2000	XYTE	Lower Verde River	2131	305-580
2001	XYTE	Lower Verde River	1574	300-440
2002	PTLU, XYTE	Lower Verde River	2248	300-350
2003	PTLU, XYTE	Lower Verde River	2427	330-400

(Jahrke and Clark 1999). Eventually, larger fish (12+ in) were stocked to overcome predation factors, but mostly in the Lower Verde River (table 2.2; Hyatt 2004).

Hyatt (2004) noted key observations about restocking razorbacks and pikeminnow:

- Since 1991, larger fish produced better results with recaptures, but introduction has been limited to 87 Colorado pikeminnow and 283 razorback suckers in the UVR.
- Recaptures were found near their original stocking areas on the Salt River, suggesting a high site fidelity relative to site introduction, but only one PIT-tagged razorback has been recaptured on the middle Verde River near Childs.
- Adult survival is at the low end and of short duration, with no recruitment.
- Continued failures to repatriate native fishes in the Verde River prevail owing to inadequate identification of causal factors such as predation (Marsh and Brooks 1989; Mueller 2003).

Rinne (Chapter 9) pioneered efforts to physically remove nonnative fish in the UVR. Physical removal may be the only reasonable choice to repatriate native fishes, as chemical treatments are currently controversial owing to their cumulative effects on aquatic organisms (Hubbs 1963; Minckley and Mihalick 1981; Magnum and Madrigal 1999; Dinger and Marks 2007; Hamilton and others 2009; Vinson and others 2010), human health risks (Tanner and others 2011), and general lack of success (Dawson and Kolar 2003). Successful reintroduction of native fishes is dependent on many factors that could have contributed to their current status. Mueller (2003) acknowledged that more than three decades of stocking endangered fishes in the Verde River has shown that unless limiting factors are accurately identified and adequately addressed, recruitment failure will continue to occur. Efforts are underway to repatriate native minnows, e.g., spikedace and loach minnow, on a segment of the UVR (USDI Bureau of Reclamation 2010). Dawson and Kolar (2003) assessed the utility of using chemical control in Arizona streams and concluded "chemical reclamations have not always been successful as indicated by reviews of hundreds of fish control projects with reported successes ranking from 43% to 82%." Dawson and Kolar (2003) further noted that the present arsenal of pisicides is not likely to be effective for controlling nonnative fishes in the southwestern United States, and that reclamation of habitats is required. This may be another controversial point since aquatic and riparian habitats have changed considerably in the last century in the UVR.

Exotic Aquatic Species—In addition to nonnative fish, other exotic aquatic fauna were also introduced by the State of Arizona (Arizona Game and Fish Department 2006), including crayfish (1940s) (*Orconectes virilis*, *Procambarus clarkii*), bullfrogs (*Rana catesbeiana*), otter (*Lutra canadensis lataxina*) (1981 to 1983), and Asiatic clam (*Corbicula fluminea*). The first three have turned out to be significant predators of native fish. Crayfish and bullfrogs were likely introduced as bait, sport, and food (Arizona Invasive Species Advisory Council 2008). Asiatic clams are filter feeders and generally abundant, but their role in the aquatic ecology of native fishes is unknown. Because of their relative abundance, they can affect stream nutrient dynamics through their effects on organic matter processing in streambed sediments (Hakenkamp and Palmer 1999) and consumption of phytoplankton (Phelps 1994). The clams are also known as bio-indicators of organic pollutants because they siphon large volumes of water on a daily basis, thereby concentrating dissolved or suspended contaminant that may be present in low concentrations in the water column (Doherty 1990).

Crayfish are omnivores (Dean 1969), and recent studies demonstrated that they are opportunistic, eating both plants and animals, including young snakes (Fernandez and Rosen 1996), lily pads, iris, insects, snails, tadpoles, frogs, baby turtles, fish eggs small fish, and other crayfish. They also are able to successfully compete with native fishes for food and cover (Carpenter 2005; Arizona Game and Fish Department 2006; USDI Geological Survey 2006).

It is unknown when or how bullfrogs were introduced into the Verde River but it was most likely during the turn of the century as a food item or as bait. Nonetheless, bullfrogs are abundant in the Verde River and have been attributed as a principal predator of sensitive species in Arizona (Rorabaugh 2008), leopard frogs (Sredl and others 1997; USDI Fish and Wildlife Service 2007b), garter snakes, endangered fish eggs and larvae (Mueller and others 2006; Witte and others 2008), and endangered fishes such as Yaqui chub and Yaqui topminnow (Schwalbe and Rosen 1988). In a study of southeastern Arizona herpetofauna, Schwalbe and Rosen (1988) commented that bullfrogs "eat anything they can get into their mouth."

The Arizona river otter (*Lutra canadensis sonora*) type locality was from Montezuma Well (Rhoads 1898) and these otters are recognized as a distinct subspecies (Wilson and Reeder 2005; ITIS 2009). The Arizona otter were extirpated and replaced with a surrogate species—the North American river otter (*L. canadensis*) from Louisiana. The Arizona Game and Fish Department introduced the Louisiana otter into the UVR during 1981 to 1983 (Arizona Game and Fish Department 1995). An assessment in the past decade indicated that the otter are doing well (Raesly 2001). However, their food habits may stress the food web dynamics of the UVR, as they relate to native fish populations. Tesky (1993) reported collectively that their fish diets include "suckers (*Catostomus* spp.), redhorses (*Moxostoma* spp.), carp (*Cyprinus* spp.), chubs (*Semotilus* spp.), daces (*Phinichthys* spp.), shiners (*Notropis* spp.), squawfish (*Ptychocheilus* spp.), bullheads and catfish (*Ictalurus* spp.), sunfish (*Lepomis* spp.), darters (*Etheostoma* spp.), and perch (*Perca* spp.)." Crayfish are also a mainstay food item when in abundance (Toweill and Tabor 1982). In general, otter are known to prefer slow-moving nongame fish, but they will eat other mammals, amphibians, insects, birds, and plants (Melquist and Dronkert 1987; Tesky 1993). As such, they pose a potential threat to other sensitive wildlife, aside from native fish, of the UVR (Toweill 1974; Melquist and

Hornocker 1983). However, otters are opportunistic and, by shifting their diets relative to abundance and availability, they could prey upon undesirable nonnative aquatic species such as crayfish, bullfrogs, and nonnative fish (Melquist and Hornocker 1983).

Pictorial Guide

The following section provides a visual montage of the UVR as well as some insights to changes in the river over the past 100 years. Figure 2.10 shows the photo locations as well as other features like main springs and tributaries.

Headwaters

Perennial flow of the Verde River originated from the Del Rio Springs at one time and flowed north along Del Rio Creek (Krieger 1965). The springs are located about 1.6 km (1 mi) south of Sullivan Dam, near the town of Paulden, Arizona. Flow from the springs has varied for the period of record from about 3.42

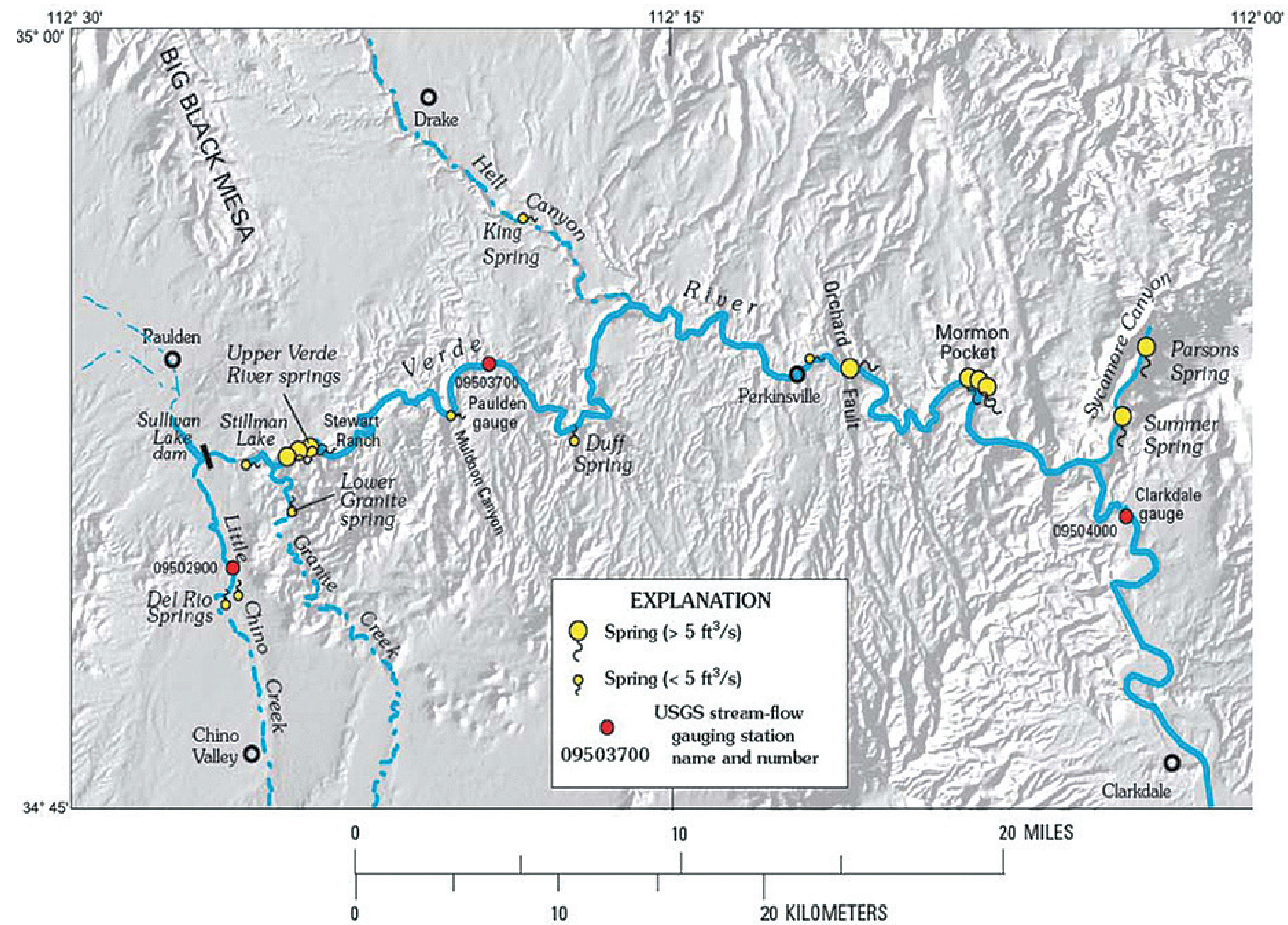


Figure 2.10—Location of known springs and photo points (numbers correspond to figure numbers; e.g., 6 = fig. 2.6 and 11 = fig. 2.11) along the UVR from Del Rio Springs and Granite Wash to Sullivan Lake to the Clarkdale gauge below Sycamore Creek (from Wirt and others 2005).

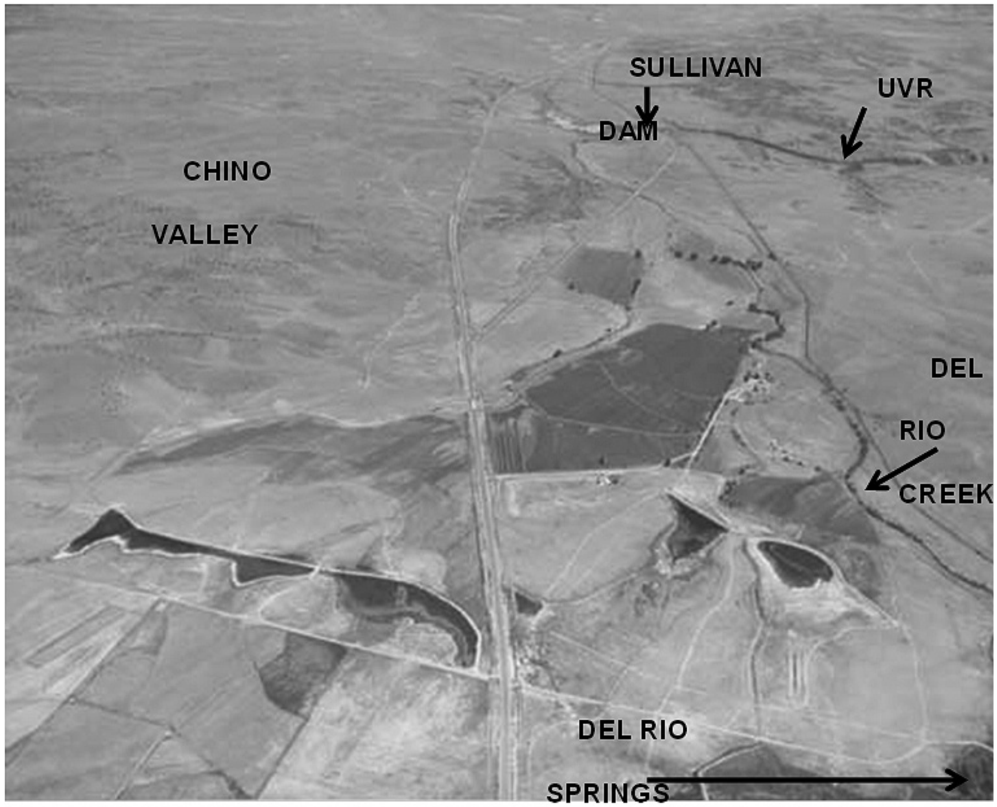
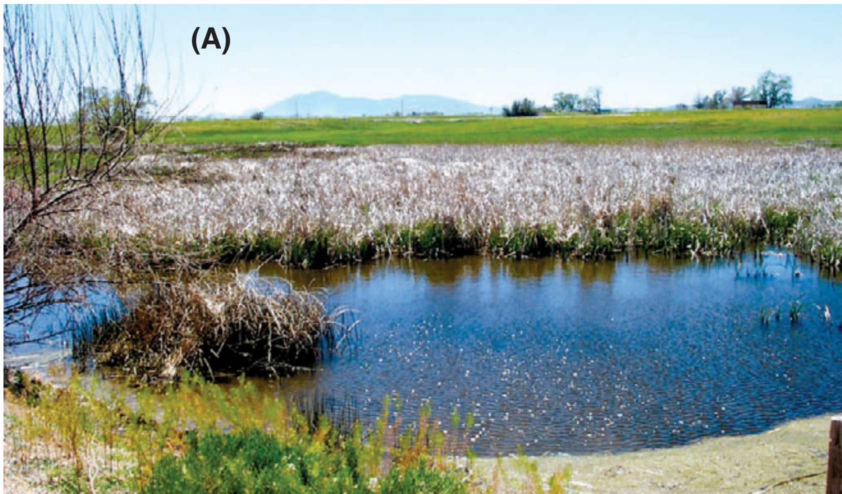


Figure 2.11—Aerial photo taken May 21, 1969, looking north from Del Rio Springs toward Sullivan Dam and the UVR (Sharlot Hall Museum call no. pb167f3i11).

x 10^6 m^3 (2,773 ac-ft) in 1939/1940 to 1.74 x 10^6 m^3 (1,410 ac-ft) in 1999 (Wirt and Hjalmarson 2000). Blasch and others (2006) reported that flow declined from the approximate 3.45 x 10^6 m^3 (2,800 ac-ft) in the early 1940s to near 1.23 x 10^6 m^3 (1,000 ac-ft) in 2003. The Del Rio Springs flow is artesian, seemingly a product of the greater artesian basin extending upstream for several miles (Remick 1983). Henson (1965) referred to this meadow-like drainage as "Cienega Creek." Remnant wetland species still remain in localized areas.

Figure 2.11 is an aerial photo from 1969 that shows the general appearance of the landscape looking north of Del Rio Springs. The cienega habitat surrounding the springs is evident in the lower right corner of the photo. A dark line formed by cottonwood trees on the right side of the photo running to the top third of the photo marks the location of Del Rio Creek. Sullivan Dam is visible as a white and dark patch in the uppermost area, and the Verde River is the dark line running to the east. A few young cottonwoods dot the area and are still present but in poor condition (fig. 2.12). Evidence of old cottonwoods is lacking for the area.

A primary source of seasonal overland flow to Sullivan Dam and the Verde River is from the Williamson Valley and the Big Chino Wash tributaries. These tributaries are located a few miles upstream to the west. The area is known for the large Big Chino aquifer that provides spring-fed sources to the Verde River (Wirt and Hjalmarson 2000; Blasch and others 2006). The valley is extensively farmed (fig. 2.13) with irrigation water originating subsurface from artesian water sources or pumped and distributed on the surface from shallow wells. Many locations retain a variety of sedges, rushes, and spikerushes.



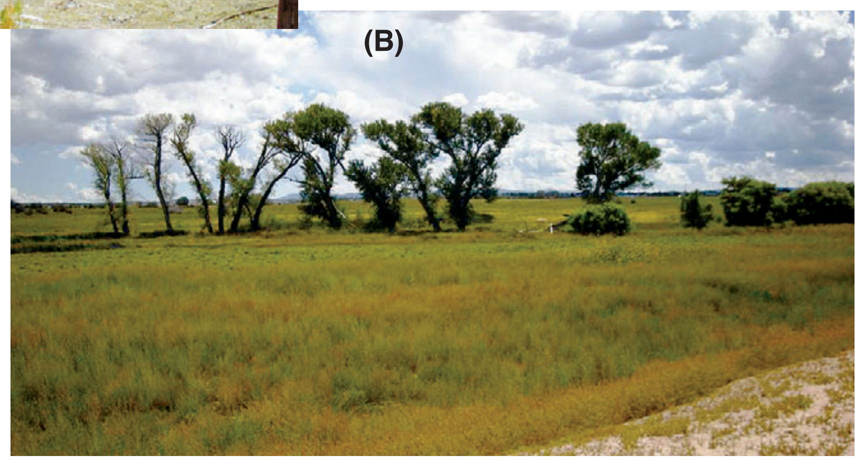


Figure 2.12—Ground view of Del Rio Springs showing riparian vegetation and the current condition of the cottonwoods seen in the aerial photo of fig. 2.10. The photos, taken on September 9, 2008, illustrate (A) the lack of woody plants around the wetland site of the springs, and (B) the condition of the cottonwoods. (Photos by Alvin L. Medina.)

Figure 2.13—Aerial views of the Williamson Valley to the west of Sullivan Dam showing the agricultural area (Upper photo courtesy of the USDI Geological Survey; bottom photo by Michael Collier.)

Sullivan Dam—The City of Prescott acquired the land for the development of Sullivan Lake from the Santa Fe Railroad in 1935. Shortly thereafter, construction of the dam ensued and was completed in 1939 (figs. 2.14, 2.15, and 2.16). By 1942, the lake had become significantly filled in with fine-textured alluvial sediments, and its capacity to store water was minimal. Sullivan Lake still served as a recreational area and was apparently stocked with fish as late as 1950s (Wagner 1954). Sullivan Lake was described by Wagner (1954) as "a shallow muddy water body that, from a fisheries point of view, could best be described as nondescript bullhead hole." With a maximum depth of 2.4 m (8 ft), the lake lacked any productivity for fish and was recommended to be managed for waterfowl (Wagner 1954). Woody vegetation was lacking about Del Rio Creek despite perennial flow as evidenced in fig. 2.15. The dam is presently private owned.

Flood flows in 1993 completely overtopped the Sullivan Dam and nearly filled the gorge downstream (fig. 2.17). The concrete seal around the wall and boulders from the wall was eroded by flood overwash from this event and several subsequent flood flows (fig. 2.18). Trees have sprouted within the exposed boulders of the wall, further compromising the structure. Future floods could breach Sullivan Dam and restore the natural stream gradient in the now intermittent portion of the UVR. This process would initiate downstream movement of sediments that have been trapped above the dam since 1939.

Figure 2.14—A 1936 photo showing the early construction phase of excavating basalt rock for the base of Sullivan Dam. Perennial flow from Del Rio Springs was routed through a sluice box visible on the right side of the rock cut. (Photo courtesy of the Sharlot Hall Museum, Prescott, Arizona.)

Figure 2.15—Photo from 1937 showing the building of the Sullivan Dam wall. Note the scarcity of woody plants and the additional seasonal flow—probably runoff from Big Chino Wash and baseflow from Del Rio Springs. (Photo courtesy of the Sharlot Hall Museum, Prescott, Arizona.)

Figure 2.16—A 1939 photo of Sullivan Dam taken shortly after the completion of the dam wall. (Photo courtesy of the Sharlot Hall Museum, Prescott, Arizona.)

Figure 2.17—Flood runoff from the February 1993 storms going over Sullivan Dam. The reddish, sediment-laden water is characteristic of the soils from the Big Chino Wash high in the watershed. (Photo by Alvin L. Medina.)

Figure 2.18—This 2011 photo illustrates the current condition of the Sullivan Dam wall and minimal water storage in the remnants of Sullivan Lake. (Photo by Alvin L. Medina.)

Granite Creek—A major tributary that affects the headwaters of the UVR is Granite Creek. The creek originates in the Bradshaw Mountains southwest of Prescott and flows north toward its confluence with the UVR east of Sullivan Lake. It is intermittent over much of its reach, and the braided channel system is the major source of bedload for the UVR headwaters during infrequent storm events (Wirt and Hjalmarson 2000; fig. 2.19). Sand and gravel mining occurs in several locations in the Granite Creek channel about 5 km (3 mi) downstream from the location shown in fig. 2.19 and within 3 km (2 mi) of Granite Creek's confluence with the UVR.

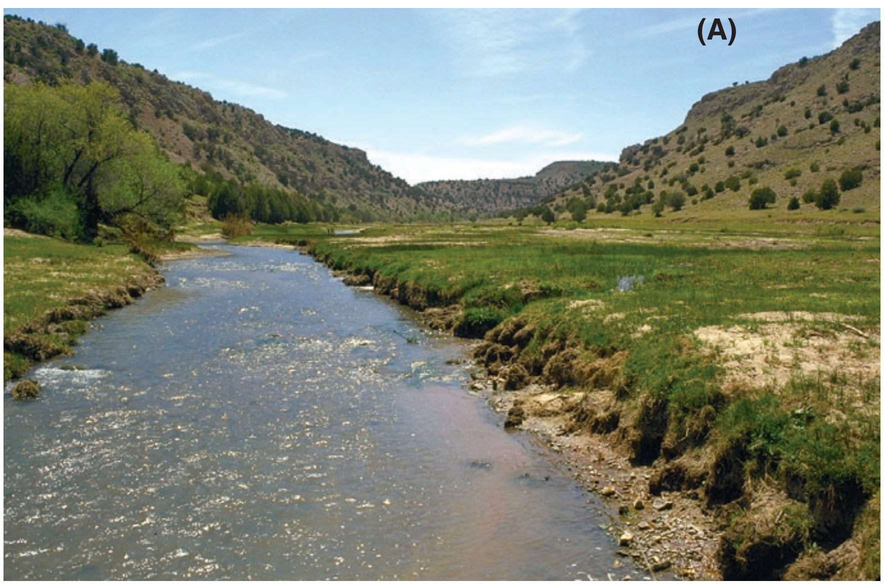
Figure 2.19—(A) aerial view of Granite Creek drainage in July 1997, looking north (downstream) towards the Verde River and (B) ground view of the confluence of Granite Creek (upper drainage) with the Verde River (flows right to left). The pool-like water feature in the lower right is referred to as Stillman Lake. The "lake" is formed by the sediment deposits at the confluence and the inflow from groundwater upstream. (Photos by Alvin L. Medina.)

Prescott National Forest Wetland—The boundary of the Prescott National Forest on the west is noted for the presence of a large historical wetland (fig. 2.5). The wetland was first confirmed in 1994 by the presence of hydric soil indicators (USDA Natural Resources Conservation Service 2006), and obligate wetland vegetation (i.e., sedges and rushes). The wetland was first photographed by Prescott National Forest staff in February 1979 (fig. 2.5A). The photo is notable because of the absence of woody plants along the channel. A photo from February 2001 (fig. 2.5B) shows the development of woody vegetation along the UVR due to stream incision that occurred during the 1993 flood. A June 1981 aerial photo (fig. 2.20) also shows the paucity of woody vegetation in contrast with the 2008 photo (fig. 2.21), which shows marked differences in woody plants and channel position.

In May 1979, Mr. James Cowlin provided ground views of the wetland (fig. 2.22A). The large tree on the upper left is a velvet ash with an understory of hackberry. Other important channel features in the 1979 photo are depth to water from the first terrace (right bank, 30 to 60 cm or 1 to 2 ft), channel width of about 3 m (9.8 ft), sand and gravel substrates, a gradient of <.01%, and pool-riffle sequences. A repeat photograph of same location in May of 2008 shows development of much different habitat conditions, with extensive growth of woody plants and cattails (fig. 2.22B). These vegetation changes have encouraged beaver to build dams on the floodplain (fig. 2.23) that have induced hydrologic and vegetation changes and created much different wetland habitats.

Figure 2.20—1981 aerial photo of the Prescott National Forest wetland showing locations of aquatic sites as dark blotches. The view is northerly with flow from bottom left to upper right. (Photo courtesy of the U.S. Geological Survey, Photo #503-30 6-6-1981.)

Figure 2.21—2008 aerial photo of the Prescott National Forest wetland contrasting woody vegetation and channel position changes since 1981 (Google, October 2008).



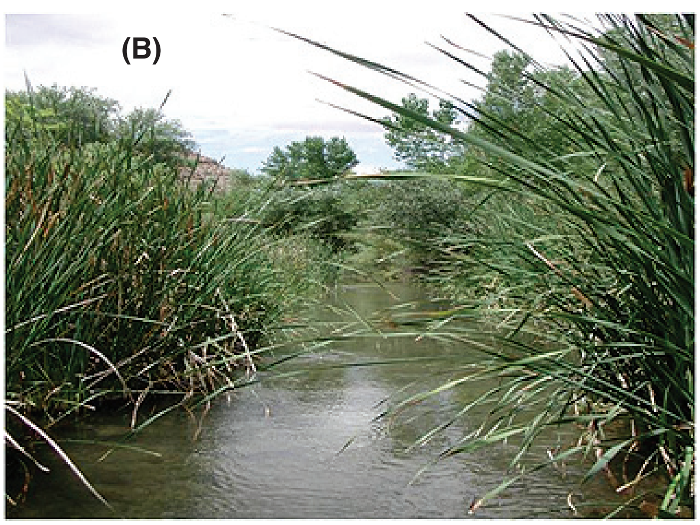


Figure 2.22—A May 1979 photo (A) showing the upstream view of the UVR wetland. (Photo by James Cowlin.) A May 2008 repeat photo (B) near the location of the 1979 photo showing occupation of mixed stands of the first terrace by cattails, cottonwoods, and willows. (Photo by Alvin L. Medina.)

Figure 2.23—Lodge in a pool formed by beaver dam construction along the UVR near the Prescott National Forest wetland. (Photo by Daniel G. Neary.)

Channel Incisions—Concomitant with these changes are evidences of erosion of paleo and historical terraces as well as the modern floodplain (figs. 2.24 and 2.25). Eroded sediments wash downstream, spiraling through the aquatic system, causing a gray-green color of the water and impairing water quality for turbidity. This process is common throughout the length of the UVR.

Terraces located above the wetland provide dramatic documentation of channel downcutting. The terrace in fig. 2.24 is about 5 m (16.4 ft) in height from the terrace level to the channel bottom. It is one of the paleoterraces documented by Cook and others (2010a, 2010b, 2010c) that date from A.D. 440 to 1650 and are composed of fairly uniform fine sediments (fine sands and silts). These terraces are major point sources of fine sediment for the UVR. Sediments are dropped into the river periodically during baseflows by bank sloughing (see fig. 2.24 center and fig. 2.25 lower left). During high flow events, large pieces of the terrace are frequently eroded. Most first terraces along the UVR are much lower in height (figs. 2.22 and 2.26). These terraces still contribute to the load of fine sediment in the UVR by bank collapse, but they do not match the magnitude of inputs from the large paleoterraces. Likewise, many small tributaries also contribute large amounts of bedload and fine sediments as they continue to headcut upstream as part of the adjustment to incision of the river (fig. 2.26).

Field documentation dates nearly all of the terrace erosions to 1993. The 1993 floods initiated the erosion of several paleoterraces throughout the length of the UVR. These terraces are a principal source of continued fine-grained sediment inputs and stream turbidity. The 1993 flood also caused the main channel to drop, thereby setting in motion the degradation of tributaries. An assessment conducted by Prescott National Forest and RMRS staff of post-flood conditions in spring and summer of 1993 identified countless tributaries in a "hanging" condition. Since 1993, these tributaries continue to adjust to the grade of the main stem by sloughing fine sediments. Grade adjustments up the UVR channel system are not yet complete on many tributaries and draws (fig. 2.25). Channel incisions of tributaries are another principal source of fine sediments to the UVR, and are commonly attributed erroneously to other land uses, e.g., grazing.

Figure 2.24—Photos A and B show typical paleoterraces located slightly upstream of the Prescott National Forest wetland. Rapid terrace erosion was initiated in 1993 and is now a major source of fine sediment. B is located downstream of the paleoterrace in A, showing active erosion of the terrace and the presence of tamarisk, Gooding willow, and assorted herbaceous weeds. (Photo by Alvin L. Medina.)

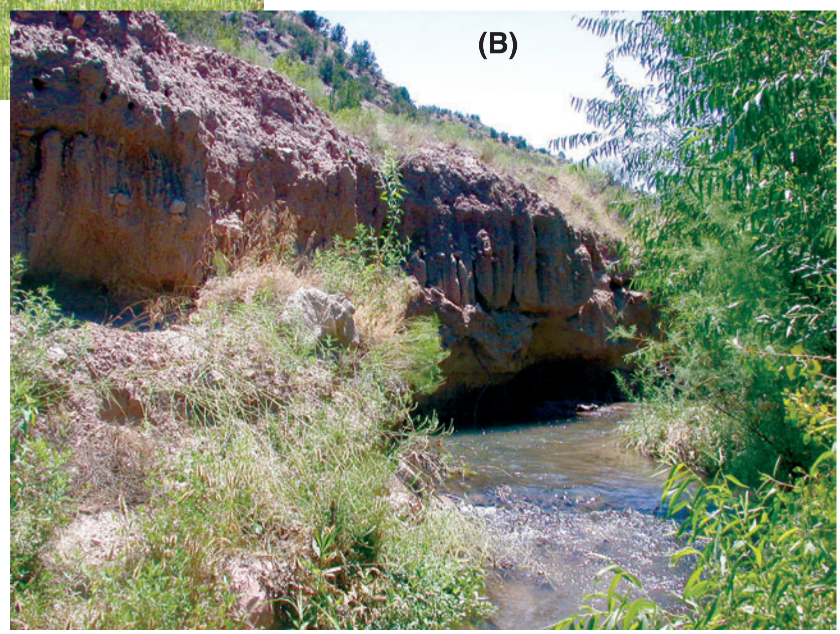


Figure 2.25—This tributary, located near Al's Spring, depicts the typical case of headcutting for many tributaries. (Photo by Alvin L. Medina.)

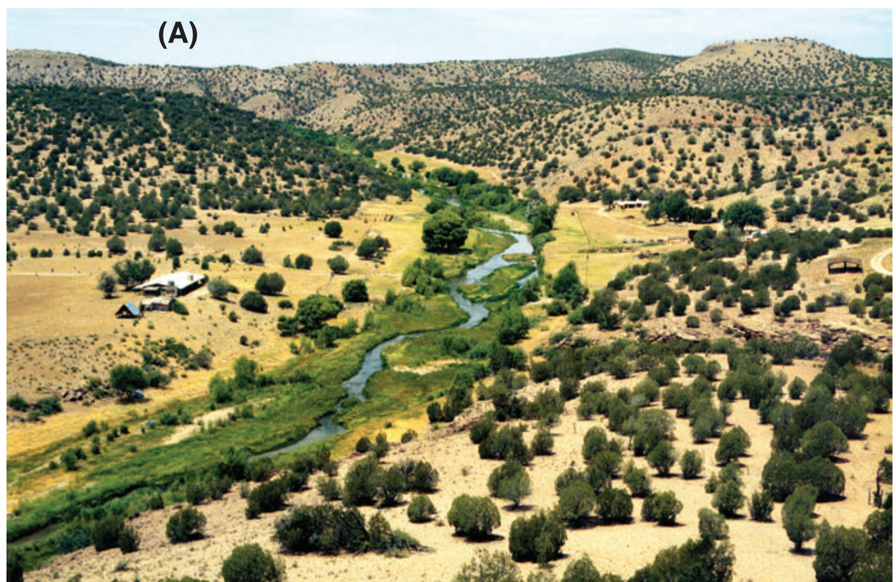
Figure 2.26—Example of smaller first terraces resulting from channel incision on the UVR. (Photo by Alvin L. Medina.)

Verde Ranch

A number of photos and other records exist from the Verde River Ranch below the USDI Geological Survey Paulden stream gauge. The UVR has been important for the cattle raising operation at the ranch because it supplies water and supports forage growth during dry periods. Cattle grazing was certainly heavier in the 1950s (fig. 2.27), but vegetation was very sparse on steeper slopes that would not be grazed at all. The dark trees are juniper and lighter colored woody plants are upland shrubs. Other light colored shrubs on the floodplain, aligned linearly, are most likely seepwillow. Figure 2.28 shows the Ranch headquarters at the present time with a clearly defined riparian zone. The area shown in this figure contains some of the rarer E-type channels (Rosgen 1996).

Figure 2.29 is an example of one of the few remaining historic wetland habitats in excellent condition. Where woody plants have encroached on streambanks, erosion around their trunks has created stream nick points and has generally destabilized the site. The streambanks shown in fig. 2.30 are occupied primarily by bulrushes, sedges, and rushes. These plant species are superior for stabilizing streambanks and dealing with the brutal impacts of episodic flood events. Woody species in close proximity to channels are often damaged or ripped out by episodic flood flows of the magnitudes experienced on the UVR. Figure 2.31 illustrates post-flood recovery by herbaceous plants adjacent to the stream channel. Herbaceous species have recovered well. The tree visible in the left side (fig. 2.31A) is the sprouting stump on the left side of fig. 2.31B. Note that no woody species recruits are visible in the 2003 photo. A similar trend is visible at another location on the Verde River Ranch (fig. 2.32). Recovery by herbaceous vegetation at an additional site was fairly swift two years after the 1993 flood (fig. 2.33A), and the site was still dominated by herbaceous vegetation on the 10th anniversary of the flood (fig. 2.33B).

Figure 2.27—Cattle drive in 1946 on the Verde River Ranch and an illustration of the riparian vegetation and geomorphological conditions at the time. (Photo courtesy of the Sharlot Hall Museum, Prescott, Arizona.)



(B)

Figure 2.28—Photo A is an aerial view of the Verde River Ranch headquarters below the U.S. Geological Survey's Paulden gauge in March 1997. The wetlands, intact for many decades, provide a valuable reference of wetland habitats of time past. These wetlands have recently been at risk of channel erosion from encroachment of woody plants. Photo B, taken in July 2011, shows some changes in woody vegetation after selective removal of several cottonwoods from the active floodplain. Removal of cottonwoods restored the freeboard needed by flood waters to flow without inducing erosion of the wetland. (Photos by Alvin L. Medina.)

Figure 2.29—Wetland site with an E-type channel on the UVR located on the Verde River Ranch headquarters, downstream of the Paulden gauge. These sedge meadows were prevalent throughout the UVR corridor prior to woody plant encroachment. (Photo by Alvin L. Medina.)

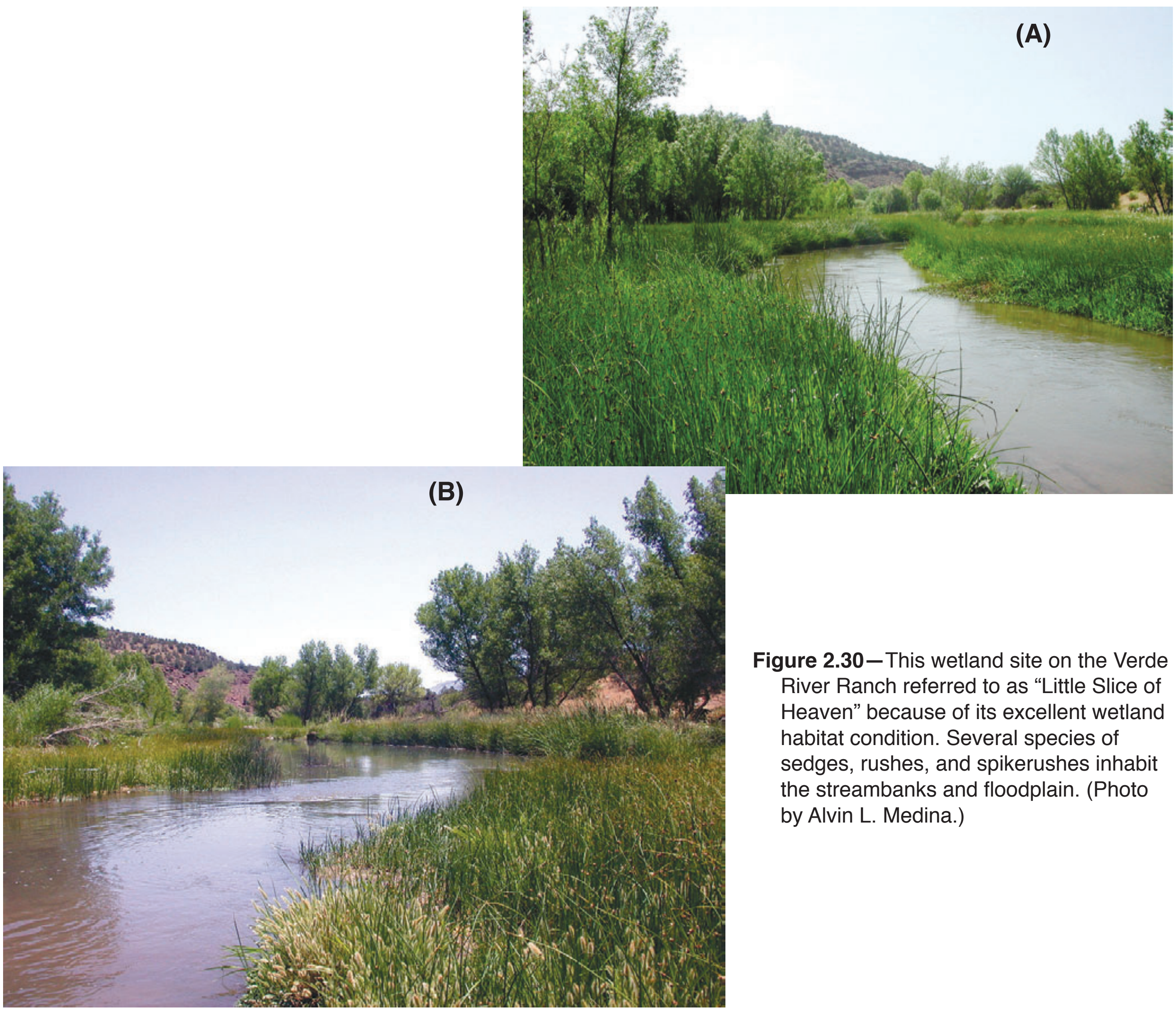


Figure 2.30—This wetland site on the Verde River Ranch referred to as “Little Slice of Heaven” because of its excellent wetland habitat condition. Several species of sedges, rushes, and spikerushes inhabit the streambanks and floodplain. (Photo by Alvin L. Medina.)

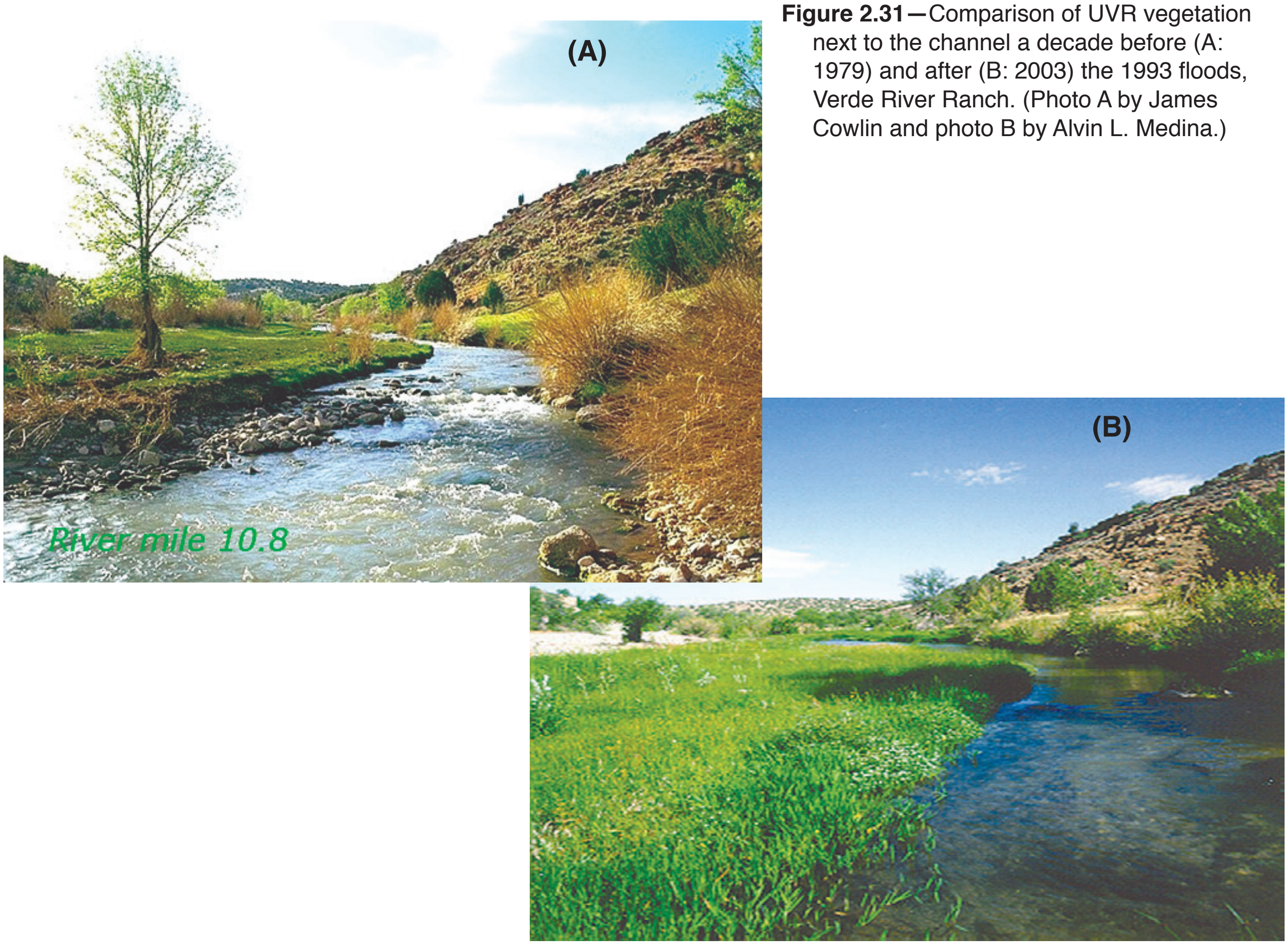


Figure 2.31—Comparison of UVR vegetation next to the channel a decade before (A: 1979) and after (B: 2003) the 1993 floods, Verde River Ranch. (Photo A by James Cowlin and photo B by Alvin L. Medina.)

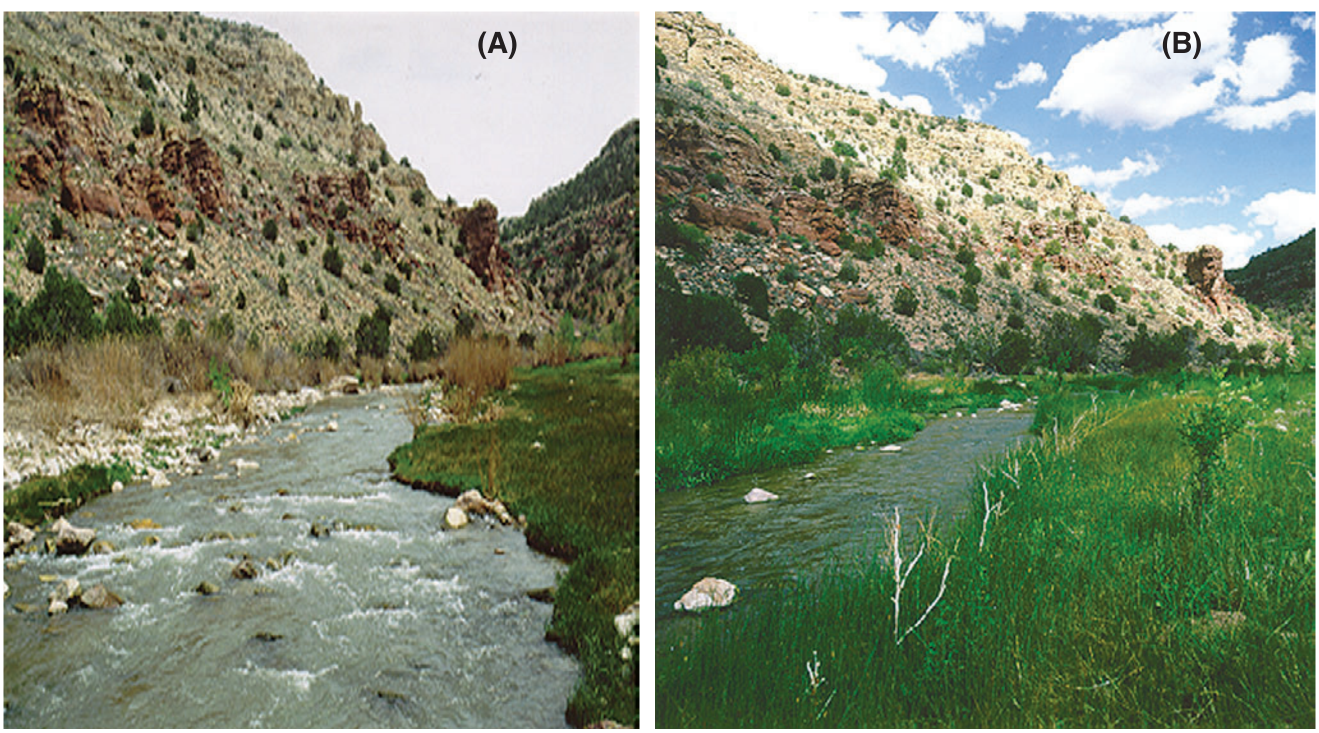


Figure 2.32—UVR vegetation recovery and channel narrowing and deepening at a second site a decade before (A: 1979) and after (B: 2003) the 1993 floods, Verde River Ranch. (Photos by James Cowlin and Alvin L. Medina.)

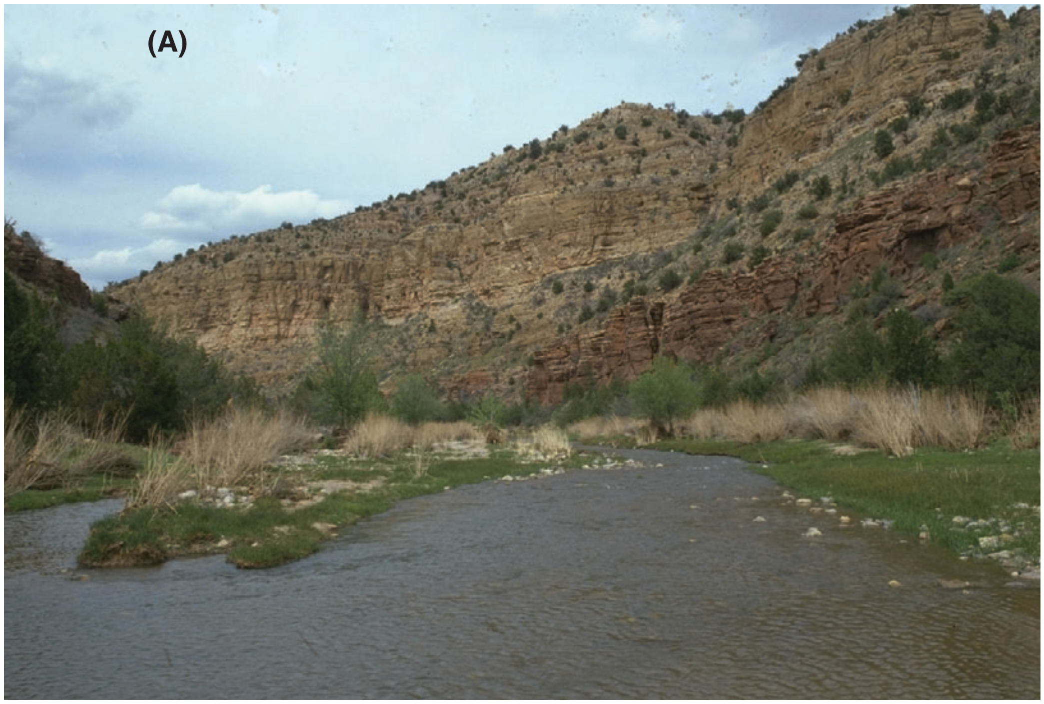


Figure 2.33—Herbaceous recovery (A) 2 years and (B) 10 years after the 1993 flood on the UVR. (Photos by Alvin L. Medina.)

Bear Siding

Bear Siding has one of the long-term fish sampling locations discussed in Chapter 9. The photo from 1979 (fig. 2.34) shows a fairly sparse riparian vegetation community even before the 1993 flood. The flood of that year scoured the riparian zone even more. By 1998, in the absence of any large floods and shortly after grazing removal in 1997, a more substantial riparian flora had re-established itself (fig. 2.35).

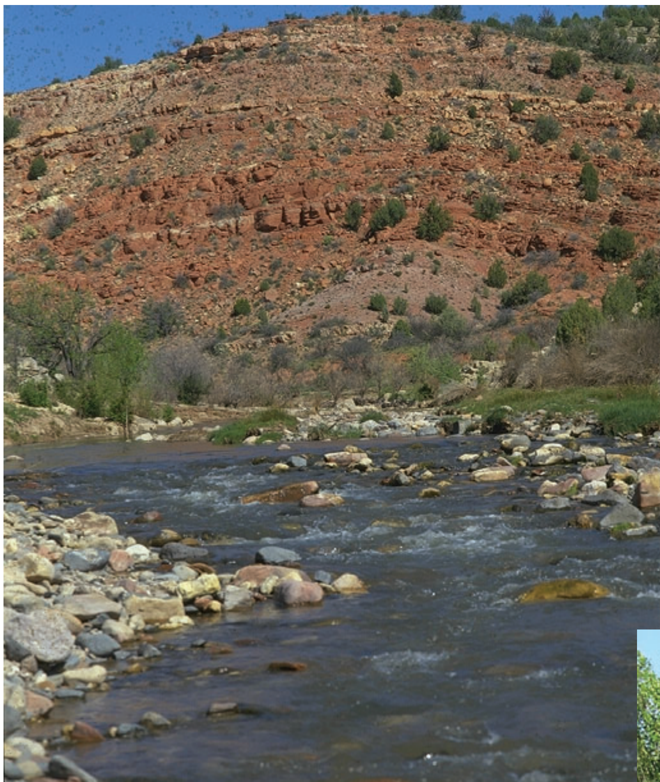


Figure 2.34—Photo of a fish study site at Bear Siding in May 1979. Note the vegetation, water color, channel substrates, and streambank conditions. The aquatic habitat is characterized as a typical C-3 type channel with interspersed riffles throughout the reach. (Photo by James Cowlin.)

Figure 2.35—Repeat photography of fig. 2.34 taken in February 1998. The exact location is inaccessible due to trees and deep water that obscure the view. Note the vegetative growth of nonnative plants, cattails, and tamarisk (right bank) on the active floodplain. The water is notably turbid, a gray-green color, and much different from the 1979 photo. The aquatic habitat consists of turbid, deep pools flanked by woody vegetation. The channel type is a C-6 with submerged riffles forming a glide-pool habitat. (Photo by Alvin L. Medina.)

Perkinsville

Perkinsville is one of the open valley bottoms in the UVR with bedrock constrained canyon sections above and below it. This area was a site of an early settlement with the establishment of the Perkins Ranch in 1900 and the construction of the Santa Fe Railways's Clarkdale to Drake spur line. This railway line is still operated by the Verde River Railroad. Note in the 1925 photo (fig. 2.36) the pinyon and juniper trees in the area are not very tall or vigorous. The riparian area is mostly free of vegetation except for the band of cottonwoods on the inside of the bend in the UVR at mid-photo. These most likely survived the paleofloods of 1891 and early 1900s and some may have been planted by the Perkins family or allowed to establish along newly constructed irrigation ditches (fig. 2.36) at the beginning of the Twentieth Century. Twenty-two years later, fig. 2.37 shows evidence of better plant growth due to wetter conditions in the latter part of the Century. By 1995, woody vegetation had expanded considerably on slopes adjacent to the UVR as well as along the channel (fig. 2.38). Another photo from 1925 shows the generally dry conditions and the sparseness of vegetation (fig. 2.39). Episodic floods kept the riverbanks scoured of vegetation (fig. 2.40). The trees that were present then were located back on second and third terraces, indicating the powerful effects of floods on woody vegetation (fig. 2.41). A repeat photograph of fig. 2.41 from 2003 shows that 78 years has resulted in a much expanded woody vegetation complex along the UVR channel, a narrower channel system, and greatly enhanced pinyon pine and juniper vegetation on the uplands (fig. 2.42). Most of the sediments in the channel are coarse gravels, cobbles, and boulders. There is no evidence of large amounts of fine sediments, which would be indicative of wide-scale and intensive erosion in the uplands.

At the downstream edge of the Perkinsville valley area is the "Black Bridge" on the Verde River Railroad (fig. 2.43) where the UVR goes into another canyon-bound reach. The channel appears to be in the same position in 2003 (fig. 2.43B) as it was in 1910 due to the influence of the solid rock wall which causes flow to divert toward the bridge. The point bar on the left seems to have the same coarse sediment composition although there is much more evidence of woody species recruitment on the bar and channel edges. The 2003 photograph indicates a greater clearance beneath the bridge than the photograph taken just after construction of the railroad in 1910. This could be evidence of channel downcutting in the interim or movement of large amounts of channel sediments. The photo from 1910 shows that there was virtually no riparian gallery forest or other woody species before the railroad arrived (fig. 2.43A). The lack of trees could be due to a variety of causes, including scouring floods; drought; long-term use by Native Americans; or early European settler use of wood for buildings, fences, and firewood. Grazing was probably not the cause or there would be larger trees evident on the landscape. Grazing animals introduced into an area usually affect only seedlings or saplings.

Figure 2.36—A 1925 photo illustrating UVR riverine and upland conditions in the Perkinsville area. (Photo by Matt Tully.)

Figure 2.37—A 1947 photograph that depicts major changes in vegetation density and composition at Perkinsville since 1925. (Photo by R. King, U.S. Forest Service, Prescott National Forest, Photo #446116.)

Figure 2.38—This is a 2008 repeat photo of fig. 2.37. Cottonwoods established along old channels, but the floodplain is generally devoid of woody species, which are washed away by recurring floods. (Photo by Alvin L. Medina.)

Figure 2.39—A 1925 photo of the Perkinsville area illustrating the drought conditions of the time. Of special significance is the absence of obligate riparian trees and shrubs. Two clusters of very large cottonwoods are evident survivors of paleofloods. Other woody vegetation are facultaive upland species, e.g., mesquite. (Photo courtesy of the Sharlot Hall Museum, Prescott, Arizona.)

Figure 2.40—A 1925 photo showing the magnitude of seasonal floods on the UVR at Perkinsville. (Photo courtesy of the Sharlot Hall Museum, Prescott, Arizona.)

Figure 2.41—A 1925 photograph of the Perkinsville area looking northwest along the Santa Fe Railroad (Verde River Railroad) toward the Station (light colored buildings in the upper right quadrant). (Photo courtesy of the Sharlot Hall Museum, Prescott, Arizona.)

Figure 2.42—A 2003 repeat photograph of the 1925 photograph (fig 2.41) of the Perkinsville area looking northwest along the Santa Fe Railroad (Verde River Railroad) toward the Station (light colored buildings in the upper right quadrant). Cottonwoods have established along old channels. This river segment of private land still remains a refuge for native minnows. (Photo by Alvin L. Medina.)

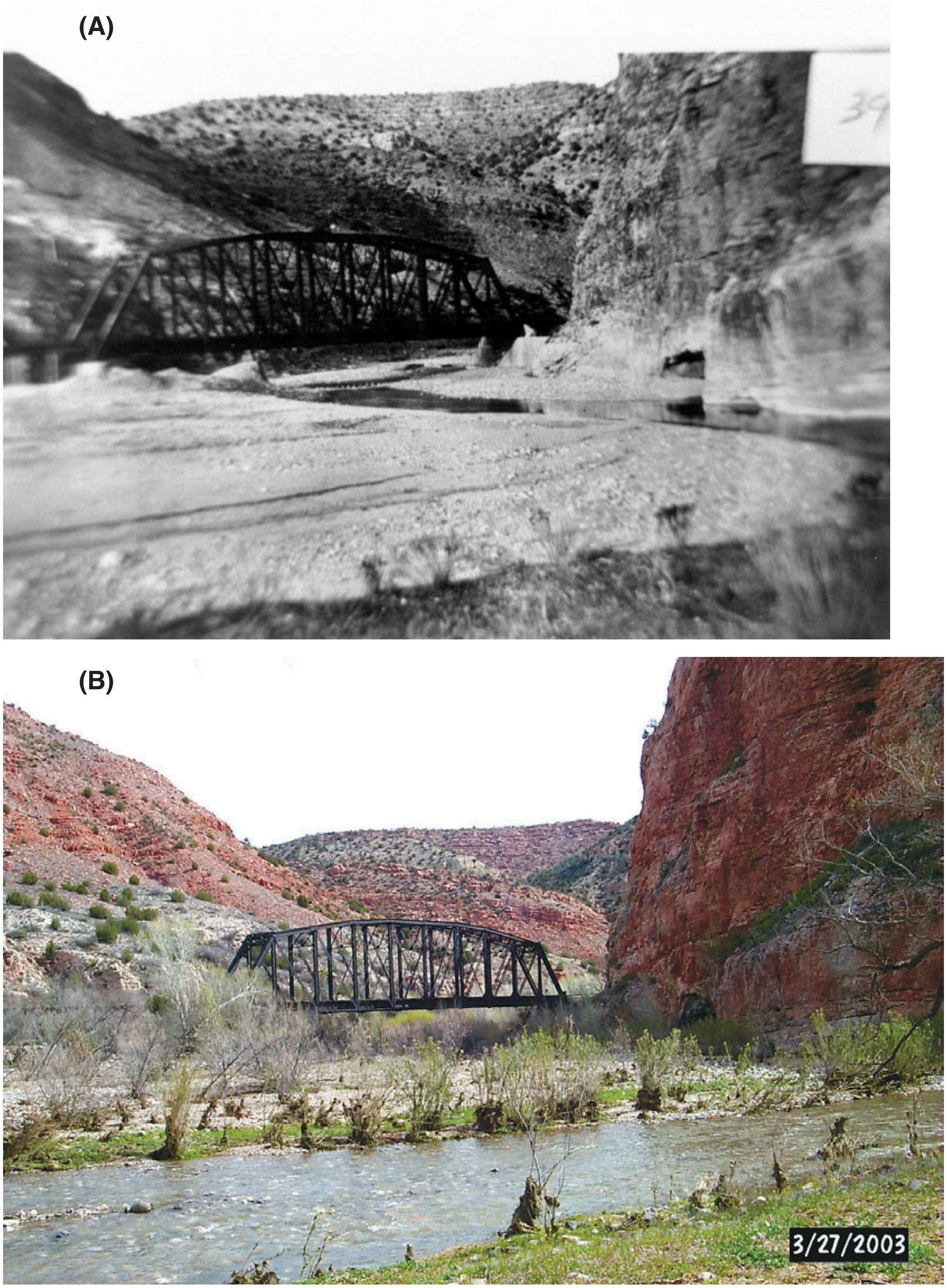


Figure 2.43—The "Black Bridge" on the Verde River Railroad downstream of Perkinsville. The photographs are from (A) 1910 and (B) 2003. (Photo A courtesy of the Sharlot Hall Museum, Prescott, Arizona; photo B by Alvin. L. Medina.)

Horseshoe Allotment

The Horseshoe Allotment is the grazing allotment that includes the Black Bridge and the south side of the downstream reach of the UVR for several kilometers. Figure 2.44A shows the condition of the UVR below the “Black Bridge” in 1925. The railroad runs along the right bank towards its terminus at Clarkdale. The repeat photo from 2003 highlights the stands of cottonwoods and willows, which have developed since the 1993 flood (fig. 2.44B). It also shows more extensive juniper growth along the UVR riparian margins and on adjacent slopes.

Figures 2.45 and 2.46 show a section of UVR channel in the Horseshoe Allotment demonstrating the scoured condition of the river bed after the 1993 flood. The subsequent photograph in 1999 shows the dense vegetation that developed in the years after the significant 1993 flood. That part of the UVR is now difficult to negotiate because of the woody and herbaceous plant growth. An additional series of photographs (figs. 2.47 to 2.49) documents vegetation changes in the UVR channel in the Horseshoe Allotment from 1994 to 1998. The distinctive mid-channel rock was

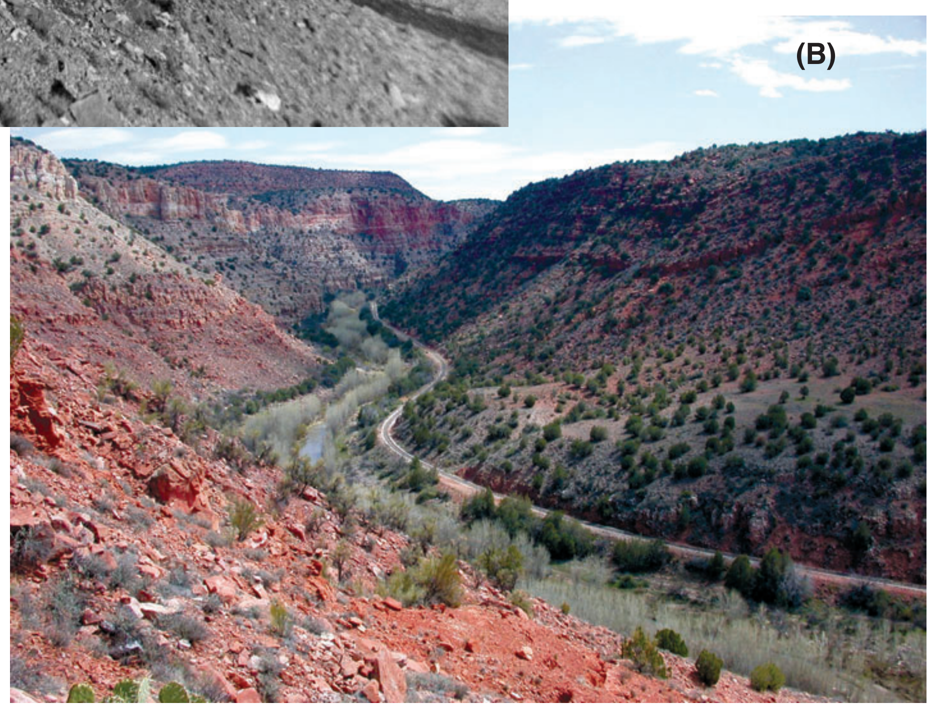


Figure 2.44—The 1925 photograph on the left (A) was taken shortly after the completion of the Verde River Railroad, then called the Santa Fe Railroad. (B) is repeat photography from March 2005. (Photo A by Matt Cully; photo B by Alvin L. Medina).

used as a reference point. The photo-series also shows how the UVR channel has narrowed and deepened.

One of the consequences of woody vegetation encroachment on the UVR channel is the formation of woody debris dams. Figure 2.50 shows young sycamore trees that were uprooted by a minor flood in 2005. These stems can be easily piled up by subsequent flood flows, creating a debris jam in the river. This process creates a risk of a debris dam backing up streamflow and then breaching during a flood event, creating a much elevated peakflow. Debris dam breach flows have a much greater impact on channel morphology and downstream structures like irrigation diversions, bridges, and residences (Cenderelli 2000; Ice and others 2004).

Figure 2.45—UVR channel in the Horseshoe Allotment after the 1993 flood. (Photo by Sharon and George Yard.)

Figure 2.46—UVR channel conditions near the area shown in fig. 2.44 in the Horseshoe Allotment in 1999, six years after the 1993 flood. (Photo by Sharon and George Yard.)

Figure 2.47—The "Otter Rock" in the UVR channel in the Horseshoe Allotment in 1994, one year after the large 1993 flood. (Photo by Sharon and George Yard.)

Figure 2.48—The "Otter Rock" in the UVR channel in the Horseshoe Allotment in 1996, three years after the large 1993 flood. (Photo by Sharon and George Yard.)

Figure 2.49—The "Otter Rock" in the UVR channel in the Horseshoe Allotment in 1998, five years after the large 1993 flood. (Photo by Alvin L. Medina).

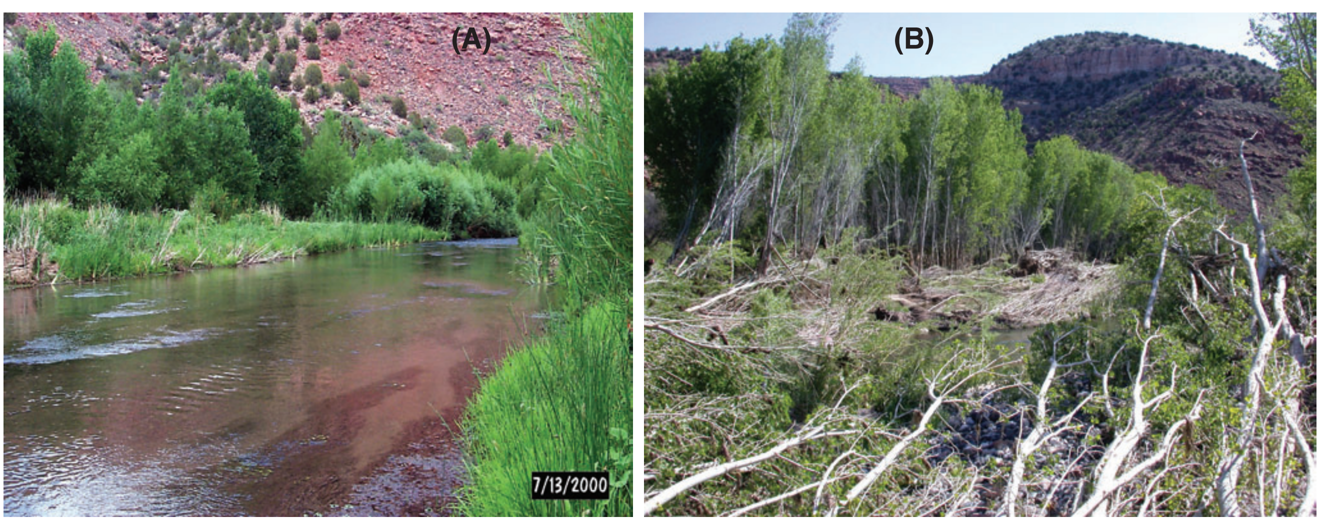


Figure 2.50—Photo A taken in July 2000 upstream of the otter rock site shows an established grove of cottonwoods and coyote willows, which were planted by the Y-D Ranch in 1994. Photo B, taken in July 2005 after a major flood, shows uprooted trees throughout the reach. Willows were also up-rooted and washed away into debris piles. (Photos by Alvin L. Medina.)

Antelope Hills Allotment and Sycamore Canyon

A set of photographs from the Antelope Hills Allotment further down the UVR demonstrates the changes that occur in river sediments and geomorphology with flood events. Figure 2.51A shows a straight reach of the UVR in 1979 that was characterized by shallow water and gravel and cobble bedload materials. It was a very long riffle reach. During the 1993 flood, this reach was scoured out and deepened. Now it is a deepened pool dominated by fine-textured sediments (fig. 2.51B). In addition, the riparian vegetation has changed completely in the 27 years separating the photos. These photographs indicate the high degree of dynamics of the river in changing both aquatic habitats and riparian vegetation.

A section of the UVR just above the confluence with Sycamore Creek also demonstrates the dynamic nature of the UVR. The reach in fig. 2.51A in 1979 was dominated by gravel and cobble bars. The river meandered through these deposits in a series of glides, runs, and riffles. During the 1993 flood, this reach was scoured out into a big, deep (2 to 3 m or 6 to 10 ft) pool, but it still contained a substantial amount of gravel-sized particles. By 1996, this section was completely filled in with sand-sized and finer sediments (fig. 2.51B). Figures 2.52 and 2.53 show the type of gravel bars and channel substrates that are left in the channel after flood events. In the absence of floods, these coarse sediments become embedded in fine-textured sediments and lose their habitat value to native fishes.

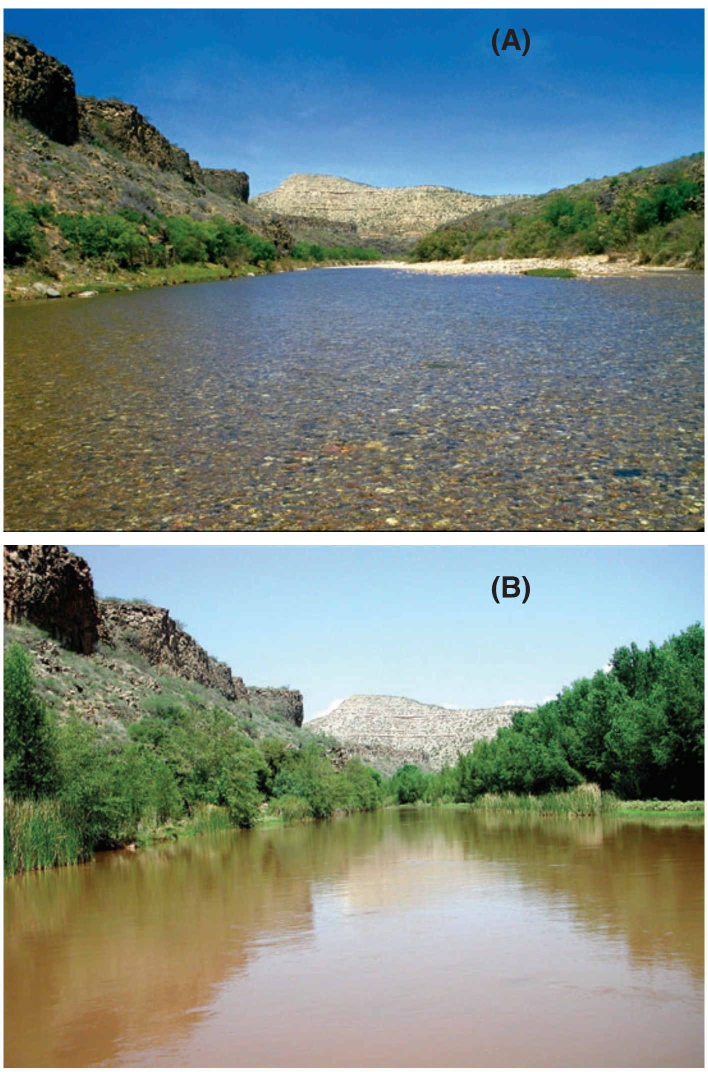


Figure 2.51—(A) 1979 photo of the UVR in the Antelope Hills Allotment, and (B) the same site in 2009. (Photo A by James Cowlin; photo B by Alvin L. Medina.)

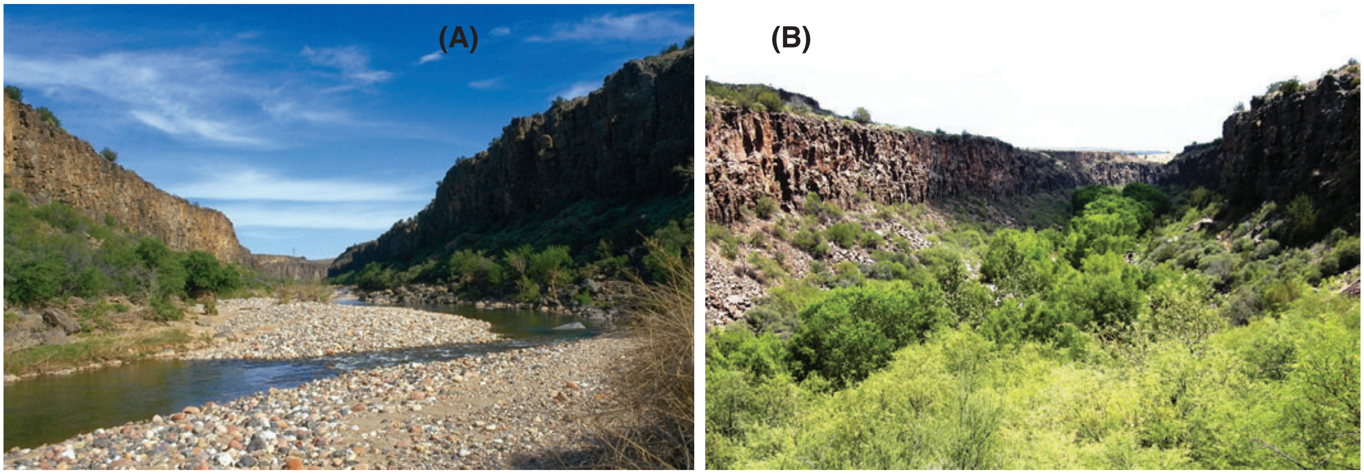


Figure 2.52—UVR below Sycamore Canyon at the Clarkdale gauging station in (A) 1979 and (B) 2005. The exact photo location in B is obscured by woody vegetation requiring an oblique aerial view of the canyon. The channel conditions are much different from the pool-riffle habitats shown in A. These have been replaced by deep glides, with submerged riffles and the channel winds about the maze of trees. (Photo A by James Cowlin; photo B by Alvin L. Medina).

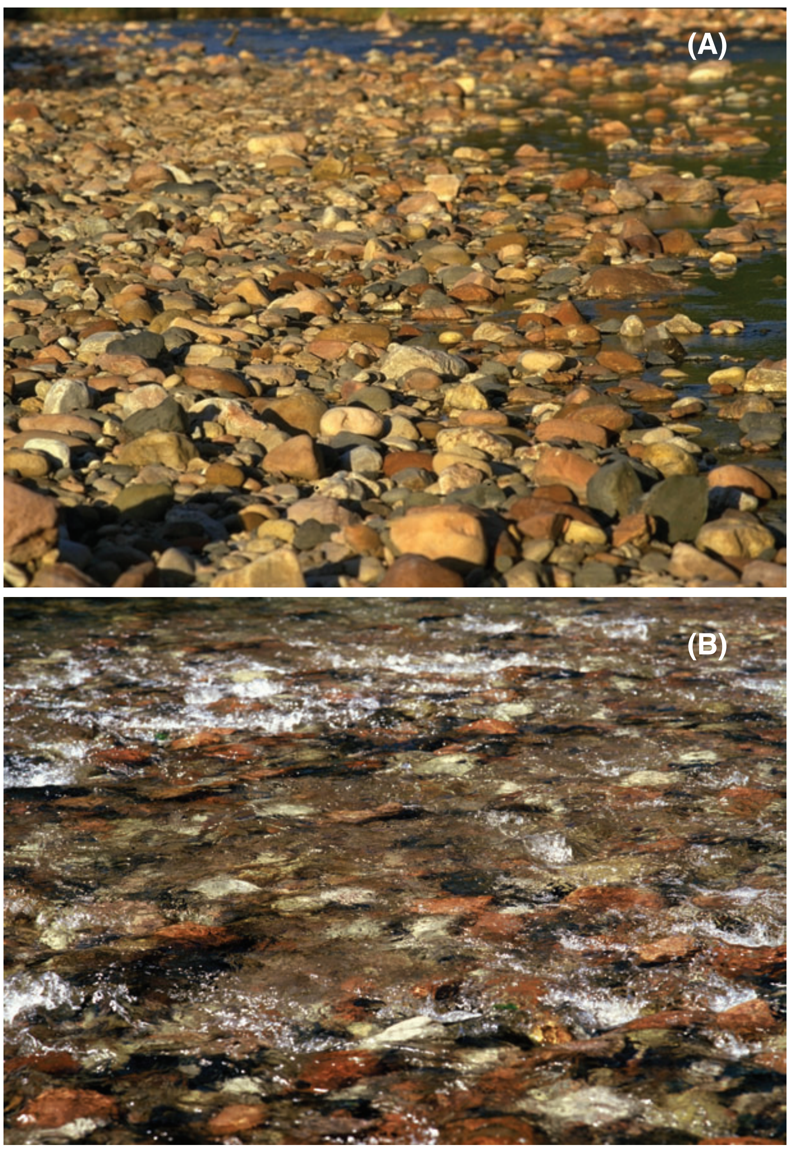


Figure 2.53—Photos of coarse cobble substrates (A) near Sycamore Canyon. These stream habitat conditions are favored by native fishes. Photo B is a reference condition for the reach in 1979, which is much different from the present. (Photos by James Cowlin).

Discussion

Vegetation Changes

Vegetation in the riparian zone of the UVR has gone through considerable change since the earliest photos from 1910. The riparian habitats are dynamic and will continue to change with future disturbances. Photographs highlight the cycle of scour and revegetation going on in the UVR's riparian zones. It is evident that climate-related events are the main drivers of vegetation dynamics, but human activities have also contributed to the changes that have been observed in the river over the past century. Cumulative and sequential effects of Sullivan Dam since 1939 on the channel dynamics that subsequently changed channel conditions, which led to changes in vegetation communities. Patterns of grazing, largely unknown, over 100+ years and recent changes to zero grazing have affected the sustainability, composition, and succession of plant communities. Major changes in recreation, e.g., from open access throughout the corridor to limited access, have further affected how the river functions and changes. Lack of information about how to manage riparian vegetation has largely resulted in a conservative approach to historical uses. In short, the vegetation of the Verde River is much different in composition, structure, and diversity than it was 100, 50 and 25 years ago, as evidenced on other Southwestern streams (Webb and others 2007). Chapters 6 and 7 of this volume present assessments of the current status of UVR riparian vegetation and will facilitate future research efforts. Of significance is how vegetation has changed over time and spatially in response to disturbance from hydrologic factors, such as Sullivan Dam. These hydrologic changes undoubtedly had direct and indirect effects on aquatic habitats and fish. The exact processes remain to be defined.

UVR Hydrologic Changes

The wet and dry cycles of the Southwest have strong influences on the geomorphology, hydrology, and ecology of the region's rivers (Grissino-Mayer 1996). Past climates have been dominated by these oscillations and future climates certainly will be affected as well (Ely 1997). There is evidence that the Holocene epoch prior to European settlement was marked by a larger quantity and intensity of flood events than has been observed in the UVR in recent years. These events significantly affected the geomorphology and vegetation conditions of the UVR. As noted above, the effects of Sullivan Dam have cumulatively affected many other physical and biological components of the UVR ecosystem.

Ecological Changes and the UVR

Numerous hypotheses have been proposed about the relationships among UVR hydrological and ecological processes, current watershed condition, land management practices, and aquatic fauna (Haney and others 2008). Understanding these processes in their paleo, historic, and modern time frames is important for determining their impact on the UVR biological system. An intellectual evolution is required to avoid assigning cause-and-effect relations to only currently visible land management activities. Some processes that have been going on for thousands of years are still affecting the UVR (flooding, drought, arroyo cutting, vegetation changes, landscape-level erosion, etc.) and others are not. Human activities such as exotic species introductions, groundwater pumping, irrigation diversions, livestock management, and mining can produce effects as profound as, greater than, or much less than natural processes.

The following chapters deal with the topics of hydrology, channel morphology, watershed condition, woody vegetation, herbaceous vegetation, water quality, and fish fauna. Some of the questions that should be considered when reading through this report are:

- Is the current watershed condition of the UVR the result of Twentieth Century land management or long-term geologic processes?
- Is arroyo and gully cutting a modern problem or one that goes back well into the Pleistocene epoch?
- What is the role of paleofloods in channel geomorphic evolution and erosion processes?
- Are gallery woody forests in the riparian zone the natural vegetation form or just an artifact between destructive floods?
- Is there evidence of landscape-scale erosion that affects the productivity and sustainability of the native UVR ecosystems?
- What roles do invasive plants and aquatic fauna play in the ecology of the UVR?
- How have changes in the hydrologic equilibrium affected channel stability, vegetation, and aquatic habitats?

Management Implications

This chapter provided historical and geophysical perspectives on the UVR. The current vegetation conditions on the river are the result of pre-European streamflows, past and present climate, a century of cattle grazing, and current land management activities. Paleofloods and droughts had far greater impacts on the riparian vegetation and channel geomorphology, as noted in other rivers of the Southwest (Webb and others 2007). Without the context of pre-Twentieth Century impacts on the river, it is too easy to attribute the currently visible conditions of the UVR to modern activities. All of the natural processes and management activities need to be considered holistically before making conclusions about current and future land uses and management activities. From the historical analysis presented here, it is apparent that the UVR has been impacted to a larger extent and intensity by hydrologic and erosion events that pre-dated modern land management. The interactions of the UVR and its surrounding landscape are far more complex than they appear at first glance. Simple cause-and-effect assumptions by land managers and technical staff should be avoided. Likewise, extrapolation of research or management results from other ecosystems or regions should be done with caution and knowledge of the risks of unintended consequences. However, Best Management Practices should always be employed to ensure the sustainability of both the river and upland ecosystems.

Summary and Conclusions

Repeat photography was used to display the vivid texture of the UVR's vegetation, channel, and valley landscapes and to contrast the historical and current conditions. These contrasts are interpreted within the context of plant ecology and hydrogeomorphology to provide a comprehensive understanding of the changes that have occurred in the past century. In some cases, additional photographs provide greater breadth for understanding the larger perspective of the area and its habitats. A principal objective is to provide a broad understanding of historical influences that is necessary to comprehend the various physical and biological processes that govern present-day conditions on the UVR. Climate and land uses undoubtedly have affected the streamflow and sediment regimes, which, in turn, influence such factors as riparian vegetation and aquatic wildlife. Paleo-reconstruction studies of historical environmental conditions are utilized to put forward alternative descriptions of the Verde River for the period of record (1890 to present). Paleoecological data are useful for discriminating environmental changes between natural and cultural influences (Swetnam and others 1999). The introduction of livestock circa 1890 is an important event that is often cited as crucially influential on present-day conditions. However, many descriptions have been extrapolated from general sources that did not recognize climatic conditions during this period that may have long-lasting consequences on the evolution of riparian and aquatic habitats in the UVR. Vegetation descriptions are consistent with Webb and others (2007) with respect to historical changes and current dominance by woody vegetation.

Chapter 3

Verde River Hydrology

Daniel G. Neary, Alvin L. Medina

Introduction

The Central Arizona Highlands are a distinct biogeographic, climatic, and physiographic province that forms a diverse ecotone between the more extensive Colorado Plateau to the north and the Sonoran Desert ecoregions to the south (Ffolliott 1999). The Highlands coincide closely to the Arizona Transition Zone identified by ecologists, geologists, and others (Karlstrom and Bowring 1988; Hendricks and Plescia 1991; Ezzo and Price 2002). The Central Arizona Highlands have been the focus of a wide range of research efforts designed to learn more about the effects of natural and human-induced disturbances on the functions, processes, and important components of the region's ecosystems, including hydrology (Arizona State Land Department 1962; Baker 1999).

The UVR area of north-central Arizona overlaps the Central Highlands and the Plateau Uplands biogeographic provinces. The UVR watershed characteristics and physiography (figs. 1.1 and 1.2) were introduced in Chapter 1. The UVR watershed encompasses the northern valley of the Verde River. The greater Verde River watershed is bounded on the north and west by the Colorado River, on the east by the Little Colorado River, and on the south by the Salt River. Perennial flow in the Verde River is a major contributor to the water resources and hydrology of Arizona since it is the only free-flowing water source in a large portion of the central and northwestern part of the state.

The Prescott National Forest manages much of the drainage area of the UVR watershed where flow is perennial. Other areas of mostly intermittent flow to the north, northeast, and east where elevations are higher are managed by the Kaibab and Coconino National Forests. Some of these tributaries have perennial flow but mostly in their lower reaches. The bulk of the UVR watershed headward of the start of perennial flow is mainly private and State of Arizona lands. Because of the unique flora and fauna of the UVR, there is a lot of public interest in landscape management surrounding the UVR.

Hydrologic regimes in the Southwest are influenced by the interactions between the amount of precipitation (generally increasing with elevation), evapotranspiration, type of vegetation, and type of parent material (Baker and others 2003). Precipitation and elevation influence vegetation as conditioned by the geologic parent material. The runoff regime is naturally influenced by the amount and distribution of precipitation, but a major factor influencing streamflow response is the geologic parent material. As previously explained in Chapter 1, parent materials that are deeply weathered and fractured and those that weather to a fine-textured regolith have a strong influence on the growth and development of vegetation. These different parent materials and subsequent differences in soil texture and depth also play an important role in runoff regimes (Baker 1987).

The shape of a runoff hydrograph is a reflection of the hydrologic responsiveness of the basin and is determined by the delivery rate of water and length of the flow path to the source area. Baker (1987) used hydrographs from gauged watersheds at Beaver Creek (fig. 1.1), Three Bar D, Castle Creek, Thomas Creek, and Workman Creek in water year 1973 (an exceptionally wet year) in Arizona to illustrate how various factors affected streamflow response and to show how much these factors interact in different areas of Arizona. Runoff efficiency rates (ratio of runoff to precipitation) nearly doubled or tripled in 1973 relative to pre-1973 data on all of the same observed basins, showing the influence of precipitation on streamflow (Baker 1987). The Three Bar D chaparral basin is at the lowest elevation of the watersheds analyzed by Baker (1987), but it received the second highest average annual precipitation (750 mm or 29.5 in). This watershed had the most attenuated or least responsive hydrograph, even though it received the second highest amount of precipitation (1,350 mm or about 53.0 in) during 1973. It also had the deepest soil (about 9 m or about 30 ft). Similar chaparral basins have been shown to be capable of producing perennial flow once the chaparral overstory is converted to grass. This occurred on a watershed at Beaver Creek following mechanical and herbicidal removal of trees and demonstrates the influence of soil depth on precipitation storage and eventual release (Hibbert and others 1974).

The most responsive or peaked hydrographs occurred on the Beaver Creek drainage area (fig. 1.1) with a mean soil depth of just under 1 m (3 ft). The Utah juniper basin at Beaver Creek received the lowest mean annual precipitation amount (about 460 mm or 18.1 in). However, the influence of the soil depth and the relatively impermeable B horizon is apparent in the highly responsive daily streamflow peaks (Baker 1987). Daily peak discharge rates, even from snowmelt, were relatively large and receded rapidly (in hours), which suggests a small soil water storage capacity and short flow paths (overland flow and shallow subsurface flow). The ponderosa pine basin on the Beaver Creek watershed had similar soil characteristics and similar responsive daily peaks. However, its higher elevation (up to 2,600 m or 8,500 ft) usually resulted each year in a delay of snowmelt of two months (from February to April). Streamflow on Beaver Creek generally terminated within a few days of the disappearance of the snowpack, though it often lasted longer on other sites in Arizona with deeper soil depths (Baker 1986, 1987; Gottfried and others 2003).

Annual precipitation on the mixed conifer basin at Workman Creek on the Sierra Ancha Experimental Forest east of Phoenix was the highest of those studied (810 mm or 31.9 in; Baker 1987), and streamflow was normally perennial. Hydrograph responsiveness was similar to that on the ponderosa pine basin, but daily peaks were higher in the beginning of the melt period and lower toward the end, demonstrating the influence of the heavy reduction in overstory basal area on snowmelt rates. Rates of snowmelt are inversely proportional to tree density and basal area due to the effect of tree canopy in shading the underlying snowpack. Streamflow in mixed conifer on the Castle Creek watershed in the White Mountains of eastern Arizona was similar to that on Workman Creek but was less responsive or more attenuated—the result of the influence of the higher elevation (2,500 m or 8,200 ft) in reducing snowmelt rates. Daily snowmelt peaks were still recognizable on Castle Creek but were greatly reduced.

The mixed conifer type on Thomas Creek watershed in the White Mountains of eastern Arizona was located at the highest elevation (2,650 m or 8,700 ft) and received the second highest annual precipitation amount (740 mm or 29.1 in) (Baker 1987). Daily snowmelt peaks were barely apparent, indicating much more resistance or longer flow distance to the channel. Overland flow or evidence of overland flow was seldom observed on this basin. Mean annual streamflow on these basins was relatively uniform (80 to 90 mm or 3.2 to 3.5 in), even though mean annual precipitation ranged from 650 to 810 mm (25.6 to 31.9 in). Although some attenuation of the hydrographs on the two higher mixed conifer basins was the result of lower snowmelt rates, the high annual precipitation amounts, longer streamflow period, and lower runoff efficiencies suggest that the major factor was the influence of soil depth and texture.

The Lower Colorado River Basin below the altitude of the UVR received an average of 330 mm (13.0 in) of annual precipitation (Hibbert 1979). The proportion of precipitation yielded as streamflow in the Lower Basin was 3 % (10 mm or <0.5 in) of streamflow in the Upper Basin. The high loss to evapotranspiration (97%) was similar to the environment that the UVR exists in. These evapotranspiration losses reflected the arid environment of the UVR and why the UVR's streamflows are important to the terrestrial, aquatic, and riparian ecosystems the river supports.

The objective of this chapter is to provide a background of the hydrological setting for the UVR. The perennial flow of the UVR makes this river fairly unique in the Southwest. Most other perennial rivers like the Colorado River or Rio Grande River drain huge basins and have snowmelt as the source of their flows. Very little of the UVR derives from snowmelt.

Hydrogeology

Blasch and others (2006) produced an extensive and detailed report on the UVR titled "Hydrogeology of the Upper and Middle Verde River Watersheds, Central Arizona." The following section contains excerpts that cover the geology of the region and the hydrological interactions with the geology. The geologic diversity of the UVR terrain provides the framework for the hydrology of the region and the diversity of plants and animals that occupy it.

Geological Setting

The UVR watershed lies within the Transition Zone between the Colorado Plateau to the north and northeast and the Basin and Range Province of Arizona to the southwest (Fenneman 1931; Wilson and Moore 1959). The Transition Zone is the locale for the UVR (fig. 3.1). It has characteristics of both geologic provinces that reflect episodes of geologic extension and compression. The result is a geologic region that has been deformed by faulting and uplift and that contains alluvial sediments from both bordering Provinces (Anderson and others 1992; Blasch and others 2006).

The stratigraphic sequence of rocks in the Verde River region consists of Precambrian metamorphic and igneous units that are overlain by Cambrian to Permian sedimentary units and then alluvial units or Tertiary to Quaternary-aged basalt flows and lake deposits (figs. 3.2 and 3.3). Precambrian rocks are generally not important aquifers, except where they have been highly fractured and weathered (Blasch and others 2006). Paleozoic rocks from the Tapeats Sandstone up to the Upper Supai Formation contain variable amounts of water. Tertiary-aged basalt flows are generally poor aquifers in the UVR region. It is the Basin and Range erosional sediments at the top of the stratigraphic sequence that provide most of the water-bearing formations that feed the UVR baseflows.

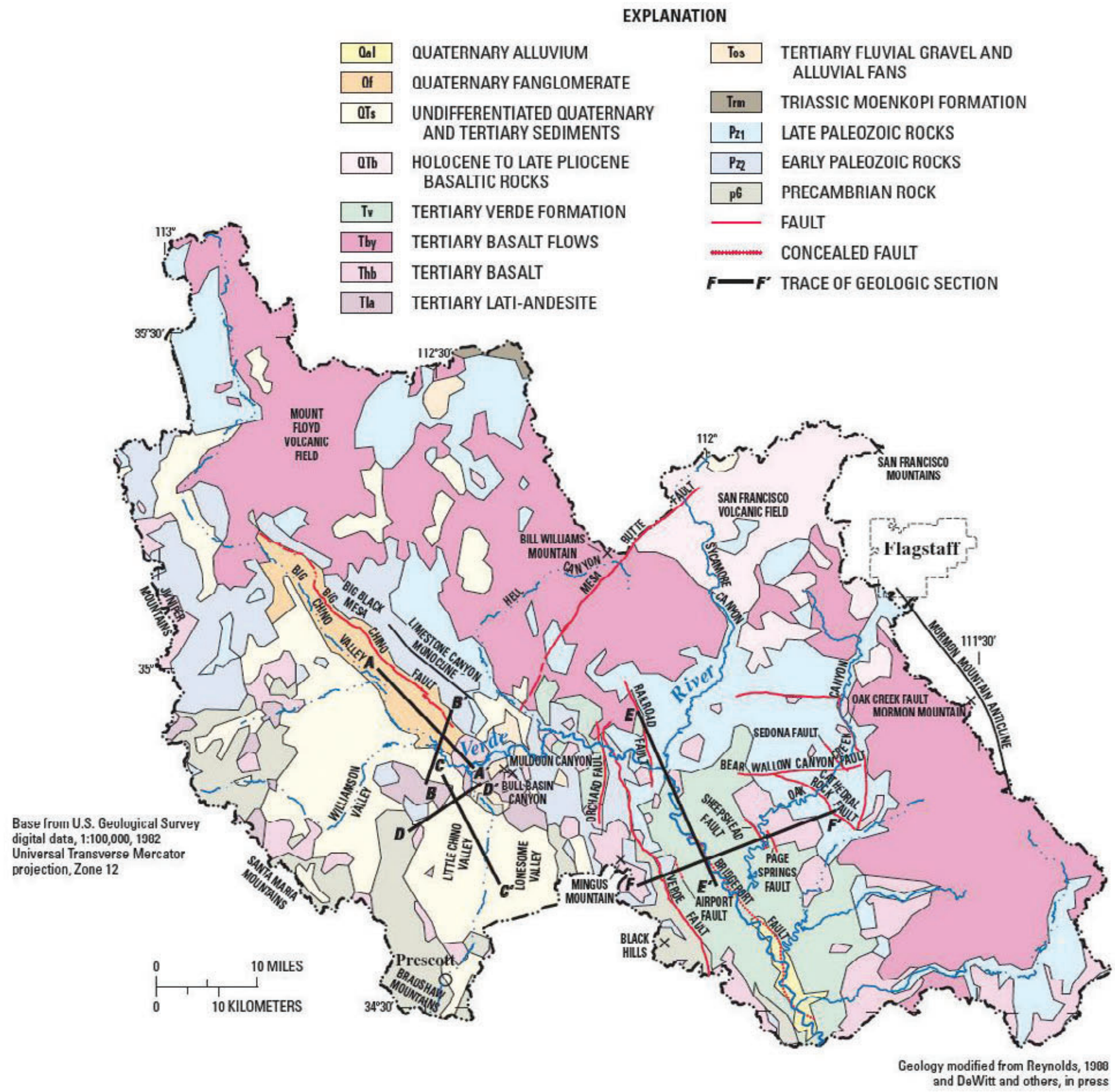


Figure 3.1—Generalized geology and geologic structures of the UVR and Middle Verde Watersheds, Yavapai County, Arizona. The Transition Zone lies northwest to southeast along the center of the geologic map (from Blasch and others 2006; based on DeWitt and others 2005).

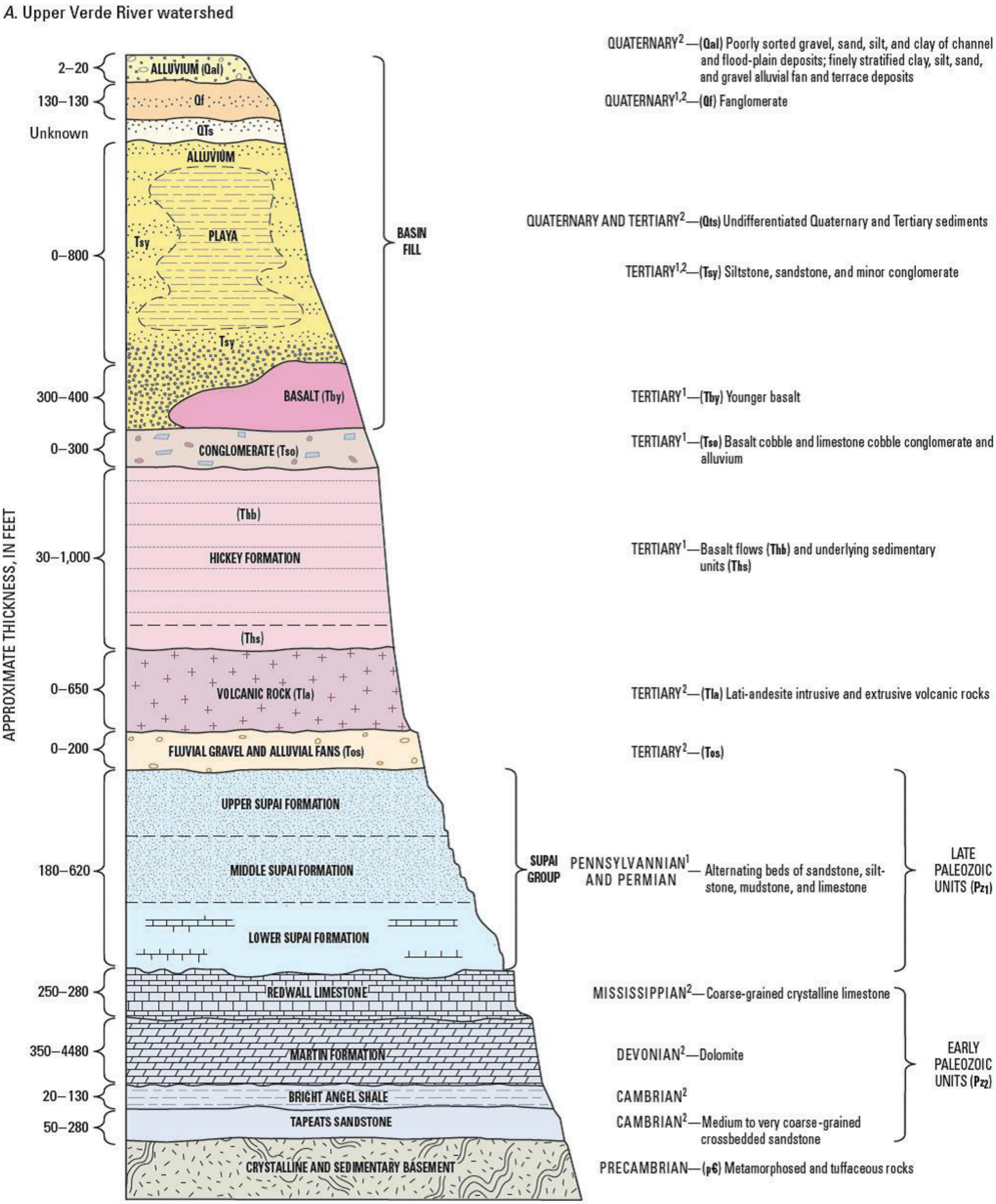


Figure 3.2—Generalized stratigraphic section of the UVR, Yavapai County, Arizona (from Blasch and others 2006; based on DeWitt and others 2005).

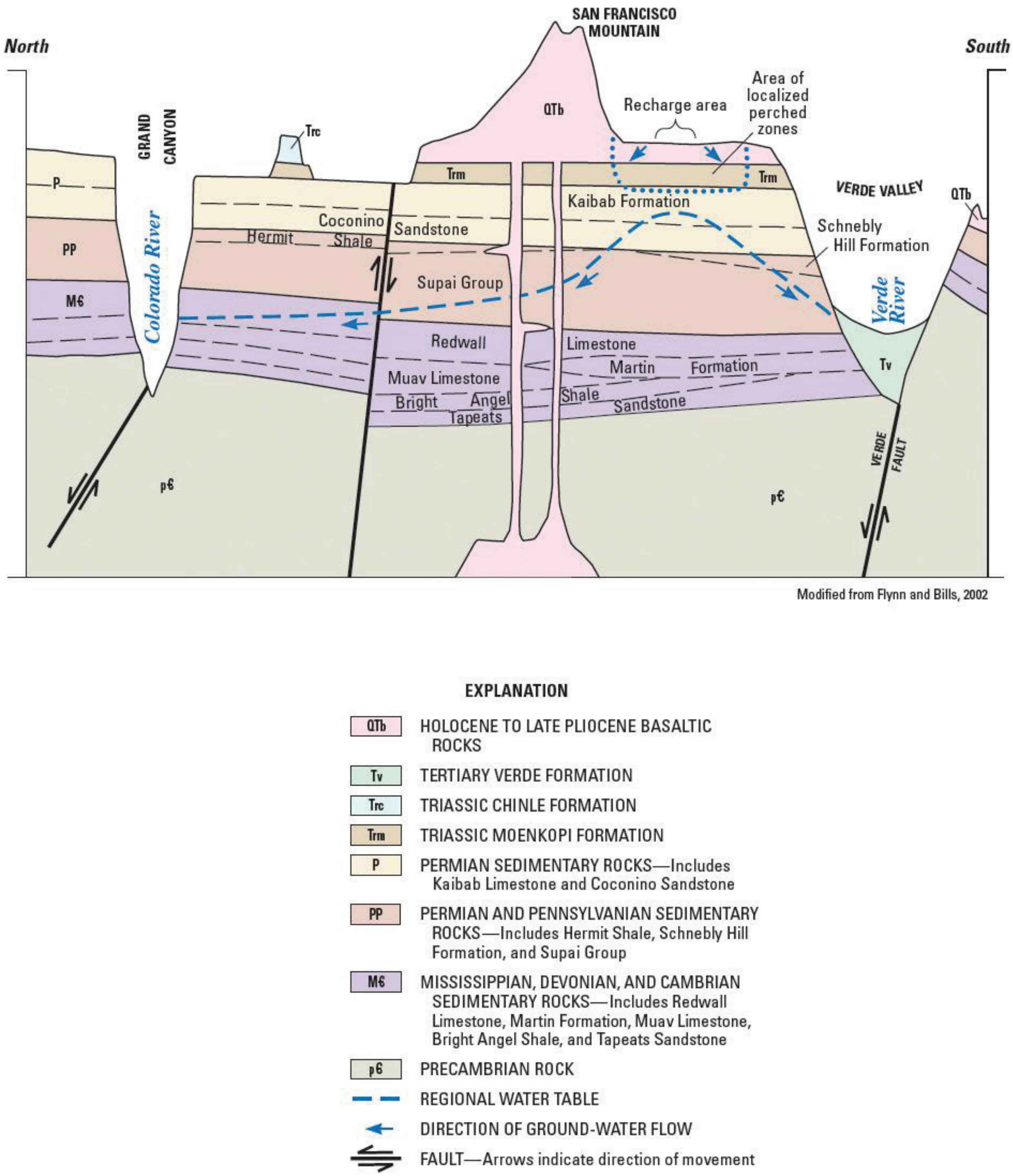


Figure 3.3—Cross section from the Colorado Plateau through the Transition Zone and into Basin and Range Formations (from Blasch and others 2006).

Geologic Structure and Aquifer Characteristics

The main structural features of the UVR and adjacent areas are the northwest to north valleys and mountain ranges as well as faults that are typical of the Basin and Range Province and associated shear zones (Blasch and others 2006). Valleys such as the Big Chino, Little Chino, Williamson, Lonesome and Verde Valley were formed by faulting which resulted in the juxtaposition of ancient Precambrian crystalline rock against younger sediments and alluvium. Valley floors consist primarily of unconsolidated to consolidated Tertiary and Quaternary sediments and stream alluvium.

An important source of water for the UVR is the Big Chino subbasin. This 4,790 km^2 (1,850 mi^2) basin consists of the Big Chino Valley, Williamson Valley, Big Black Mesa, and the western part of the Coconino Plateau. The Big Chino Valley is a 45 km (28 mi) long northwest trending structure that formed 10 to 2 million years ago in faulting associated with a crustal extension during the Basin and Range Province formation (DeWitt and others 2005). The graben associated with the valley formation is 3 km (about 2 mi) wide at its northwest end and 10 km (6 mi) at its southeast end near Paulden, where flow on the UVR begins. Alluvial deposits filled the graben to a depth of 870 m (2,500 ft). The associated Williamson Valley is slightly shallower and smaller in dimension. Together, the two valleys contain 260 km^3 (about 210 x 10^6 ac-ft) of interbedded alluvial sediments that are 74% saturated with water.

Groundwater in the Big Chino subbasin resides in two primary aquifers. The upper aquifer consists of unconsolidated sedimentary deposits and interbedded volcanic rocks to an average depth of 133 m (435 ft). The upper aquifer is a major source of irrigation water and domestic supplies and is being targeted as a potential water supply for Prescott and Prescott Valley municipal areas. Average discharge rates vary from 3.0 to 18.9 m^3 min^{-1} (800 to 5,000 gal min^{-1}). The lower aquifer consists of Paleozoic rocks that underlie the upper aquifer throughout the Big Chino Valley (figs. 3.1 and 3.2) and has both confined and unconfined units. Discharge rates from these aquifer units are lower (<3.0 m^3 min^{-1}or 800 gal min^{-1}) (Blasch and Bryson 2007, Montgomery and Harshbarger 1992; Wirt and Hjalmarson 2000;).

Hydrology

Climate

The UVR section of the Verde River Valley is semi-arid in nature with precipitation averaging less than 460 mm (18.0 in) (fig. 3.4a; from Blasch and others 2006). The signature characteristic of climate of this region is not the average, but the wide range in extremes. Except for higher terrain to the north that provides streamflow for Sycamore Canyon and Hell's Canyon, most of the precipitation occurs as rainfall rather than as snow (fig. 3.4). Monthly precipitation varies by over a factor of five from the spring dry period (13 mm or 0.5 in) to the summer monsoon period (70 mm or 2.8 in). Over the past century, rainfall in the UVR region has gone through several cycles of wet and dry periods (fig. 3.5). Blasch and others (2006) analysis of rainfall records since 1900 has shown that the UVR is in a lower rainfall cycle that started in 1994 and that snowfall for the UVR and Middle Verde watersheds has been mostly below normal since 1955 (fig. 3.5). Potential

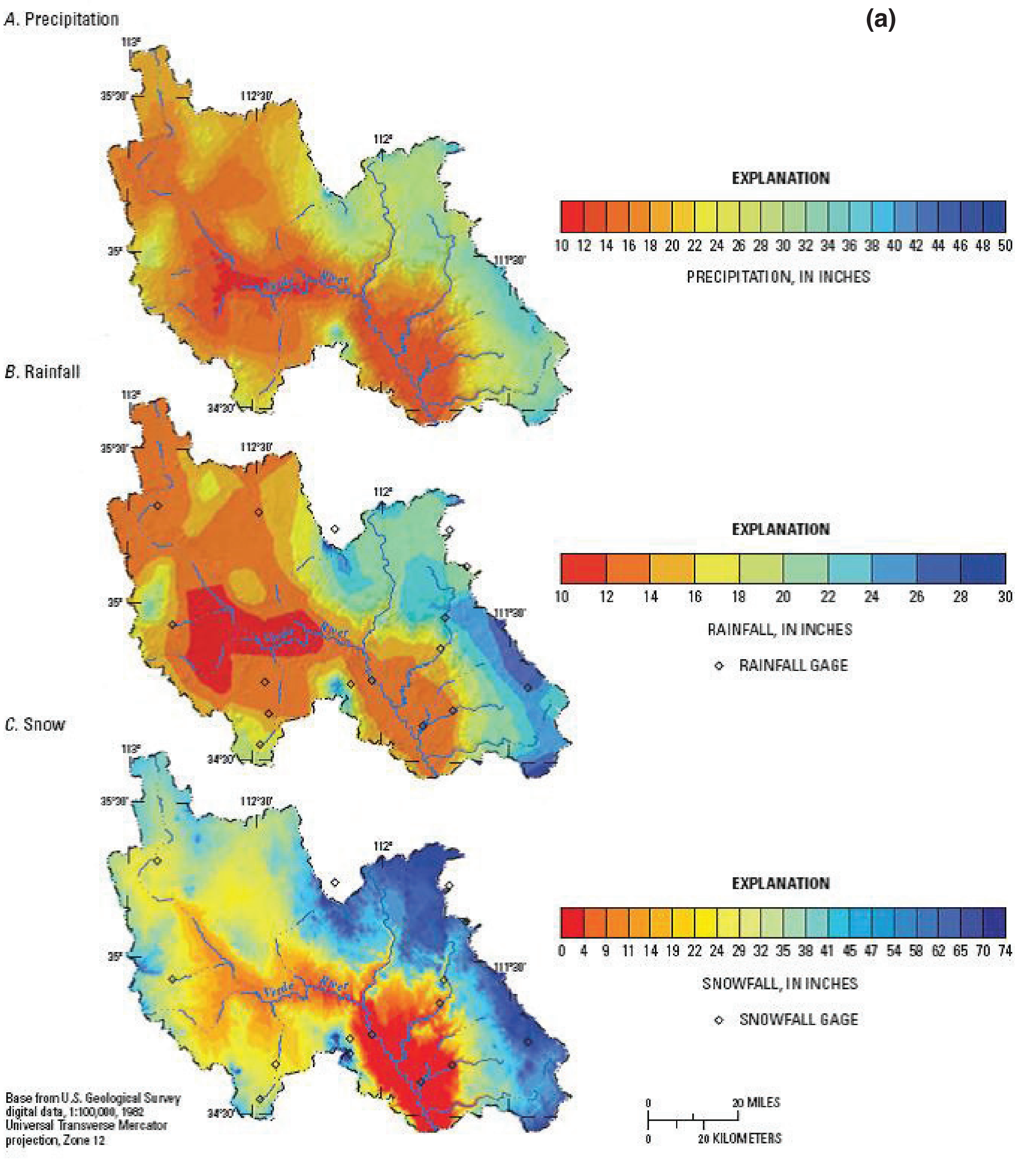
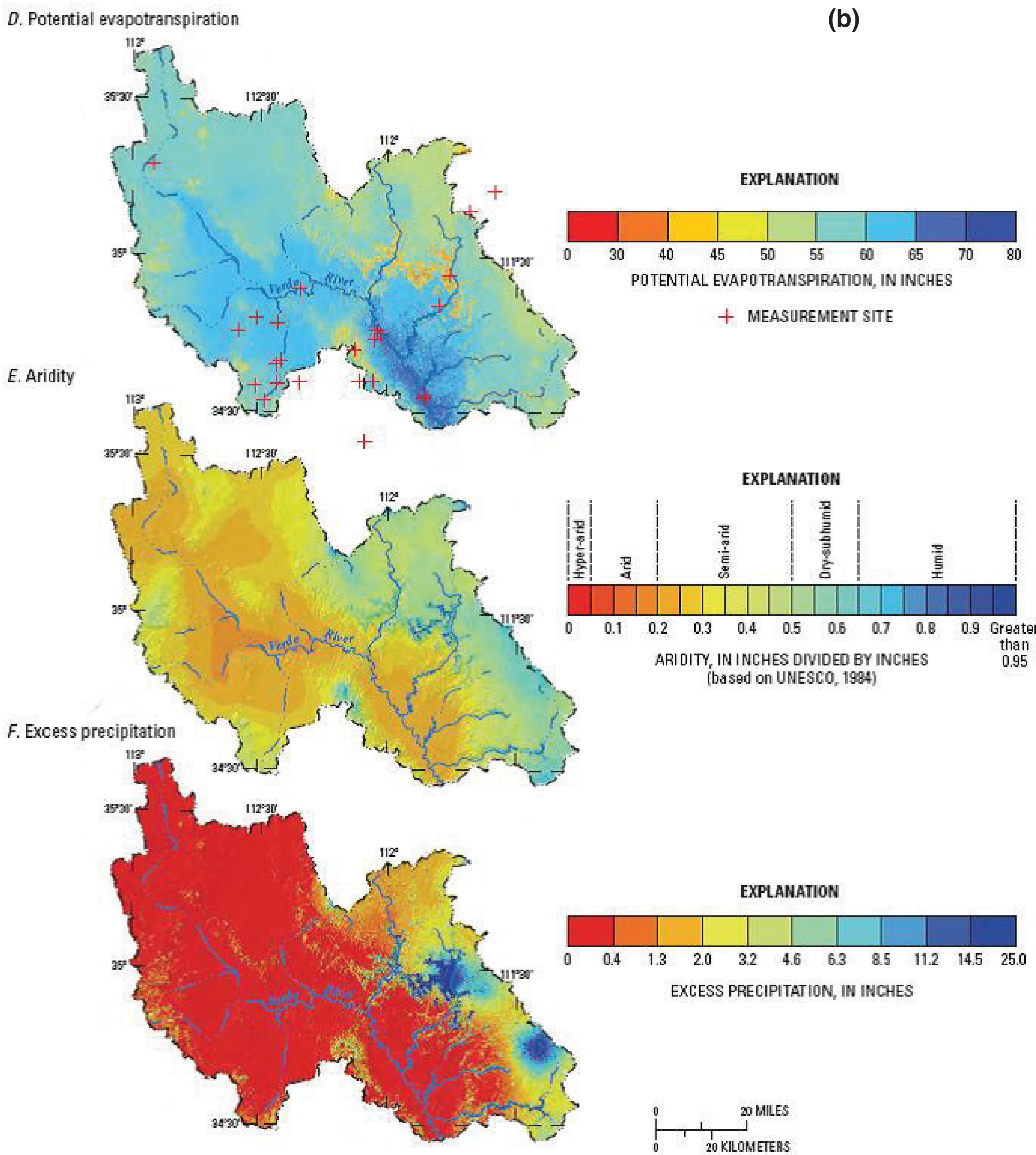


Figure 3.4—Average annual climate values for the UVR and Middle Verde River watersheds: (a) precipitation, rainfall, and snowfall; and (b) potential evapotranspiration, aridity, and excess precipitation (from Blasch and others 2006).



(b)
D. Potential evapotranspiration
EXPLANATION
0 30 40 45 50 55 60 65 70 80
POTENTIAL EVAPOTRANSPIRATION, IN INCHES
MEASUREMENT SITE
E. Aridity
EXPLANATION
Hyper-arid
Arid
Semi-arid
Dry-subhumid
Humid
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 Greater than 0.95
ARIDITY, IN INCHES DIVIDED BY INCHES
(based on UNESCO, 1984)
F. Excess precipitation
EXPLANATION
0 0.4 1.3 2.0 3.2 4.6 6.3 8.5 11.2 14.5 25.0
EXCESS PRECIPITATION, IN INCHES
Verde River
0 20 MILES
0 20 KILOMETERS

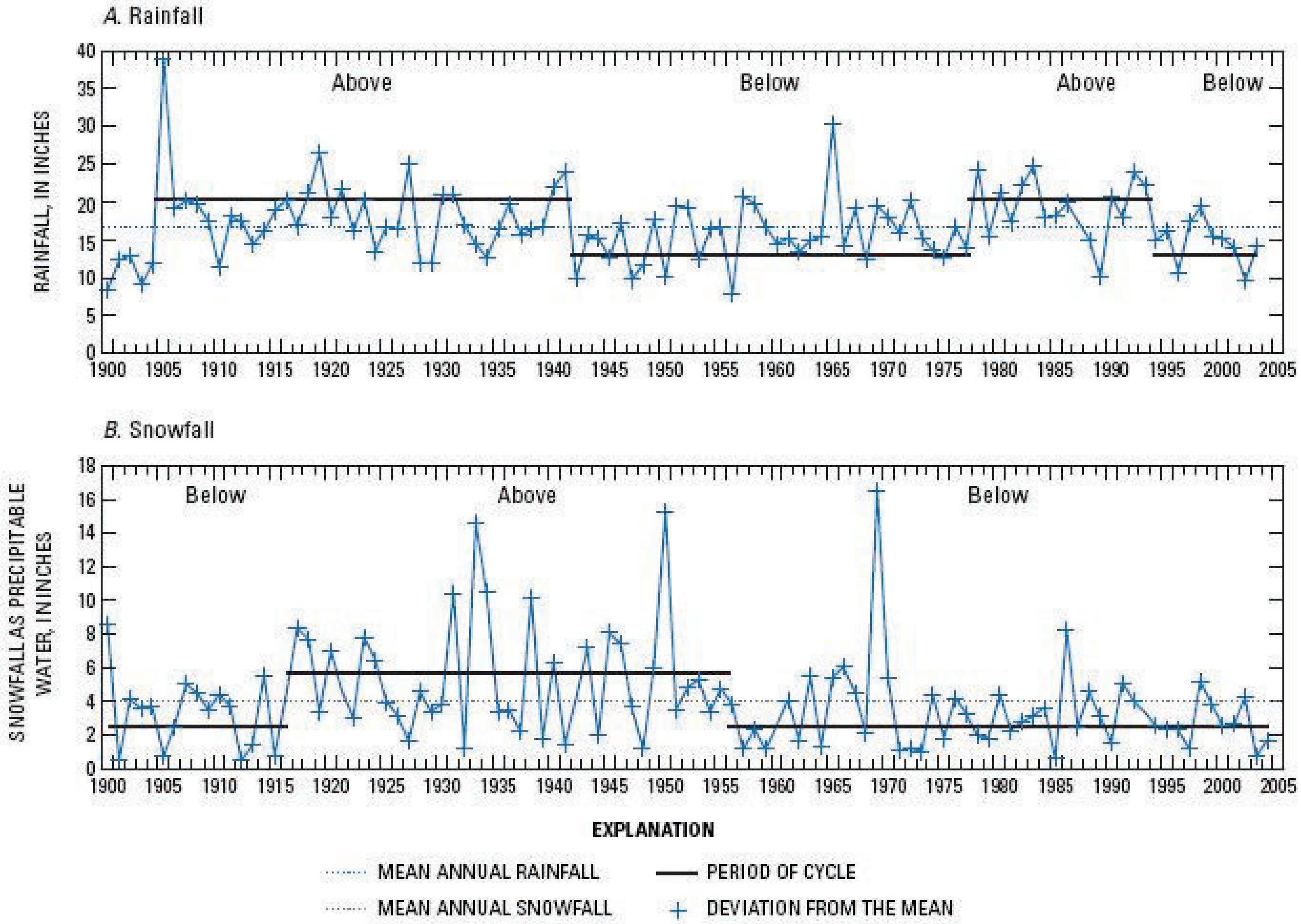


Figure 3.5—Annual deviations in rainfall and snowfall for the UVR and Middle Verde River basins, 1900 to 2005 (from Blasch and others 2006).

evapotranspiration rates average in excess of 1520 mm (60.0 in yr^{-1}), which creates the semi-arid conditions (fig. 3.4b).

UVR Groundwater

Background—The steady baseflow that characterizes the UVR is supplied by a series of river-channel springs emanating into the river near the beginning of the perennial reach (Wirt and Hjalmarson 2000). The UVR distance designations of River Kilometer (RK) and River Mile (RM) used in this chapter follow the conventions of Wirt and Hjalmarson (2000) and Blasch and others (2006). Most of the baseflow discharge up stream of Perkinsville at RK 42 (RM 26) occurs in the upper reach between RKs 3 and 6 (RM 2 and 4), respectively (figs. 1.1 and 1.5). Other small sources are discrete streambank springs and interflow from the Granite Creek sand and gravel bed (fig. 2.19). Average baseflow reported by Wirt and Hjalmarson (2000) from 1963 to 2000 for the USDI Geological Survey Paulden gauge (RK 16 or RM 10) was 0.70 m^3 sec^{-1} (24.9 ft^3 sec^{-1}), but mean daily baseflow ranges from 60 to 133% of that amount. Although the source springs are fairly well defined, the sources of the groundwater feeding these springs are quite complex. The springs supply a steady source of baseflow that is important for aquatic fauna such as the threatened spikedace (*Meda fulgida,* see Chapter 9), other aquatic fauna, riparian vegetation, and downstream water uses as far south as Phoenix. The USDI Fish and Wildlife Service (1999) considered designating the Verde River below Sullivan Dam (figs. 2.14 through 2.18) as critical habitat for several native fish species. In 1984, Congress declared parts of the Verde River in the middle and lower sections below Camp Verde as Wild and Scenic River areas. There have been discussions amongst local environmental groups of nominating parts of the UVR in canyon-bound reaches as Wild and Scenic River areas.

The UVR watershed is mostly within the fastest growing non-metropolitan county in Arizona (Yavapai County). It has a growth rate of 3.4%, which is four times the national average (Woods & Poole Economics, Incorporated 1999). Population is expected to rise from 37,000 in 1970 to 313,000 by the year 2020 (Woods & Poole Economics, Incorporated 1999). Since there are no significant surface water sources in the Prescott area, much of this growth has relied on groundwater in the Little Chino aquifer. Since 1940, groundwater levels in Little Chino Valley have receded by more than 23 m (75 ft) in the margin of the basin closest to the source springs of the Verde River (Arizona Department of Water Resources 1998, 1999). Although the Little Chino and Big Chino Valleys route all surface-water drainage to the UVR above Hell Canyon, there have been on-going discussions between local, State, and Federal officials and scientists over the issue of these basins being a major source of groundwater flow versus aquifers to the north of the river. Wirt and Hjalmarson's (2000) analysis clearly points out the overriding importance of the Big Chino and Little Chino aquifers.

Wirt and Hjalmarson's (2000) review appears to leave no doubt that groundwater discharge from Little Chino Valley to the Verde River has substantially declined during the past six decades when groundwater withdrawals have increased due to urbanization of the Prescott area. Perennial flow that was once continuous from Del Rio Springs into Lake Sullivan and that served as the head of perennial flow in the UVR no longer occurs (Krieger 1965). Del Rio Springs is fed by the Little Chino artesian aquifer, which has been depleted substantially since the 1940s. Surface discharge from Del Rio Springs has also been diverted for municipal and agricultural uses.

Demand for water in the UVR Valley is increasing because of rapid population growth near the city of Prescott. There is concern that over-use of Big and Little Chino Valley groundwater could eventually deplete baseflows in the UVR and dry up the river during low-flow periods (Neary and Rinne 1998, 2001a). In the past several decades, baseflow in the UVR has actually increased slightly due to a wet climate cycle and decreasing agricultural irrigation in Big Chino Valley. Improved understanding of groundwater sources and their relative contributions to the baseflow of the UVR, flow pathways, and future consumptive uses are needed so that the water resources in Big and Little Chino aquifers can be managed effectively to maintain UVR baseflow.

Geology—The geology of the UVR headwaters and aquifers is extremely complex (fig. 3.1). However, a simplified conceptual view presents a better picture of the groundwater flows that feed the perennial baseflows of the UVR (fig. 3.6). Paleozoic limestones form the basement rocks of a structurally controlled half graben. Both the Little Chino and Big Chino valleys are filled with unconsolidated alluvium and 4.5 million-year-old basalt intrusions. The alluvium consists of gravels inter-bedded with fine-textured lake bottom sediments. The Big Chino Fault is an important structural feature relevant to the hydrology of the Big Chino Valley because it is a large regional feature that has been delineated running northwest of Paulden for 42 km (26 mi) (Krieger 1965). Substantial groundwater flow occurs along and through this fault. Solution features in the limestone such as caves,

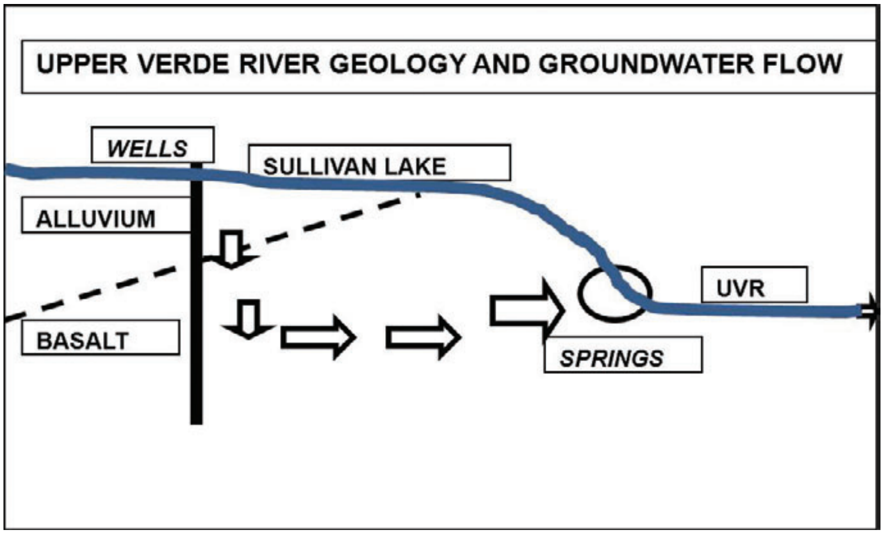


Figure 3.6—Simplified schematic of the UVR geology and groundwater flow (adapted from Wirt and Hjalmarson 2000).

joints, fractures, and faults as well as other irregular subsurface characteristics provide the likely hydrologic connection between Big Chino Valley and the UVR springs that begin the perennial baseflow of the river (fig. 3.6).

Wells and Spring Discharge—According to Wirt and Hjalmarson (2000), groundwater changes in the Big Chino Valley have been relatively small as a result of human activities. Initial changes were due to agricultural withdrawals that have diminished in recent years as municipal pumping has increased. Conversely, the Little Chino artesian aquifer has been extensively developed for public water supply, industry, and agriculture since the late Nineteenth Century. The perennial flow at Del Rio Springs was once known as a reliable source of water to the earliest explorers and settlers. Camp Whipple was established at Del Rio Springs on December 23, 1863, to provide the territorial governor's entourage with a secure base for further exploration (Henson 1965). Accounts by these explorers reported that Del Rio Springs (then named Cienega Creek) was the headwater tributary of the Verde River. The springs were developed in the early part of the century for water supply and irrigation. Krieger (1965) reported that in 1901, the City of Prescott built a 34-km (21-mi) pipeline that pumped 1,890 m^3 day^{-1} (500,000 gal day^{-1}) (Baker and others 1973) from Del Rio Springs to Prescott from 1904 to 1927 (Matlock and others 1973). Although the supply of water was adequate for Prescott's needs, the cost of pumping was considered excessive and the pipeline was eventually disassembled (Krieger 1965). One hundred years later, the groundwater supply of the Big Chino aquifer is being considered as the solution to water supply shortages in Prescott and Prescott Valley. Impacts on streamflow in the UVR could become significant if this inter-basin groundwater transfer is allowed.

Well drilling and pumping out of the Little Chino aquifer began around 1925. Wells were developed for local use in the town of Chino Valley, Prescott, and for the Santa Fe Railroad. According to sources listed by Wirt and Hjalmarson (2000), groundwater levels have dropped by as much as 23 m (75 ft) (Remick 1983, Corkhill and Mason 1995, Arizona Department of Water Resources 1998, 1999). Artesian wells that used to flow at the surface or to within a few meters of the ground surface no longer do so. Groundwater flows from the Little Chino aquifer system toward the UVR headwaters have declined from pre-development flows of 4.93 to 6.17 x 10^6 m^3 yr^{-1} (4,000 to 5,000 ac-ft yr^{-1}) to less than 2.47 x 10^6 m^3 yr^{-1} (<2,000 ac-ft yr^{-1}).

A large cienega below Del Rio Springs supported permanent baseflow from lower Little Chino Creek to Sullivan Lake. Since the early 1970s, the lower reach of Little Chino Creek has been ephemeral. Sullivan Lake (figs. 2.10 and 2.11) has been mostly dry except during winter and monsoon storm runoff from Big Chino Wash, Williamson Valley Wash, or Little Chino Creek. The first 1.6 km (1 mi) of the UVR below Sullivan Lake has lacked any sustained flowing water due to declining flow from Del Rio Springs as a result of extensive groundwater pumping (Corkhill and Mason 1995).

Conclusions—Wirt and Hjalmarson (2000) concluded at the end of their report on the UVR that virtually all of the baseflow in the UVR originates in the spring networks of the Big Chino Springs and Lower Granite Springs. They noted that there is a strong hydrologic connection between the Big Chino Valley groundwater and Big Chino Springs. This source of water accounts for 80% of the total baseflow of the UVR, not the Ash Fork, Big Black Mesa, and Bill Williams Mountain aquifers north of the river. Wirt and Hjalmarson (2000) pointed out that higher-altitude drainages such as Williamson Valley Wash and Walnut Creek are the most likely sources of recharge to the Big Chino Valley aquifer. They reported that the most likely sources of Lower Granite Spring, a major contributor to UVR baseflow, is a combination of the Little Chino Valley aquifer and the Big Chino unconfined aquifer. Another overriding finding was that groundwater discharge to the UVR has declined in the past 20 to 30 years due to a number of natural and human-caused impacts on the aquifers.

The most important implication of the Wirt and Hjalmarson (2000) report is that continued urbanization and use of the Big Chino aquifer may have substantial negative impacts on baseflows of the UVR. This would, in turn, seriously affect habitat of the native fish fauna of the UVR and other uses of the UVR flows, including irrigation in the Middle Verde River reach and municipal water supply for Phoenix via the Verde and Salt Rivers reservoir system.

UVR Streamflow

General Characteristics—Streamflow is composed of two components: surface runoff and base flow. Surface runoff has little effect on the amount of water available for use in the UVR area since it occurs over short periods of time and no major impoundments are present for the storage of high flows or flow regulation (Owen-Joyce and Bell 1983; Wirt and Hjalmarson 2000). Consequently, baseflow is an extremely important source of water for in-stream flows, especially for the fish fauna of the UVR. In some reaches, baseflow increases downstream because of groundwater discharge; in other reaches, it is depleted by evaporation and transpiration by riparian vegetation. The availability of streamflow, therefore, is limited by natural low flows and upstream usage.

Flows are gauged in the UVR at Paulden and Clarkdale (figs. 1.1 and 2.10). The discussion in this chapter will use data from the Paulden gauge only. Paulden has a period of record extending from 1963 to the present (2011). Flows at Clarkdale are higher numerically, but they follow the same trends. The Paulden gauge is in Yavapai County, Arizona. Its Hydrologic Unit Code is 15060202. The gauge, with a natural control section, is located at latitude 34°53’42”, longitude 112°20’32” at 1,255 m (4,120 ft) above sea level. It has a drainage area of 6,490 km^2 (2,507 mi^2) (USDI Geological Survey 2009). At the Paulden gauge, the mean annual discharge over 45 years of record is 1.26 m^3 s^{-1} (44 ft^3 s^{-1}) (USDI Geological Survey 2009). The mean minimum daily discharge, a critical flow for fish habitat, is 0.60 m^3 s^{-1} (22 ft^3 s^{-1}), and the mean maximum daily peakflow is 95.40 m^3 s^{-1} (3,369 ft^3 s^{-1})

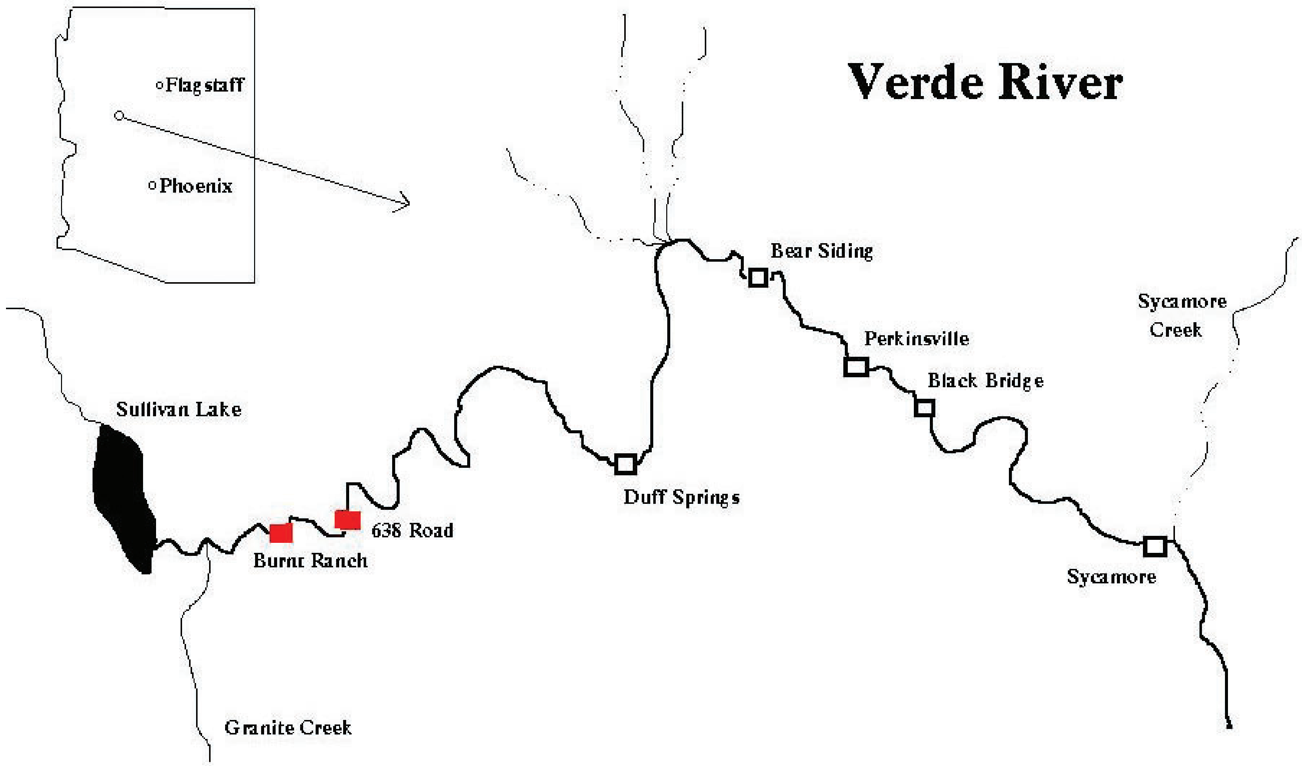


Figure 3.7—Sullivan Lake, UVR study sites, and USDI Geological Survey Paulden Gauge, Yavapai County, Arizona (Gauge #09503700).

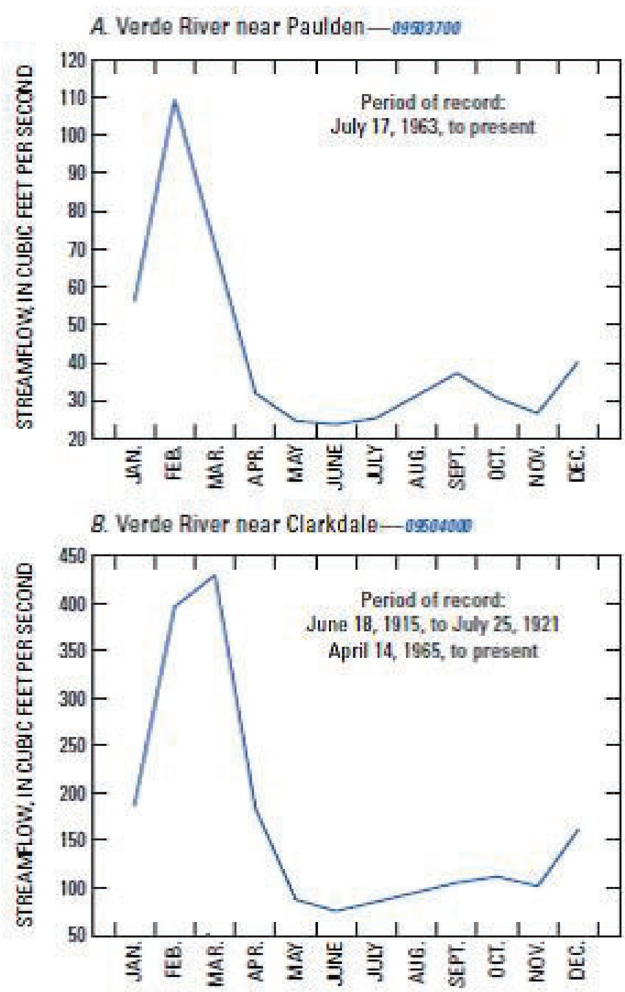


Figure 3.8—Average monthly streamflow for the Paulden Gauge (09503700) and Clarkdale Gauge (0950400) (adapted from Blasch and others 2006).

with a range over three orders of magnitude from 2.04 to 657.00 $m^3 s^{-1}$ (72 to 23,200 $ft^3 s^{-1}$) . Nearly 50% of the annual flow is produced in three months from January through March. The remainder of the year flow is dominated by baseflows (fig. 3.8).

The important flows for aquatic organisms like fishes are the minimum low flows and the peak flows. Low flows affect the amount of aquatic habitat, produce organism stress, and magnify predation effects by confining fish in smaller volumes of water such as pools. Bankfull flows are the major channel-forming flows in the short term (Rosgen 1994. However, large, episodic peak flows produce significant disturbances in the aquatic environment and move large channel sediments around. They play an important role in forming UVR channels and cleaning coarser sediments. Peak flows stress all fish species, but the native fishes are adapted to the episodic, high peak flows of Arizona rivers while nonnative fishes are not (Rinne and Stefferud 1997; Rinne 2003a, 2006). Native fish reproduction also is stimulated by flood flows. Because of its importance in the flow regime and habitat maintenance of the spikedace, baseflow is emphasized more than surface storm runoff in the following analyses of streamflow.

Baseflow—The baseflow characteristics of the UVR and its major tributaries are a function of precipitation on the landscape and the properties of the regional aquifers. The capacity of the aquifers to receive, store, and transmit water has a significant effect on baseflow. Long-term changes in the baseflow may indicate changes in the volume of water stored in the aquifer and how discharge from the aquifer is distributed among well pumpage, stream flow, and evapotranspiration losses.

The baseflow in the Verde River (fig 3.9) and in most tributaries varies seasonally in relation to the amount of water used by plants (Wirt and Hjalmarson 2000; fig. 3.8). Baseflow is at a maximum in January and February and at a minimum in July and August. The year-to-year variation in base flow that enters the Middle Verde River valley by way of the UVR and tributaries can be small or quite large depending on the climate of the region (fig. 3.10). Since much of the flow of the UVR is dependent on annual rainfall, the wet and dry cycles typical of the Southwest are reflected in baseflow. Future climate change of increased aridity in the Southwest

Figure 3.9—Baseflow on the UVR downstream of the Verde River Ranch. (Photo by Alvin L. Medina).

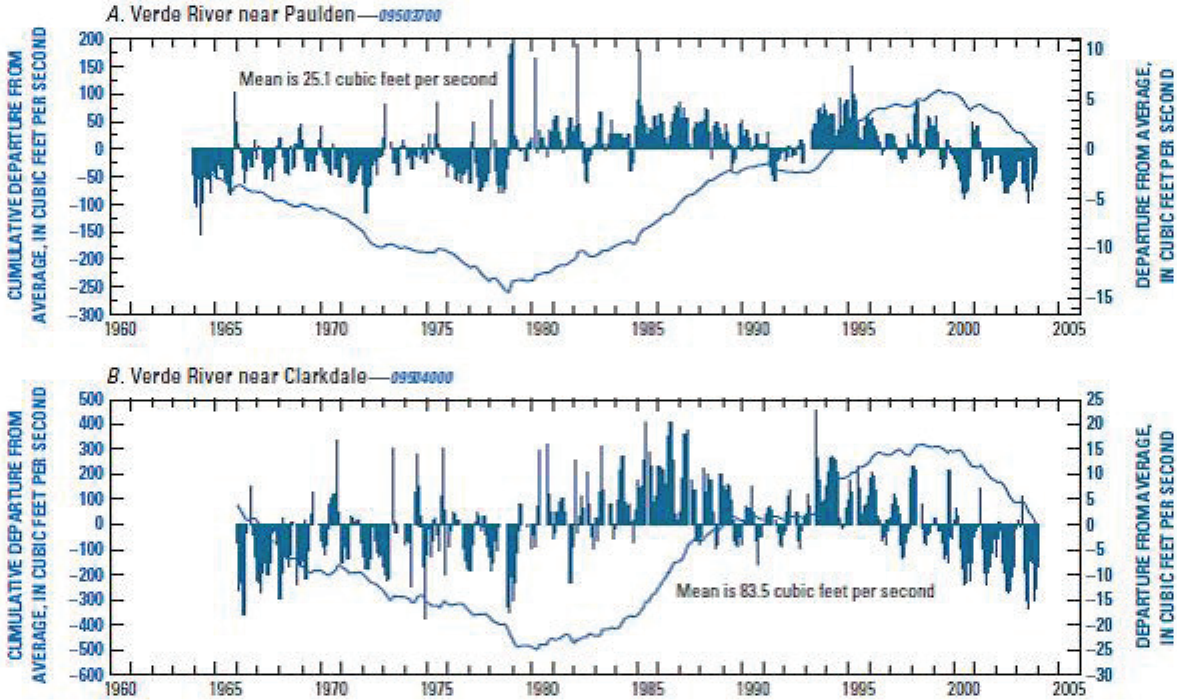


Figure 3.10—Cumulative departure from average winter base flow for the Paulden and Clarkdale gauges (adapted from Blasch and others 2006).

will probably affect baseflow on the UVR to a greater extent than in the past. Following a series of wet years from 1993 to 2000, baseflows are declining from the long-term mean. The seasonal variation in baseflow is an indication of evapotranspiration losses in the drainage area upstream from a gaging station. Baseflow is at a maximum in January and February when plants are dormant and evaporation is low. The high baseflow in January represents the average groundwater discharge from the regional aquifers.

Perennial flow in the UVR begins near Granite Creek (fig. 2.10), the first tributary downstream of Sullivan Lake (fig. 2.19). Sullivan Lake is a misnomer since the lake was filled in not too long after its construction at the turn of the Twentieth Century; it now functions as a channel step. Discharge measurements made in 1977 indicate that the Verde River gained 0.57 $m^3\ s^{-1}$ (20 $ft^3\ s^{-1}$) between Granite Creek and Burnt Ranch (Owen-Joyce and Bell 1983; Wirt and Hjalmarson 2000). Between Burnt Ranch and the Verde River near Paulden gauge, discharge measurements indicated a gain of 0.20 $m^3\ s^{-1}$ (7 $ft^3\ s^{-1}$). Baseflow at the Paulden gauge is relatively constant and ranges from 0.57 to 0.74 $m^3\ s^{-1}$ (20 to 26 $ft^3\ s^{-1}$) during the year. The seasonal variation in the median baseflow hydrograph is from 0.62 to 0.68 $m^3\ s^{-1}$ (22 to 24 $ft^3\ s^{-1}$). Between the gauge near Paulden and the gauge near Clarkdale, baseflow increases to 1.70 to 2.63 $m^3\ s^{-1}$ (60 to 93 $ft^3\ s^{-1}$), and the seasonal variation in median baseflow is from 1.93 to 2.35 $m^3\ s^{-1}$ (68 to 83 $ft^3\ s^{-1}$). Discharge measurements made in 1977 and 1979 (Levings and Mann 1980; Wirt and Hjalmarson 2000; Wirt 2005) show a gain in flow attributed to groundwater of about 0.62 $m^3\ s^{-1}$ (22 $ft^3\ s^{-1}$) at Mormon Pocket, 0.25 $m^3\ s^{-1}$ (9 $ft^3\ s^{-1}$) from below Mormon Pocket to Sycamore Creek, and 0.34 $m^3\ s^{-1}$ (12 ft^3/s) downstream from Sycamore Creek. No groundwater discharges to the Verde River occur in the 3-km (2-mi) reach below the Paulden gauge, but about 0.06 $m^3\ s^{-1}$ (2 $ft^3\ s^{-1}$) discharges between there and in Mormon Pocket. Tributary inflow from Sycamore Creek is 0.25 $m^3\ s^{-1}$ (9 $ft^3\ s^{-1}$).

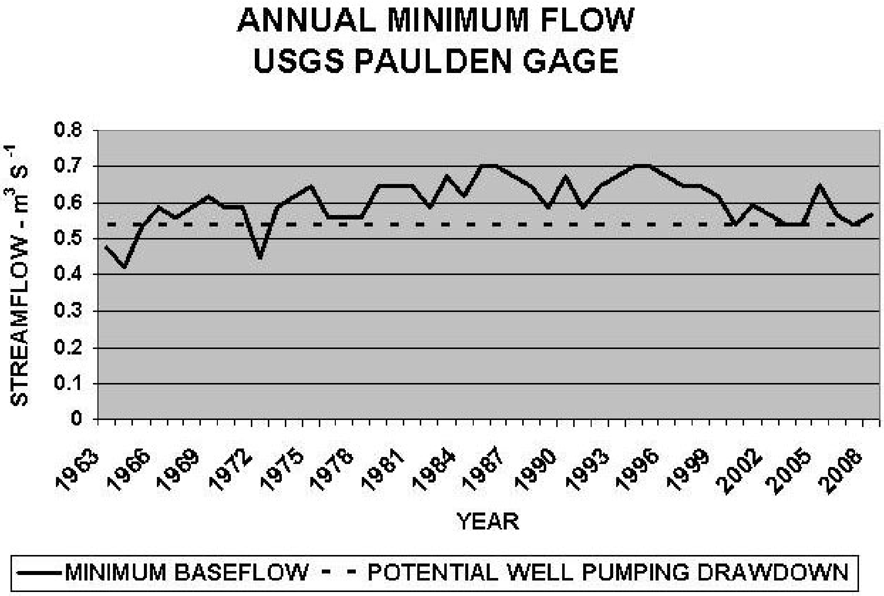


Figure 3.11—Minimum baseflow variation in the UVR, Paulden gauging site 1963 to 2008 (USDI Geological Survey 2009).

The small seasonal variation at the Paulden and Clarkdale gauges is associated with the low water use in this region and low loss of water from the river surface to evapotranspiration. The water lost to evapotranspiration between Sullivan Lake and Clarkdale is only 8% of the loss that occurs below Clarkdale (Anderson 1976). Records for the station near Clarkdale from June 1915 to June 1921 indicate that the base flow is identical to the base flow calculated for data collected from April 1965 to September 1978. The lack of change suggests that the groundwater system upstream from Clarkdale is still in an equilibrium condition.

A critical baseflow parameter for fish species such as the spikedace is the annual minimum flow (Neary and Rinne 1998, 2001a). Loss of physical habitat is absolutely critical to aquatic species since they don't survive well in ephemeral systems. Figure 3.11 shows the annual minimum baseflow at the Paulden gauge. There have been cyclical oscillations in baseflow, with a period of increase from 1982 to 1998 (Neary and Rinne 1998, 2001a) that appeared to indicate a trend of increasing baseflows. However since then, the trend has been downward, reflecting regional drought trends and increased urbanization of the Little and Big Chino Valleys. This is in response to rainfall patterns over the period of record. The absolute minimum baseflow over the period of record was 0.42 $m^3 s^{-1}$ (15 $ft^3 s^{-1}$) in 1964.

The level line in fig. 3.11 indicates the potential pumping rate from proposed municipal well development in Chino Valley for the city of Prescott. The line does not suggest that pumping will immediately consume that amount of water from the UVR. It is just an indication of a potential effect given the linkage between baseflow of the Verde River and groundwater elucidated by Owen-Joyce and Bell (1983). It is a warning that groundwater pumping in the Chino Valley to support rapid urbanization on the Prescott area may pose a significant threat to fish in the UVR that goes beyond all existing threats. Well pumping to export water just to Prescott could de-water the UVR and put aquatic habitat in jeopardy. Other groundwater usage not accounted for in this analysis would just exacerbate the situation.

Prescott Consumptive Use of the Big Chino Aquifer—In 2004, the City of Prescott proposed pumping up to 170 million m^3 (45 billion gallons) of groundwater from the Big Chino Basin could seriously impact minimum daily flows on the

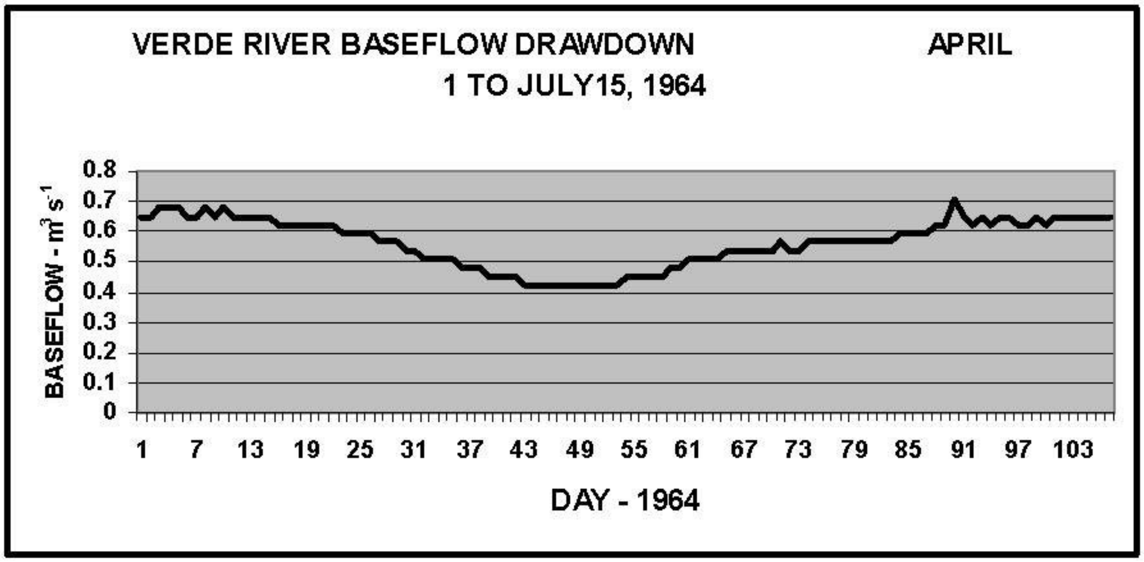


Figure 3.12—Baseflow drawdown from groundwater pumping in the Chino Valley, Paulden Gauge, April 1 to July 15, 1964.

Verde. Pumping the full allotment (equivalent to 0.54 $m^3\ s^{-1}$ or 19 $ft^3\ s^{-1}$; dotted line in fig. 3.11) could significantly affect baseflow in the UVR in the driest of the past 46 years. Wirt and Hjalmarson (2000) concluded that 80% or more of the UVR's baseflow comes from interconnected aquifers in the Big Chino Valley. The authors also noted that groundwater pumping at a rate of 24.61 $m^3\ min^{-1}$ (6,500 gal min^{-1}) in the spring of 1964 to fill several lakes decreased baseflows at Paulden by 25% (fig. 3.12). The 1964 groundwater pumping was two-thirds the potential maximum rate that the Prescott pumping would involve. With baseflow reductions, both native and nonnative fish populations would be forced into remnant pools, thereby aggravating an already serious predation problem that is contributing to the decline of native fish species.

Flow-Duration Curve—A flow-duration curve is a cumulative frequency curve that shows the percentage of time during the period studied that a specified rate of flow was equaled or exceeded. The curve provides a useful method for analyzing the availability and variability of streamflow without regard to the sequence of the flow events. The distribution of streamflow with respect to time is a function of many variables such as the amounts and type of precipitation, topography, soils, geology, vegetal cover, groundwater movement, and water-use patterns. A steeply sloping duration curve indicates high variability in flow rates and small amounts of natural storage, and a gently sloping curve indicates a low variability, which is characteristic of a consistent component of baseflow per unit drainage area.

The flow-duration curve for Paulden is shown in fig. 3.13. It is indicative of high variability in flow rates between peak flow and base flow. It also indicates that the UVR is usually in stable baseflow most of the time—large storm flows occur <1% of the time, but it is those large peakflows that shape channels and move sediment. The stable baseflows are important for maintaining aquatic habitat in a semi-desert to desert region.

Peak Flows—Peak flows are the channel-forming flows that occur episodically during floods on desert rivers like the UVR (fig. 3.14). The maximum daily instantaneous peak flows in each year for the period of record are presented in fig. 3.15. Only 15 of the 45 years had instantaneous peak flows that exceeded the 5-year return period maximum 24-hour peak flow rate of 57.48 $m^3\ s^{-1}$ (2,030 $ft^3\ s^{-1}$). The

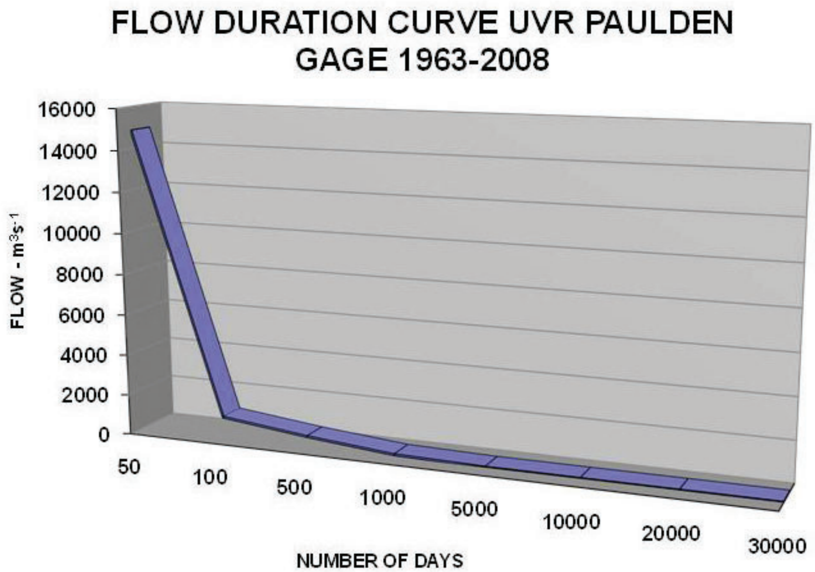


Figure 3.13—Flow-duration curve for the UVR, Paulden Gauge 1963 to 2008 (USDI Geological Survey 2009).

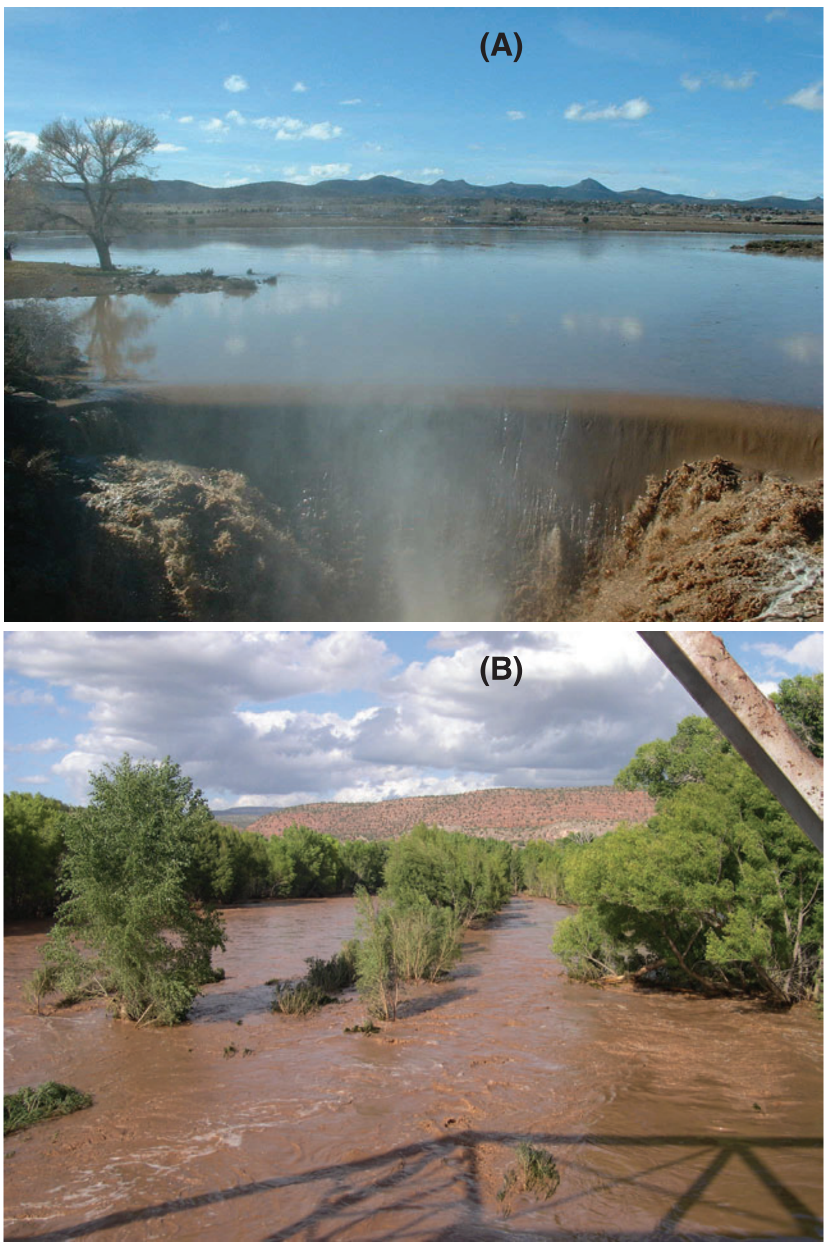


Figure 3.14—Flood flows on the UVR at: (a) Sullivan Dam and (b) Perkinsville. (Photos by Alvin L. Medina.)

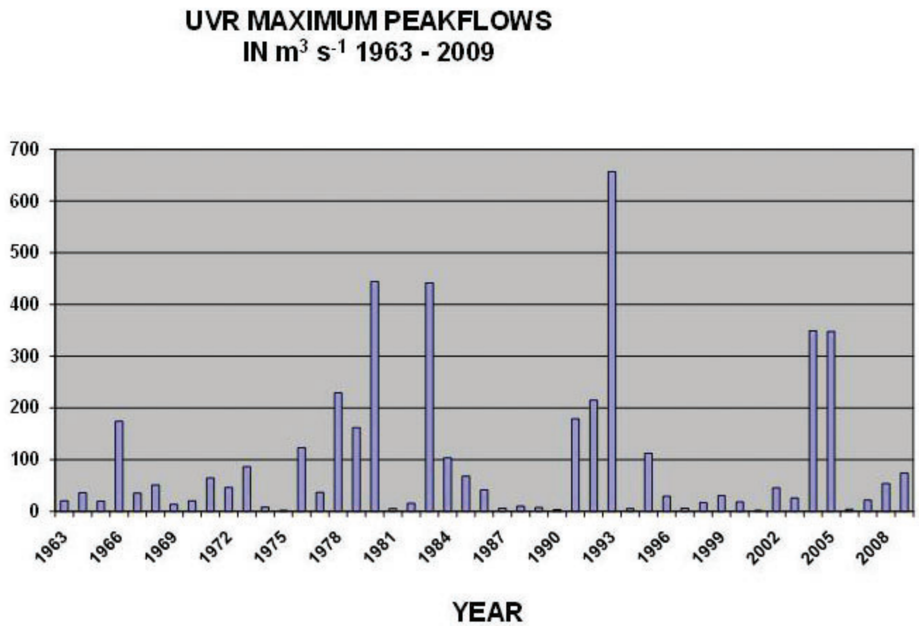


Figure 3.15—Maximum daily instantaneous peak flows, UVR at Paulden, 1963 to 2008 (USDI Geological Survey 2009).

largest storm (in 1993) had a 24-hour flow of 40.80 $m^3 s^{-1}$ (1,441 $ft^3 s^{-1}$). Based on UVR records of 24-hour flows, this was a 37-year return interval storm. The instantaneous peak flow for that storm, shown in fig. 3.15, was 16 times higher at 656.92 $m^3 s^{-1}$ (23,199 $ft^3 s^{-1}$) with a return interval of 72 years. This information again points out the episodic nature of large storm events on the UVR. The vast majority of sediment transported in the UVR over the 37-year period of record can be attributed to one storm, the 1993 flood with the record peak flow. The episodic nature of UVR peak storm flows is also noticeable in fig. 3.15 in that the five-year return interval storms in the data record have been clumped in nature. There is also a trend toward increasing peak flows over the period of record for the Paulden gauge that correlates with precipitation patterns (Neary and Rinne 1998, 2001a).

Supporting Data From Beaver Creek

Large storms like the 1993 flood on the UVR are major, clock-setting events for riparian areas and channel systems. Much of the sediment transported over many decades can be traced back to one storm. The hydrologic, geomorphic, and sedimentation effects are usually a function of precipitation intensity and often occur irrespective of past or present land use. The Labor Day Storm of 1970 was one such event. This storm produced a peakflow at the Paulden gauge on the UVR of just under 20 $m^3 s^{-1}$, considerably less than peakflows measured further south at Beaver Creek and Tonto Creek in the same storm. Hydrological and meteorological information on that same storm was available from the intensively studied Beaver Creek watersheds located south of the UVR in a tributary of the Middle River section (see figs. 1.5 and 1.6). That information is presented here to provide another perspective on large floods in Central Arizona and, in particular, on the 1993 UVR flood.

The 1970 Labor Day Storm caused more loss of human life than any other storm in Arizona's recent history, many dwellings, roads, bridges, and other structures were also damaged or destroyed (Thorud and Ffolliott 1971, 1972). Most of the widespread and unprecedented losses, both economic and of human life, occurred in central and northeastern Arizona with other losses reported in southeastern Utah and southwestern Colorado (Roeske and others 1978). Although it is difficult to assess the total dollar cost of the storm, it has been estimated that initial expenditures to repair or replace storm-damaged infrastructures totaled nearly $25 million by today's standards.

Conditions that led to the Labor Day Storm developed with a northward advance of moist, unstable air associated with tropical storm Norma from the Pacific Ocean and Gulf of California. The triggering mechanisms that contributed to the heavy rainfall in Arizona included orographic uplift associated with strong southerly winds in the lower atmosphere, the invasion of an unusually intense late summer cold air mass from the Pacific Northwest with its associated frontal activity, and daytime heating over the Arizona desert valleys. Rainfall totals of 130 mm (5 in) or more (a 100-year event in many areas of Arizona) were associated with the Mogollon Rim and other high country areas of Arizona. New precipitation records for a 24-hour period were established. Rainfall intensities of greater than 80 mm (3 in) in four hours were reported and easily exceeded the infiltration rates on many watersheds with shallow soils on top of bedrock, thereby facilitating a large amount of surface runoff and high peak stream flows.

Peak discharges of several streams in central Arizona exceeded the 20-to 25-year flood event with much higher return periods on small watersheds of 64.7 km^2 (<25 mi^2). At least 30 USDI Geological Survey gauging stations in the Gila River Basin measured record peak stream flows (Roeske and others 1978). An estimated peak flow of about 521 $m^3 s^{-1}$ (18,400 $ft^3 s^{-1}$) occurred on upper Tonto Creek and combined with high flows from two tributaries (Christopher and Haigler Creeks), resulting in a peakflow of 1,064 $m^3 s^{-1}$ (38,000 $ft^3 s^{-1}$) on upper Tonto Creek near Gisela, Arizona. The upper Tonto Creek peak streamflow was 162% of the UVR peakflow in the 1993 storm.

Many stream channels on upland watersheds were detrimentally altered as a result of flooding. Damage included accumulations of uprooted trees and other materials in debris dams, depositions of boulder field, channel scouring (to bedrock in some cases), and bank cutting. Massive boulder fields were deposited at various locations. Some deposits were 3 to 9 m (10 to 30 ft) in depth, extending the width of the channel, and up to 0.8 km (0.5 mi) in length. Damage to fisheries was extensive. Streams were sometimes split into multiple channels by rock piles, often with insufficient flow to support fish populations. Other conditions detrimental to fishes and invertebrates included channel scouring to bedrock; filling of pools with boulders, sand, and silt; and the diversion of channels.

On one pair of pinyon-juniper woodland watersheds, total runoff, peak stream flows, and total sediment yields were found to be higher on the treated watershed that had been mechanically cleared (cabled) of its overstory (Clary and others 1974). Peak rainfall intensity was 36 mm hr^{-1} (1.4 in hr^{-1}). On another pair of watersheds, the peak discharge occurred on the untreated watershed where rainfall peaked at 46 mm/hr (1.8 in hr^{-1}). The overall maximum peak flow response for Beaver Creek during the Labor Day Storm came from an untreated ponderosa pine watershed where peak rainfall intensity was 50 mm hr^{-1} (2.0 in hr^{-1}). Rainfall intensity, not vegetation treatment, determined peak flow response and concomitant watershed and riparian area damage. Thus, it is very important that the real cause of peak flow increases (peak rainfall intensity) be determined instead of it being blamed on vegetation management treatments (Thorud and Fffolliott 1971, 1972).

Restoration activities on the larger, perennial streams included corrective actions taken to mitigate the effects of boulder accumulation, timber-related debris, vertical stream banks, channel scour, sand and silt deposits, stream channel diversions, road and trail damage, loss of streamside vegetation, and bank-hanging and pedestaled trees. The most extensive of these restoration activities occurred on Tonto Creek, the East Verde River, and Christopher Creek. Approximately 22 km (14 mi) of stream channel required restoration activities of some kind because of potential hazard to life and property. All of this work was performed within the riparian zones of the various streams.

Insights to the degree of damage mitigation in the first 30 years after the Labor Day Storm were derived from limited and largely qualitative observations from the Tonto Creek and Beaver Creek watersheds areas using color photographs (Ffolliott and Baker 2001). Trees and other vegetative materials in the debris dams have largely decomposed. Only a few larger tree parts and some of the larger accumulated sediment remain visible. Channel restoration on some of the streams after the flood has further obliterated signs of the dams. Vegetation has become established in some of the boulder fields and many of the scoured areas contain accumulations of sediment. The fishery resource has responded favorably. Creation of pools and riffles and re-establishment of streamside vegetation have benefitted trout populations. The Tonto Creek Hatchery was rebuilt by the Arizona Game and Fish Department after it was destroyed by an 11 m (36 ft) high leading edge of a flash flood during the storm.

Observations on impacts of the storm flows and the effectiveness of restoration activities suggest that the hydrologic functioning of both the restoration-treated and unrestored streams was largely returned to normal dynamic conditions. These types of damaging storms are natural components of the hydrologic cycle in the Southwest. Current bank erosion is not excessive, streamflow response to precipitation appears relatively slow, and baseflow is sustained between storms. Streamside vegetation consisting of small trees, shrubs, and herbaceous plants was re-established artificially and naturally to stabilize most banks and help maintain water temperatures in a range favorable to trout populations.

Management Implications

There are two major management implications relative to the hydrology of the UVR. The first is that future urban growth could adversely affect baseflows in the river. Consumptive use of groundwater by urban populations in Prescott, Prescott Valley, and Chino Valley has already produced groundwater level depressions. Evidence is already in the hydrologic record of UVR baseflow impacts from excessive well pumping. Projected future use of the Little Chino and Big Chino aquifers could dry up parts or all of the UVR. This is not a process that the Prescott National Forest can manage. Any land management activities it conducts with the objective of improving habitat for native aquatic fauna might have no net positive effect. Compared to de-watering of the UVR from aquifer overuse by municipal entities, other land management activities will have minimal effects.

Secondly, flood flows that occur on the UVR are episodic in nature and increase flows by three or four orders of magnitude but are beyond the ability or jurisdiction of the Prescott National Forest to manage. They are important flows for the geomorphology of the river and the creation of aquatic habitat for endangered species like the spikedace (*Meda fulgida*).

Summary and Conclusions

In this chapter, the geology and hydrology of the UVR were examined with special reference to the peak flows that form river geomorphology and habitat, and baseflows that support the aquatic fauna and riparian vegetation. Research is being conducted by a number of non-governmental organizations and State, and Federal agencies to improve understanding of the UVR. Flows in the river are mostly stable baseflows due to steady contributions of groundwater flow from the Big Chino and other aquifers. This river is unique in Arizona because of that important feature. Like other stream systems in Arizona, the UVR is subject to rare, episodic flood flows that rise three to four orders of magnitude above its baseflows. While drought can have an impact on the steady baseflows of the river, the overwhelming future impact on the sustainability of UVR perennial flow is urbanization of the Prescott and Chino Valley areas.

Chapter 4

Watershed Condition

Daniel G. Neary, Jonathan W. Long, Malchus B. Baker, Jr.

Introduction

Managers of the Prescott National Forest are obliged to evaluate the conditions of watersheds under their jurisdiction in order to guide informed decisions concerning grazing allotments, forest and woodland management, restoration treatments, and other management initiatives. Watershed condition has been delineated by contrasts between "good" and "poor" conditions (DeBano and Schmidt 1989). Good condition is characterized by vegetation and litter cover that is capable of absorbing precipitation, temporarily storing it, and slowly releasing it through a network of channels with minimal drainage density. Poor condition applies to areas where precipitation induces soil erosion and rapid sediment-laden runoff through an expanding network of channels. Evaluations of watershed condition face substantial challenges in attempting to determine a reference condition, the extent of departure from that condition, causes of that departure, and management actions that can return the watershed back toward the reference condition (McCammon and others 1998). These challenges are particularly great in watersheds of the arid and semi-arid Southwest, where flashy, sediment-laden runoff is a common natural condition.

Evaluation of watershed condition was a central topic in the Prescott National Forest's biological evaluation on selected grazing allotments for the spikedace and the loach minnow on the UVR watershed (Prescott National Forest 2001; King 2002). The authors examined aquatic conditions (based on water quality, macroinvertebrate populations, fish populations, and substrate pebble counts), riparian conditions (based on proper functioning condition surveys and vegetation transects), soil conditions (based on data from the Terrestrial Ecosystem Survey [TES]), and resource impacts (tributary and gully systems, livestock grazing, roads and trails, pinyon/juniper woodlands, desert shrublands, and land use patterns). Through a subjective synthesis of those factors, the major subwatersheds were ranked in terms of high, medium, or low "integrity relative to potential."

Attempting to reduce complex ecological relationships across a heterogeneous landscape could lead to faulty inferences. A critical element of watershed analysis is to demonstrate the chain of logic and assumptions used to form recommendation for treatments (McCammon and others 1998). This chapter addresses watershed condition using information from the TES (Robertson and others 2000) with the goals of distinguishing important ecological concepts and guiding management decisions for the UVR.

Methods

Study Area

The watershed of the UVR encompasses an area of diverse topography and lithology since it traverses the Transition Zone from highlands on the southwestern edge of the Colorado Plateau into a large basin that is more typical of the desert Southwest. This study is limited to lands within the Prescott National Forest (fig. 1.1) since those are the areas for which data are available and for which the Prescott National Forest makes management decisions. Tapco, just upstream of Clarkdale and below the UVR's confluence with Sycamore Creek, is used as the lower boundary of this analysis. This area coincides with the first of three reaches included in the biological evaluation by the Prescott National Forest (2001). The UVR watershed encompasses seven "5th code" hydrologic units (HUCs) from the Big Chino Wash downstream to Tapco. The Williamson Valley Wash (#1506020107), Hell Canyon (#1506020202), and Sycamore Creek (#1506020203) hydrologic units are true watersheds, but the Middle Big Chino Wash (#1506020106), Lower Big Chino Wash (#1506020108), Granite Creek/UVR (#1506020201), and Grindstone Wash/UVR (#1506020204) hydrologic units are not, because parts of their watersheds are contained by other HUCs. A major disadvantage of using HUCs that are not true watersheds is that their boundaries are arbitrary. Consequently, boundaries of some of the HUCs reported here do not coincide precisely with those used in the Prescott National Forest's biological evaluation.

Terrestrial Ecosystem Survey

The Prescott National Forest collected TES field data between 1992 and 1997 for classifying areas into similar map units through a systematic analysis of geology, soils, erosion, vegetative composition, and vegetative production (Robertson and others 2000). Designers of the Survey hoped to evaluate and modify land uses on the Forest according to the natural limitations and potentials of its natural resources. Accordingly, the TES is intended to provide a basis for evaluating watershed condition at a coarse scale across the Forest using criteria such as soil condition ratings and various soil loss rates.

Soil Condition—The TES evaluation of soil condition uses a three-way classification ranging from "unsatisfactory" (signifying that vital soil functions have been lost) to "satisfactory" (signifying that soil functions are proper, normal, and sustainable), with "impaired" representing an intermediate condition (Robertson and others 2000). The TES for the Prescott National Forest rated soil conditions based on three interrelated soil functions: hydrologic function, soil stability and nutrient cycling. This approach was more complex than surveys completed on other National Forests, which instead used a single indicator, soil stability or soil loss rate to evaluate soil condition (Barnett and Hawkins 2002).

However, it must be noted very clearly that the three soil condition ratings used in the Prescott National Forest TES do not necessarily imply a one-to-one correspondence with erosion rates or potential delivery of sediment to channels. They are simply a way of integrating ecological conditions of the landscape units. These ratings are more influenced by potential site productivity than by anything else.

The rates of soil loss used in the TES are predicted using the Universal Soil Loss Equation under different scenarios (Robertson and others 2000). The "natural" soil loss rate is the minimum rate of loss, which would be expected under a climax vegetative state. “Current” soil loss rates reflect conditions under the current land management regime. The “potential” soil loss rate is the rate that would be expected when all vegetative ground cover is removed. The “tolerable” soil rate is the rate above which reductions in primary plant productivity would be expected. Short-term increases in herbaceous plant productivity might occur with soil losses above the tolerable level due to competition reduction. Also, soil cultivation might temporarily raise productivity due to improved soil structure and water-holding capacity (Neary and others 1990; Burger 2002).

Scale and Precision—Issues of scale and precision are very important when evaluating watershed condition. The soil condition metric may be useful at the large watershed scale, but it may not be an accurate reflection of the condition of specific points within smaller management units (Barnett and Hawkins 2002). Differences due to management can cause areas within the same map unit to have very different conditions. For example, different livestock management practices on individual range allotments can result in a soil unit being impaired on one allotment and satisfactory on another. Staff of the Prescott National Forest collected site-specific data to verify the TES data. Their results indicated that map units in the TES soil condition ratings were generally consistent with the individual site information (Prescott National Forest 2001). As a result of the verification process, Prescott National Forest staff changed only three of the dominant map unit ratings from the original TES ratings.

GIS Analyses of Watershed Condition—Because the various soil metrics in the TES provide different information about watershed condition, the results of using those metrics were compared to classify conditions across the UVR watershed. A Geographic Information System (GIS), with layers representing the different TES map units, provided a tool for evaluating these metrics. The Prescott National Forest GIS coordinator provided a layer with the TES map units along with a database containing the various soil ratings and loss rates, and another layer containing the 5th code HUC delineations made by the Natural Resources Conservation Service. By overlaying these layers, it became possible to query and represent the TES data within hydrologic units.

Soil Loss Analysis

The Prescott National Forest TES analysis estimated soil loss rates for each mapping unit that were based on soil rainfall-runoff erosivity, erodbility, length and steepness of slopes, ground cover information, and conservation practices factors that comprise the revised Universal Soil Loss Equation (Renard and others 1991). “Natural” soil loss refers to soil loss that would occur under conditions with an expected climax vegetation. “Current” soil loss refers to erosion rates with the exisiting ground cover. “Tolerance” soil losses are those that can occur without degrading site productivity. “Potential” soil loss rates are the maximum rates that would occur if litter and vegetation were completely removed. This level is usually seen only with high-severity wildfire.

Table 4.1 summarizes the acres, annual soil loss, and weighted average soil losses for the seven 5th code HUC watersheds within the boundaries of the Prescott National Forest. The total area was nearly equally divided among satisfactory, impaired, and unsatisfactory soil condition ratings. In terms of annual soil losses, over half (53.3%) of all estimated soil loss came from areas rated as satisfactory, while only one-fifth (20.3%) of estimated loss came from unsatisfactory areas.

Table 4.1—Acreage, annual soil loss, and weighted average soil loss (Mg ha^{-1} yr^{-1}) for seven 5th code HUC units on the Prescott National Forest (PNF) (from Robertson and others 2000).

Area Hydrologic unit	Satisfactory	Impaired	Unsatisfactory	Total for All Categories	Portion of Total Area
	ha				%
Middle Big Chino Wash	5937	7721	6290	19948	8.35
Williamson Valley Wash	18913	19173	14404	52490	21.97
Granite Creek/UVR	12793	3424	4049	20266	8.48
Grindstone Wash/UVR	23386	18457	17197	59040	24.71
Hell Canyon	2855	9688	14818	27361	11.45
Lower Big Chino Wash	17473	21603	11698	50774	21.25
Sycamore Creek	4559	1190	3332	9082	3.80
Total UVR within PNF	85917	81256	71787	238960	100.00
Overall %	35.95	34.00	30.04	100.00	

Annual Soil Loss Hydrologic unit	Satisfactory	Impaired	Unsatisfactory	Total for All Categories	Portion of Total Area
	Mg yr^{-1}				%
Middle Big Chino Wash	22755	11348	5950	40053	6.23
Williamson Valley Wash	42156	50286	33635	126077	19.62
Granite Creek/UVR	36775	9249	6572	52595	8.18
Grindstone Wash/UVR	131811	40804	37331	209946	32.66
Hell Canyon	17165	16733	18285	52183	8.12
Lower Big Chino Wash	65355	38136	15404	118896	18.50
Sycamore Creek	26761	3232	12999	42993	6.69
Total UVR within PNF	342779	169788	130175	642741	100.00
Overall %	53.33	26.42	20.25	100.00	

Average Soil Loss Hydrologic unit	Satisfactory	Impaired	Unsatisfactory	Overall Average Weighted by Area
	Mg ha^{-1} yr^{-1}			
Middle Big Chino Wash	3.83	1.47	0.95	2.01
Williamson Valley Wash	2.23	2.62	2.34	2.40
Granite Creek/UVR	2.87	2.70	1.62	2.60
Grindstone Wash/UVR	5.64	2.21	2.17	3.56
Hell Canyon	6.01	1.73	1.23	1.91
Lower Big Chino Wash	3.74	1.77	1.32	2.34
Sycamore Creek	5.87	2.72	3.90	4.73
Total UVR within PNF	3.99	2.09	1.81	2.69

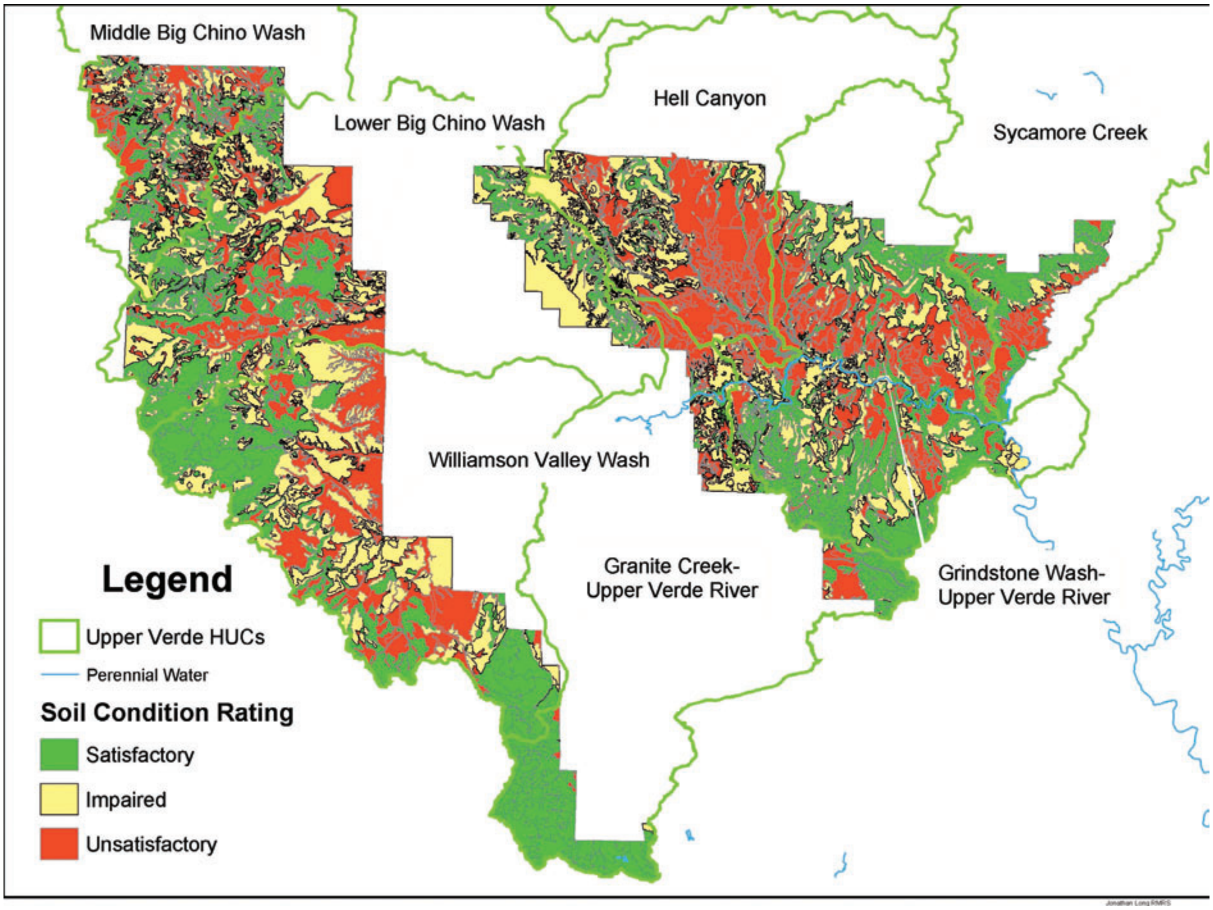


Figure 4.1—Soil condition ratings on the Prescott National Forest within the UVR watershed.

Satisfactory classification units had higher average erosion rates per unit area than did impaired or unsatisfactory map units in six of the seven hydrologic units because of their deeper soils. For example, in the Hell Canyon HUC, the average soil loss for soil units rated as satisfactory was nearly five times that of units rated as unsatisfactory. The latter soil units are shallow and rocky and, therefore, have less soil material to erode.

Unsatisfactory soils were fairly evenly distributed across the Forest, although the Hell Canyon watershed stood out for poor ratings (fig. 4.1). However, a map of current soil loss rates (fig. 4.2) yields a very different interpretation than the map of soil condition rating. For example, while only 10.4% of the area in the Hell Canyon watershed was rated as satisfactory, one half of the area was estimated to lose soil at a rate of less than 1 Mg ha^{-1} yr^{-1} (2.2 tons ac^{-1} yr^{-1}). The areas of highest weighted average soil loss rates were in the Grindstone Wash/UVR and the Sycamore Creek HUCs (quantified in the bottom section of table 4.1), both of which include steep terrain.

The difference between current soil loss rates and natural loss rates (fig. 4.3) may point to areas that suffer from excessive soil erosion. By that measure, areas with relatively excessive soil loss rates occurred in the upper Williamson Valley Wash watershed, the lower part of the Big Chino Wash, and the lower part of the Grindstone Wash/UVR and Sycamore Creek HUCs. However, 81% of the areas on the Forest had current soil loss rates that were less than 1 Mg ha^{-1} yr^{-1} (2.2 tons ac^{-1} yr^{-1}) above the estimated "natural" loss rates. The remaining 19% (44,600 ha or 110,210 ac), was estimated to produce 1 Mg ha^{-1} yr^{-1} (2.2 tons ac^{-1} yr^{-1}) above

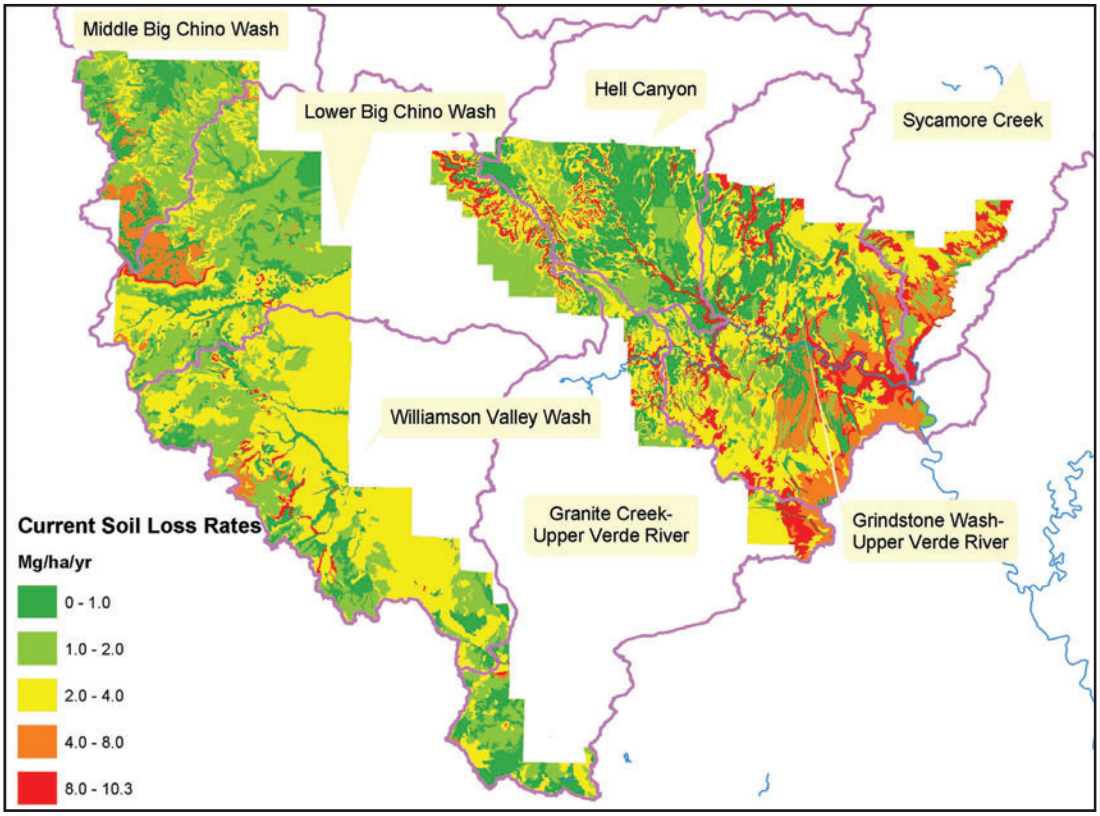


Figure 4.2—Estimated current soil loss rates in Mg ha^{-1} yr^{-1} on the Prescott National Forest within the UVR Watershed (Robertson and others 2000). Colors in red, gold, and yellow designate the higher erosion rates.

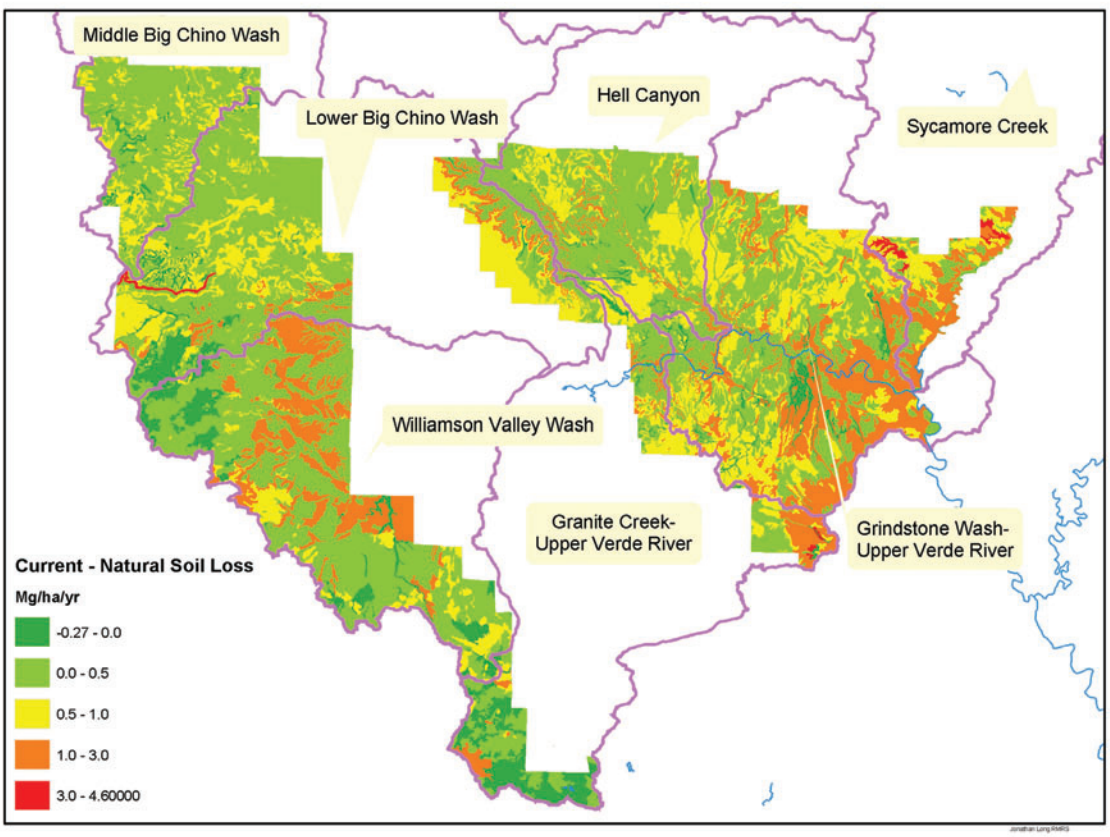


Figure 4.3—Estimated current soil loss rates minus natural soil loss rates in Mg ha^{-1} yr^{-1} on the Prescott National Forest within the UVR watershed (Robertson and others 2000). Colors in red, gold, and yellow designate the higher erosion rates.

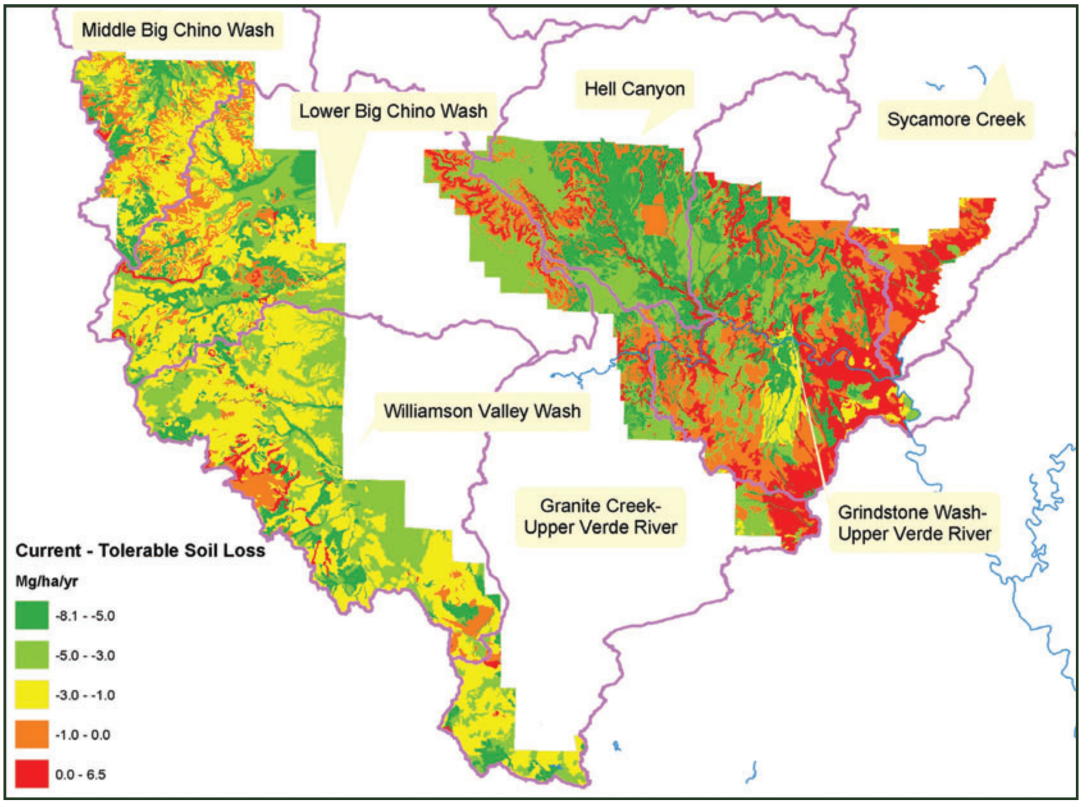


Figure 4.4—Estimated current soil loss rates minus tolerable soil loss rates in Mg ha^{-1} yr^{-1} on the Prescott National Forest within the UVR watershed (Robertson and others 2000). Colors in red, gold, and yellow designate the higher erosion rates.

estimated natural rates. Half of these areas were characterized by relatively steep slopes, but were rated as "satisfactory," typically with a corresponding label of "inherently unstable." Only 10% of the areas producing over 1 Mg ha^{-1} yr^{-1} (2.2 tons ac^{-1} yr^{-1}) of excess sediment above natural levels were rated as "unsatisfactory," all corresponding to a single map unit (455).

Mapping the difference between current and tolerable soil losses (fig. 4.4) helps to identify areas where soil sustainability may be in jeopardy. This map presents a picture similar to fig. 4.3, indicating that the highest net losses were concentrated in the lower portion of the Grindstone Wash/UVR watershed and Sycamore Creek HUCs. However, 80% of the areas estimated to have current losses in excess of tolerable levels were also locations where natural soil loss rates exceeded tolerable rates due to steep slopes.

The vegetation types on the UVR watershed within the Prescott National Forest (fig. 4.5) are dominated by pinyon-juniper communities (87% of total area). Most of the grassland areas within the watershed are not located on National Forest lands, except for a small part of the central Plains grasslands in the eastern corner of the Lower Big Chino hydrologic unit and a moderate expanse of Aristida spp. (three-awn) subclimax grassland (primarily occurring in areas treated to reduce junipers) within the Hell Canyon watershed. The lower watershed areas that had the most elevated soil erosion rates are primarily covered with pinyon-juniper and chaparral. By contrast, high-elevation ponderosa pine forest had relatively low soil erosion rates.

Table 4.2 relates soil condition ratings to geology across the UVR watershed within the Prescott National Forest. Nearly half of the areas comprised of Older

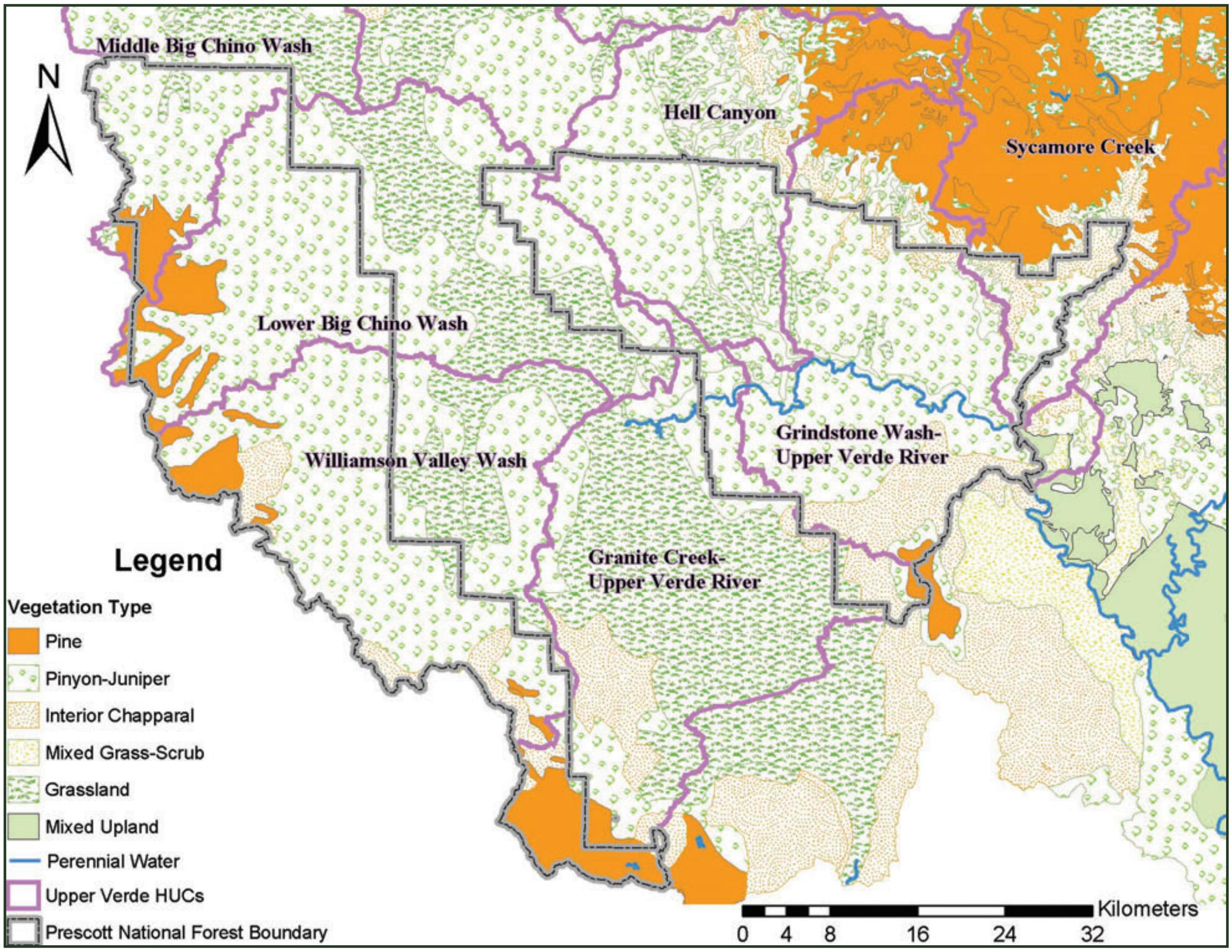


Figure 4.5—Vegetation types in the UVR watershed within and surrounding the Prescott National Forest.

Quaternary alluvium and the Tertiary Verde Formation were rated as having unsatisfactory conditions. The latter formation constitutes over 15% of the study area on the Prescott National Forest. Both of those geologic formations are relatively more abundant on private lands in the Verde watershed. The naturally erodible red sandstones and siltstones of the Paleozoic Supai Formation and the naturally less erodible Tertiary basaltic rocks also had unsatisfactory soil conditions across 42% of their areas. On the other hand, Precambrian crystalline rocks and the late Permian Kaibab and Coconino sedimentary rocks were typically in satisfactory condition. These formations generally lie at higher elevations under ponderosa pine forests.

Figure 4.6 compares estimated soil loss rates along the boundary between the Prescott National Forest and the neighboring Kaibab National Forest as a means of evaluating the consistency of TES data for particular areas. There is some topographic variation associated with the boundary, as terrain becomes steeper south of the Mogollon Rim. However, striking incongruities in the figure may also reflect high spatial variability within map units, sampling errors, or perhaps differences due to when the field data were collected (the Kaibab National Forest was sampled in the late 1980s, while the Prescott National Forest was sampled in the mid 1990s).

Table 4.2—Total hectares in each soil condition rating for different geologic types within the UVR Watershed on the Prescott National Forest (from Robertson and others 2000).

Geology	Condition Satisfactory	Impaired ha	Unsatisfactory	Total ha	Percent Unsatisfactory %
Rocks					
Precambrian crystalline	29195	6687	5898	41781	14
Redwall Limestone	21954	24519	11179	57652	19
Supai Formation	6519	7828	10196	24544	42
Kaibab/Coconino Sandstones	5737	1994	872	8604	10
Formations					
Tertiary basaltic rocks	12498	12821	18570	43888	42
Tertiary volcanic rocks	1672	3235	1107	6014	18
Tertiary Verde Formations	5409	13423	16813	35646	47
Other Tertiary sedimentary	1502	3196	2771	7469	37
Older Quaternary alluvium	588	4043	4343	8974	48
Young Quaternary alluvium	842	3722	44	4608	1
Total	85917	81468	71794	239179	30

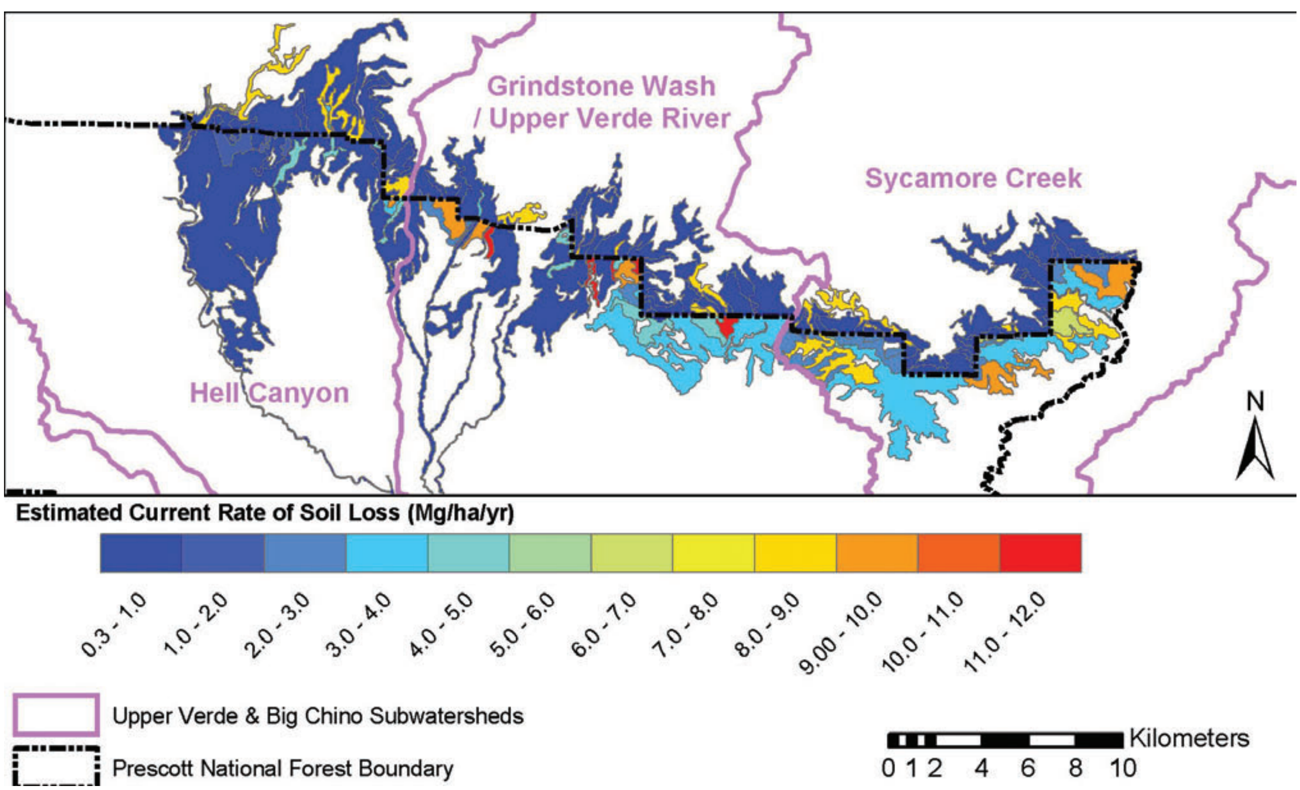


Figure 4.6—Comparison of estimated soil loss rates along the boundary between the Prescott and Kaibab National Forests. The estimated rates on the Prescott National Forest are substantially higher east of the Hell Canyon watershed. Current estimated soil losses in this figure grade from least (red) to most (blue). The Kaibab National Forest lies above the dashed line in the figure and the Prescott National Forest lies below the line.

Watershed Condition

Because watershed condition represents the complex interaction of sediment and water flows, it does not always directly correspond to watershed condition ratings. Basing management decisions solely upon categorical soil condition ratings is risky since cause-and-effect relationships and temporal factors are generally ignored when designating the ratings. Subjective categories such as "satisfactory" and "impaired" can mislead untrained users of TES data because such terms can be interpreted as evaluations of current management practices (Barnett and Hawkins 2002). An inexperienced interpreter of soil condition ratings might infer that a high level of unsatisfactory soil conditions implies poor watershed condition and excessive sedimentation that can threaten aquatic habitat. Watershed condition ratings developed during the TES process do provide positive information for Forest land managers to prioritize actions and resources needed to improve overall productivity of the Forest landscape. There are a number of uses for the Forest TES evaluation of watershed condition on the UVR, and these are discussed in the following sections.

Watershed Condition Evaluations

Identifying Inherently Unstable Geology and Soils—Firstly, the TES identified many areas as inherently erodible due to lithology and slope. An additional TES category of "inherently unstable" soils was needed to distinguish such soils from those that are unstable due to management practices (Barnett and Hawkins 2002). However, inherently unstable areas were assigned soil condition ratings ranging from satisfactory, to impaired, to unsatisfactory. The watershed condition assessment report prepared by the Prescott National Forest in 2001 (Prescott National Forest 2001) recognized that map units such as Unit 455 could be considered "satisfactory-naturally erosive" and would not be expected to change much over time due to "inherent instability and steep slopes." There are areas of the Prescott National Forest landscape that are steep and rocky. They have been for centuries and most likely won't change for centuries or be amenable to restoration. This is part of the natural state of affairs for a forest in a semi-arid, mountainous landscape. Those areas need to be adequately identified in order to recognize that management activities within the UVR Watershed in the past had no involvement with the current condition, nor are future restoration activities likely to change these landscape units to a better condition with any amount of restoration inputs.

Identifying Areas With Legacy Degradation—It is important to identify the size and location of legacy impacts in order to guide future Prescott National Forest management actions and current assessments. Soil condition ratings in the TES do not indicate at what time a decline in ecological function may have occurred. Indeed, undesirable watershed and soil conditions in the pinyon-juniper woodlands of the Prescott National Forest were evident almost a century ago (Leopold 1924). Consequently, while many unsatisfactory soil condition ratings are associated with historical degradation, an untrained user of the TES might assume that current land management practices are responsible. Unsatisfactory ratings were also applied to areas that had been intensively treated to remove juniper trees in previous decades (e.g., map units 470 and 471). This type of land management activity was halted at one point but has been initiated again to achieve well-defined ecological objectives.

Identifying Cause-and-Effect Relationships—Setting grazing policies based on current soil condition ratings rests on assumptions about how changes in grazing will ameliorate unsatisfactory conditions. However, decades ago, Leopold (1921) contended that changes in range controls alone would be insufficient to reverse erosion processes. The prevalence of unsatisfactory soil conditions in pinyon-juniper areas may support a call for active treatments to abate erosion. However, the pushing and chaining of pinyon-juniper communities does not appear to have substantially ameliorated these conditions, as the TES survey identified many of those treated areas as being in unsatisfactory soil condition. Pushing and chaining involves using bulldozer blades (pushing) or dragging large chains (chaining) to remove dense pinyon-juniper stands in a cost-effective treatment. Inter-tree cover in pinyon-juniper communities is often sparse, thereby increasing the probability of higher levels of erosion. Herbaceous cover recovery after pushing and chaining is often slow due to low rainfall rates and the lack of seed sources. Deeper tilling of soils is often required after pinyon-juniper removal to improve plant rooting depth and moisture holding capacity. Some dense pinyon-juniper woodland areas have exhibited changes, but not improvements, in soil condition as bare soils have been replaced by erosion pavements (Barnett and Hawkins 2002).

Unsatisfactory soil condition ratings may also be associated with inherent geologic or soil properties that impede recovery but do not necessarily indicate how the soils will respond to grazing or to rest from grazing. For example, some limestone-derived soils have high carbonate contents while some basaltic soils have high shrink-swell potential due to the presence of montmorillonitic clays. Soils with high montmorillonite contents shrink and crack when dried out and expand considerably when wet. These properties may be associated with a greater proportion of unsatisfactory soil conditions because they can impede herbaceous revegetation, reduce animal and vehicle trafficability, and limit water infiltration (O'Rourke and Odgen 1969; Clary 1971). As a result, an unsatisfactory rating might or might not warrant a change in grazing management.

It is even more difficult to extrapolate soil condition from an upland part of the landscape to conditions in the riparian zone of the UVR. While the soil condition ratings do present a snapshot of soil conditions and potential to generate sediment, estimated erosion rates need to be examined first before any conclusions can be drawn about the status of sedimentation in the UVR. In addition, in channel sediment delivery processes and sediment routing from lands off the Prescott National Forest need to be considered. Determining cause-and-effect from past or current land management practices must be done judiciously and by trained geosciences professionals.

Correlating Poor Soil Conditions with Stream Sedimentation—The soil condition ratings given by the Prescott National Forest TES do not directly measure sediment yield to stream channels (Robertson and others 2000). Map units classified as satisfactory often have an estimated higher rate of soil loss than those rated as impaired or unsatisfactory. Unsatisfactory areas may have already lost much of their erodible fine soils. Consequently, a soil with a satisfactory rating could be a higher priority for managing sedimentation. Decisions on management of such soil units need to be made on the basis of all the factors that go into the rating, not just erosion.

Alternative Metrics for Evaluating Soils and Watershed Condition

The TES provides several metrics that serve to distinguish among naturally erodible areas and areas that may be managed to reduce erosion. Natural soil loss rates refer to estimates of soil loss due to erosion under conditions associated with a climax vegetation cover. Current soil losses occur with the existing vegetative ground cover. Tolerable soil loss rates refer to losses that could occur and still maintain inherent soil productivity. One way to evaluate unsustainable amounts of erosion is to determine where current soil loss rates exceed tolerable soil loss rates. The Prescott National Forest TES applied this relatively simple approach (Robertson and others 2000; Barnett and Hawkins 2002). By this standard, only 11% of the UVR watershed within the Prescott National Forest had current estimated soil loss rates in excess of tolerable levels, and the vast majority of those areas had natural soil loss rates that exceeded tolerable soil loss rates. For most areas that were rated unsatisfactory, current soil loss rates were estimated to be close to natural rates and well below tolerable loss rates.

Another approach for evaluating potential sedimentation is to subtract natural loss rates from current loss rates. This metric provides an estimate of excess soil erosion beyond postulated climax vegetative conditions. Standards based on estimated soil loss rates are intuitively easier to relate to evaluations of sedimentation problems than the complex soil condition ratings. However, these soil condition ratings may also be problematic because the estimates are rarely validated in wildland situations and they may underpredict erosion losses on gentle slopes (Barnett and Hawkins 2002). The maps of potential problem areas in figs. 4.3 and 4.4 likely reflect a methodological bias toward steeply-sloped, naturally erodible areas. The estimated erosion rates in some of those areas were higher than in bordering areas on the Kaibab National Forest (fig. 4.6), reinforcing the possibility that the differences may be an artifact of methodology.

Greater understanding of ecological thresholds and dynamics are needed to evaluate the ecological significance of departures from postulated climax groundcover conditions. Departures from climax vegetation should not necessarily be considered "abnormal," since natural disturbances such as fires would have maintained patches of reduced vegetation and eroding soils. From an upland management perspective, Leopold (1921) claimed that differentiating "normal" from "abnormal" erosion was academic because he considered it desirable to curtail preventable erosion wherever possible. In a similar vein, the watershed assessment by the Prescott National Forest concluded that, "for the purpose of this assessment, [the naturally unstable map unit 455] has been considered unsatisfactory because it is a source of sediment to the Verde River." This rationale, however, would tend to direct management resources toward remediation of a naturally unstable area where the prospects for improvement appear low.

Linkages to the River System—Maintaining "normal" levels of sedimentation, where normal is defined as within the natural range of variation for the given climatic conditions, may be a reasonable goal from a riverine management perspective. Influxes of sediment are important in maintaining or rebuilding habitat for native fishes and riparian plants (Medina and others 1997; Benda and others 2003; Long and others 2003). Conditions of channels downstream from the watersheds should indicate whether current sediment production rates are too high for the channels to process effectively. Results from morphology studies (Pearthree 1996; Beyer 1997; see also Chapter 5) do not indicate that reaches on the main stem of the Verde River are braiding or aggrading, which would be signs of excessive sedimentation. Although in-stream substrate dynamics vary considerably from reach to reach due to local geomorphic controls along the Verde River, the overall river system "conveys water and sediment in a fairly efficient manner" (Beyer 1997). Indeed, Beyer (1998) estimated that two-year flood events were capable of mobilizing most of the sediment in the low flow channel along its course.

Figure 4.7—Vertical streambank collapse as a source of sediment in the UVR. (Photo by Daniel G. Neary.)

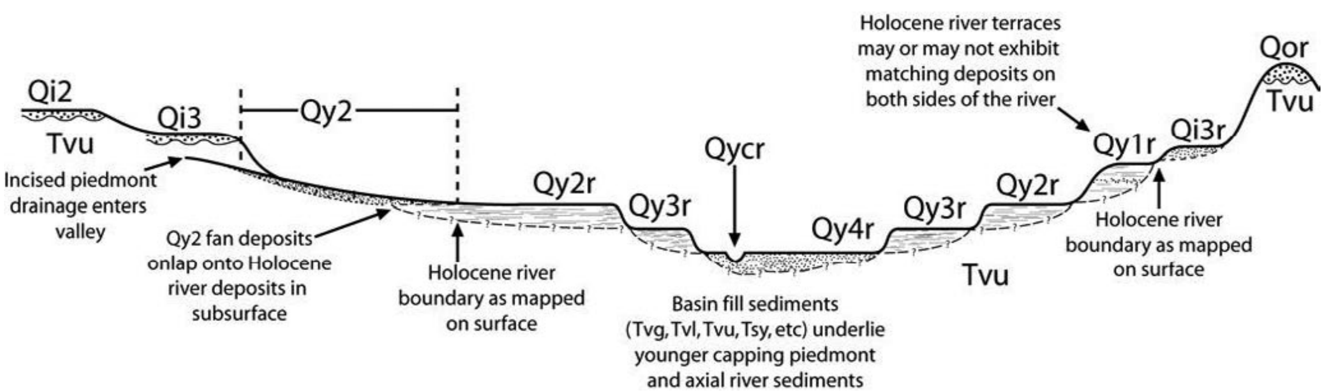


Figure 4.8—Generalized UVR cross section showing geomorphic relationships between Tertiary basin fill sediments, Pleistocene erosion fan and river deposits, and Holocene alluvial fan and river deposits (from Cook and others 2010).

Rather than being sediment-enriched, the Verde River may have experienced reduced influxes of fine sediment due to retention by Sullivan Dam and dams on Granite Creek (Medina and others 1997).

Another important source of sediment in the UVR that is usually excluded in watershed condition assessments is channel bank collapse (fig. 4.7). These river terrace sediments provide constant inputs of fine sediments into the UVR because of their close proximity to the current channels and vertical banks. They are classified as the Qy3r unit shown in fig. 4.8 and described in table 4.3 (Cook and others 2010a, 2010b, 2010c). This alluvium unit consists of historical river terrace deposits that occupy elevations of 2 to 3 m (6 to 10 ft) above the river. The sediments were deposited by paleofloods between A.D. 440 and 1650 according to radiocarbon dating. They are composed of poorly sorted sand, silt, pebbles, and cobbles capped by a layer of fine sand and silt. Gradual erosion of these deposits occurs with baseflow, and rapid erosion and channel widening are characteristic of flood flows. Rates of bank collapse and sediment input into the UVR channel are not known but they certainly contribute the bulk of suspended solids measured during baseflow on the UVR rather than upland sources.

Condition of Tributaries—In gravel-bed rivers affected by high rates of sediment input, surface grain size declines as inputs of fine sediments increase

Table 4.3—UVR sediment classification, age, and material source (from Cook and others 2010).

Unit Name	Sediment Origin Epoch	Age -Years	Sediment Deposit Source
Qycr	Historical Holocene	A.D. 1993-2011	Current UVR Alluvium
Qy4r	Historical Holocene	A.D. 1650-1993	UVR Alluvium 1st Terrace
Qy3r	Historical Holocene	A.D. 440-1650	UVR Alluvium 1st-2nd Terrace
Qy2r	Late Holocene	A.D. 430-1640	UVR Alluvium 3rd Terrace
Qy1r	Late to Early Holocene	2,000-10,000 BP*	UVR Alluvium 4th Terrace
Qy2	Late Holocene	1,000-2,000 BP	Upland Alluvium Erosion Fans
Qi3	Late Pleistocene	10,000-12,000 BP	Upland Alluvium Erosion Fans
Qi2	Middle to late Pleistocene	130,000 BP	Upland Alluvium Erosion Fans
Qi3r	Late Pleistocene	10,000-12,000 BP	UVR and Erosion Fans
Qor	Early Pleistocene	1-2 M BP	UVR Deposits on Alluvial Fans
Tvu	Late Miocene to Pliocene	5.3 M BP	Sandstone and Conglomerate

*YBP = Years before present

(Buffington and Montgomery 1999). Without temporal data, it is difficult to evaluate whether a particular stream reach is becoming sediment-enriched or whether it is naturally dominated by fine sediments. Moreover, pebble counts do not provide absolute indicators of sediment input, but instead can indicate increases in fine sediments relative to their water yield. For example, a large tributary could be a source of fine sediments, but that sediment contribution could be offset by a correspondingly high water yield (particularly in high-elevation tributaries such as Hell Canyon and Sycamore Creek).

The watershed evaluation by the Prescott National Forest used other criteria to evaluate sources of sediment to the UVR. Specifically, the report rated watershed condition as poor in the Hell Canyon-Grindstone Wash-MC Canyon-Bear Canyon complex based on the assertion that, "during high flows, all four tributaries carry huge sediment loads comprised primarily of large cobble. Channels are wide and shallow, often splitting into multiple channels and overflow channels." The report seemed inconsistent however, first stating that "channel features at the mouth of Hell Canyon suggest tremendous flows, scouring and redepositing huge amounts of sediment," but then stating, "flow events large enough to move this material probably occur rarely." That discussion confused the size of particles being moved with the rate of sedimentation. The sediment size is large in Hell Canyon but huge amounts of sediment are not being moved into or through the canyon. There is very little fine sediment that is the usual indicator or high rates of erosion and sedimentation. The watershed evaluation is correct in reporting that flow events large enough to move the coarse sediments are rare. In the absence of these events the larger cobble and boulder material just remains in place.

The Hell Canyon watershed features an unusual drainage configuration, as four large drainages converge just above the confluence with the Verde River. The coarse particle sizes dominating those systems may reflect that unusual geomorphology as well as flashy runoff, but they do not necessarily indicate a sedimentation problem. The soil condition ratings in that watershed do not indicate that degradation has been extensive or that conditions would be substantially improved through changing management. Consequently, evaluating the condition of that watershed as particularly "unsatisfactory," might lead managers in an unfruitful direction.

Gully Networks—Another important facet of identifying poor watershed condition is an expanding drainage network in the form of gullies. Sedimentation caused by active gully erosion and by roads will be underrepresented in the TES because the Universal Soil Loss Equation is not designed to deal with those erosional processes. Most gully networks in the UVR watershed on the Prescott National Forest appear to have stabilized, although areas of active gully erosion are present such as Railroad Draw and Red Point Tank (Prescott National Forest 2001). Barnett and Hawkins (2002) also noted that portions of the Sheepshead subwatershed experienced dense networks of steeply walled gullies. In many cases, gully erosion may have begun due to roads and development rather than with grazing. Also, gullies may represent a legacy of past impacts rather than a reflection of present management. Such conditions warrant a site-specific assessment of causes, effects, and treatments rather than a landscape-level prescription for land use. As Leopold (1921) contended nearly a century ago, healing gully erosion requires active treatments in conjunction with abating the causes of gullying, which are often improper road drainage but may also include animal impacts.

Management Implications

Evaluating the condition of the UVR watershed based largely on TES data could lead to an inefficient allocation of management resources because inherently unstable units were not rated consistently and soil condition ratings do not have direct relationships to soil loss rates. TES data were not designed for making management decisions for particular rangeland sites. More detailed monitoring of key functional attributes—such as the amount of bare soil and litter; the amount, composition and vigor of range plants; and the extent of soil compaction, pedestal development, rill formation, and gully incision—provide appropriate information for guiding range management actions at the site level (USDI Bureau of Land Management 2000; O'Brien and others 2003). Discrepancies between ground cover data along the boundary between the Kaibab and Prescott National Forests suggests that increased monitoring and verification of ground cover data may improve the information available to managers. Rather than relying heavily on estimates of vegetative cover (litter plus total vegetative basal area), more sophisticated evaluations of groundcover conditions (based on cover and condition of desirable range species) would improve decision making.

Management efforts might yield greater returns by targeting areas where hydrologic conditions could be improved by increasing herbaceous cover on gently sloped uplands and by treating active gullies with rock-wire gabions, geotextiles, and plantings (Heede 1978). Pinyon-juniper woodlands are likely to be a focus on the Prescott National Forest given their wide distribution; general association with higher erosion rates; and the suggestion in the TES that soil erosion rates in many areas reflect historical grazing impacts, changes in fire regime, and past clearing efforts. Although juniper treatments continue on the Prescott National Forest, research demonstrates that the effects of past widespread efforts frequently lasted only a few years (Clary and Jameson 1981; Baker 1999).

Chaparral areas constitute another area where prescribed fire and reseeding may be effective in restoring herbaceous cover (Baker 1999), but such treatment effects have appeared less persistent than those in pinyon-juniper (Huebner and others 1999). Substantial landscape variation warrants against making generalizations about the potential to improve watershed condition across these communities. Instead, site-specific efforts need to be planned, monitored, and evaluated across the landscape through an adaptive management framework.

Summary and Conclusions

When examined at a coarse scale of analysis, the TES can suggest which subwatersheds may be contributing unusually high amounts of fine sediment; such information, in turn, can direct field monitoring to validate whether tributaries are inducing sedimentation of the main river. A comparison of current sediment yields relative to natural yields (fig. 4.3) suggests that priority areas for reducing soil loss lie in the lower portions of the UVR watershed (Grindstone Wash/UVR hydrologic unit), the lower portion of Sycamore Creek watershed, and the Williamson Valley. Because the differences in soil losses that were calculated using the Universal Soil Loss Equation under current and hypothesized "natural" conditions are largely attributable to differences in ground cover, it is important to validate the relationships between ground cover and soil erosion for particular areas rather than relying on questionable assumptions.

In contrast to this analysis, the watershed assessment prepared by the Prescott National Forest suggested that the Tri-Canyon area (Hell Canyon HU) represented the greatest departure from potential watershed condition rating. The impaired rating for the Hell Canyon HU was apparently based on the high percentage of unsatisfactory/impaired soil condition ratings as well as the abundance of very coarse substrates in the tributary channels. Historic watershed degradation that induced a flashier watershed condition would account for the geomorphic condition of the channels and the widespread occurrence of "unsatisfactory" soil conditions. Past accounts of flash flooding in the UVR watershed and its tributaries extend to an early historic period (Barnett and Hawkins 2002). The potential to improve watershed conditions, particularly in steep, rocky, and relatively arid areas, is naturally quite limited. The paucity of precipitation and the presence of shallow, rocky soils are difficult to overcome no matter what future condition is desired.

The upland soil units of the UVR watershed have a range of watershed conditions that reflect the geology and semi-arid nature of the Prescott National Forest. There are units that have very skeletal and unproductive soils and that show evidence of significant erosion in the geologic past. However, linkages between these erosion processes, land management, and channel geomorphology are tenuous at best. This topic is discussed further in Chapter 5.

Chapter 5

Channel Morphology

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Introduction

Channel morphology has become an increasingly important subject for analyzing the health of rivers and associated fish populations, particularly since the popularization of channel classification and assessment methods. Morphological data can help to evaluate the flows of sediment and water that influence aquatic and riparian habitat. Channel classification systems, such as the one developed by Rosgen (1994) provide a useful shorthand for summarizing key morphological attributes of a river system. Accordingly, researchers have hypothesized that channel classifications could explain variation in native fish populations in rivers of the Southwest (Rinne and Neary 1997; Rinne 2005). Rosgen's (1996) full methodology encompasses several levels of analysis arranged hierarchically from a general characterization of a stream basin to detailed measurements of channel change in specific reaches. The second and most popular level (Level II) of the Rosgen (1996) methodology provides a framework for categorizing stream reaches based on channel form and dominant substrate. While this classification is useful for describing variations in channel morphology, critics argue that it is less useful and perhaps even misleading for making inferences about channel condition and processes of development (Miller and Ritter 1996).

The objective of this chapter is to evaluate the results of using the Rosgen's (1996) Level II methodology to analyze morphological data collected from the Upper Verde River (UVR) of the Prescott National Forest between 1997 and 2000 (Medina and others 1997). Level II methods utilize channel materials, channel slope, entrenchment ratio, width/depth ratio, and sinuosity to classify streams as types A, B, C, D, E, F, and G (fig 5.1).

- A-type streams are incised headwater creeks and rivers with narrow and deep channels and steep slopes. They have single channels, entrenchment ratios <1.4, width/depth rations of <12, and slopes >4%.
- B-type steams are moderately incised, wide, and shallow with moderate slopes and are found in colluvial valleys. They are single channel streams with entrenchment ratios of 1.4 to 2.2, width/depth ratios >12, and slopes between 2 and 4%.
- C-type streams are wide and shallow but are not incised as they are typical of low slope alluvial valleys on the lower portions of landscapes. These streams have higher entrenchment ratios (>2.2), width/depth ratios >12, and slopes <2%.
- D-channels are indicative of high sedimentation environments in that they are wide and shallow with multiple channels and low slopes. Entrenchment rations are >2.2 and width/depth ratios are >40. Slopes are generally <2% but can range up to 4%.

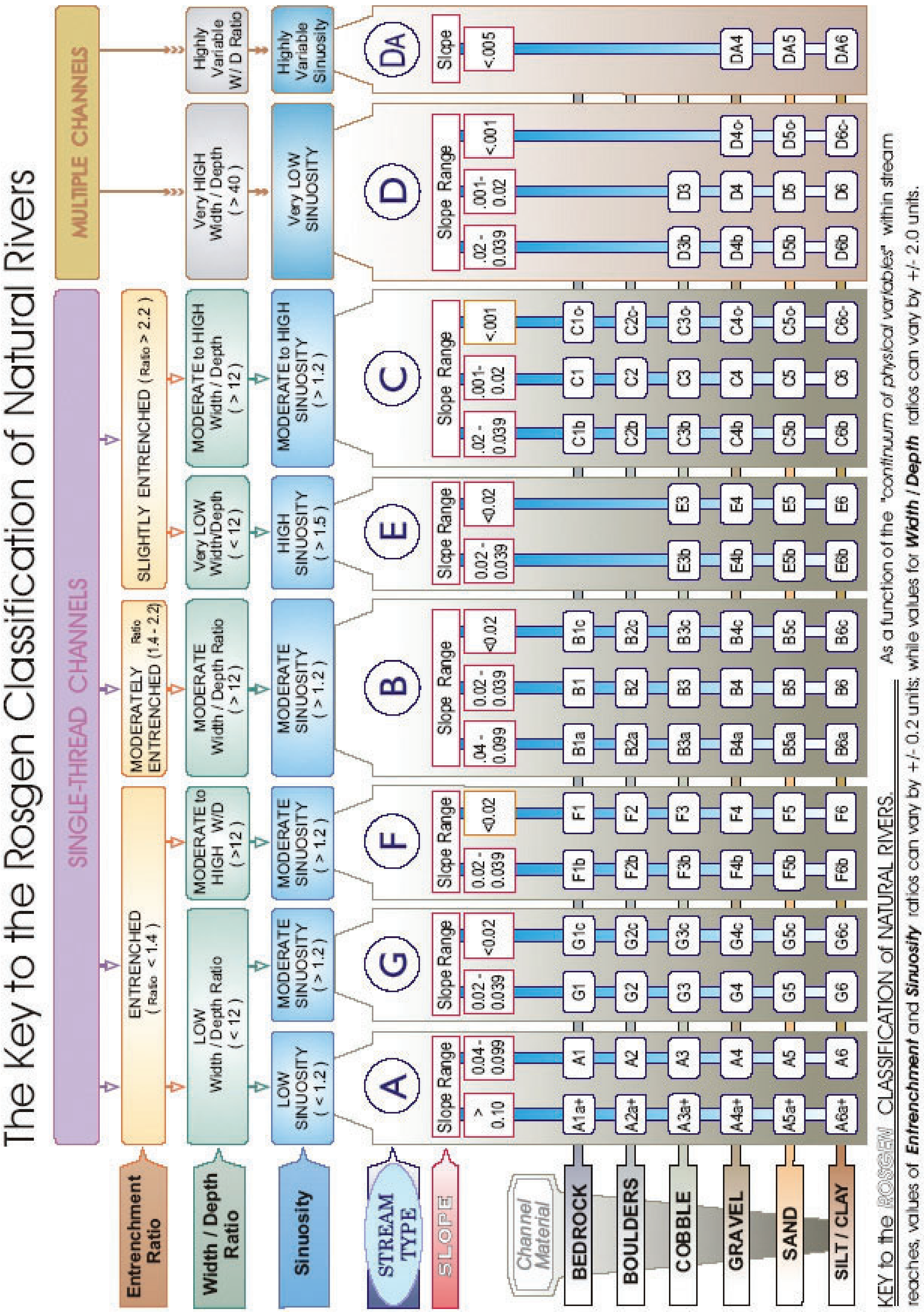


Figure 5.1—Rosgen (1996) classification system for natural rivers (from Endreny 2003).

- E-type channels represent one end point of channel evolution in that they are not incised and are narrow and deep in nature. They are representative of low slope (<2%) alluvial valleys. Entrenchment ratios are usually >2.2 and width/depth ratios are <12.
- F-type channels are single thread channels that are deeply incised. However, they are wide and shallow with slopes <2%. Entrenchment ratios are <1.4 and width/depth ratios are >12.
- G-type streams are single channels that are incised, narrow and deep in nature, and moderately sloped. Entrenchment ratios are <1.4 and width/depth ratios are <12. Slopes can be 2 to 4% in contrast to the lower gradient F-type channels.

Distinctive attributes of the river identified through the classification methodology helps to identify the prominent physical characteristics of the river that are important for its management. Such attributes can be considered when relating morphology and habitat suitability for native fishes. This analysis also examines problems in collecting and interpreting the data using the Level II framework. These findings are important for providing recommendations to land managers and other researchers to improve evaluations of the associations between morphology and native fish populations in the river.

Methods

Study Area

The Verde River and its tributaries flow through diverse geologic formations as they descend from the Colorado Plateau into a basin that had been closed as recently as a few million years ago (Pearthree 1993). Much of the UVR corridor (fig. 5.2) is lined with Paleozoic limestones and siltstones (fig. 5.3), but some reaches course through more erodible Holocene sediments (fig. 5.4).

These river terrace sediments were described by Cook and others (2010a, 2010b, 2010c) and consist of historical river terrace deposits that were deposited by paleofloods between A.D. 440 and 1650 according to radiocarbon dating. Other reaches are narrowly confined by relatively young basalt flows (fig. 5.5). Some reaches are relatively linear due to the bedrock confinement of the river (fig. 1.10A), but others contain meanders that have formed within recent river alluvium (fig. 1.10B). Due to confinement by basalt and sedimentary bedrock, the valley of the UVR can be characterized as moderately to highly confined, low gradient, and low relief. The physiography of the river changes dramatically below Sycamore Creek and into the Middle Verde River where extensive deposits of the Verde Formation along with younger alluvial deposits (fig. 5.2) permit the stream to follow a more broadly meandering pattern.

Data Collection

Channel morphology data were collected by hydrologic technicians on the Prescott National Forest at 138 locations sampled in the months of June and July between 1997 and 2000 (Medina and others 1997; fig. 5.6). Sampling locations were concentrated within segments of the UVR, in large part because those segments included more variable reaches and reaches with unusual channel form. However, some distinctive areas, such as the Perkinsville Basin, appear

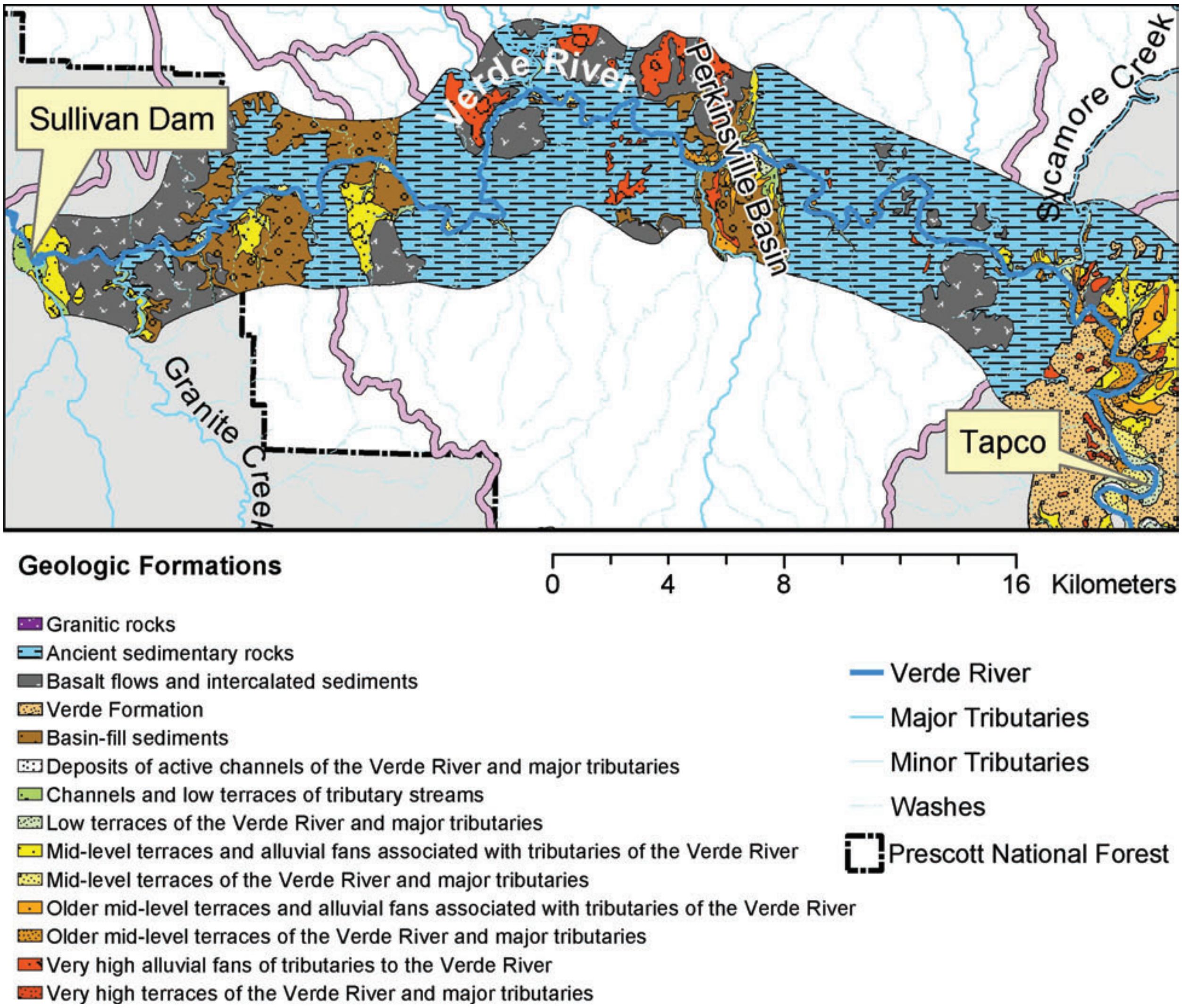


Figure 5.2—Geologic formations along the UVR, Prescott National Forest, Arizona. The major colors indicate: ancient sedimentary rocks (blue), basalt flows and inter-layered sediments (gray), older mid-level terraces of the UVR and its tributaries (brown), very high alluvial fans of tributaries of the UVR (orange), mid-level terraces and fans associated with tributaries of the UVR (yellow), and channels and low terraces of tributary streams (green).

underrepresented due to access limitations on some private lands. The technicians were trained and supervised by a Prescott National Forest hydrologist to survey channel cross-sections, to identify bankfull levels, and to measure slope and sinuosity following procedures detailed by Harrelson and others (1994) and Rosgen (1996). The field crews measured slope and sinuosity alog longitudinal profiles at 115 of the locations (these data were not collected in 2000). The crews also conducted pebble counts at 110 of the sampling locations using the pebble count methodology developed by Bevenger and King (1995). In 1997, 75% of the pebble count samples included 100 particles each. The remaining samples and those in subsequent years included 315 particles each. The total length of surveyed reaches was 26 km (16 mi), which represents approximately 44% of the total 60 km (37 mi) from Sullivan Dam to the confluence with Sycamore Creek. The habitat at each cross-section was subjectively categorized as riffle, run, glide, or pool, depending on feature gradient and velocity.

Figure 5.3—Limestone and siltstone bedrock near Duff Springs in the UVR. (Photo by Alvin L. Medina.)

Figure 5.4—Unconsolidated Holocene river-deposited sediments along the UVR channel near Burnt Ranch. (Photo by Daniel G. Neary.)

Figure 5.5—Basalt cliffs along the UVR downstream of Sullivan Lake. (Photo by Daniel G. Neary.)

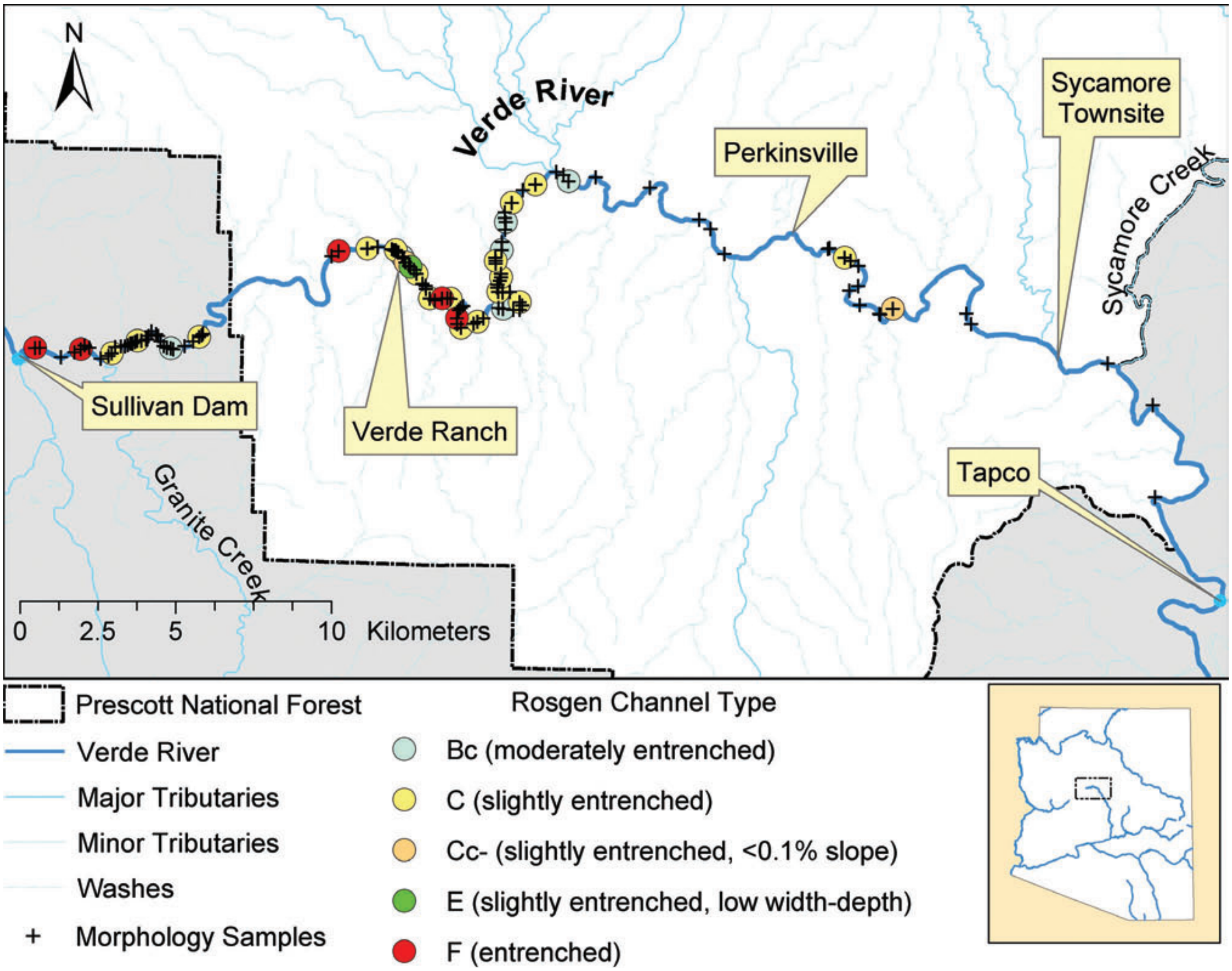


Figure 5.6—Location of channel morphology sampling sites, with differently colored dots representing reaches that were classified into different Rosgen Level I channel types.

Data Reduction and Analysis

Dataset—The large dataset developed by the field work was filtered and aggregated to render it useful for channel classification in accordance with Rosgen's (1994, 1996) methodology. The filtering involved elimination of data used in the classification analysis where data were incomplete or measurement stations were missing. In some years, sufficient funds were not available to re-measure every station. Aggradation of data was based on similarity within one year. The objective was to produce a dataset with common stations across all the years of the analysis. To yield more consistent estimates of bankfull dimensions, cross-sections were excluded that were established in glides, pools, or where low flows were split into two channels. Bankfull markers were found to be too inconsistent or confusing to be used reliably. Where suitable cross-sections were located within 20 channel widths of each other in reaches that appeared to have similar dimensions, average bankfull dimensions, slopes, and sinuosity were calculated for the entire reach encompassing those cross-sections. Figure 5.7 displays the channel types for 31 reaches that were classified in this manner, along with all 136 locations where morphological data were collected. Seven additional reaches were long enough to classify, but they were not because their associated cross-sections had been located

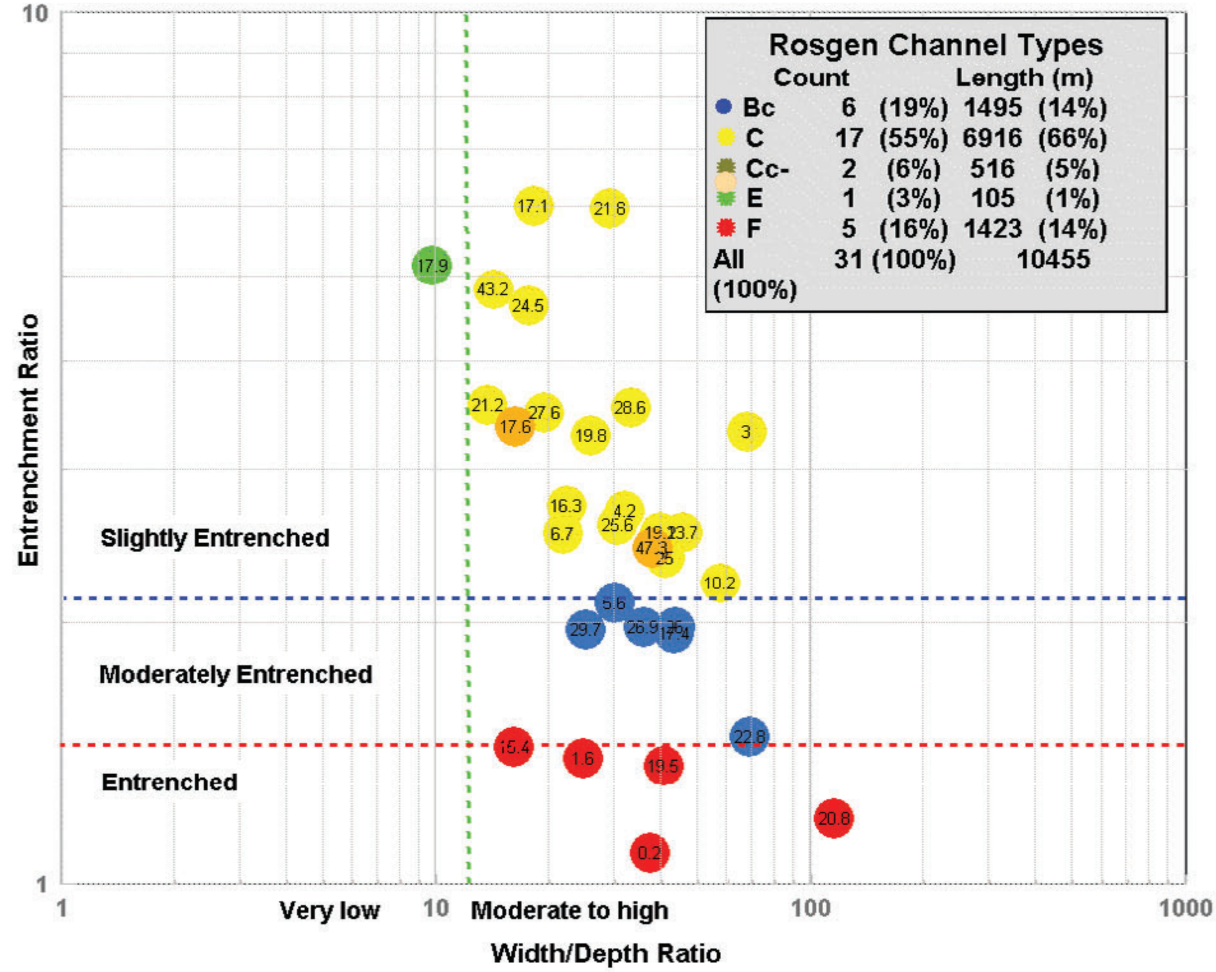


Figure 5.7—Width-depth ratios, entrenchment ratios, and Rosgen (1996) Level I channel types for classified reaches. Numbers within data point circles are width-depth ratios.

in pools or glides. Differences in cross-sections and pebble count distributions were examined at two reaches near the Paulden stream gauge (approximately 16.3 and 16.6 km or 10.2 and 10.4 mi downstream from Sullivan Dam) that had first been surveyed in 1997 and were re-surveyed in 2000. Differences in the percentage of fine sediments were calculated at those two reaches using a Chi-square contingency table (Bevenger and King 1995).

Hierarchical Analysis—A hierarchical assessment provides the physical, hydrologic, and geomorphic context for linking the driving forces and response variables at all scales of inquiry (Rosgen 1996). There are four levels to the Rosgen hierarchy (fig. 5.8). Level I describes the geomorphic characteristics that result from the integration of basin relief, landform, and valley morphology. Level II provides a more detailed morphological description of stream types based on channel dominant substrates and extrapolated from field-determined reach information. Level III describes the existing condition or "state" of the stream as it relates to its channel stability, sediment supply, erosion response potential, flow regime, and overall geomorphic function. Additional field parameters are evaluated that influence the stream state (e.g., riparian vegetation, sediment supply, flow regime, debris occurrence, depositional features, channel stability, bank erodibility, and direct channel disturbances). These analyses are both reach- and feature-specific and are especially useful as a basis for integrating companion studies (e.g., fish habitat indices and surveys of riparian communities). Measurements are taken to

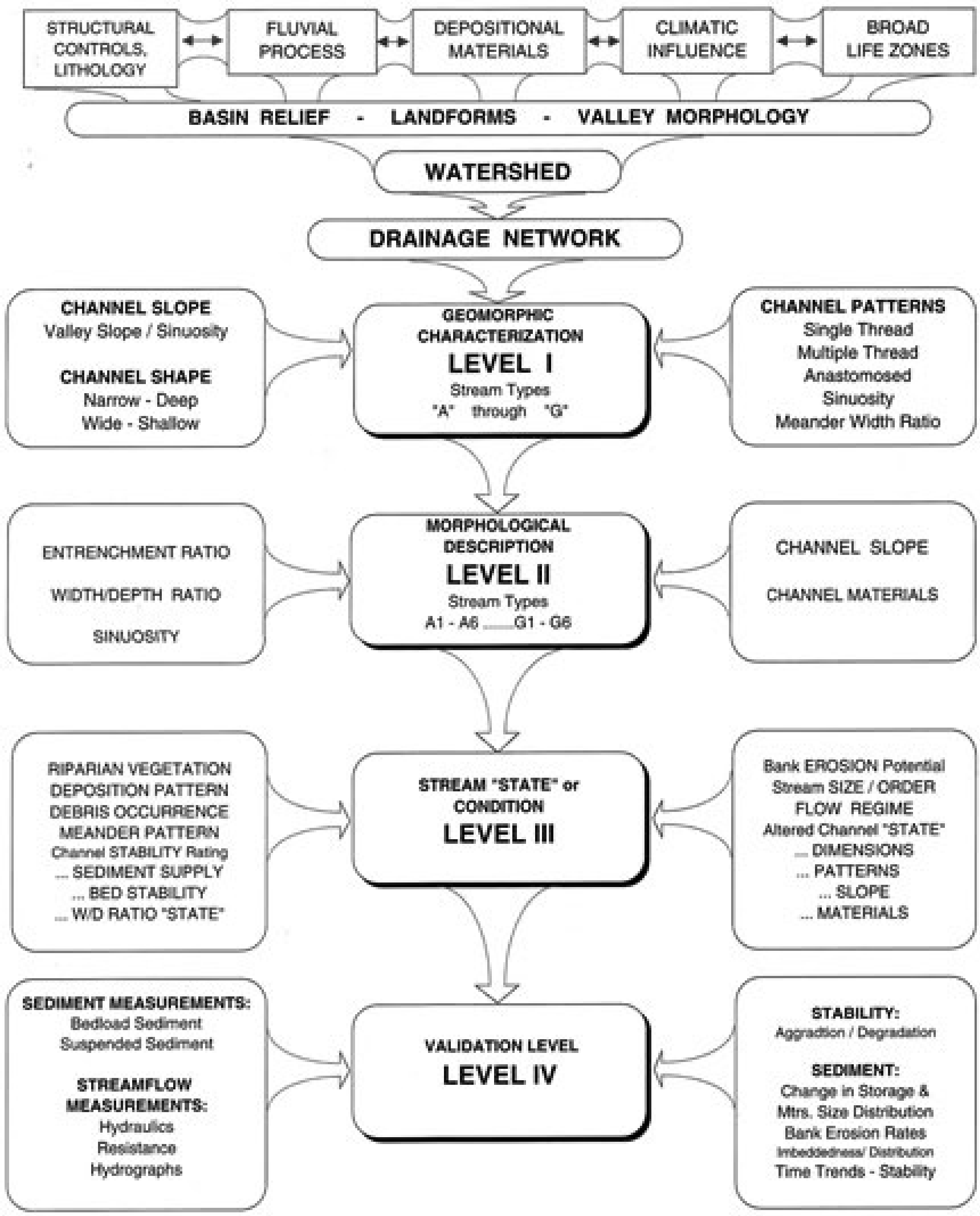


Figure 5.8—Rosgen's (1996) stream classification hierarchy used in the UVR channel classification (from Endreny 2003).

Level IV to verify process relationships inferred from preceding analyses. The objective is to establish empirical relationships for use in prediction (e.g., to develop Manning's "n" values from measured velocity; correlating bedload versus discharge by stream type to determine sediment transport relationships; or calculating hydraulic geometry from gaging station data). Empirical relationships are specific to individual stream types for a given statistic and enable extrapolation to other similar reaches for which Level IV data are not available.

Stream classification data used in the Level I through IV analyses of the UVR include a number of geomorphic and fluvial parameters. An example of typical data is shown in table 5.1. The distinctions between the basic types use uppercase letters (e.g., A, B, C, F, and E). Distinctions between the gradient subclasses within the basic classification types utilize the lowercase letters (e.g., Bc and Cc).

Table 5.1—Examples of Level II stream classification data for UVR cross-sections (Rosgen 1996). Data are: year (Yr), station number (STN), bankfull width (BFW), bankfull maximum depth (BFMD), flood prone area (FPA), valley distance (VD), stream distance (SD), channel slope (CSLP) and valley slope (VSLP), width/depth ratio (W/D), entrenchment (ENT), sinuosity (SIN), channel type (CHT), and median sediment diameter (D50).

Stream geomorphic parameters used in classification													
Yr	**STN**	**BFW**	**BFMD**	**FPA**	**VD**	**SD**	**CSLP**	**VLSP**	**W/D**	**ENT**	**SIN**	**CHT**	**D50**
				m			*%*	*%*					*mm*
97	15b	9.71	0.48	21.02	840	843	0.223	0.224	35.96	2.16	1.000	B4c	6.8
97	111	9.28	0.52	32.63	545	619	0.115	0.130	33.14	3.52	1.135	C4	1.5
97	5	9.15	0.67	12.76	76.4	97	1.330	1.688	24.73	1.39	1.270	F3	154.0
97	33	6.03	0.75	16.09	771	1104	0.272	0.389	11.17	2.67	1.430	E4	9.6

Results

Valley Type

The UVR valley is a type IV valley (fig. 5.9). Rosgen (1994, 1996) described it as the classic meandering, entrenched or deeply incised, and confined landform. This valley is the typical canyon and gorge type often with gentle elevation relief and valley-floor gradients of generally less than 2%. Steeper reaches are well interspersed with low-gradient reaches, thereby diversifying habitats. These valleys are generally structurally controlled and incised in highly weathered materials. However, F-type streams are often found in this valley type where the width of the valley floor accommodates both the channel and a floodplain (fig. 5.10). C-type channels are also often found in this type of valley. This is the case on the UVR where 61% of the channels are C-type, 19% are B-type channels, 16% are F-type channels, and 3% are E-type channels (figs. 5.1, 5.7 and 5.10; table 5.2). Depending on streamside materials, the sediment supply is generally moderate to high.

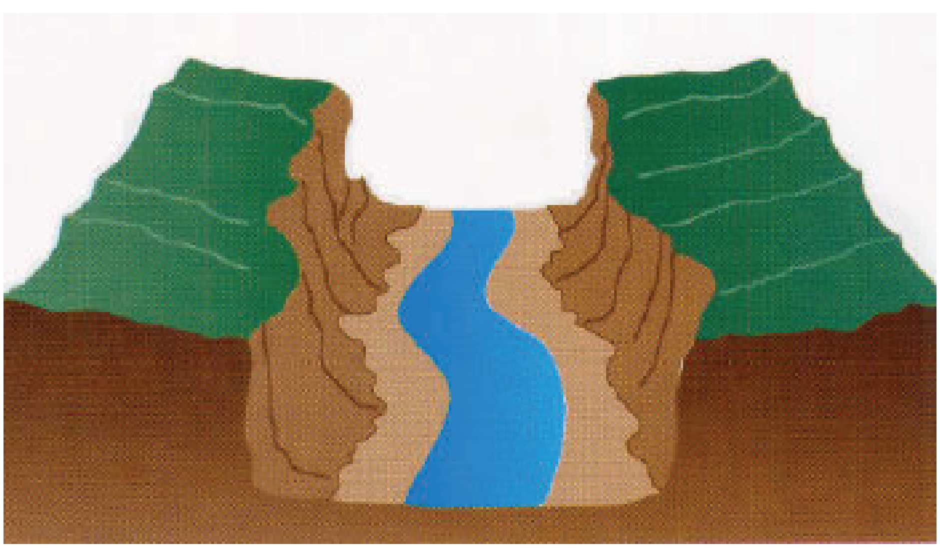


Figure 5.9—Rosgen (1996) Type IV valley form that comprises much of the UVR (from Endreny 2003).

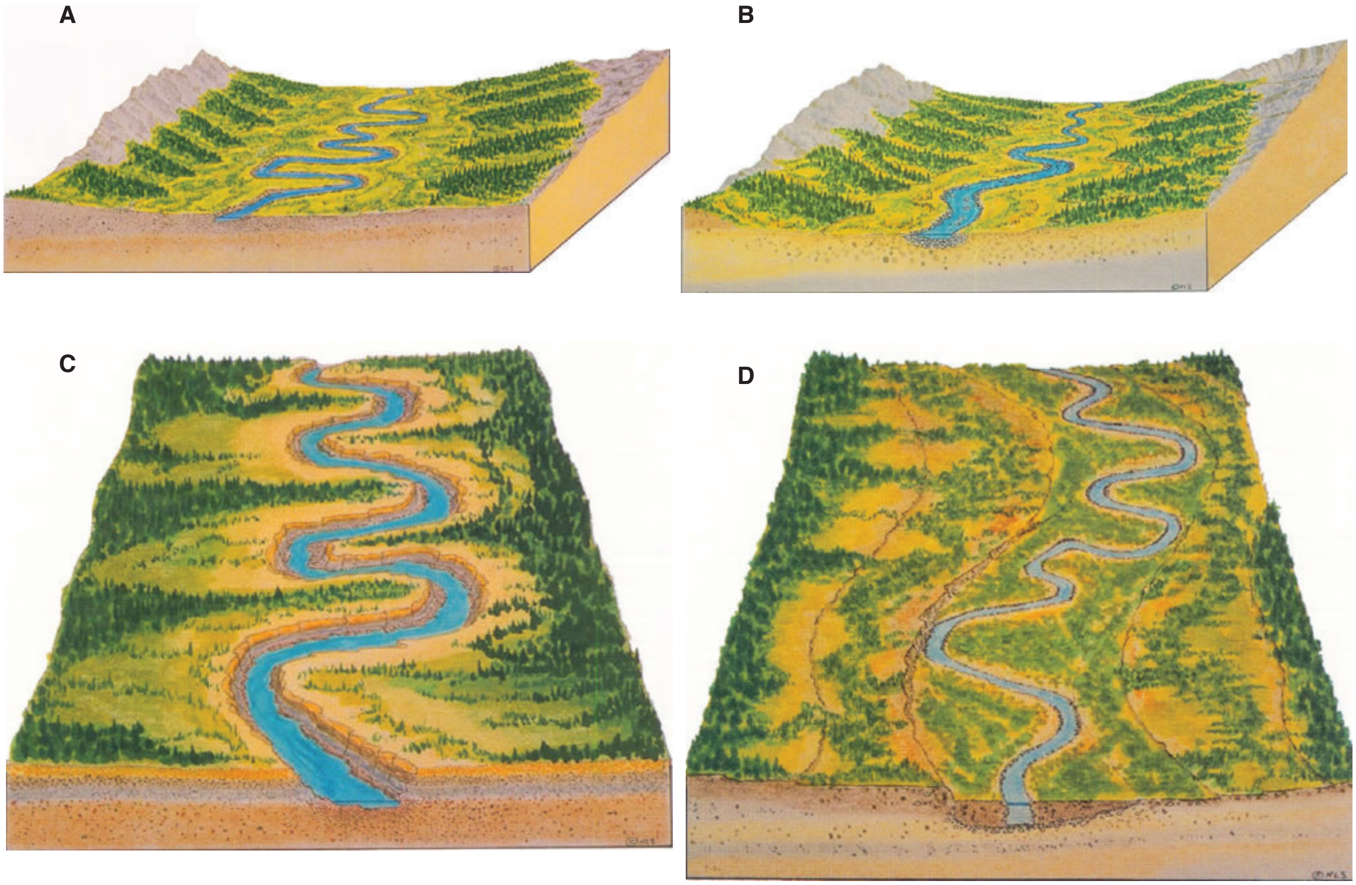


Figure 5.10—Channel types of the UVR according to Rosgen (1996) (from Endreny 2003): A = C-type channel and valley, B = B-type channel and valley, C = F-type channel and valley, D = E-type channel and valley.

Table 5.2—Characteristics typical of C-, B-, F-, and E-type stream channels found in the UVR.

Stream type	Portion of UVR	Entrenchment ratio	Width/depth ratio	Sinuosity	Slope range
	%				%
C	61	>2.2	>12	>1.2	<0.1-3.9
B	19	1.4-2.2	>12	>1.2	<2.0-9.9
F	16	<1.4	>12	>1.2	<2.0-3.9
E	3	>2.2	<12	>1.5	<2.0-3.9

Cross-Sectional Dimensions and Channel Types

Figure 5.7 shows the breakdown of channel type classifications relative to width-depth ratio and entrenchment ratio. This arrangement shows that channel types can be seen as a falling along a continuum rather than lying into discrete categories since some reaches lie close to the boundaries between channel type classes. The majority of reaches in the study area were slightly entrenched alluvial channels characterized by riffle-pool sequences (Rosgen C-types and Cc-subtypes).

About one-third of the reaches were moderately entrenched (Bc-type) or highly entrenched (F-types). The moderately entrenched reaches commonly featured long pools separated by short rapids, and they often occurred downstream of tributary confluences where alluvial deposits impinged on the main channel. Highly entrenched channels occurred in canyon reaches, including two reaches in the basalt-walled canyon that extends several kilometers below Sullivan Dam (figs. 5.2 and 5.5). One reach that met the criteria for the very narrow, vegetation-dominated (E-type) channel is a contiguous but relatively short (105 m or 345 ft) section of the UVR at the Verde Ranch. Other E-type channels are widely dispersed in the UVR, even shorter in length, and not considered in the general channel-type distribution.

The Verde River did not exhibit consistent channel dimensions downstream, but rather showed substantial variation from one reach to the next. Figure 5.11 depicts estimated width of the flood-prone area at the reaches used for channel classification, arranged longitudinally downstream. The chart suggests high variability in the width of the floodplain, which, in part, reflects the patchy distribution of canyon-bound and broad valleys. However, estimates of flood-prone area widths are very sensitive to the identification of bankfull level. Figure 5.12 indicates that there was roughly a one-half order of magnitude in variation of field-determined bankfull width, mean depth, and cross-sectional area. That variation may have been due to differences in identification of the bankfull level between survey crews, complex channel morphology, differences in substrates (e.g., finer sands and silts versus cobbles and boulders), and/or indistinct indictors of bankfull levels.

One of the most important observations about the channel classes of the UVR is the lack of D channels. These channels are multiple channel systems described as "braided streams" within broad alluvial valleys or on alluvial fans (Rosgen 1996). Braided channels are characterized by high bank erosion rates, excessive deposition, and annual bed location changes. The conditions that result in channel braiding are: high sediment supply, high bank erodibility, moderately steep gradients, and very flashy storm runoff conditions. Although flashy runoff can occur in the UVR, as indicated by the flow duration curves, most of the other conditions do not hold (see Chapter 4). This lack of D-type channels is an important piece of evidence indicating that the watershed condition of the surrounding uplands at present is definitely satisfactory. The UVR is simply not experiencing high levels of sediment input. The channel classes, entrenchment ratio, and continued narrowing and deeper are not indicative of a river system with high sediment loading. The Verde River is processing all of its sediment and then some because it still shows evidence of downcutting. The major fine sediment river deposits adjacent to the UVR channel that were mapped by Cook and others (2010) date from A.D. 440 to 1650 so they have nothing to do with modern management of the UVR (see Chapter 4).

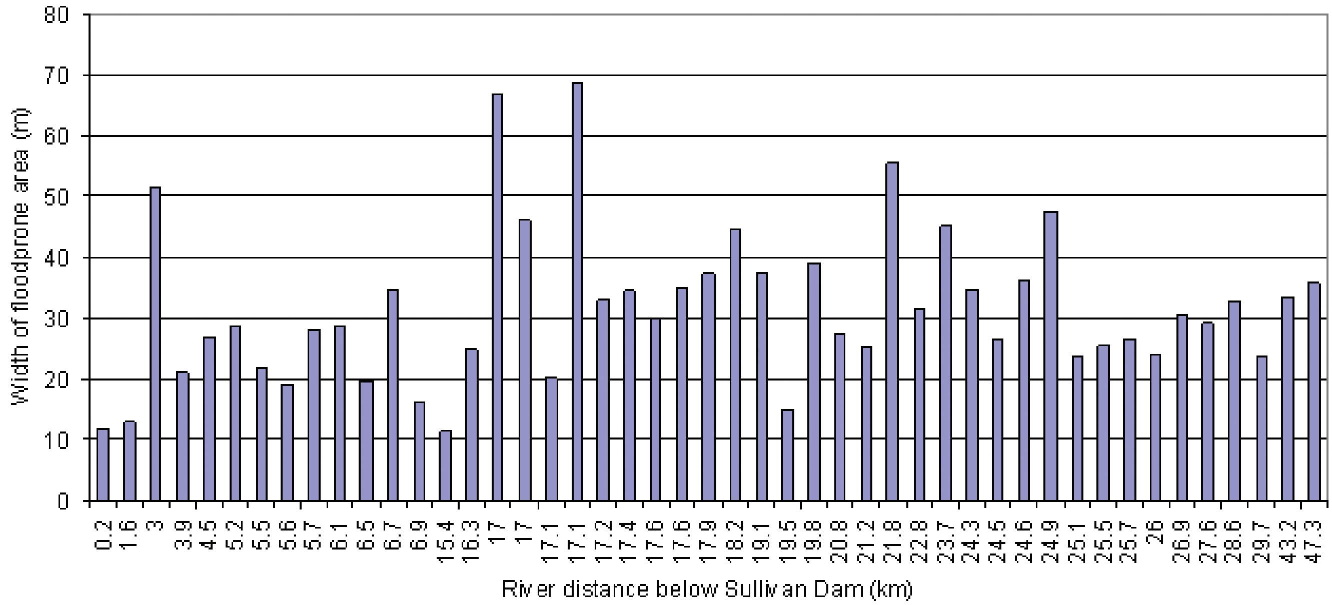


Figure 5.11—Floodprone area width at the reaches used for channel classification, arranged longitudinally downstream.

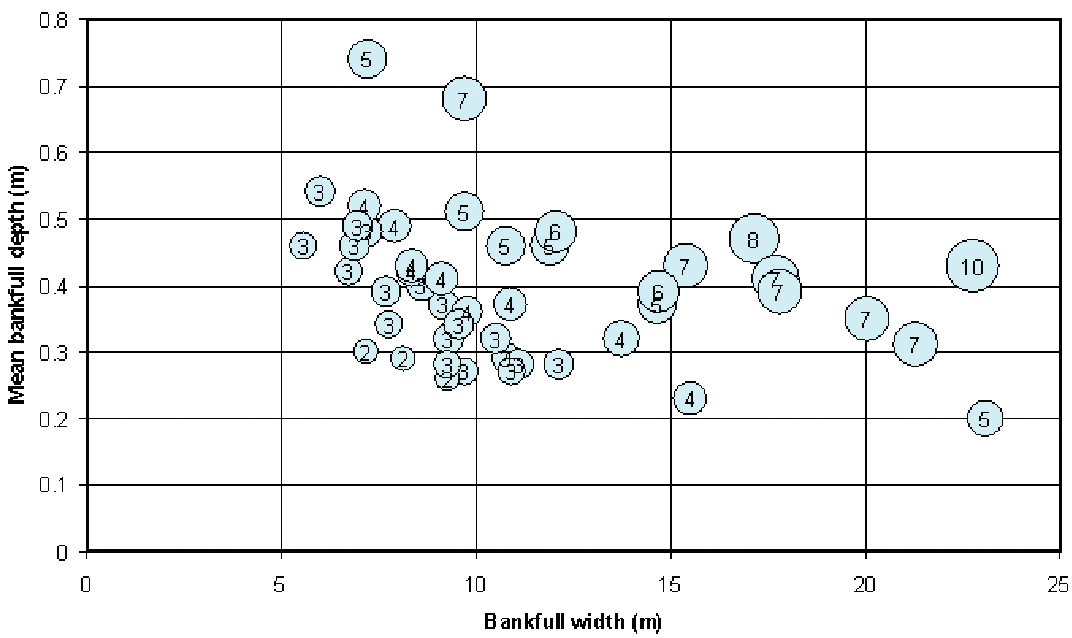


Figure 5.12—Bankfull width (X-axis), bankfull mean depth (Y-axis), and approximate bankfull cross-sectional area (size of bubbles) for classified reaches.

Channel Sinuosity and Gradient

A combination of low-gradient and relatively straight reaches characterized much of the UVR. Variation in slope was analyzed at two scales. First, slopes for the 38 reaches that were long enough for classification were summarized. Gradient of these reaches was consistently below 2%, with two reaches (Cc-types) being extremely low gradient (<0.001 slope). However, field crews surveyed three reaches with slopes >2%. Those reaches were too short to meet the requirements for channel classification, since Rosgen (1996) recommended measuring a reach that is a minimum of 20 channel widths in length or two meander wavelengths. The data for those reaches serve to characterize variation in sinuosity and slope at a finer scale. Sinuosity of individual reaches ranged from 1 to 1.6, with a mean of 1.15 (fig. 5.13a). Slopes of individual reaches ranged from 0.0% to 2.4%, with a mean of 0.5% (fig. 5.13b). The median slope across all sampled reaches (0.4%) was equal to the total slope across all sampled reaches (the total elevation drop divided by the total length of all sampled reaches). Both of those values were equal to the overall 0.4% estimated river slope from Sullivan Dam to the town site of Sycamore above the confluence with Sycamore Creek. This suggests that the sampled reaches were representative of the UVR.

Dominant Particle Sizes

Analysis of pebble count data reveals that the median (D50) particle size was predominantly gravel or very coarse sand in riffle reaches, while the dominant particle in pool reaches tended to be fine gravel or sand (fig. 5.14). Boulder-dominated reaches were restricted to the uppermost reach in a basalt-bound canyon. Many of these boulder deposits were moved about and depositied during the 1993 flood on the UVR (fig. 5.16). Reaches with large amounts of silts or clays were not commonly found, and then only in reaches where the channel gradient was diminished due to bedrock controls, coarse sediment deposits, woody debris, or beaver dams.

Temporal Consistency

The two cross-sections at the Paulden gauge that were resurveyed in June 2000 had equivalent lateral determinations of bankfull (fig. 5.15). The cross-section in a riffle reach filled (estimated bankfull cross-sectional area decreased by 11%, from 3.7 to 3.3 m^2), while the cross-section in a pool reach scoured (estimated bankfull cross-sectional area increased by 27% from, 8.3 to 10.5 m^2). The wetted widths of the channel decreased 16% at the riffle cross-section and 36% at the pool cross-section. Part of this change is attributable to a 13% smaller flow on the day when the cross-section was surveyed in 2000 (0.65 $m^3 s^{-1}$ on 7/16/1997 versus 0.57 $m^3 s^{-1}$ on 6/5/2000, according to U.S. Geological Survey gauge data). Mean water depth decreased by 25% in the riffle reach (from 0.28 to 0.21 m), while it increased by 22% in the pool reach (from 0.16 to 0.19 m). Particle size distributions differed between pebble count samples on July 16, 1997 and July 12, 2000, as fines in a riffle reach decreased from 40% to 28% (P-value = 0.016, chi-square test), while fines in a pool reach decreased from 62% to 49% (P-value = 0.015, chi-square test)."

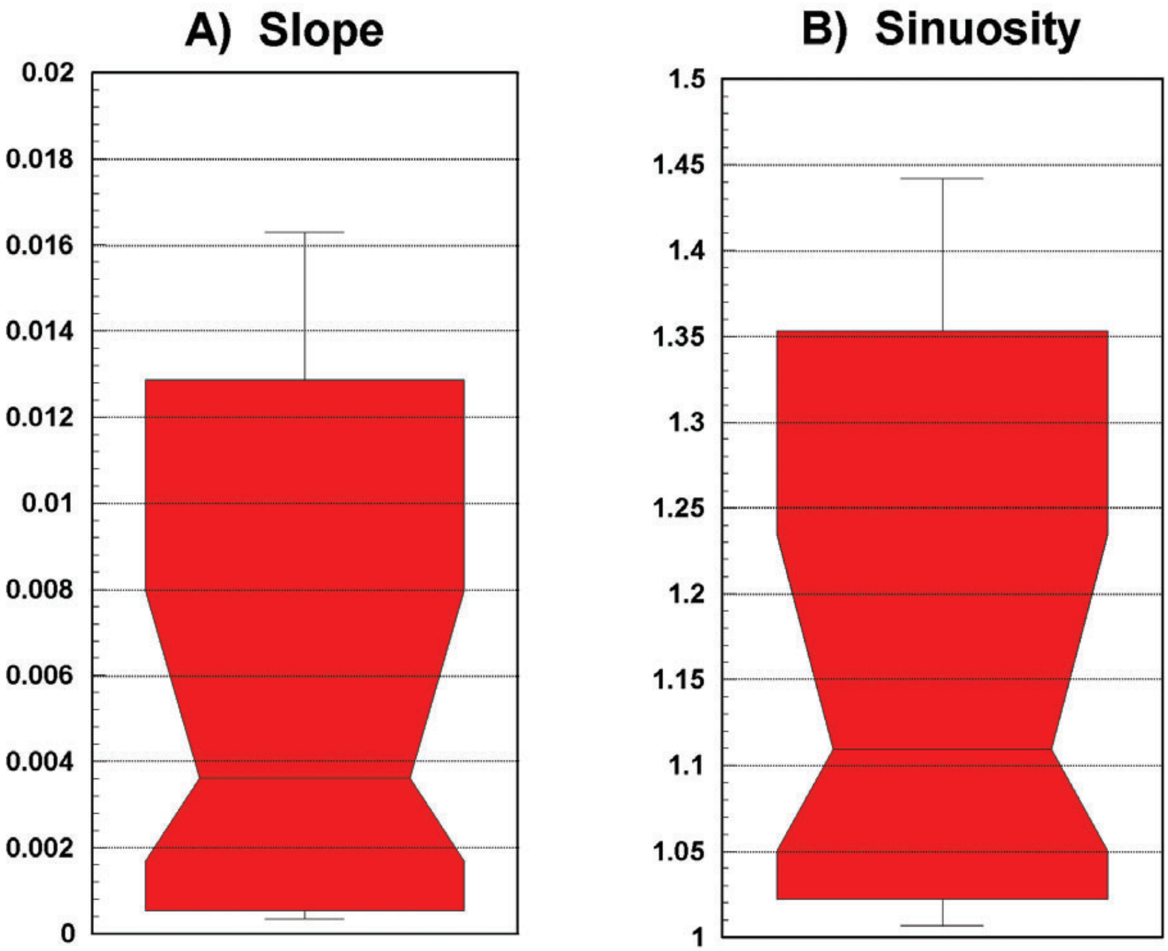


Figure 5.13—Box-and-whisker plots of sinuosity (a) and slope (b) across sampled reaches. Notches indicate the median values and the upper and lower edges of the box indicate the 25th and 75th percentiles (Frigge and others 1989).

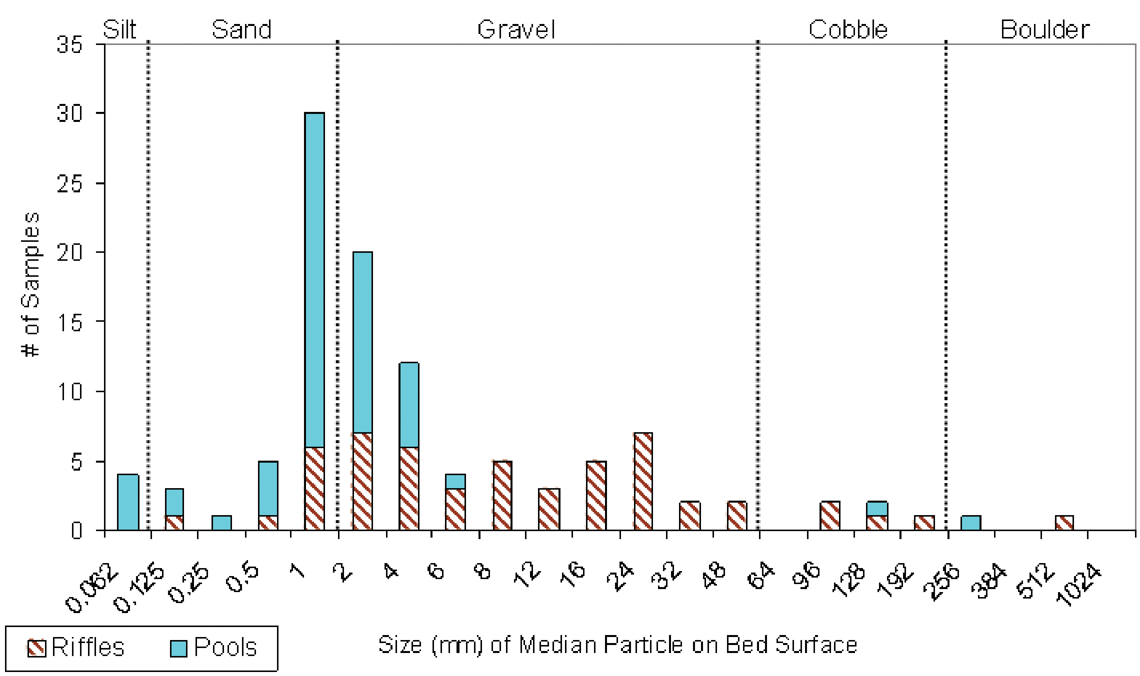


Figure 5.14—Distribution of median particle sizes (in mm) at all sampling reaches (1997 to 2000).

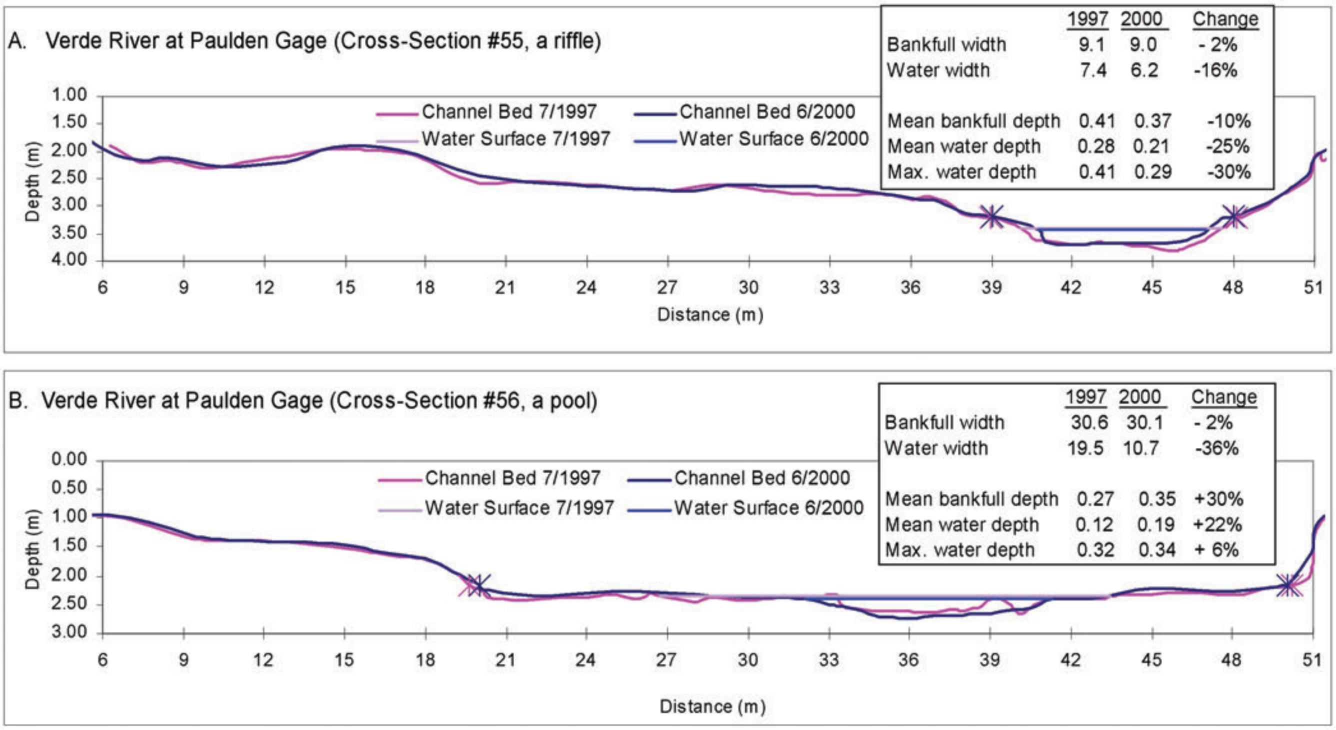


Figure 5.15—Overlay of repeated cross-sections that were measured in July, 1997, and June, 2000, across a riffle (A) and a pool (B) on the UVR near the Paulden gauge. The table within each figure summarize the dimensions of the bankfull and wetted channels.

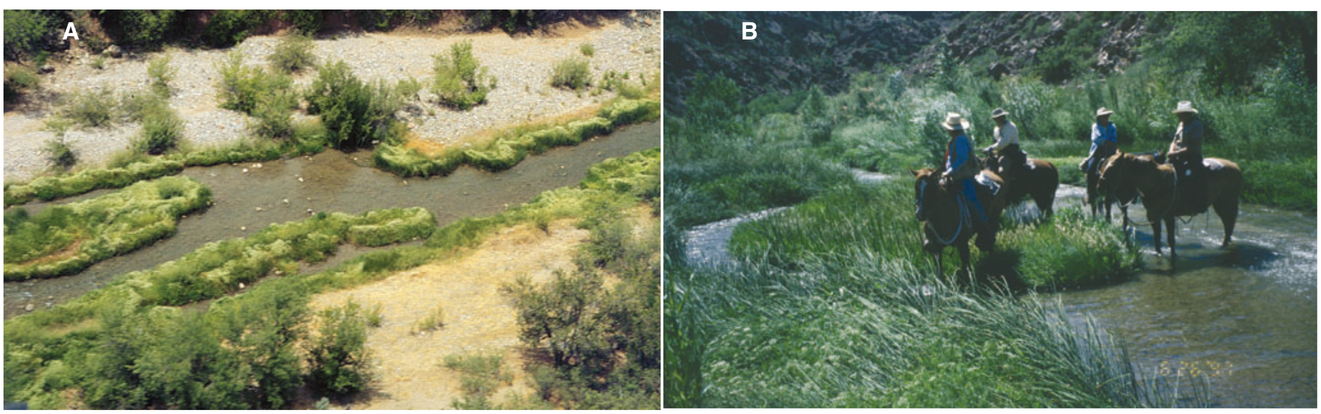


Figure 5.16—UVR channels (A) in a boulder-cominated sediment bar near Hells Canyon confluence and (B) downstream from the Verde Ranch and upstream of a canyon-confined river reach showing a C-type channel with elements of a E-type channel.

Discussion

Confined alluvial valleys with low gradients, like the UVR, are typically dominated by low-gradient entrenched channels (F-types), but less entrenched channels (C-types) often develop where the valley floor widens sufficiently to accommodate a floodplain (Rosgen 1996). Two areas in particular, the Verde Ranch and the Perkinsville Basin, feature broader valley settings where more sinuous channel types (C- and E-types) can develop (fig. 1.10). Narrow, deep, and highly sinuous channels (E-types) are often considered an end-point of channel development resulting from dense growth of herbaceous riparian vegetation (Rosgen 1996). One reach on the private lands of the Verde Ranch attained a very low width-depth ratio in association with dense growth of three-square bulrush (*Schoenoplectus americanus*) (fig. 5.16).

The frequent occurrence of moderately entrenched (Bc-type) and highly entrenched (F-type) channels reflects the control of bedrock and old alluvial deposits geologic controls on floodplain development. Entrenchment can result from recent channel degradation due to land uses or it may be a natural outcome of geologic confinement. The cause and timeframe of entrenchment is important for evaluating channel stability, since a channel in a bedrock-walled canyon will be more stable than a system that has experienced recent degradation. Entrenchment of the UVR appears to be a reflection of natural geologic confinement and long-term degradation rather than a recent response to other factors (Pearthree 1996).

Methodological Concerns in Channel Typing

Channel typing has many practical limitations for management of riverine ecosystems, which include technical challenges (Juracek and Fitzpatrick 2003) as well as the possibility that classification systems can distort views of natural systems (Kondolf 1995). A key element of evaluating river morphology using the Rosgen channel classification is the proper identification of bankfull level and the flood-prone area. Some scientists have questioned the geomorphic significance of both of these features, particularly in arid regions (Miller and Ritter 1996). Others have pointed out that the high potential for errors in identifying bankfull could lead to inappropriate inferences about river morphology (Juracek and Fitzpatrick 2003). Such errors are more likely when survey crews are inexperienced and change from year to year.

A lack of consistency between bankfull indicators from site to site may not simply be a measurement problem, but it may also reflect natural fragmentation in geologically complex areas (Fonstad 2003). Variation in bankfull is also common along confined rivers, because they can have floodplains that vertically accrete and erode episodically at different points along the river (Nanson 1986). Recently stripped floodplains will have greater frequency of bankfull flow, while more mature floodplains will have less frequent bankfull flows.

The re-surveys of two reaches near the Paulden gauge yielded consistent bankfull estimates, suggesting that crews were observing consistent morphological features. However, the UVR features a variety of flat surfaces, including floodplain terraces (Medina and others 1997), side channels, and sediment bars behind woody plants. Such complexity makes it difficult to determine bankfull level using field features. As a result, one would expect to see high variation in bankfull dimensions based on field measurements, as shown in fig. 5.12. Differences in slope and roughness could account for substantial variation in bankfull dimensions, but it also seems likely that the variation reflects inconsistencies in identifying bankfull. Such variation remained even after excluding more than half of the cross-sections that were measured in pools and glides. Because bankfull dimensions should be measured in riffle reaches where the channel reaches its narrowest point (Rosgen 1996), bankfull dimensions measured in pool reaches would tend to be overestimates.

Results from this analysis were compared with other studies of the Verde River to assess the accuracy of the bankfull identifications. The median cross-sectional area from the data examined in this study was 3.5 m^2 (38 ft^2) and the median bankfull width was 9.7 m (32 ft). These results were very close to the median values that were obtained from the cross-section closest to the stream gauge on the UVR near Paulden. At that same location, Moody and Odem (1999) estimated bankfull area to be 15.9 m^2 (171 ft^2), bankfull width to be 28.2 m (93 ft), mean depth to be 0.6 m (2 ft), and bankfull discharge to be 26.8 $m^3 s^{-1}$ (946 $ft^3 s^{-1}$), with a corresponding return interval of 1.7 years. That result was considerably higher than the 1.3 year return interval for two gauges further downstream on the Verde River, and it was at the high end of the range for all of the streams that were surveyed.

Validating field bankfull measurements with measured flows would help to resolve discrepancies in field determinations. Phillips and Ingersoll (1998) reported historic stream gauge data indicating that the "low-flow" channel at the Paulden gauge had an area of 12.9 m^2 (139 ft^2), with a top width of 20.8 m (68 ft), a mean depth of 0.6 m (2 ft), and a discharge of 8.9 m^3 s^{-1} (313 ft^3 s^{-1}). That discharge, which was only one-third of that estimated by Moody and Odem (1999), corresponds to a 1.3-year return interval. An accompanying photograph of the river during that measurement (April 16, 1995) suggested that the flow was consistent with bankfull, i.e., the water was beginning to spread laterally across the floodplain. Rosgen (1996) suggested that bankfull levels are often overestimated, as observers mistake a low terrace for the active floodplain, which could explain the high values reported by Moody and Odem (1999). Such discrepancies in bankfull dimensions could have important implications for interpreting the energy level of the system, and therefore, its behavior. For example, Moody and Odem's (1999) high estimates of bankfull flow (26.8 m^3 s^{-1}) and channel slope (1.6%) would place the river among high-energy streams that are prone to braiding, as characterized by Leopold and Wolman (1957) and Kondolf and others (2001), or to episodic floodplain stripping (Nanson and Croke 1992). The results from Phillips and Ingersoll (1998), by comparison, fall within the range of lower-energy meandering streams. If bankfull is not consistent, then it becomes difficult to interpret the river's dynamics using channel typing methodologies.

The bankfull dimensions at most of the cross-sections in this dataset (fig. 5.12) are smaller than those reported by Phillips and Ingersoll (1998). However, the authors' measurements included a much lower value for water-surface slope (0.0008 or 0.08%) than the slope measurements in this dataset. Increasing slope by a factor of 10 would correspond to reducing channel area by half, to approximately 6.5 m^2 (70 ft^2). Such a value would fall within the range of the data reported here (fig. 5.12), but it would still be higher than the median value. Raising estimates of bankfull dimensions would have altered the estimates for UVR entrenchment and width-depth ratios, which, in turn, could have changed the categorization of reaches at the margins between Rosgen channel types (figs. 5.7 and 5.10). Specifically, it would likely have shifted channel classifications toward the more entrenched types, but fig. 5.7 indicates that few reaches lay close to the boundary for F- types. Consequently, in this situation, the overall distribution of channel types likely would not have changed very much.

While channel typing is useful for inventory of large areas, users must recognize that existing classification systems impose arbitrary boundaries across a continuum of natural channel characteristics and processes (Kondolf 1995; Miller and Ritter 1996; Juracek and Fitzpatrick 2003). For the UVR sample, Rosgen's (1994, 1996) classification denotes categories along a continuum from unentrenched reaches (C- and E-types) to entrenched reaches (F-types); with the Bc-type representing an intermediate zone (fig. 5.7). Although Rosgen (1994) acknowledged that reaches with borderline dimensions may be placed into one type or another, his "management interpretations" emphasize the discrete categories. As a consequence, a naïve interpreter might conclude that the Bc-type reaches of the UVR are qualitatively more stable, have less potential for bank erosion, and have higher recovery potential than either the C- or F-type reaches, which seems inconsistent with the idea that these reaches represent variations along a continuum.

Channel type classifications often do not clearly explain that divisions may be arbitrary and therefore of questionable ecological significance (Kondolf 1995; Miller and Ritter 1996). Moody and others (1998) categorized the Verde River at Paulden as a Bc-type, but Moody and Odem (1999) re-categorized it as an F-type in their report. They stated that the Bc-type was quite common in central and southern Arizona, and that the study sites that represented these channel types appeared "relatively stable, which is consistent with the classification system." However, the authors classified other channels with similarly low gradient and moderate entrenchment as F-types because the channels "showed signs of instability (i.e., active cut banks)." Managers reviewing such evaluations should be mindful that the first two levels of the Rosgen methodology do not provide an objective basis for evaluating stream stability (Miller and Ritter 1996; Juracek and Fitzpatrick 2003).

Significance of Channel Types

A coarse analysis of channel morphology helps to describe qualities of the UVR that provide structure to its important aquatic habitats. The majority of reaches in the UVR were low-gradient, gravel-bedded, alluvial channels that fit within the parameters of the Rosgen C4-type. The uppermost segment between Sullivan Dam and Granite Creek departs from this general pattern, as boulder-dominated, entrenched channels (Rosgen F2-type) predominate. Basalt formations confine this segment, and the effects of the dam may limit deposition of the fine sediments required for extensive growth of riparian vegetation (Medina and others 1997). Both of these types are associated with low gradients, which is a distinctive feature of the UVR. Low-gradient channels are normally highly sinuous (Rosgen 1994), but sinuosity throughout the UVR is relatively low, owing to the confinement by canyon walls and resistant floodplain terraces (Pearthree 1996). Moody and Odem's (1999) regional study of channel types also found that alluvial channels of the UVR and central Arizona, in general, were relatively less sinuous than is typical for low-gradient systems.

The UVR is distinctive in the Southwest because it is relatively stable in terms of hydrology (see Chapter 3) and geomorphology (Pearthree 1996; Beyer 1998;). Although secondary channels are common below confluences with tributaries, the upper segment of the Verde River lacks braided conditions (Rosgen D-types), which often indicates instability due to a high sediment supply and/or losses of riparian vegetation (Kondolf 1995; Rosgen 1996; Montgomery and Buffington 1998). Although Rosgen's Level II classification does not provide a sufficient basis for interpreting stream stability and sediment loading, more detailed analyses of historical geomorphology, bank erosion, and hydraulic measurements can address those issues (Juracek and Fitzpatrick 2003). For the UVR, the conclusions of a historical geomorphology study (Pearthree 1996) and a channel stability study based on shear stress calculations (Beyer 1998) are both consistent with the lack of braided channels in suggesting that the river is able to efficiently process its sediment loads.

Although the UVR appears geomorphically stable, that stability is not necessarily favorable for native fishes because braided channels provide habitat for riffle-dwelling natives (Rinne 2003a, 2003b). Narrow, well-vegetated channels (typified by Rosgen E-types), on the other hand, may favor nonnative predators (Rinne and Neary 1997). Vegetative growth can induce channel narrowing and retention of sediments that can shift C-type channels toward E-type channels (Rosgen 1996). Indeed, Beard (2004) reported that several small stream channels in central Arizona had narrowed and deepened in response to vegetative growth attributed to exclusion of livestock grazing. However, George and others (2002) found no changes in bankfull channel width in grazing intermittent streams in central California, which they attributed to presence of bedrock controls, coarse soil textures, a lack of undercut banks, and a natural lack of woody species conducive to trapping sediment. Kondolf (1993) suggested that many years of exclusion may be needed to induce significant changes in channel morphology.

A lack of floods, high base flows, and livestock exclusion facilitated dense growth of streamside aquatic vegetation along the UVR (see Chapters 6 and 7), and pebble counts at the site that was re-sampled showed a significant increase in fine sediment. Nevertheless, most reaches in this study did not qualify as E-types. The lack of extremely narrow channels may reflect the fact that major floods in the UVR during recent decades have primarily been winter scouring events, which did not result in the extensive deposition of fine sediments in the floodplain that would facilitate narrowing. As a general principle, channels of low-energy streams with modest sediment loads are expected to change slowly (Kondolf 1995). Consequently, the Verde River was unlikely to exhibit major changes in channel type between scouring floods, even in reaches where the amount of fine substrates and aquatic vegetation increased.

On the other hand, Rinne and Miller (2006) reported that the wetted channel substantially narrowed and deepened at two fish sampling sites along the upper Verde River between 1994 and 2000. Furthermore, streamside aquatic vegetation grew dramatically along the river during this period. Results from the two cross-sections (one riffle and one pool) that were resurveyed at the Paulden gauge support the possibility that the wetted channel narrowed without corresponding changes in the bankfull channel. The cross-sectional area of the wetted channel in the riffle shrank by 38%, substantially more than the approximately 13% decrease in flow between the two sampling periods. The combination of narrowing and filling of the low-flow channel implies that water velocity increased through the riffle cross-section. Water flowing through the pool cross-section, on the other hand, narrowed and deepened. Pebble counts at the two reaches showed significant decreases in fine sediment, which could have been the result of flushing as the water flow became faster and narrower. The results from these two reaches support more widespread observations that that the wetted channel narrowed due to vegetative growth along the river. The two reaches also demonstrate the value of examining changes in both pools and riffles separately, since examining changes only in the riffle would have missed the deepening of the pool.

Limitations of Channel Typing

Despite its virtues as a communication tool, channel classification does not provide a deep understanding of fundamental geomorphic processes that regulate riverine development (Doyle and others 1999; Goodwin 2004). The Rosgen channel type classification was designed to describe variation across huge regions, so it is not surprising that its value for explaining variation in aquatic habitat for a particular river has considerable limitations. Moreover, the distinctive qualities of the Verde River may require methods that focus on finer scales. For example, due to its hydro-geomorphic stability, aquatic habitat in the river may experience important successional processes even as bankfull characteristics remain unchanged. In addition, the Rosgen classification focuses on variations in slope that are largely irrelevant to the UVR because it does not emphasize distinctions within the 0 and 2% slope range. Rosgen's (1994, 1996) system sorts unusually low-gradient B- and

C-type streams into Bc- and Cc-subtypes, but the management interpretations emphasize the distinctions between the basic types (the upper-cased letters) rather than distinctions between the gradient subclasses (the lower-cased letters). This limitation is not unique to the Rosgen classification, as an alternative reach classification system developed by Montgomery and Buffington (1998) also does not provide for discrimination within low-gradient, pool-riffle systems. Consequently, classifications applied at the reach scale suggest that variation in geomorphic response would be relatively limited along the UVR.

Analysis at finer scales, however, suggests that the proportions and gradients of particular channel units (riffles and pools) are biologically important. In particular, high-gradient riffles constitute important habitats for riffle-dwelling native fishes. Because they are relatively steep (>2%), these features assume the appearance of Rosgen's (1994, 1996) B-types or Montgomery and Buffington's (1998) plane bed channel types. Indeed, one of the sampled reaches was initially classified as a B-type channel with a slope of 2.3%. However, it was only 24 m (79 ft) long, or two times the estimated bankfull width of that reach. Rosgen (1994) suggested that distinct categories can be applied to reaches that are only tens of meters long, but his field procedures suggest that two bankfull widths is far too short to constitute a full reach. Applying a methodology that does not recognize such features as ecologically significant could lead to misinterpretations. For example, after examining associations between native fishes and channel types in a segment of the UVR, Rinne and Neary (1997) argued that C-type channels appeared more favorable to native fishes than did E-type channels. However, the authors also recognized that a high-gradient riffle located within an E-type channel had disproportionately high numbers of the native desert sucker (*Catostomus clarki*). Reach-scale classifications often fail to explain variations in velocity, gradient, and substrate that are strongly tied to native fish abundance (Converse and others 1998). Although understanding relationships across scales is always critical when evaluating aquatic habitats (Frissell and others 1986), the low gradient of the Verde River may render fine-scale morphologic variation particularly important.

Management Implications

To obtain useful information for sustaining the upper Verde River ecosystem, managers need to consider both technical and conceptual issues concerning data collection. These issues are intertwined, because obtaining useful information at finer scales generally requires more precise techniques and explicit stratifications. Careful applications of the Rosgen level II classification can be informative, but managers should be cautious when interpreting results of channel typing. For example, the 1999 report by Moody and Odem conveyed the impression that the gaging sites that they examined had high energy and highly entrenched channels which they characterized as unstable. However, a lower bankfull estimate, as we and others have found, suggested that the stream has more moderate energy and is dominated by the C channel type that is typical for an alluvial river. Overall, the morphology and channel typing data that we examined reveals that the Verde River has a distinctively low gradient, moderate entrenchment, and low sinuosity.

Channel typing does provide useful guidance for managers, but time-trend monitoring requires more detailed procedures. For example, Rosgen's (1994, 1996) methodology for pebble counts, as well as the zigzag procedure used to obtain the data in this study, loses resolution by mixing geomorphically distinctive units

(Kondolf 1997). Because both of those methods sample the bankfull channel, they may not be as relevant for aquatic assessments as sampling only the wetted channel. Furthermore, designing cross-section measurements to satisfy the requirements of channel typing tends to ignore changes in pool dimensions that may provide valuable information on sediment dynamics and predator habitat. More detailed, repeated sampling, as suggested in the fourth level of Rosgen's methodology, is needed to examine trends in fish habitat at fine scales.

A sound scheme for stream monitoring needs to consider geo-fluvial and biological processes in three-dimensions, through time, and across spatial scales (Poole and others 1997). The morphology data in this study is not well-suited for examining fine-scale changes in habitat units that are most relevant to fish. Pool habitats tend to expand in the aftermath of floods and exclusion from grazing (Gunderson 1968, Magilligan and McDowell 1997, Madej 1999). Monitoring techniques need to be sensitive to changes in those key habitat units. Fisheries monitoring efforts commonly classify and measure pools, riffles, and other channel units using methods that are not particularly repeatable, precise, and reliably quantifiable (Poole and others 1997). To understand how the channel is evolving, repeated measurements of longitudinal profiles would provide useful data (Madej 1999); however, profiles are difficult to monument in systems that are prone to scouring floods. Integrated mapping and classification of morphology and substrate has been recommended for quantifying physical differences and changes in aquatic habitat (Buffington and Montgomery 1999). Such intensive, small-scale procedures are more time-consuming than reach-scale channel classifications, but they would serve to more reliably evaluate morphological influences on fish habitat.

Summary and Conclusions

Measurements of channel morphology and application of channel classification have become a common tool for describing variation in rivers. The Rosgen (1994, 1996) classification system was applied to geomorphic data collected at 138 locations on the UVR between 1997 and 2000. The results showed that this segment of the river is dominated by gravel-bedded alluvial channels (B-, C-, and E-types) across a continuum of entrenchment. While channel typing is not a sufficient basis for evaluating channel stability, the lack of braided channels (D-type) is consistent with more detailed studies that describe the UVR as hydrogeomorphically stable. Channel typing does reveal that the river has a distinctive combination of low slope and low sinuosity. Due to the river's distinctive qualities, changes in riparian vegetation and aquatic habitat will occur at scales that are finer than those used for channel classification. Managers and researchers should adapt their sampling methods to focus on understanding such fine-scale changes in the river.

Chapter 6

Woody Vegetation of the Upper Verde River: 1996-2007

Alvin L. Medina

Introduction

Streamside vegetation is an integral component of a stable riparian ecosystem, providing benefits to both terrestrial and aquatic fauna (Brown and others 1977; National Research Council 2002) as well as Native Americans (Betancourt and Van Devender 1981). On the UVR, stable streambanks are a desirable management goal to attain channel stability for a variety of wildlife and fishery needs. Only recently have efforts begun to quantify streamside plant communities—owing to a paucity of adequate descriptions of riparian habitats and to address the managers need for qualitative and general descriptions (McLaughlin 2004). Vegetation environments are a focal point for land managers regulating land uses, such as livestock grazing, that could potentially impact aquatic communities. Managers rely on descriptions of the plant communities associated with streamside environments for qualitative and general descriptions (Brown and others 1979; Laurenzi and others 1983; McLaughlin 2004).

Previous vegetation studies on the Verde River (Brock 1987; Szaro 1989, 1990; Black and others 2005, Stromberg 2008) have provided some insight into riparian habitats, but the vegetation descriptions were unusable to managers interested in sensitive aquatic species management or their work was limited to flow-vegetation studies of the middle or lower Verde River (Beauchamp and Stromberg 2008). Shaw (2006) examined historic plant communities of the watershed and noted limited evidence of riparian communities. Szaro and Patton (1986) and Szaro (1989, 1990) provided generalized vegetation type descriptions that included the Verde River. Most vegetation descriptions for the UVR come from generalized species accounts and vegetation mapping using aerial photographs (Black and others 2005, Stromberg (2008).

The objective of this chapter is to provide a quantitative description of woody streamside vegetation along the UVR from 1996 to 2007. A need to understand the complexity of existing riparian vegetation, amidst the various changes in land uses and climate, is paramount for land managers (Pase and Layser 1977). The UVR possessed aquatic habitat highly suitable for native fishes decades ago. Today, riparian and aquatic habitats are much different raising questions about relationships between terrestrial and aquatic components that should benefit TES fishes. This description of the riparian vegetation will further the understanding of its role in management of TES species and other associated wildlife and plants in the ecosystem. All woody plants occurring within the streamside areas sampled are included in the analysis to reflect existing habitat conditions that vary from aquic to mesic, depending on their state.

Study Area

The UVR study area is defined as that portion bounded by the eastern edge of the Prescott National Forest near Tapco to Sullivan Dam on the west (see Chapter 1; figs. 1.1, 1.2, 1.3 and 6.1). The area lies within the transition zone between the Basin and Range and Colorado Plateau provinces. As such, the landscape displays lithologies common to both provinces, interspersed throughout the riparian corridor and uplands. Granitic materials are most common to the south, while limestone, sandstone, and basalt rock types are most common north of the river (Krieger 1965). For details, see Chapter 2.

The Verde River watershed covers 17,151 km^2 (6,622 mi^2) or about 6% of the State of Arizona. It is divided into three subwatersheds or HUCs—Upper, Middle, and Lower Verde River (Figure 6.2). The study area lies within the UVR subwatershed, which encompasses about 6,477.6 km^2 (2,501 mi^2) (Black and others 2005). The length of the Verde River is about 368.5 km (229 mi), of which the study reach approximates 56.3 km (35 mi). The elevation at the headwaters is about 1,311 m (4,300 ft) and about 1,067 m (3,500 ft) near the USDI Geological Survey Clarkdale stream gauge on the east end, averaging about 0.4% gradient. In the UVR corridor, landscapes vary from long, steep and narrow canyons to short and open valley forms. Likewise, floodplain widths range from 20 to 200 m (65.6 to 656.2 ft). The valley floor receives less rainfall than the average 508 mm (20 in)

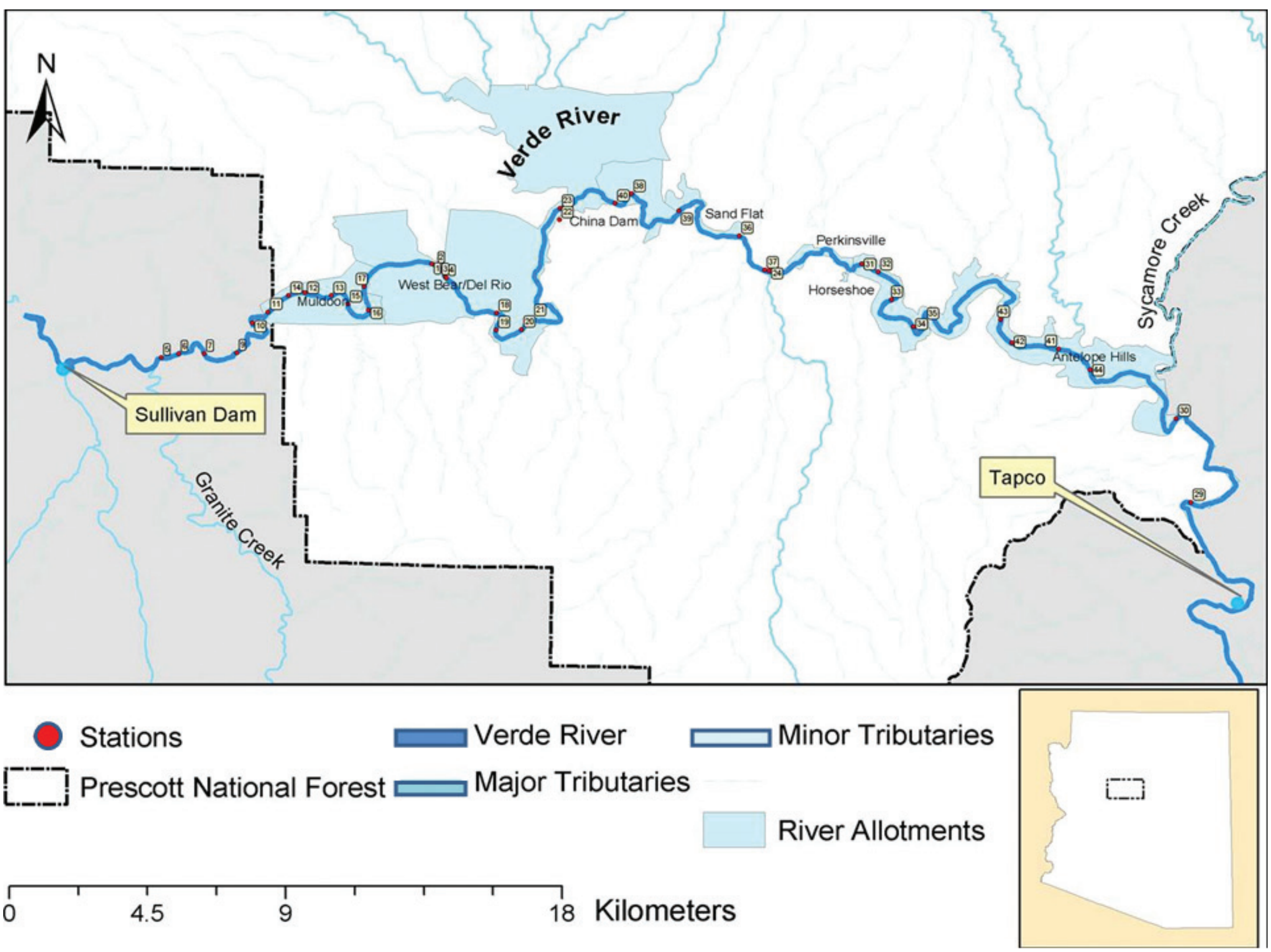


Figure 6.1—Location of UVR vegetation monitoring stations, Prescott National Forest, Arizona.

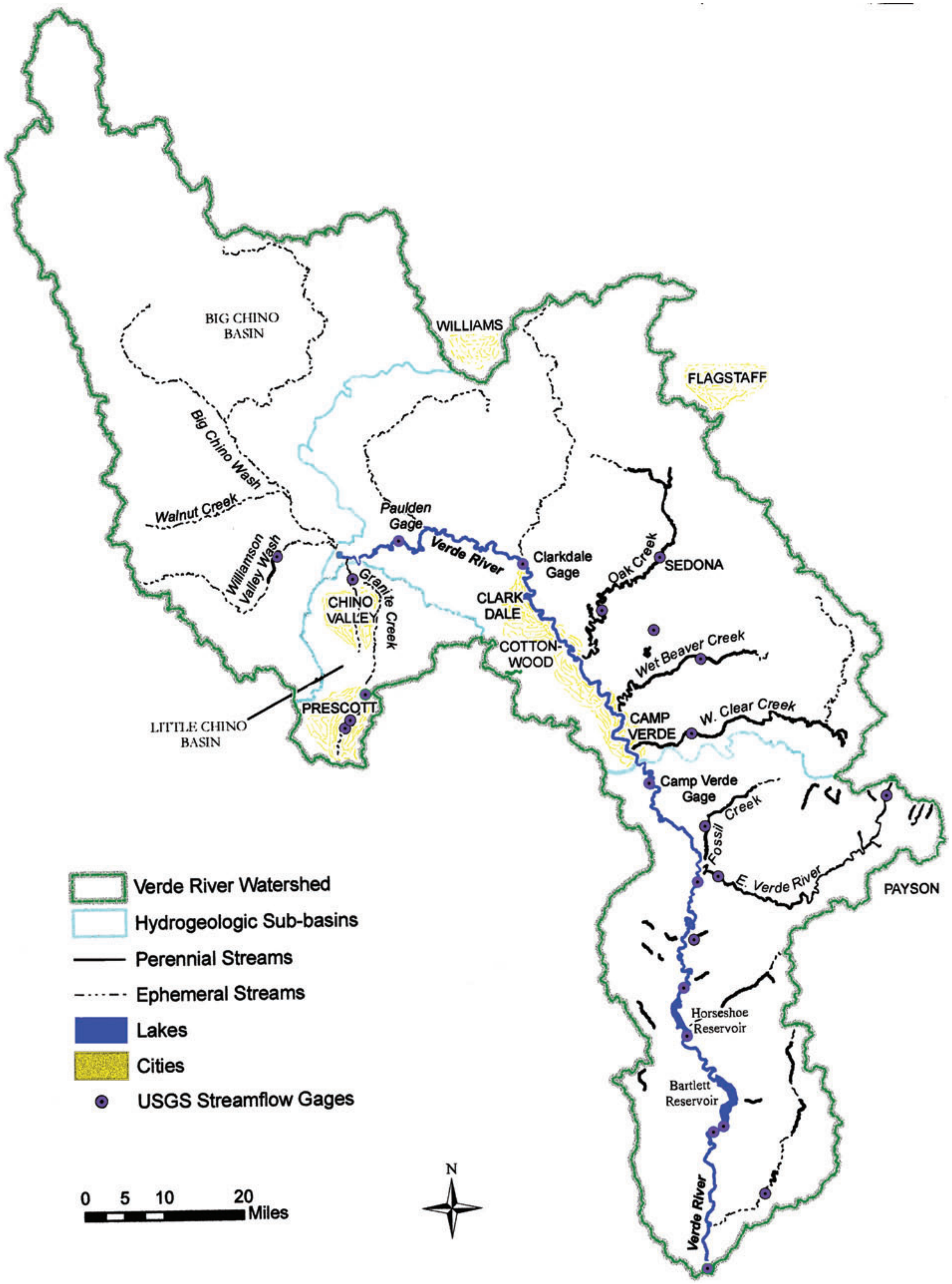


Figure 6.2—Verde River watershed showing HUCs 1506021, 15060202, and 15060203; basins; flow gauge locations; and proximity of major population centers.

for the watershed. In contrast, maximum summer temperatures can be greater within the narrow canyon landscapes than in the uplands.

Flows on the UVR have been highly variable for the period of record (see Chapter 3). Ely and others (1993) and Ely (1997) examined the paleofloods for the last 5,000 years and reported a high frequency in "extreme floods" correlated to periods of relatively cool, wet climate. Ely and others (1993) further noted unusually high frequency and magnitude of floods on the Verde River for the last 200 to 400 years. The largest recent flood was in 1993 and caused widespread channel scour and removal of woody vegetation. However, floods from the late 1800s and early 1900s were orders of magnitude larger. Peak flows at the Paulden Gauge and Clarkdale Gauge in 1993 approximated 657.0 and 1506.5 m^3 sec^{-1} (23,200 and 53,200 ft^3 sec^{-1}), respectively. Typically, (median) base flows are around 0.7 and 2.3 m^3 sec^{-1} (24 and 80 ft^3 sec^{-1}), respectively. Drought has also influenced the hydrology of the UVR (Ely and others 1993) to produce intermittent flow conditions (Wagner 1954). A survey of the UVR by Wagner (1954) recorded flows within the upper 38.6 km (24 mi) downstream from Sullivan Dam as "little perceptible flow." He further noted that flow was dependent on spring runoff and, when exhausted "the river ceases to flow, with any volume, until the arrival of summer rains."

Grazing by livestock occurred from the late 1890s until 1998. Today, principal herbivores are elk and beaver. Elk are a recent introduction to the UVR, moving in from adjacent mountains. Beaver have been historically common (Whittlesey 1997) and largely limited to dens within streambanks where large boulders afford protection from floods. Since 1993, more beaver dams have been evident, primarily within the floodplain in the extreme headwater reaches where flows and stream gradients are lower. A complete treatise on historical aspects and the setting of UVR is provided in Chapter 2.

Methodology

Site Selection

Streamside vegetation was sampled at 56 locations along the UVR (fig. 6.1). One-hundred sites were initially identified on aerial photographs in 1996. They were then stratified based on presence of pool, glide-run or riffle habitat, and 44 sites were randomly selected. In 1996, five additional sites were randomly established within a wetland meadow subject to high risk from erosion and inundation. Two additional sites were randomly established on private land in 2000, and five additional sites were methodically selected in 2006 on riffle habitats. Sites were selected and established to provide long-term monitoring points for both vegetation and channel conditions. Reaches immediately adjacent to side drainages and those near major changes in channel gradient were avoided.

Sampling

Time of Sampling—Five stations within a wetland meadow were sampled in 1996. Twenty-four of the stations were sampled in 1997, and 16 more were sampled in 1998. Eighteen of those stations, along with two new stations, were sampled in 2000, and all but two of the stations were sampled again in 2001. Finally, five additional stations were sampled from 2006 to 2007. Some sites were sampled across several years while others were only sampled once, depending on

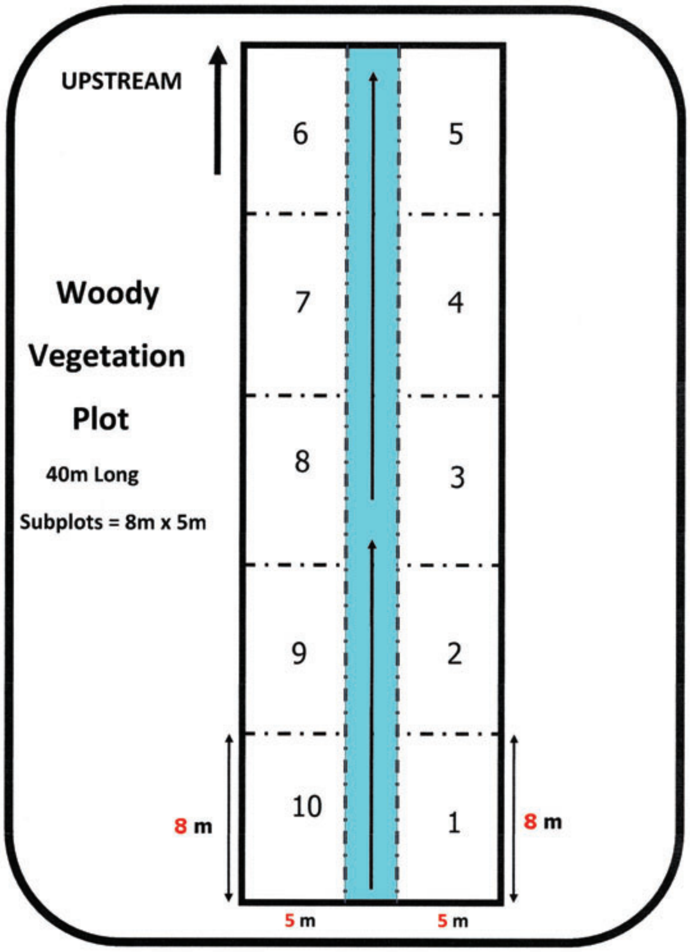


Figure 6.3—The sampling layout for woody vegetation consisted of a 40 m (131.2 ft) long plot, subdivided into 10-40 m^2 (430.6 ft^2) macro plots 5 x 8 m (16.4 x 26.25 ft).

the site's stability. For example, the wetland site was sampled once because subsequent floods eroded and inundated the sample locations.

General Sampling Methods—This study design allowed analysis of eight years of vegetation data for species composition and dominance. Vegetation was sampled during summers (June through August) of respective years. At each site, measurements of streamside herbaceous and woody vegetation were made within 40-m (131-ft) sampling transects (fig. 6.3). Transects were established along stream reaches with relatively uniform channel characteristics and vegetation. For all sampling work, the convention of denoting right and left streambanks facing upstream was used.

Woody Vegetation Sampling—Plant density estimates were determined using a technique designed to place emphasis on vegetation along the water's edge and on the streambanks immediately adjacent to the channel. Woody plant density was estimated using a modified Daubenmire (1959) approach tested on Southwestern riparian habitats (Medina 1986). Transects followed the edge of the streambank and thus were not straight lines, as illustrated in fig. 6.3. Woody vegetation was sampled in 5 x 8 m (16.4 x 26.2 ft) plots (10 total) along the same 40-m (131-ft) sampling reaches (i.e., stations). The term station was used to identify permanent sampling locations. Plot numbers 1 through 5 were located on the right streambank, while plots 6 through 10 were located on the left streambank (fig. 6.3). All tree and shrub species were counted and assigned to height and diameter size classes (table 6.1).

Table 6.1—Diameter and height classes for woody plants in the UVR survey.

Diameter class size	Height class	Size (trees)	Size (shrubs)
dm		*m*	
0-0.5	0	<1	<1 *dm*
0.5-0.9	0.5	1-1.9	1-1.9 *dm*
1-1.9	1	2-4.9	2-4.9 *dm*
2-2.9	2	5-9.9	5-9.9 *dm*
3-3.9	3	10-19.9	1-1.9 *m*
4-4.9	4	20-20.9	>2 m
5-5.9			
6-6.9			
7-7.9			
8-8.9			
9-9.9			
10>10			

Data Analysis

For the classification, data were used from the taxa that were identified as dominant species based on their average importance value (Curtis and Macintosh 1951). Relative importance values were derived for each relevé by dividing by the number of sampling events. A "relevé" consists of the entire collection of vegetation data for a given sampling station. Importance values (IV = relative dominance/constancy + relative density + relative frequency) were determined for the 22 major species (Braun-Blanquet 1932). For the classification, data from nine major tree species were used, both native and nonnative, and were limited to mature individuals.

For each vegetation type, Euclidean distance matrices were calculated as per Romesburg (1984) using IV values. Cluster analyses were performed using SAS Institute Incorporated (2002) procedures and Ward's Minimum Variance Method (Ward 1963) to produce dendrograms to estimate the dissimilarity between sites using measures of correlation. Vegetation groups were defined based on concurrence of the semi-partial-R^2, R^2, root-mean-square standard deviations, and examination of relevés for distinctness in taxa (Romesburg 1984). Community type names were assigned to each cluster group based on the relative species dominance (Shimwell 1971) indicated by the IV matrix. Estimates of frequency and density/cover were calculated for each community. Shrub species were incorporated into the final cluster groupings to identify important co-dominant strata using dominance data. Community descriptions are discussed in relative order of overall dominance in the study area.

Results

Flora

The woody vegetation of streamside habitats of the UVR consists of 62 species (tables 6.2A through 6.2C). Nomenclature follows the USDA Plant Database (http://plants.usda.gov). The UVR flora represents 12 years of plant collections on permanent stations. Plant identification of questionable taxa was performed by the

Table 6.2A—Woody taxa (ACGR/FAPA) found on riparian study plots (Stations) of the UVR 1996 to 2007. Abbreviations in this table are: **Life Form**: T = Tree, S = Shrub, SS = Sub-Shrub; **Native Status**: N = Native, I = Invasive; **Wetland Status**: U = Upland, F = Facultative, FW = Facultative Wetland, FU = Facultative Upland, O = Obligate Wetland, and NI = Native Invasive.

Taxa code	Genus	Species	Life form	Native status	Wetland indicator status	Common name
ACGR	*Acacia*	*greggii*	T/S	N	U	catclaw acacia
ACNE2	*Acer*	*negundo*	T	N	FW	boxelder
ALOB2	*Alnus*	*oblongifolia*	T	I	FU	Arizona alder
ALWR	*Aloysia*	*wrightii*	T	N	FW	Wright's beebrush
AMFR	*Amorpha*	*fruticosa*	S	N	FW	desert false indigo
ARLU	*Artemisia*	*ludoviciana*	SS	N	U	white sagebrush
ATCA2	*Atriplex*	*canescens*	S	N	U	fourwing saltbush
BAEM	*Baccharis*	*emoryi*	S	N	FW	Emory's baccharis
BAPT	*Baccharis*	*pteronioides*	S	N	U	yerba de pasmo
BASA2	*Baccharis*	*sarothroides*	S	N	F	desertbroom
BASA4	*Baccharis*	*salicifolia*	S	N	FW	seepwillow
BASE	*Baccharis*	*sergiloides*	S	N	F	desert baccharis
BRCA3	*Brickellia*	*californica*	S/SS	N	FU	CA brickellbush
CEPA	*Ceanothus*	*palmeri*	S	N	U	Palmer ceanothus
CELAR	*Celtis*	*laevigata*	T/S	N	FU	netleaf hackberry
CHLI2	*Chilopsis*	*linearis*	T/S	N	U	desert willow
ELAN	*Elaeagnus*	*angustifolia*	T/S	I	FW	Russian olive
EPVI	*Ephedra*	*viridis*	SS	N	U	Mormon tea
ERWR	*Eriogonum*	*wrightii*	S/SS	N	NI	bastardsage
FAPA	*Fallugia*	*paradoxa*	S	N	FU	Apache plume

Table 6.2B—Woody taxa (FOSP2/POHI8) found on riparian study plots (Stations) of the UVR 1996 to 2007. Abbreviations in this table are: **Life Form**: T = Tree, S = Shrub, SS = Sub-Shrub; **Native Status**: N = Native, I = Invasive; **Wetland Status**: U = Upland, F = Facultative, FW= Facultative Wetland, FU= Facultative Upland, O = Obligate Wetland, and NI = Native Invasive.

Taxa code	Genus	Species	Life form	Native status	Wetland indicator status	Common name
FOSP2	*Fouquieria*	*splendens*	S	N	U	ocotillo
FOPU2	*Forestiera*	*pubescens*	S	N	FU	stretchberry
FRVE2	*Fraxinus*	*velutina*	T	N	F	velvet ash
GAWR3	*Garrya*	*wrightii*	S	N	U	Wright's silktassel
GLSP	*Glossepetalon*	*spinescens*	SS/S	N	U	spiny greasebush
GUSA2	*Gutierrezia*	*sarothrae*	S/SS	N	U	broom snakeweed
JUMA	*Juglans*	*major*	T	N	FW	Arizona walnut
JUMO	*Juniperus*	*monosperma*	T	N	U	oneseed juniper
JUOS	*Juniperus*	*osteosperma*	T	N	U	Utah juniper
LYPA	*Lycium*	*pallidum*	S	N	U	pale desert thorn
MAFR3	*Mahonia*	*fremontii*	S	N	U	Fremont's mahonia
MAHA4	*Mahonia*	*haematocarpa*	S	N	U	red barberry
MIAC3	*Mimosa*	*aculeaticarpa*	T/S	N	U	catclaw mimosa
NOMI	*Nolina*	*microcarpa*	S/SS	N	U	sacahuista
PAQU2	*Parthenocissus*	*quinquefolia*	V	N	NI	Virginia creeper
PHAN3	*Phaseolus*	*angustissimus*	V	N	NI	slimleaf bean
PHAU7	*Phragmites*	*australis*	SS/S	N	FW	common reed
PLWR2	*Platanus*	*wrightii*	T	N	FW	Arizona sycamore
POFR2	*Populus*	*fremontii*	T	N	FW	Fremont cottonwood
POHI8	*Populus*	*hinckleyana*	T	N	FW	Hinckley poplar

Table 6.2C—Woody taxa found on riparian study plots (Stations) of the UVR 1996 to 2007. Abbreviations in this table are: **Life Form**: T = Tree, S = Shrub, SS = Sub-Shrub; **Native Status**: N = Native, I = Invasive; **Wetland Status**: U = Upland; F = Facultative, FW = Facultative Wetland, FU = Facultative Upland, O = Obligate Wetland, and NI = Native Invasive.

Taxa code	Genus	Species	Life form	Native status	Wetland indicator status	Common name
POGL9	*Potentilla*	*glandulosa*	SS	N	O	gland cinquefoil
PRVE	*Prosopis*	*velutina*	T/S	N	U	velvet mesquite
QUEM	*Quercus*	*emoryi*	T/S	N	U	Emory oak
QUGA	*Quercus*	*gambelii*	T/S	N	U	gambel oak
QUTU2	*Quercus*	*turbinella*	T/S	N	U	sonoran scrub oak
RHTR	*Rhus*	*trilobata*	S	N	U	skunkbush sumac
RHCA3	*Rhamnus*	*cathartica*	T/S	I	NI(FU)	common buckthorn
RIAU	*Ribes*	*aureum*	S	N	FW	golden currant
RICE	*Ribes*	*cereum*	S	N	U	wax currant
RONE	*Robinia*	*neomexicana*	T/S	N	U	New Mexican locust
SABO	*Salix*	*bonplandiana*	T	N	FW	Bonpland willow
SAEX	*Salix*	*exigua*	T/S	N	O	coyote willow
SAGO	*Salix*	*goodingii*	T	N	O	Gooding willow
SALA3	*Salix*	*laevigata*	S	N	O	red willow
SALA6	*Salix*	*lasiolepis*	T/S	N	FW	arroyo willow
SASA4	*Sapindus*	*saponaria*	T/S	N	U	wingleaf soapberry
TACH2	*Tamarix*	*chinensis*	T/S	I	NI	fivestamen tamarisk
TARA	*Tamarix*	*ramosissima*	T/S	I	NI	tamarisk, saltcedar
TORA2	*Toxicodendron*	*radicans*	S/SS	N	FW	poison ivy
ULPU	*Ulmus*	*pumila*	T/S	I	F	Siberian elm
VIAR2	*Vitus*	*arizonicus*	V	N	F	canyon grape
ZIOB	*Ziziphus*	*obtusifolia*	T/S	N	NI	lotebush

Rocky Mountain National Herbarium at the University of Wyoming in Laramie. The flora contains many obligate, facultative, and upland species. Obligate, facultative, and upland species are identified as per the "Wetland Indicator Status" descriptions in the USDA Plant Database (USDA Natural Resources Conservation Service 2008). Presence of facultative and upland species is a common occurrence, as many obligate species are recent (post-1993) to developing riparian-wetland habitats. In addition, the present erosional state of the channel is such that terraces are actively eroding with the active channel abutting upland terraces, thereby creating frequent streambank-terrace disturbances. Six nonnative species were found, of which saltcedar (*Tamarix ramosissima*) was the most frequent and abundant, existing as multiple single stems to very large dense colonies (fig. 6.4) approximating 25 to 5,000 stems ha^{-1}. Siberian elm (*Ulmus pumila*) commonly occurs as large mature trees (DBH = 0.2 to 0.8 m [7.9 to 31.5 in]) throughout the study area, while Russian olive (*Elaeagnus angustifolia*) occurs as young trees (DBH = 0.05 to 0.2 m, [2.0 to 7.9 in]) primarily in the upper reaches and camping areas. A species of interest is Hinckley's poplar (*Populus × hinckleyana Correll [pro sp.] [angustifolia × fremontii]*), which is proposed as a distinct species (Integrated Taxonomic Iinformation System 2010). It is most similar to Fremont cottonwood (*P. fremontii*) and relatively more abundant. However, no distinction was made between the two species during the early study periods. Hence, all references to Fremont cottonwood are equally applicable to Hinckley's poplar.

Cluster analysis resulted in the definition of 12 community types at $R^2 = 0.796$ (fig. 6.5). Approximately 80% of the variation is accounted for at this level. Plant communities were determined by using the statistical indicators and from examination of species data by groups, which revealed distinct types. Descriptions of the community types can be found in the following sections. Estimates of the community's species frequency and density are listed in the respective tables of each

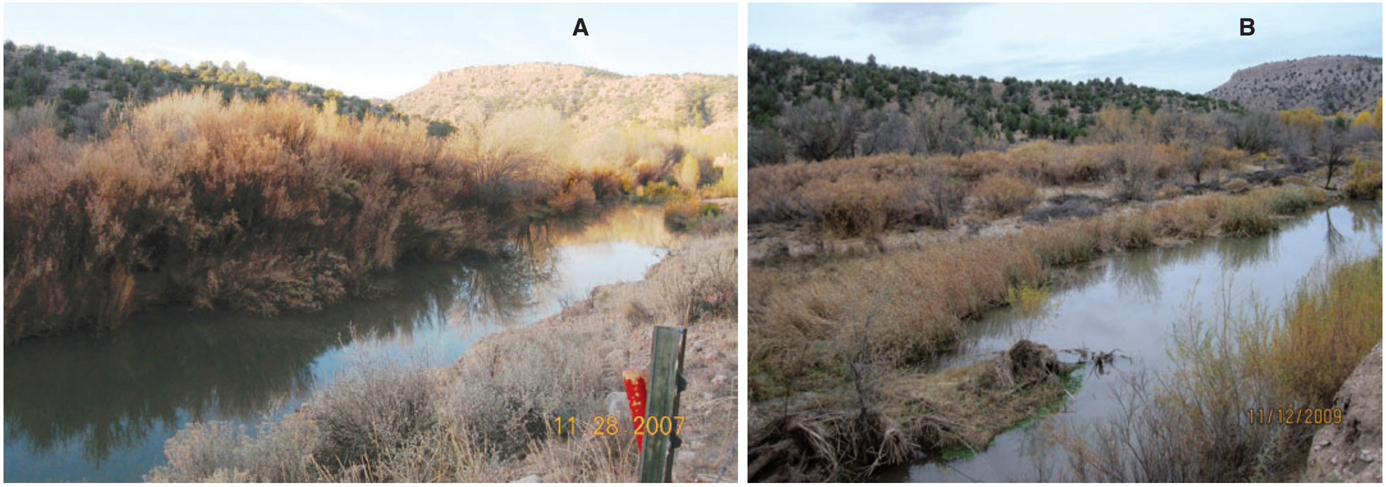


Figure 6.4—A large tamarisk stand occupies the entire streambank for about 350 m (1,148 ft) on the UVR (photo A taken in Oct 2007). These stands are relatively new with the oldest dating back to mid-1950s and pre-date most riparian trees and shrubs. B shows the site after the tamarisk stand was removed in 2007. (Photos by Alvin L. Medina.)

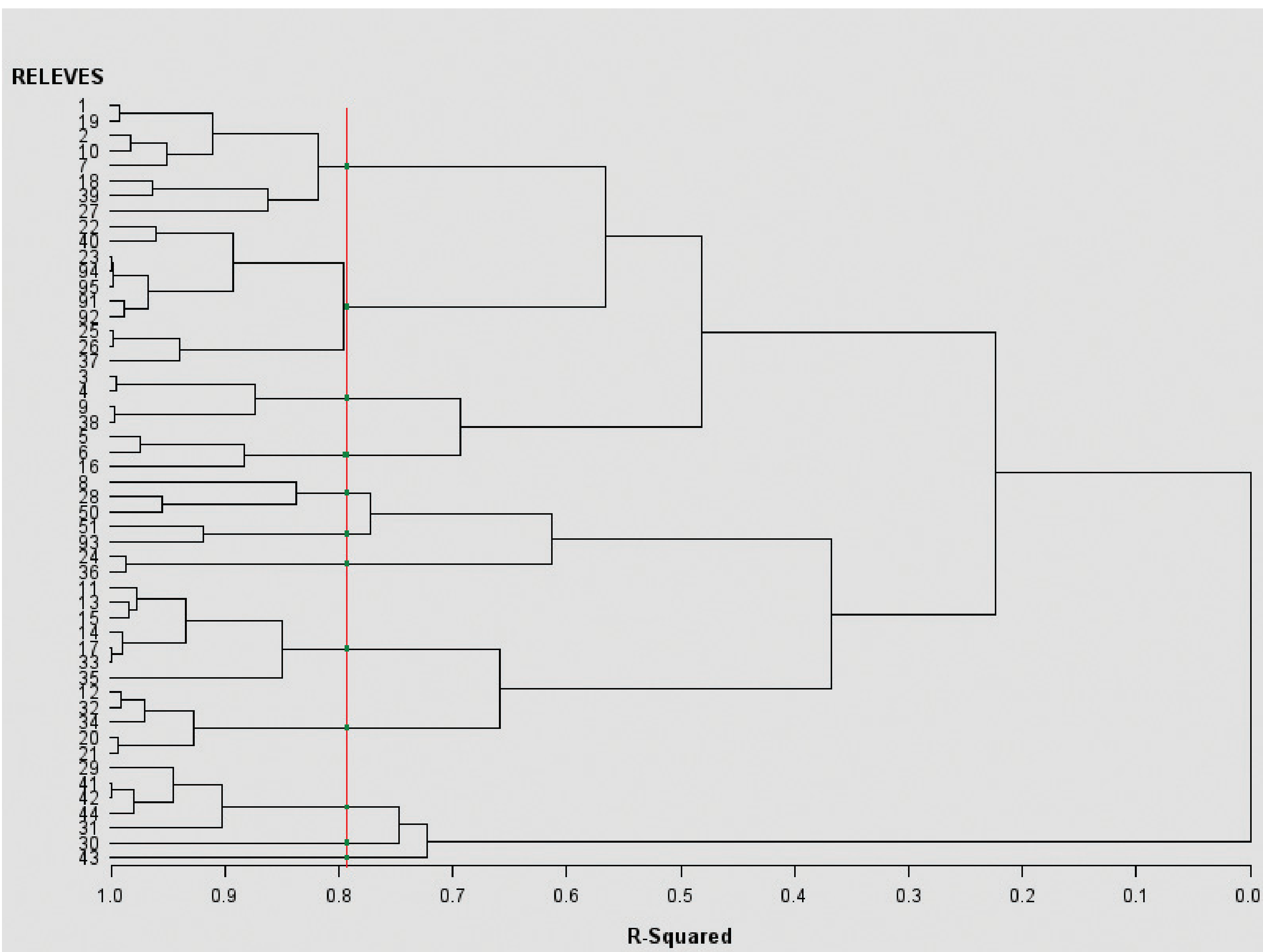


Figure 6.5—This dendrogram identifies 12 plant communities at an $R^2 = 0.796$ on the X-axis (red line). The nodes of the unions of relevés are noted with a green square. Communities may be unions of several relevés or only one when the relevé is unique. Relevés, identified as Station numbers, are listed on the Y-axis.

community. Parentheses indicate the number of stations comprising the community. Most stands of obligate species are dated to the 1993 flood.

*Gooding Willow (*Salix goodingii*) Series*

***Salix goodingii/Salix laevigata* (SAGO/SALA3) Community (N = 2)**—This community is characterized by the relative dominance of Gooding's willow in the overstory and red willow in the understory (fig. 6.6, table 6.3). Velvet ash (*Fraxinus velutina*) and boxelder (*Acer negundo*) are common mid-story species. This community is similar to the SAGO/FRVE2 community except that it is common on open, wet sites. Mature Fremont cottonwood (*Populus fremontii*) and saltcedar (*Tamarix ramosissima*) are generally absent. Depending on channel changes affecting water status, these two communities could become increasingly distinct or

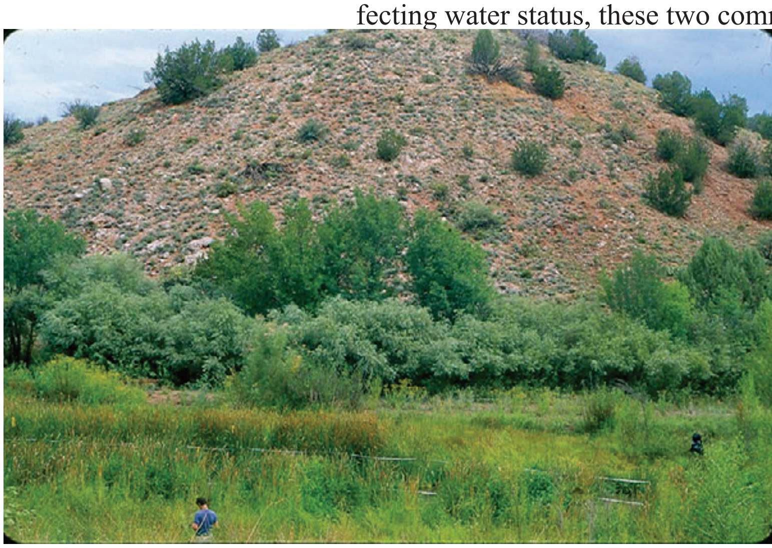


Figure 6.6—UVR representative *Salix goodingii/Salix laevigata* (SAGO/SALA3) community. (Photo by Alvin L. Medina.)

Table 6.3—Dominant woody taxa of the Salix goodingii/Salix laevigata (SAGO/SALA3) community.

Taxa	Total frequency	Mature mean density	Young mean density
	%	*Number ha^{-1}*	*Number ha^{-1}*
ACNE2	100	5	8
FRVE2	100	5	21
POFR2	50		3
SAGO	100	6	112
SALA3	100	16	188
TARA	100		127

Table 6.4—Comparison of species attributes for UVR communities.

Community	Species richness	Nonnative species	Obligate species
		Number	*Number*
ALOB/FRVE2	14	0	1
FRVE	37	3	3
FRVE/JUOS	33	2	3
FRVE/JUOS/CELAR	31	3	3
SAGO/ACNE2	11	2	2
SAGO/FRVE2	6	1	2
SAGO/FRVE2/JUOS	28	3	3
SAGO/SALA3	6	1	2
SAGO/SALA3/POFR2	31	4	3
SAGO/SASA4	16	1	2
POFR/SAGO	26	2	3
POFR/SALA3	21	2	3

similar (wet or dry). This community and the SAGO/FRVE2 community exhibited the lowest species richness (table 6.4).

***Salix goodingii/Salix laevigata/Populus fremontii* (SAGO/SALA3/POFR2) Community (N = 7)**—This community is characterized by the dominance of Gooding's willow in the overstory and red willow in the mid-story (fig. 6.7, table 6.5). Fremont cottonwood (*Populus fremontii*) is an important co-dominant on some sites with Gooding's willow. Velvet ash (*Fraxinus velutina*) is infrequent but may attain prevalence on some sites as young trees. Seepwillow (*Baccharis salicifolia*) is common in association with cattails (*Typha* spp.) and coyote willow (*Salix exigua*). It is common for some sites to have one streambank dominated by obligate species, while the opposite bank may be an actively eroding terrace or an

Figure 6.7—UVR representative *Salix goodingii/Salix laevigata/Populus fremontii* (SAGO/SALA3/POFR) community. (Photo by Alvin L. Medina.)

Table 6.5—Dominant woody taxa of the *Salix goodingii/Salix laevigata/Populus fremontii* (SAGO/SALA3/POFR2) community.

Taxa	Total frequency	Mature mean density	Young mean density
	%	*Number ha^{-1}*	*Number ha^{-1}*
ACGR	29		32
AMFR	86		14
ATCA2	14		3
BASA2	14		182
BASA4	100		211
BEFR	14		25
CELA	14		8
CHLI2	43	4	53
COLY2	14		3
ELPU	14		3
FOPU2	29		6
FOSP	14		20
FRVE2	100	7	19
GAWR3	14		28
JUMA	14		10
JUOS	29	4	5
MIBI3	29		3
POFR2	100	5	23
PRVE	14		49
RHTR	14		9
RONE	29		13
SABO	86	3	35
SAEX	57		189
SAGO	100	13	76
SALA3	100	13	68
SALA6	29		21
TACH2	100		37
TARA	100	3	24
ULPU	14	5	3
VIAR2	14		3

eroded terrace transitioning into an aquic streambank. This relevé is diverse—represented by 31 woody species (table 6.4).

***Salix goodingii/Acer negundo* (SAGO/ACNE2) Community (N = 2)—**This community is characterized by the relative dominance of Gooding's willow in the overstory with boxelder and velvet ash (*Fraxinus velutina*) in the mid-story (fig. 6.8, table 6.6). Velvet ash occurs in some stands and may be rare in others. Boxelder is a common mid-story co-dominant of Southwestern rivers and streams (Boles and Dick-Peddie 1983; Medina 1986; Skartvedt 2000). This community is similar to other Gooding's willow associations found on the Verde River, e.g., SAGO/FRVE2, SAGO/SALA3, except that here it is common on open, drier sites. Mature trees of other riparian obligate species are generally lacking. Various upland species, such as golden currant (*Ribes aureum)*, may dominate one streambank, while the opposite bank (or the active channel) is inhabited by common riparian shrubs, such as coyote willow (*Salix exigua*) or seepwillow (*Baccharis salicifolia*). This community has the lowest total stem density of young plants in

Figure 6.8—UVR representative *Salix goodingii/Acer negundo* (SAGO/ACNE2) community. (Photo by Alvin L. Medina.)

Table 6.6—Dominant woody taxa of the *Salix goodingii/Acer negundo* (SAGO/ACNE2) community.

Taxa	Total frequency	Mature mean density	Young mean density
	%	*Number ha^{-1}*	*Number ha^{-1}*
ACNE2	100	5	19
BASA4	100		79
FOPU2	50		29
FRVE2	100	3	19
JUMA	100		3
POFR2	100		18
RIAU	50		197
SAEX	50		223
SAGO	100	5	93
TACH2	100		31
TARA	100		3

an otherwise shrubby, mixed understory. Relatively, species richness is moderately low (table 6.4).

***Salix Goodingii/Fraxinus velutina* (SAGO/FRVE2) Community (N = 3)—** This community is characterized by the relative dominance of Gooding's willow and velvet ash in the overstory (fig. 6.9, table 6.7). Fremont cottonwood (*Populus fremontii*) and red willow (*Salix laevigata)* are co-dominants on wetter sites, whereas boxelder (*Acer negundo*) and saltcedar (*Tamarix ramosissima*) are co-dominant on drier sites. It is different from the SAGO/FRVE/JUOS type because boxelder is

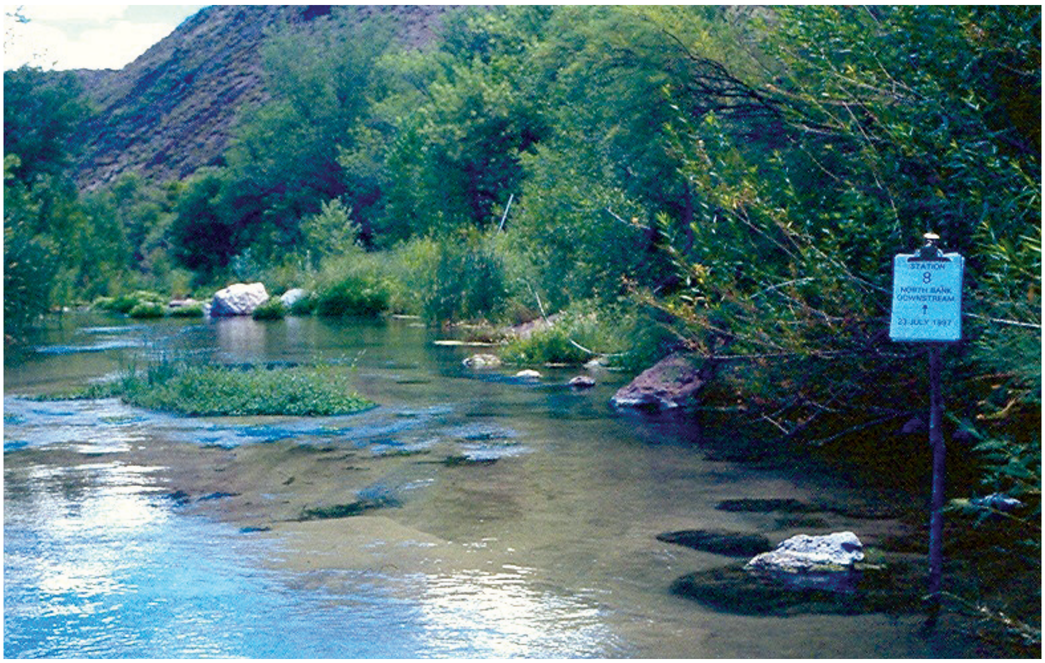


Figure 6.9—UVR representative *Salix Goodingii/ Fraxinus velutina* (SAGO/FRVE2) community. (Photo by Alvin L. Medina.)

Table 6.7—Dominant woody taxa of the *Salix Goodingii/Fraxinus velutina* (SAGO-FRVE2) community.

Taxa	Total frequency	Mature mean density	Young mean density
	%	*Number ha^{-1}*	*Number ha^{-1}*
ACNE2	67	8	13
FRVE2	100	6	37
POFR2	100	3	48
SAGO	100	5	28
SALA3	33	13	71
TARA	100	3	59

present, this type occupies generally wetter sites, and the vegetation is limited to six principal woody species. Species richness was relatively low (table 6.4).

***Salix goodingii/Fraxinus velutina/Juniperus osteosperma* (SAGO/FRVE2/JUOS) Community (N = 8)—**This community is the most common and characterized by the relative dominance of Gooding's willow and velvet ash in the overstory and Utah juniper in the mid-story (fig. 6.10, table 6.8). It is represented by at least 28 woody species, mostly upland species. Occasional mature cottonwoods dot the landscape. Young stands of Gooding's willow are generally absent, with mature stands dating to their establishment in 1993. Like many other communities, its habitat is characterized by an aquic streamside habitat occurring opposite a mesic terrace. Utah juniper is common on the floodplain and adjacent terraces. Recent flood disturbances have eroded channels onto the floodplain and against terraces, forming complex streamside habitats. Many obligate and facultative species quickly colonize newly formed habitats. Established upland and facultative species remain interspersed, thereby forming non-classical riparian habitat conditions. Levees are commonly found on drier sites. (Levees are microhabitats produced by the erosion of channel materials on both sides of impediments to flow, for example

Figure 6.10—UVR representative *Salix goodingii/Fraxinus velutina/Juniperus osteosperma* (SAGO/FRVE2/JUOS) community. (Photo by Alvin L. Medina.)

Table 6.8—Dominant woody taxa of the *Salix goodingii/Fraxinus velutina/Juniperus osteosperma* (SAGO/FRVE2/JUOS) community.

Taxa	Total frequency	Mature mean density	Young mean density
	%	*Number ha^{-1}*	*Number ha^{-1}*
ACGR	13		41
ALWR	13		30
AMFR	63		19
BASA4	88		194
BEFR	38		13
CELAR	13		3
CHLI2	25	3	16
FOPU2	25		92
FOSP	13		10
FRVE2	88	5	25
GAWR3	13		16
JUOS	25	4	6
MAHA4	13		5
PAQU2	13		45
POFR2	100	3	16
PRVE	13		3
QUGA	13	8	0
RONE	13		16
SABO	75		17
SAEX	88		151
SAGO	100	10	63
SALA3	50	3	16
TACH2	75		176
TARA	100	35	92
ULPU	13	3	4
VIAR2	13		6
ZIOB	13		3

trees and cattails.) Eroded materials deposit linearly behind the impediment. A variety of woody species quickly colonized these microhabitats. Minor floods may continue to erode and enhance the levee. Levees are common throughout the active floodplain, and depending on the age of the levee, observed streamflow may be within 1 to 2 m (3.3 to 6.6 ft) or more distant (4 to 12 m [13.1 to 39.4 ft]), hence the wet and dry site conditions. Total woody plant density is relatively high. Saltcedar (*Tamarix ramosissima*) is common on these sites. Species richness is moderately high (table 6.4).

***Salix goodingii/Sapindus saponaria* (SAGO/SASA4) Community (N = 1)—** An uncommon plant group on the Verde River makes up this community. It is characterized by the relative dominance of Gooding's willow in the overstory and soapberry in the understory (fig. 6.11, table 6.9). Soapberry occurs in limited quantities in other communities. Medina (1986) found similar stands in southwestern New Mexico but with much higher stand density (338 trees ha^{-1} or 137 trees ac^{-1}). Soapberry typically occurs away from the water's edge on mesic terrace sites but in close proximity to other obligate riparian trees. The diverse taxa found on this site are indicative of a site whose streambanks are distinct. One streambank might be populated by obligate riparian species, while the opposite bank might be a mesic terrace occupied by a variety of upland species. These microhabitat types are common on the Verde River, owing to active terrace erosion and channel downcutting. The absence of other mature trees suggests that the community is transitional.

Figure 6.11—UVR representative *Salix goodingii/Sapindus saponaria* (SAGO/SASA4) community. (Photo by Alvin L. Medina.)

Table 6.9—Dominant woody taxa of the Salix goodingii/Sapindus saponaria (SAGO/SASA4) community.

Taxa	Total frequency	Mature mean density	Young mean density
	%	*Number ha^{-1}*	*Number ha^{-1}*
ACGR	100		15
ACNE2	100		3
AMFR	100		47
BASA4	100		358
BEFR	100		94
CELAR	100		8
FRVE2	100		677
JUOS	100		3
PLWR2	0		20
POFR2	100		26
PRVE	100		23
SAEX	100		23
SAGO	100	8	21
SASA4	100	13	10
TACH2	0		3
ZIOB	0		6

This community has a moderately high total stem density of young plants. Species richness is relatively moderate (table 6.4).

*Fremont Cottonwood (*Populus fremontii*) Series*

***Populus fremontii/Salix goodingii* (POFR/SAGO) Community (N = 5)—** The co-dominance of Fremont cottonwood and Gooding's willow in the overstory characterizes this community (fig. 6.12, table 6.10). Velvet ash (*Fraxinus velutina*) is an important mid-story species with a frequency of 40% in the mature class and 100% in the young class. Seepwillow (*Baccharis salicifolia*) is dominant in the understory with high frequency and density. In general, this community is represented by 24 woody species and has a variety of both upland and riparian shrub species. This community has the highest total stem density of young plants and

Figure 6.12—UVR representative *Populus fremontii/Salix goodingii* (POFR/SAGO) community. (Photo by Alvin L. Medina.)

Table 6.10—Dominant woody taxa found on the *Populus fremontii/Salix goodingii* (POFR/SAGO) community.

Taxa	Total frequency	Mature mean density	Young mean density
	%	*Number ha^{-1}*	*Number ha^{-1}*
ACGR	60		5
AMFR	0		18
BASA4	100		273
BASE	20		26
BEFR	20		38
CELAR	40	35	15
CHLI2	40		45
FOPU2	40		17
FRVE2	100	12	16
GAWR3	20		3
JUOS	40	3	12
LERE	20		10
PLWR2	80		4
POFR2	100	13	109
PRVE	60		7
QUTU2	20		28
RONE	20		13
SABO	20		5
SAEX	20		520
SAGO	100	10	118
SALA6	20		13
TACH2	20		43
TARA	60		17

relatively high species richness (Table 6.4). Cattails (*Typha* spp.) may also be a co-dominant with coyote willow (*Salix exigua*) on some sites.

***Populus fremontii/Salix laevigata* (POFR/SALA3) Community (N = 3)**—This community is uniquely characterized by the dominance of Fremont cottonwood in the overstory and red willow in the mid-story (fig. 6.13, table 6.11). The shrub understory is comprised of dense stands of coyote willow (*Salix exigua*) interspersed with seepwillow (*Baccharis salicifolia*). The community is represented by 21 woody species and has relatively high species richness (table 6.4). Some sites are occupied by dense stands of cattails, usually occurring on opposite streambanks. The sites are generally aquic, but some sites may have streambanks along actively eroding terraces, hence, the occasional presence of upland species. In other cases, facultative species may extend into the eroded floodplain where desert willow (*Chilopsis linearis*) or saltcedar (*Tamarix ramosissima*) are present in mesic sites.

Figure 6.13—UVR representative *Populus fremontii/Salix laevigata* (POFR/SALA3) community. (Photo by Alvin L. Medina.)

Table 6.11—Dominant woody taxa found on the *Populus fremontii/Salix laevigata* (POFR/SALA3) community.

Taxa	Total frequency	Mature mean density	Young mean density
	%	*Number ha^{-1}*	*Number ha^{-1}*
AMFR	67		15
BASA4	100		720
CELA	33		28
CELAR	33		17
CHLI2	33		56
COLY2	33		6
FOPU2	33		46
FOSP	33		6
FRVE2	67		3
JUMA	33	4	4
JUOS	33	3	3
LYPA	67		24
POFR2	33	5	4
POHI8	67		3
SABO	33		96
SAEX	67		687
SAGO	100		3
SALA3	100	7	36
TACH2	67		72
TARA	33		35

Saltcedar is largely limited to occasional young stands adjacent to the water's edge and in association with coyote willow.

*Velvet Ash (*Fraxinus velutina*) Series*

***Fraxinus velutina* (FRVE) Community (N = 4)**—The FRVE community is common and characterized by the dominance of velvet ash (fig. 6.14, table 6.12). The community is very diverse with at least 36 woody species (table 6.4). Obligate species, e.g., Fremont cottonwood (*Populus fremontii*), are uncommon. The community is mostly mesic and typified by streamside conditions that include actively eroding terraces and floodplain, recent levee formations, and very old alluvial terraces with many boulders adjoining the water's edge. Total woody plant density is relatively moderate. Many species are represented in the young size classes, but their density is relatively low. Many obligate species, e.g., Gooding's willow, fail to establish because of erosion from floods. This community has elements that resemble other communities, e.g., SAGO/SASA4, FRVE/JUOS, but the presence

Table 6.12—Dominant woody taxa found on the *Fraxinus velutina* (FRVE) community.

Taxa	Total frequency	Mature mean density	Young mean density
	%	*Number ha^{-1}*	*Number ha^{-1}*
AMFR	75		41
BASA4	100		133
BEFR	50		19
BRCA3	50		104
CELAR	100	3	27
CEPA	25	3	3
CHLI2	50	4	110
ELAN	25	4	8
EPVI	25		63
ERWR	25		8
FAPA	25		10
FOPU2	75		15
FRVE2	100	8	19
GAWR3	25		5
GUSA	50		14
JUMA	100		7
JUMO	25		3
JUOS	50	3	6
MAHA4	50		3
POFR2	100	3	8
POHI8	25		4
PRVE	25		5
QUEM	25	8	9
QUTU2	50	10	58
RHCA	25		14
RHTR	50		8
SABO	50		33
SAEX	75		36
SAGO	100		9
SALA3	50		10
SASA4	50		66
TACH2	100	8	34
TARA	100	4	100
VIAR2	25		10
ZIOB	25		3

Figure 6.14—UVR representative *Fraxinus velutina* (FRVE) community. (Photo by Alvin L. Medina.)

of some species such as Emory oak (*Quercus emoryii*) or turbinella oak (*Q. turbinella*) is distinctive in some cases. In other cases, Arizona walnut (*Juglans major*) or netleaf hackberry (*Celtis laevigata)* are distinctive indicators.

Fraxinus velutina/Juniperus osteosperma **(FRVE/JUOS) Community (N = 5)—**The FRVE/JUOS community is characterized by the dominance of velvet ash and Utah juniper as dominant overstory species (fig. 6.15, table 6.13). The community is different from the FRVE community in that oak species are absent. Gooding's willow (*Salix goodingii*) is locally important on some sites but does not impart overall relative importance. Occasional mature Fremont cottonwood trees (*Populus fremontii*) are found in association with coyote willow (*Salix exigua*) or cattails (*Typha* spp.) on aquic sites. This community is mesic with more than 33

Figure 6.15—UVR representative *Fraxinus velutina/Juniperus osteosperma* (FRVE/JUOS) community. (Photo by Alvin L. Medina.)

Table 6.13—Dominant woody taxa found on the *Fraxinus velutina/Juniperus osteosperma* (FRVE/JUOS) community.

Taxa	Total frequency	Mature mean density	Young mean density
	%	*Number ha^{-1}*	*Number ha^{-1}*
ACGR	80	3	9
ALWR	20		5
AMFR	40		9
ARLU	20		8
ATCA2	40		60
BAPT	20		3
BASA2	20		69
BASA4	100		119
BEFR	40		28
CELAR	40	3	9
FOPU2	100		97
FRVE2	40	5	16
GAWR3	20		20
GUSA	40		8
JUMO	20	3	0
JUOS	20	9	12
LYPA	60		30
MAHA4	20		4
NOMI	20		10
PAQU2	100		51
POFR2	80	8	29
PRVE	20	11	29
RIAU	20		150
RICE	20		100
RONE	20		24
SABO	40		5
SAEX	100		55
SAGO	100	8	34
SALA3	20	6	31
TACH2	60		5
TARA	100		7
ZIOB	100		28

woody species and 23 facultative or upland types, and it ranks second in species richness (table 6.4). In addition, the presence of many upland and facultative species is indicative of a highly disturbed community. Streamside habitats are mostly along eroded terraces, with sloughed or sloughing streambanks. Obligate woody species occur on opposite banks. Some sites are typified by the presence of multiple levees where saltcedar (*Tamarix ramosissima*) or other facultative species establish. This community type is different from the FRVE/JUOS/CELAR type because of the presence of Wright's beebrush (*Aloysia wrightii*), white sagebrush (*Artemisia ludoviciana*), fourwing saltbush (*Atriplex canescens*), yerba de pasmo (*Baccharis pteronioides*), one-seeded juniper (*Juniperus monosperma*), sacahuista (*Nolina microcarpa*), Virginia creeper (*Parthenocissus quinquefolia*), golden currant (*Ribes aureum*), and wax currant (*Ribes cereum*).

***Fraxinus velutina/Juniperus osteosperma/Celtis laevigata* (FRVE/JUOS/CELAR) Community (N = 10)**—This community is characterized by the dominance of velvet ash in the overstory of aquic sites (fig. 6.16, table 6.14). Utah juniper and netleaf hackberry are co-dominants on mesic sites. The community is diverse (table 6.4), being represented by 31 woody species. Obligate species are present at low densities, but are infrequent in the community and lack constancy. Most obligate species occur as young stems. This community is different from the FRVE/JUOS community because of the presence of eight distinct species—boxelder (*Acer negundo*), Emory's baccharis (*Baccharis emoryi*), desert willow

Figure 6.16—UVR representative *Fraxinus velutina/Juniperus osteosperma/Celtis laevigata* (FRVE/JUOS/CELAR) community. (Photo by Alvin L. Medina.)

Table 6.14—Dominant woody taxa found on the *Fraxinus velutina-Juniperus osteosperma/Celtis laevigata* (FRVE/JUOS/CELAR) community.

Taxa	Total frequency	Mature mean density	Young mean density
	%	*Number ha^{-1}*	*Number ha^{-1}*
ACGR	20		8
ACNE2	10		3
AMFR	20		10
BAEM	20		5
BASA2	10		3
BASA4	100		60
BEFR	20		57
CELAR	40	15	72
CHLI2	30		29
COLY2	10		5
FOPU2	30		57
FRVE2	90	9	36
GAWR3	20		40
JUOS	30	6	11
LYPA	20		6
MAHA4	10		5
POFR2	30		3
PRVE	40		12
RHTR	10		3
RONE	10		25
SABO	40	3	4
SAEX	20		125
SAGO	90	4	44
SALA3	20		17
SASA4	10		4
TACH2	20		44
TARA	70	8	35
ULPU	10		10
ZIOB	20		18

(*Chilopsis linearis*), skunkbush (*Rhus trilobata)*, soapberry (*Sapindus saponaria*), southern cattail (*Typha domingensis*), Siberian elm (*Ulmus pumila*), and saltcedar (*Tamarix ramosissima*) (present in large tree form).

Alnus oblongifolia/Fraxinus velutina **(ALOB/FRVE2) Community (N = 1)—** This community is uniquely characterized by the dominance of Arizona alder in the overstory and velvet ash in the mid-story (fig. 6.17, table 6.15). It is comparatively poor in species richness (table 6.4). The community is relatively mesic, as exhibited by the prevalence of facultative and upland woody species. Obligate species are limited to narrow bands around the water's edge. Despite an abundance of young Gooding's willow (*Salix goodingii*), streambank scour limits seedling establishment and development into saplings. Arizona alder, although present in other communities, occurs with limited density of young stems. Alder is largely limited in distribution to sections at or immediately below Sycamore Creek. This community occurs at an elevation of 1,070 m (3,512 ft) but is common at higher elevations up on the creek. Alder and other obligate species fail to establish mature stands because of flooding scour of streambanks and also likely it is at the lower limits of its range. This community is similar to the alder type described by Szaro (1989, 1990).

Figure 6.17—UVR representative *Alnus oblongifolia/Fraxinus velutina* (ALOB/FRVE2) community. (Photo by Alvin L. Medina.)

Table 6.15—Dominant woody taxa found on the *Alnus oblongifolia/Fraxinus velutina* (ALOB/FRVE2) community.

Taxa	Total frequency	Mature mean density	Young mean density
	%	*Number ha^{-1}*	*Number ha^{-1}*
ALOB2	100	3	18
BASA4	100		50
BEFR	100		30
CELAR	100		55
FRVE2	100	3	49
JUOS	100		9
PAQU2	100		8
PLWR2	100	3	3
POFR2	100		5
PRVE	100		36
RHCA	100		67
SABO	100		3
SAGO	100		131
VIAR2	100		5

Species Richness, Nonnative Species, and Obligate Species

Species richness in the woody vegetation communities was greatest in FVRE (37) and lowest in SAGO/FRVE2 and the SAGO/SALA3 communities (6) (table 6.4). Nonnative species ranged from 0 to 4 across the range of communities with SAGO/SALA3/POFR2 containing the most nonnative species. Obligate woody species ranged from 1 to 3 across the communities.

Tree and Shrub Density

Mean tree and shrub density was highly variable (tables 6.16 and 6.17) across species. Seepwillow and Gooding's willow exhibited the highest relative frequency, constancy, and density of all shrubs and trees, respectively. Other tree species of importance were Arizona walnut (*Juglans major*), saltcedar (*Tamarix ramosissima*), velvet ash (*Fraxinus velutina*), and boxelder (*Acer negundo*). Important shrub species were all facultative and included New Mexican locust (*Robinia neomexicana*), catclaw acacia (*Acacia greggii*), desert false indigo (*Amorpha fruticosa*), and coyote willow (*Salix exigua*). Facultative species of both trees and shrubs were generally more dominant than obligate. This may be a result of the young age of stands with obligate species.

Table 6.16—Descriptive statistics for major tree species of the UVR, 1997 to 2007. Species order is ranked from largest to smallest sum of percent relative frequency, constancy, and density. Relative frequency refers to the occurrence of the species within relevés. Relative constancy refers to the occurrence of the species across all relevés.

Taxa code	Relative frequency	Relative constancy	Relative density	Mean stem density	Stem density range
	%	*%*	*%*	*Number ha^{-1} and (SD)*	*Number ha^{-1}*
SAGO	8.6	1.6	12.6	178 (313.1)	25-5000
JUMA	4.1	2.0	2.7	41 (27.8)	25-125
TARA	3.7	1.5	3.0	226 (379)	25-5000
FRVE2	3.9	3.4	0.8	111 (340.3)	25-6250
ACNE2	3.8	2.2	1.9	93 (135.1)	25-625
ULPU	2.7	1.5	1.5	45 (51)	25-175
PLWR2	2.2	1.0	1.5	58 (42.8)	25-175
SASA4	2.1	1.3	1.0	77 (80.7)	25-300
ELAN	1.7	1.1	0.7	54 (71.4)	25-200
JUMO	1.7	1.1	0.7	25 (0.0)	1-25
ZIOB	1.6	0.9	0.9	95 (144)	25-625
ALOB2	1.6	0.9	0.7	75 (86.6)	25-175
JUOS	0.7	0.0	2.5	49 (55.9)	25-500
PRVE	1.2	0.3	1.6	133 (182.3)	25-1000
POFR2	1.2	1.8	0.0	154 (405.5)	13-6250
CHLI2	1.3	1.1	0.3	257 (481.8)	25-3250
SALA3	0.4	0.0	1.3	181 (277.1)	25-2500
CELAR	0.7	0.2	0.8	140 (191.9)	25-1375
SABO	0.0	0.0	0.3	147 (229.1)	25-1800

Table 6.17—Descriptive statistics for major shrub species of the UVR, 1997 to 2007. Species order is ranked from largest to smallest sum of percent relative frequency, constancy, and density. Relative frequency refers to the occurrence of the species within relevés. Relative constancy refers to the occurrence of the species across all relevés.

Taxa code	Relative frequency	Relative constancy	Relative density	Mean stem density	Stem density range
	%	*%*	*%*	*Number ha^{-1} and (SD)*	*Number ha^{-1}*
BASA4	10.5	1.5	9.9	541 (1179.5)	25-25250
RONE	2.0	0.2	2.0	119 (96)	25-375
ACGR	1.3	0.0	2.5	112 (149.5)	25-1000
AMFR	0.3	1.1	2.4	206 (254.7)	25-1250
NOMI	1.6	0.3	1.4	59 (22.9)	25-75
MAHA4	1.4	0.2	1.3	42 (17.7)	25-75
SAEX	1.2	0.0	1.7	802 (1447.1)	25-10000
PAQU2	1.1	0.2	1.0	113 (92.2)	25-325
RHCA	1.0	0.2	0.9	417 (612.8)	25-2000
BASA2	0.9	0.3	0.6	489 (514.1)	25-1500
ALWR	0.8	0.2	0.6	163 (165.2)	50-400
FAPA	0.2	0.3	1.1	50 (35.4)	25-100
FOPU2	0.8	0.1	0.7	339 (728.5)	25-6250
GAWR3	0.7	0.1	0.7	135 (127.3)	25-500
SALA6	0.7	0.1	0.7	175 (141.4)	25-400
BRCA3	0.6	0.1	0.7	350 (363)	25-1000
QUTU2	0.7	0.1	0.6	114 (80.2)	25-250
RHTR	0.6	0.1	0.7	95 (95.9)	25-250
RIAU	0.7	0.3	0.4	888 (1548.8)	75-6250
BEFR	0.1	0.4	0.8	228 (251.8)	25-1125
VIAR2	0.6	0.0	0.7	41 (23.1)	25-75
ATCA2	0.5	0.0	0.6	251 (369.7)	25-1500
FOSP	0.1	0.2	0.7	83 (40.9)	25-125
LYPA	0.3	0.0	0.7	109 (69.8)	25-250

Discussion

The classification and description plant associations does not imply that communities types are discrete units. By virtue of the relative association of species within relevés, and their physical attributes, the proposed community types are reasonably predictable communities of the UVR as of current time. The riparian habitats are undergoing considerable change (see Chapter 2) and are apt to change relative to invasive species, erosional processes, and land uses. As such, species belonging to one community can be members of other communities (Begon and others 2006). However, abstract classification of plant communities remains useful for understanding the inherent variability and environmental complexity of plant-water relationships. In addition, some form of "discrete" units remains essential for land use planning and day-to-day decisions on land uses. In other cases, plant community attributes are used in monitoring and assessment of habitats.

The plant associations described for the UVR contain species that are common to other streams of the Sub-Mogollon region of the Southwest. Boles and Dick-Peddie (1983), Medina (1986), Skartvedt (2000), and Danzer and others (2001) all noted common obligate and facultative species, such as Fremont cottonwood, Gooding's willow, and various other species of willows. However, one difference is the relatively high frequency and abundance of upland woody species found in close association with obligate species on the Verde River. The presence of many facultative and upland species is attributed to the general absence of obligate

Figure 6.18—This large Fremont cottonwood is a rare find on the UVR. They are normally found on point bars, high on a terrace, within a wide valley, and protected from flood flows. Their girths approximate 1.5 to 2 m (5 to 6.5 ft) DBH. (Photo by Alvin L. Medina.)

species until recent time (circa 1980). Large cottonwood stands or willow thickets were absent until post-1993. Essentially, nearly all woody obligate (e.g., cottonwood) and facultative (boxelder) species established within the floodplain can be dated to 1993. Mature stands of velvet ash, Arizona walnut, and netleaf hackberry are common along the historical high water mark (3-8 m [9.8-26.3 ft] above present water levels) in and amongst talus boulders. Brock (1987) characterized the riparian vegetation as a shrub community dominated by seepwillow with interspersed species of velvet ash, Arizona walnut, Gooding's willow, Utah juniper, velvet mesquite, and desert willow. Oral accounts from the Perkins family, original settlers on the UVR, state that some cottonwoods were present in the Perkinsville area circa 1890 (Whiffen and Kayser 1966). However, photographs from 1920s show a limited number of mature trees (see Chapter 2). Large mature cottonwood trees such as those shown in fig. 6.18, are very rare, likely constituting less than 0.01% of all trees counted and observed along the UVR. In addition, historical land surveys (Fuller 2003) and channel change studies and aerial photography (Medina and others 1997) reveal that the general form of the flood channels has not changed substantially since at least since 1937, and probably not since the floods of the early 1900s.

Webb and others (1991, 2007) demonstrated that many Southwestern riparian habitats, including the Verde River, were historically devoid of typical gallery forests. They attributed floods as a principal agent in limiting the expansion of woody vegetation in Southwest rivers (Turner 1974; Turner and Karpiscak 1980; Webb and Baker 1987; Turner and others 2003). Evidence from climate and hydrologic reconstruction studies are strongly linked with photographic evidence to conclude that woody vegetation is a recent (Twentieth Century) phenomenon of Southwest riparian ecosystems. Similarly, vegetation data from this study and photographic data (see Chapter 2) do not support the popular belief that gallery forests were prevalent in the Twentieth Century on the UVR. Cottonwoods and similar woody species were likely present in open valleys but in very limited numbers and widely scattered stands. Arizona ash was more likely the dominant tree, as mature trees remain in greater abundance on terraces.

Some communities have similar attributes to others of the region. Medina (1986) found similar soapberry stands in southwestern New Mexico but with much higher stand density (338 trees ha^{-1} or 137 trees ac^{-1}) and prevalence. In this study, soapberry was limited to one stand. It is unlikely that soapberry was prevalent on the Upper and Middle Verde River, as its habitat is generally lacking and absent from plant surveys (Brock 1987; Whittlesey and others 1997; Schmidt and others 2005; Shaw 2006). The species is a Madro-tertiary (tropical) remnant with a preference for relatively moist sites and calcareous-clayey soils (Read 1974). Its occurrence on terraces is likely an artifact of recent hydrologic disturbances, as soapberry is commonly associated with various upland species (Hastings and Turner 1965; Szaro 1989) common to the UVR.

In general, several communities are similar to those described by Szaro (1989) regarding dominant woody species. Exceptions are noted for instances where upland species, e.g., Utah juniper (*Juniperus osterosperma*), are co-dominant in the mid- and understory. Szaro (1989, 1990) emphasized tree dominance, whereas this study considered all woody species in a structural context. Hence, small statured plants can be co-dominants as mid-story components. A major difference between this study and Szaro (1989, 1990) is red willow (*Salix laevigata*). Red willow is abundant on the UVR, whereas *S. irrorata* and *S. bondplandiana* are noted important species in Szaro (1989). It is possible that Szaro (1989, 1990) treated red willow as a *S. bonplandiana* synonym.

Many upland species, e.g., Apache plume (*Fallugia paradoxa*) and bricklebush (*Brickelia* spp.), were found in association with typical riparian obligate species. This is likely due to the recent expansion of obligate species upon former mesic habitats as a net result of flood disturbances and concomitant channel changes, e.g., incision and paleoterrace erosion. Browning (1989) described arroyo habitats in southern New Mexico where Apache plume (*Fallugia paradoxa*), bricklebush (*Brickelia* spp.), and sumacs (*Rhus* spp.) were dominant components. Hence, the common presence of upland species in mixtures with obligate riparian species suggests that a mesic environment likely predominated prior to the recent expansion of gallery species post-1993.

Management Implications

This analysis presents a current view of the dynamic woody flora of the UVR. It provides a reference for future Prescott National Forest management actions relative to exotic species invasions, floods, grazing, fire, or other disturbances. This effort provides the Prescott National Forest with a basis for conducting future surveys to determine status and trends of UVR woody flora. It also provides a basis for future research studies on the woody plants found in the riparian zone of the UVR. Management decisions regarding current and future use of the Prescott National Forest uplands can be made relative to the woody flora of the river, but the present data cannot be used for cause-and-effect determinations of the impacts of land uses. The UVR riparian ecosystem is dynamic, and natural processes of flood and drought can easily override human interventions. The largest human-related impact on the UVR plant communities could come from de-watering the river for human water consumption. Of special significance is use of the vegetation databases and analyses for management of TES species, e.g., native fishes, which has a long and contentious history in the UVR region (see Chapter 2). For decades, the fishery management model for UVR has been one that emulates the "trout model"—deep and cold water habitats with abundant overstory—versus the "warmwater model" with shallow, open canopy and chaotic flood disturbances (see Chapter 2).

The abundance of woody plants in the UVR is a recent occurrence and has initiated hydrological processes that lead to channel degradation (Richter and others 1996). These processes further complicate understanding the relationships between TES species and riparian vegetation. Certain aquatic habitats have changed considerably from shallow (riffles) and clear water to deep pools and glides and turbid gray-green water (see Chapters 2 and 8). These processes in combination with sediment and bedload deprivation from Sullivan Dam have induced long-term, irreversible changes to the UVR ecosystem.

With an eye to future management of woody plants and their debris in the UVR, a precautionary note is offered with respect to producing hyperabundance of woody material. Figure 6.19 shows downfall of large amounts of Fremont and Hinckley cottonwoods, a Gooding's willow, and coyote willow, following a moderate flood in spring 2005. The trees were not completely uprooted, and they continued to grow both laterally and vertically. Thousands of new sprouts emerged amongst the debris, further entangling the woody debris. Riparian soils were very shallow (<40 cm or 16 in) and woody plants had difficulty anchoring through the bedrock and armored bed. This site is in the narrowest canyon region below Perkinsville and

Figure 6.19—Heavy cottonwood downfall along the channel below Perkinsville following a 2005 spring flood in a canyon reach of the UVR. The trees are dated to 1993, when most riparian woody plants were established. The coyote willows in this reach were planted by the Y-D Ranch after the flood. (Photo by Alvin L. Medina.)

above the Camp Verde Valley. Should this debris amass during a larger flood, it could cause a debris jam that could send torrent flows downstream to Camp Verde. Dense tree growth of this magnitude was not witnessed along the UVR channel in the past century.

Finally, the removal of saltcedar, Siberian elm, and Russian olive in the upper 20 km (12.5 mi) of the headwaters (from 2008 to 2010) is apt to change the composition of woody communities. Niche voids will likely be colonized with a myriad other woody and herbaceous species. It is expected that additional channel erosion and levee building will occur as floods seek freeboard about the floodplain. The processes are certain to further change the terrestrial and aquatic habitats, and possibly limiting their availability for TES species. Herein lies an opportunity to manage aquatic habitats by managing riparian vegetation through silviculture or grazing.

Summary and Conclusions

This chapter contains a quantitative description of the woody vegetation of the UVR based on 56 permanently monumented sampling sites. At present, the UVR contains a large diversity of woody species (62) and plant associations. The plant associations found in the UVR contain species that are common to other streams of the Sub-Mogollon region of the Southwest. However, one notable difference is the relatively high frequency and abundance of upland woody species found in close association with obligate species on the Verde River. The presence of many facultative and upland species is attributable to the lack of conditions suitable for obligate species until recent time (circa 1980). Large cottonwood stands or willow thickets were absent until post-1993. Essentially, nearly all woody obligate (e.g., cottonwood) and facultative (e.g., boxelder) species established within the floodplain can be dated to 1993. Mature stands of velvet ash, Arizona walnut, and netleaf hackberry are common along the historical high water mark, in and amongst talus boulders. Brock (1987) characterized the riparian vegetation as a shrub community dominated by seepwillow, with interspersed species of velvet ash, Arizona walnut, Gooding's willow, Utah juniper, velvet mesquite, and desert willow. Species richness varies from low to very high and coincidentally with streambank disturbance. Generally, the greater the disturbance from erosional forces, either induced or natural, the higher the richness.

Webb and others (1991, 2007) demonstrated that, historically, many Southwest riparian habitats, including the Verde River, were largely devoid of typical gallery forests. The authors attributed floods as a principal agent in limiting the expansion of woody vegetation in Southwest rivers (Turner 1974; Turner and Karpiscak 1980; Webb and Baker 1987; Turner and others 2003). The same disturbances caused by major floods also created niches where riparian vegetation such as cottonwoods and willows establish. Evidence from climate and hydrologic reconstruction studies are strongly linked with photographic evidence to conclude that woody vegetation is a recent (Twentieth Century) phenomenon in the UVR. Similarly, vegetation data from this study coupled with photographic data and detailed observations of riparian soils and terraces (see Chapter 2) do not support the popular belief that gallery forests were prevalent in the Twentieth Century on the UVR. Cottonwoods and similar woody species were present in open valleys like Perkinsville but in very limited numbers. Arizona ash was more likely the dominant tree, as mature trees remain in greater abundance on terraces.

Chapter 7

Spatial and Temporal Variation in Streamside Herbaceous Vegetation of the Upper Verde River: 1996-2001

Alvin L. Medina, Jonathan W. Long

Introduction

Streamside environments are inherently dynamic, yet streamside vegetation plays a key stabilizing role on riparian and aquatic habitats (Van Devender and Spaulding 1979; Van Devender and others 1987). Because of its dynamism, streamside vegetation is rarely the subject of classification analyses, yet it is a focal point for land managers regulating land uses, such as livestock grazing, that could potentially impact aquatic communities (Brown and others 1979). Livestock grazing along the UVR has been a politically charged issue, with recent years (1998 to present) witnessing a removal of livestock from the river corridor under Prescott National Forest management. However, livestock still graze on private lands, with some strays roaming onto State and Forest lands (see Chapter 2). During the same period, researchers observed declining populations of native fishes in the UVR, largely attributable to predation by introduced fishes (see Chapter 9), as well as to vast growth of woody plants post-1993 floods (see Chapter 2), and lateral erosion of historical terraces. Concomitantly, researchers have suggested that increases in woody streamside vegetation might be related to the cessation of livestock grazing (Rinne and Neary 1977; Neary and Rinne 1998, 2001a) as well as to other hydrological factors (see Chapter 2).

The objective of this study was to describe quantitatively herbaceous streamside vegetation along the UVR from 1997 to 2001. The study examines patterns of vegetation in relation to major geomorphic and geologic attributes along the river. This analysis examines how streamside vegetation in these different reaches changed during this period of stable flows. By better understanding longitudinal variation, temporal variation, and their interactions within highly dynamic areas of the river, we hoped that the study would yield insights into how these critical streamside habitats can be managed to achieve societal goals. The study was designed as a long-term monitoring project to evaluate changes in vegetation, channel conditions, aquatic habitats, and water quality in response to changes, or lack thereof, in management. The UVR has a long history of land uses (see Chapter 2). Some land uses, e.g., grazing, have been attributed to declining aquatic habitat quality.

Previous Studies of UVR Vegetation and Morphology

Vegetation studies (Brock 1987; Szaro 1989) on the UVR have been general with limited community type descriptions, some of which have been generalized from remotely sensed data (Black and others 2005; Stromberg 2008). Medina (see

Chapter 6) provides the first quantitative descriptions of the woody plant communities of the UVR.

Beyer (1997, 1998) described the Verde River as a highly "fragmented" system, meaning that there was significant and discontinuous longitudinal variability in the river system. She particularly noted changes in river morphology associated with the degree of valley confinement and contributions by tributary streams. Spatial studies of the riverine ecosystem (e.g., Rinne and others 1998) often greatly simplifies such longitudinal variation, perhaps due to the frequent assumption that riverine communities tend to exhibit progressive downstream change in accordance with the River Continuum Concept (Vannote and others 1980). In contrast, Poole (2002), Montgomery (1999), and Benda and others (2004) have proposed alternative explanations that recognize patchy, discontinuous features over a longitudinal gradient, particularly in geologically heterogeneous watersheds. The latter concept is operative on the UVR and documented in this chapter.

One consequence of ignoring meso-scale variation is that localized differences may be attributed to local human impacts rather than to natural hydrogeomorphic attributes. Accordingly, an important objective of this study was to determine the relative importance of progressive longitudinal variation versus fragmentation in herbaceous streamside vegetation.

Methodology

Study Sites

Geology—A complete discussion of UVR geology can be found in Chapters 2, 3, 4, and 5. There are four major bedrock types in the watershed. The first zone is dominated by granitic sediments from Granite Creek and basaltic rocks near Sullivan dam. Substrates in this reach are dominated by whitish sands. The second zone passes through the Redwall limestone, which results in reddening of the sands (the formation is commonly stained red from percolation of hematite in groundwater from overlying formations). The third zone begins as the watershed enters areas overlain by the red interbedded sandstones, siltstones, and mudstones of the Supai Formation. This formation contributes finer-grained, red-brown sediments to the river. The last zone in the study area occurs below the confluence with Sycamore Creek, a large watershed that changes the hydrologic character of the Verde River from a highly stable river into one that experiences much larger floods on a regular basis. This hydrogeographic change coincides with a shift into Tertiary volcanic rocks in the uplands and confinement of the river by basalt flows.

There are two major alluvial basins, Chino Basin and Verde Basin (Nations and others 1981) bisected by the UVR. These basins are dominated by Holocene alluvium (Cook and others 2010a, 2010b, 2010c) and illustrate that floodplain alluvium is very thin and recent. The headwater reach to Tapco (Prescott National Forest boundary) is characterized as alternating wide alluvial valleys and constricted basalt steep-walled canyons. The valleys have historically provided some of the most suitable areas for livestock grazing and native fish habitat (see Chapter 2).

Geologic Variation and Vegetation—A description of geomorphic variation along the river was used to provide a framework for interpreting longitudinal variation in streamside vegetation. Two kinds of variation were particularly important: (1) degrees of channel confinement by bedrock, and (2) substrate quality associated with lithologic transitions in the watersheds. These two types of variation were related to hydrologic variability because confluences with large tributaries were associated with changes in valley form and substrates. To account for channel confinement, the width across the valley was measured between bedrock outcrops using an alluvial geology map (Pearthree 1993). All reaches less than 250 m (820 ft) wide were designated as confined, and all reaches greater than 250 m (820 ft) were designated as unconfined. These widths are generally coincident with canyon bound reaches and wide valley bottoms. A 250-m threshold is generally consistent with the distinctions suggested by Cook and others (2010a, 2010b, 2010c). In bedrock lined reaches, the UVR floodplain may be confined to 30- to 122-m (100- to 400-ft) widths across, whereas in less confined reaches, the Holocene floodplain typically is 305 to 915 m (1,000 to 3,000 ft) wide.

Site Selection—Potential study sites (100) were selected during reconnaissance of the 56-km (35-mile) reach from the headwaters to the Prescott National Forest boundary to the east from 1994 to 1996. These sites were categorized into riffle or pool/glide habitat and dominant vegetation type—woody or herbaceous. Using these stratifications, 42 stations were randomly selected for sampling both to describe longitudinal variation along the river and to characterize distinctive vegetation types. Sites were established to provide long-term monitoring points for vegetation and channel conditions. Reaches immediately adjacent to side drainages and those near major changes in channel gradient were avoided. Based on these initial samples, additional stations could be added in time. Streamside vegetation was sampled at the 42 stations along the UVR (fig. 7.1). Permanent study plots were installed on the most homogenous area of each station. Descriptive techniques were employed to reveal longitudinal and temporal patterns along the river. For all sampling work, the convention of denoting right and left streambanks, facing upstream, was used.

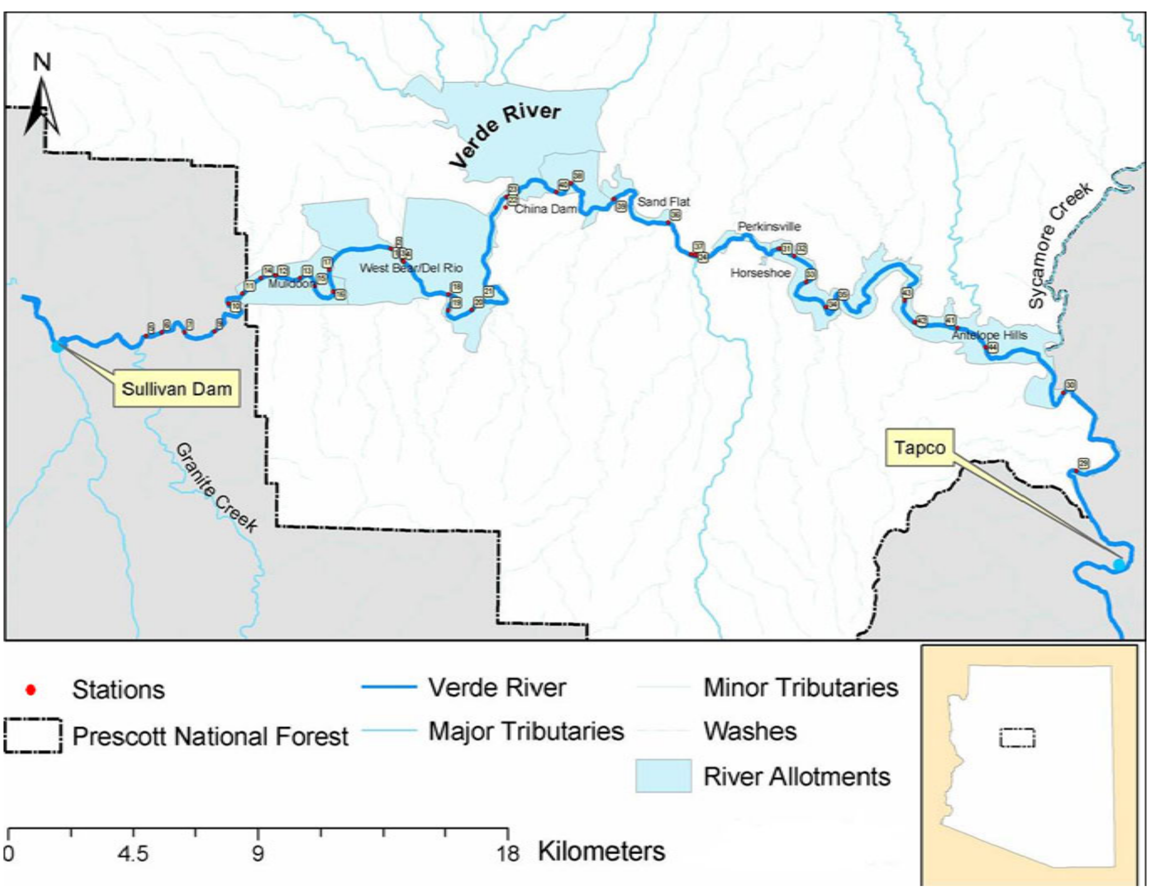


Figure 7.1—UVR vegetation monitoring transects, Prescott National Forest, Arizona.

Time of Sampling—Vegetation was sampled during summers (June to August) of respective years. Twenty-four stations were sampled in 1997, 16 more in 1998, and 2 additional in 2000, totaling 42. Sampling was staggered across years because the goal was to establish 40+ permanent stations and because of budget constraints. Twenty of 42 stations were sampled in 2000. Finally, all but two of the stations were sampled again in 2001. This study design allowed evaluation of longitudinal variation as well as temporal variation, although the two components of variation are not completely separable because temporal and spatial variation was somewhat confounded, owing to differences in time (i.e., 1997 versus 1998) when sampling occurred. The 2001 dataset allows comparison of most of the reaches during a single growing season. The three- to four-year time frame of the dataset is relatively short, but it represents an ecologically significant period. Near record floods scoured the river in 1993 and a second large event struck in 1995. Shortly thereafter, livestock grazing was removed from the Prescott National Forest in 1998. Grazing continued only on small private parcels. Between 1993 and 1998 spikedace populations went from common to absent. From 1995 through 2001, the UVR experienced no two-year recurrence interval floods at the Paulden and Clarkdale gauges (see Chapter 5).

Sampling and Analysis Methods

Vegetation Sampling—At each site, two permanent vegetation plots (8 x 40 m or 26.2 x 131 ft) were established parallel to the channel. Measurements of streamside herbaceous and woody plant foliar cover were made within the plots (fig. 7.2). Since woody taxa respond more slowly than herbaceous taxa, changes in their cover and frequency were also less informative. Data on woody riparian communities are better represented by the larger macroplots than by the streamside

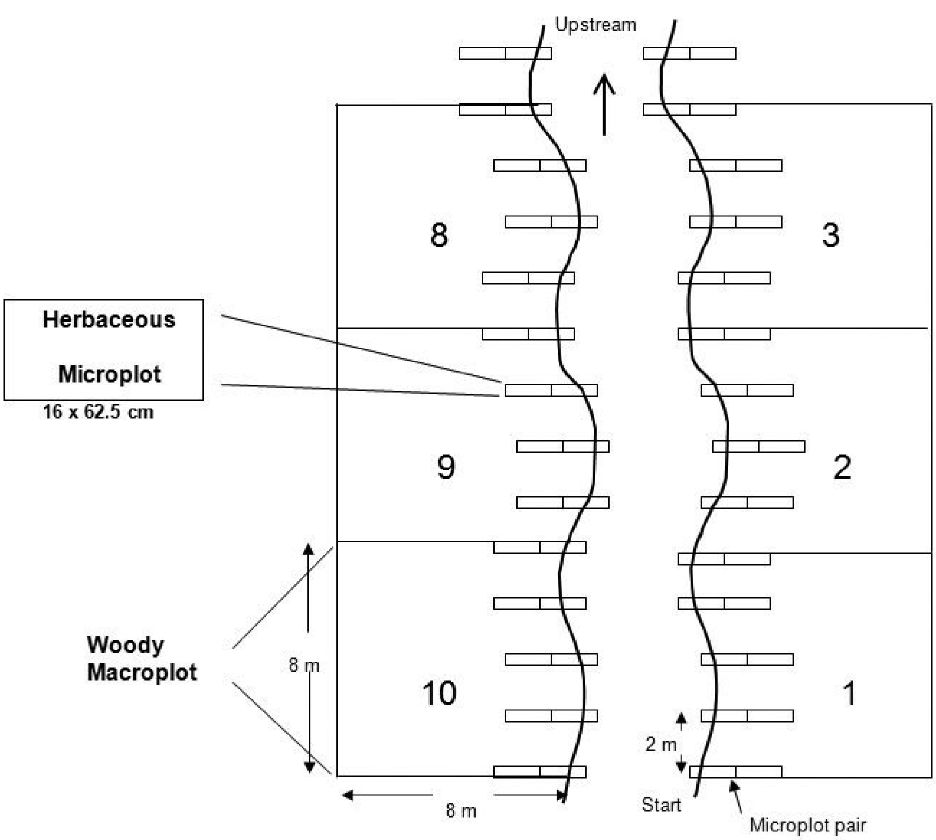


Figure 7.2—Layout of herbaceous microplots within each vegetation sampling plot, UVR.

microplots (see Chapter 6). The herbaceous transect (1.25 x 40 m or 4.1 x 131 ft) followed the water's edge, projected unto the water. A major purpose of measuring herbaceous vegetation aligned with the water's edge was to focus on streambank vegetation that was most likely utilized by ungulates and subject to channel erosion or physical ungulate impact. The starting point of each transect was marked with rebar and a T-post. The study plot was photographed crossways, reverse, and oblique-aerial from adjacent slopes, where feasible. Additionally, rock monuments (with rebar) were established perpendicular to the starting point rebar at slope locations above flood heights. These were used to re-establish buried or lost markers and re-photograph points.

Herbaceous and woody plant foliar cover was estimated using a modified Daubenmire (1959) approach (Medina 1986). Within each sampling station, herbaceous and woody vegetation was sampled within quadrats (16.0 x 62.5 cm [6.3 x 4.6 in]) located along two 40-m (131-ft) transects (one on each streambank) (fig. 7.2). These transects followed the edge of the stream channel and thus were not straight lines. Transects contained 40 quadrats positioned in pairs at 2-m (6.6-ft) intervals. Quadrats were orientated with their long axis perpendicular to the stream channel. One quadrat of each pair extended 25 cm (9.8 in) into the stream channel to sample aquatic plants, while the other quadrat was placed adjacent to the first and extending away from the channel. Foliar cover within quadrats was separated by species and assigned to the categories (table 7.1) developed by Bailey and Poulton (1968). Cover of fine-textured soil (<2 mm diameter [0.08 in]), gravel (2 mm to 7.5 cm [0.08 to 0.3 in]), rock (>7.5 cm [0.3 in]), litter, and cryptogams was also recorded.

Data Analysis—Analyzing riparian vegetation in a highly dynamic fluvial setting demands considerable efforts to generate meaningful results. Cluster analysis was considered to describe different types of herbaceous streamside vegetation along the river, but the results revealed that there were not distinct groups at the herbaceous level. Varying abundances of several dominant taxa with smatterings of less (numerically) important taxa were observed. Consequently, a data ordination approach was used to visualize variation within the herbaceous plant assemblage, as well as to highlight sites with distinctive vegetative composition. Any ordination is a highly abstracted view of reality that is intended to separate meaningful environmental variation from noise. The purpose of applying ordination was to reduce the data so that relationships among the sites would become more apparent.

This survey focused on hydrophytic vegetation (facultative and obligate wetland taxa), as identified in USDA Natural Resources Conservation Service (2011), because non-hydrophytic taxa are likely to be less persistent and reliable descriptors

Table 7.1—Herbaceous plant cover classes, UVR herbaceous plant transects.

Range in plant foliar cover	Percent value recorded
%	%
Present on site	0.01
< 1	0.5
1–5	3
5–25	15
25–50	38
50–75	62
75–95	85
95–100	98

Table 7.2—Steps to reduce the herbaceous plant taxa dataset for ordination.

Step of reduction	Rationale for reduction	Reduced number of taxa
		Number
All taxa sampled in microplots	Focus on streamside environment	140
Problematic species combined (*Typha angustifolia/latifolia/x glauca*, *Eleocharis palustris/ parvifola*, *Scirpus pungens/ americanus*, *Juncus balticus/ mexicanus*)	Difficulty in identification of species could induce differences due to sampling rather than environmental	135
Herbaceous taxa only	Woody plants slower to respond and represented better by macroplots	99
Perennial taxa only	Annual plants vary seasonally; therefore, fluctuations likely to reflect time of sampling	62
Hydrophytic vegetation only (facultative and obligate wetland species)	Non-hydrophytic vegetation likely to be less persistent and reflections of local disturbance	42
Native vegetation only (excluding *Mentha spicata, Rumex crispus, Plantago major, Potamogeton crispus, Agrostis alba, Festuca arundinaceae, Polypogon viridis)*	Nonnative taxa are weedy species that tend to fluctuate greatly	35
Only taxa present in at least four samples	Rare taxa more likely to represent sampling	29
Remaining taxa present in 2000-2001 samples	Excluded from second period analysis only	22

of the riverine environment. By focusing on hydrophytic vegetation, all nonnative taxa were excluded. The analysis was reduced to 29 taxa that were included in at least 4 samples to reduce the potential influence of very rare taxa that were not persistent (table 7.2).

To analyze change through time, data were grouped into two time periods—1997 to 1998 (period 1) and 2000 to 2001 (period 2)—along with two additional sites not included in the original sampling that were sampled both in 2000 and 2001. For the ordination, data were used from herbaceous, perennial, hydrophytic, and native taxa that were sampled in the streamside microplots. The primary analyses were restricted to perennial herbaceous taxa in order to focus on changes in the streamside environment at the scale of years. Annual species were excluded because their cover and frequency varies seasonally.

Nonmetric multidimensional scaling (NMDS) was selected to analyze the herbaceous plant data because it was evident that the underlying data were nonlinear and non-normal (Anderson 1971). NMDS was run using PC-ORD with 50 runs of the real data along with 100 runs of randomized data. For the remaining taxa, frequency (number of microplots in which the taxon was sampled/80 per transect) and cover were calculated. Cover of these perennial herbaceous, hydrophytic, native plants ranged widely across the samples, from 4% to over 70%. The sites with lowest cover values were typically dominated by weedy annuals such as beggarstick (*Bidens laevis*). To compensate for variation in cover of these plants, cover was relativized for each taxon by the total percent contribution of those taxa. In addition, the number of species sampled at each site was calculated. Overall species richness at sites ranged from a high of 44 to a low of 8, with a mean of 22.6 (SD = 8.2).

Results

Species Ordination

A NMDS ordination of all the sites when first sampled shows a slight downstream progression in the data along the Y-axis (fig. 7.3). However, because the lower half of the sites were sampled one year later than the upper half, this longitudinal pattern could represent time as well as distance along the river. In addition, some vegetation differences are also expected because of historical grazing patterns throughout the corridor and respective of specific allotment. Some allotments were year-long grazing while others were seasonal use. Confinement (X-axis) does not appear to differentiate among groups. However, a geological clustering difference is evident between sites under confined/unconfined Limestone and confined Supai and appears strongly longitudinal downstream (Y-axis). A seemingly strong clustering difference appears between confined Granite Basalt groups and Confined Supai groups, likely due to substrate and/or a contributing artifact of distance.

Figure 7.4 presents an NMDS ordination of all the sites when sampled for the second time. The goal is to determine whether the environmental relationships and species associations in the ordination appear similar to fig. 7.3. Because all of the sites except the two lowermost—River Kilometers 66.6 and 72.2 (River Miles 37.5 and 45.1)—were sampled in 2001, longitudinal variation (distance along the river is roughly associated with movement from left to right) is most likely associated with spatial attributes of the river. Groups are not necessarily "tighter" as they are different in their orientation, with a seemingly uniform shift in all data points,

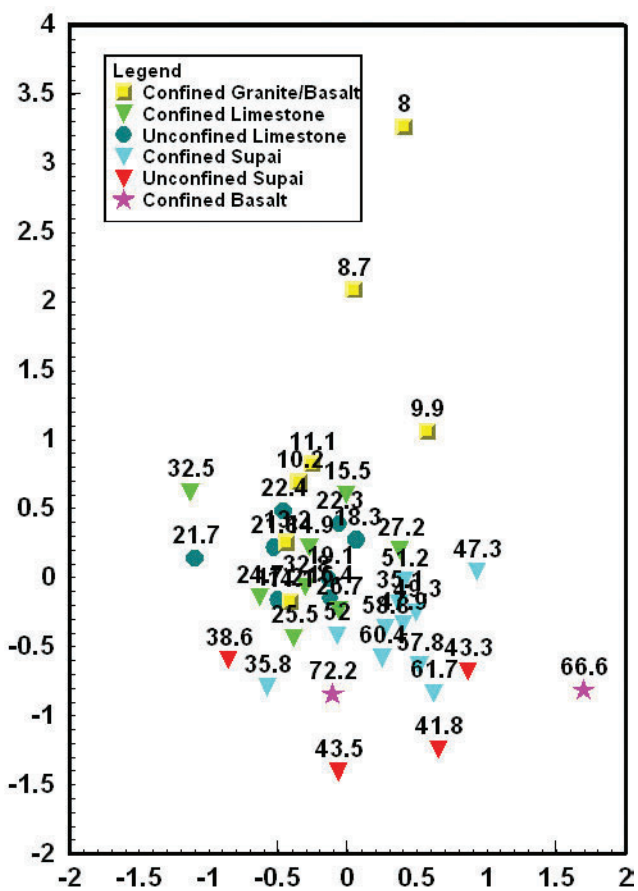


Figure 7.3—Ordination of sites in period 1 (1997 to 1998), labeled by distance in kilometers along the UVR downstream from Sullivan Dam to the Prescott National Forest boundary at Tapco.

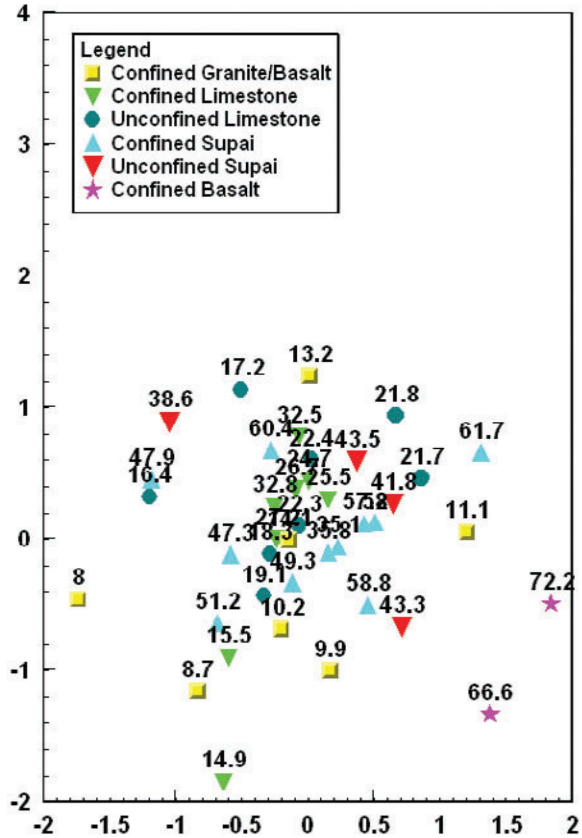


Figure 7.4—Ordination of sites in period 2 (2001 for all sites except 66.6 and 72.2, which were sampled in 2000), labeled by distance in kilometers along the UVR downstream from Sullivan Dam to the Prescott National Forest boundary at Tapco.

respectively, which gives the appearance of greater overlap. This effect may be the result of differences in plant cover between years (greater in the second year).

Figure 7.5 combines the information in the two ordinations into a single ordination. Samples are connected with lines showing their change from the initial sample to the second sample (all lines point north except for site 38). Many of the outlying samples in previous ordinations have shifted more than others, suggesting greater homogenization of the streamside vegetation.

Figure 7.6 charts changes in relative canopy cover at sites from period 1 to period 2 for the seven perennial native hydrophytic herbaceous taxa that showed the most change in relative cover (figures for changes in relative cover reveal the same patterns but are less straightforward to interpret quantitatively). Beggarstick, a weedy annual not used in the ordination, was included in fig. 7.6 because it was observed to dramatically increase at many sites. Beggarstick, rice cut-grass (*Leersia oryzoides*), cattails (*Typha* spp.), and cutleaf water-parsnip (*Berula erecta*), all predominantly aquatic species, showed an overall increase in cover across the sites. Rice cut-grass increased in relative cover at 32 of the 40 sites, cattails increased at 27 sites, and beggarstick increased at 23 sites, although a few sites (e.g., Muldoon 13) experienced large increases in cover of this weed. Cover of cutleaf water-parsnip increased at 19 of the sites and decreased in the other 21. Horsetail (*Equisetum* spp.), spikerush (*Eleocharis* spp.), common three-square bulrush (*Schoenoplectus pungens*), and knotgrass (*Paspalum distichum*) exhibited decreases in relative cover from period 1 to period 2 in at least 30 sites. Decreases in relative cover of knotgrass occurred at 36 of the 40 sites, but decreases were most pronounced at the downstream sites where knotgrass was initially more abundant. Reductions in relative cover of three-square bulrush were most pronounced at the upstream sites. Changes in plant cover could be detected if the original streambank changed

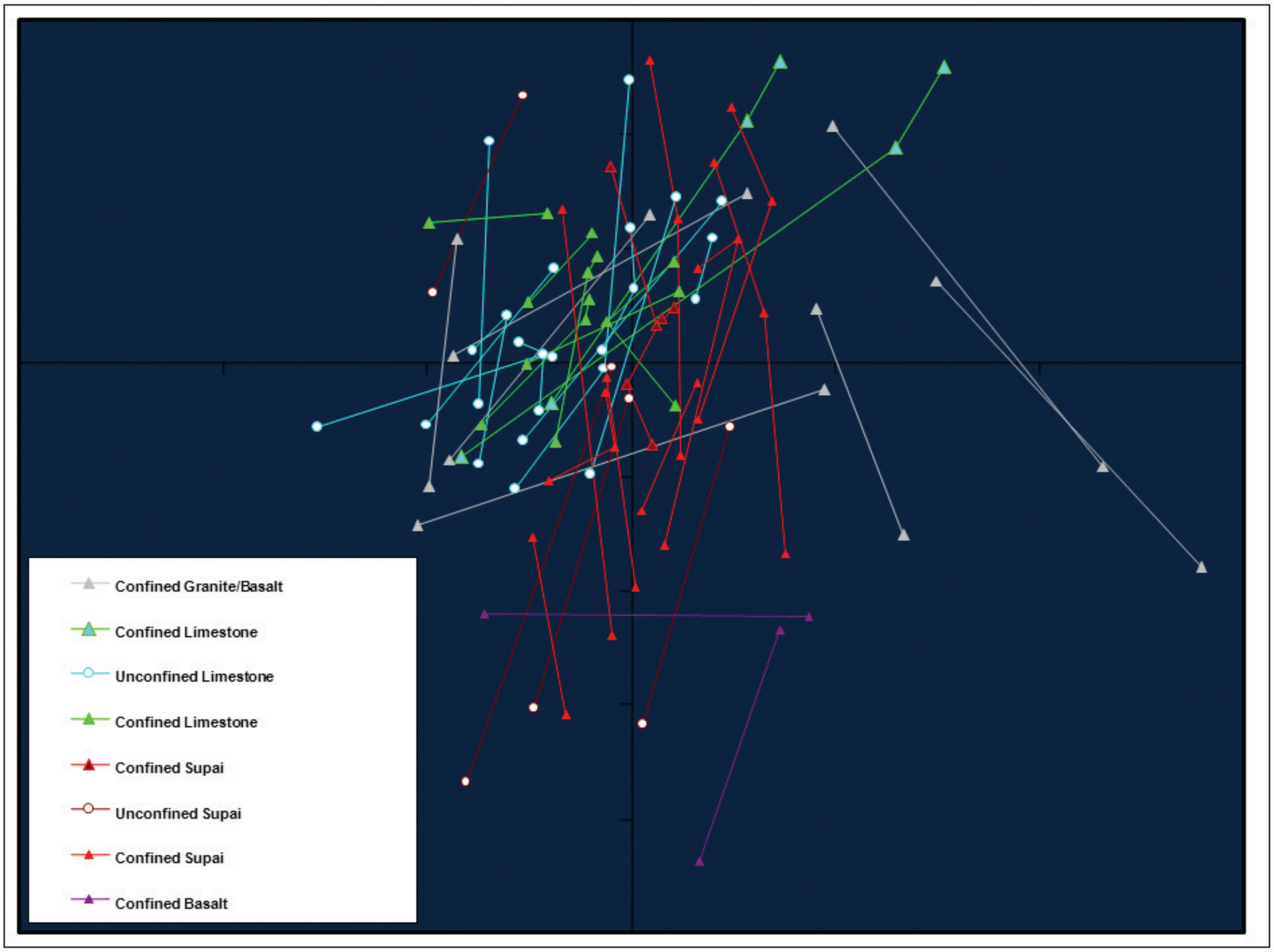


Figure 7.5—Ordination of all UVR sites, with lines indicating changes from initial samples to subsequent samples at individual sites.

in response to erosion or flooding. Hence, measuring changes over multiple years is best to detect species relationships to events and local conditions. Photo points illustrate a general increase in aquatic taxa between the two periods despite inter-year differences for some species. Mean species richness at the 40 sites decreased from 26.5 (SD = 9.4) in period 1 to 19.8 (SD = 6.2) in period 2. This is a common response when taller perennial aquatic taxa (e.g., bulrushes [*Schoenoplectus* spp.], sedges [*Carex* spp.], and rushes [*Juncus* spp.] increase in local abundance and out compete or shade out smaller annuals.

Discussion

Separating Noise from Meaningful Variation

Streamside herbaceous vegetation provides inherently noisy data. An attempt was made to reduce that noise by focusing on perennial, hydrophytic, native species. However, the efforts to reduce the dataset to more interpretable data might have missed other patterns that are ecologically significant. Nevertheless, the reductions identify ecological patterns that are more likely to be persistent and informative. To understand these patterns would require multiple years of sampling since various hydrological, biological, and climatic factors are operative on a daily basis.

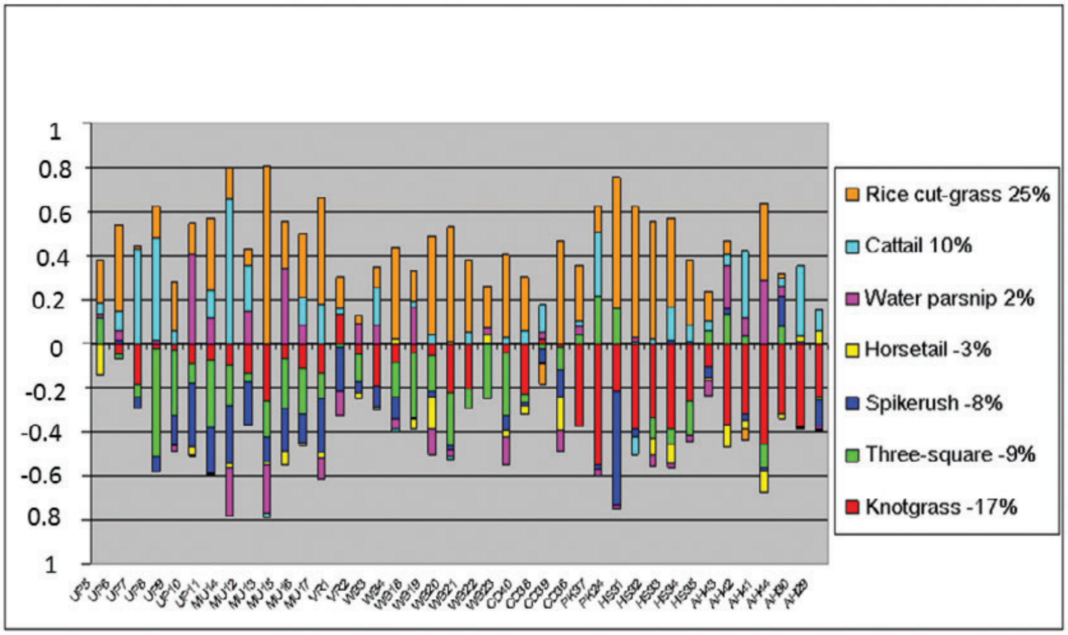


Figure 7.6—Changes in relative cover of key perennial hydrophytic herbaceous taxa between periods 1 (1997 to 1998) and 2 (2000 to 2001).

Patterns in Longitudinal Variation

These analyses show that progressive longitudinal patterns in vegetative are important. The dominant plants are widespread, which is not surprising since riparian vegetation can move upstream and downstream along the river corridor, and since our sampling methodology focused on the narrow bands of streamside vegetation that are present in nearly all reaches. The consistent changes along the entire study reach support the proposal that patchy habitats may persist throughout the corridor and are likely subject to similar temporal variability. An analysis focusing on other vegetation types, such as woody plants, or using larger sampling units, might have revealed more variation associated with valley confinement.

Some species become more dominant at particular points along the river, probably due to a variety of factors, including changes in base flow and substrates, local landscapes and bedrock influences, presence or absence of shading, grazing from ungulates (e.g., elk and stray livestock), beaver dams, or flood-induced erosion of terraces (see Chapter 2). For example, several aquatic forbs (monkey flower, [*Mimulus guttatus*], watercress [*Rorippa nasturtium-aquaticum*], and duckweed [*Lemna* spp.] were initially quite prominent at the upstream reaches, where highly stable spring-fed flows provide preferred habitat. Knotgrass (*Paspalum distichum*) was more abundant in the lower half of the sites, likely due to increased clay-silt content since it prefers fine-textured soils (USDA Natural Resources Conservation Service 2011). However, the UVR is undergoing major terrace erosion throughout the study reach, and the deposition of fine materials has led to expansion of other species like knotgrass. Swamp carex (*Carex senta*) was sampled only at a few sites at the downstream end of the river, but it became locally very important at the lowermost site below Sycamore Creek. Swamp carex is particularly common along Sycamore Creek, perhaps due to an association with steeper, bouldery habitat and/or the cooler climate of the narrow canyon. Its occurrence downstream and upstream from the confluence may reflect changes in geology and topography in that region. In contrast, sedges such as clustered field sedge (*Carex praegracilis*) and wooly sedge (*C. pellita*) are common in abandoned wetland habitats that have become localized relative to current streambank habitats. These species require open habitats typical of unconfined valleys and are rare in the steep, narrow canyon bottoms.

Other species do not demonstrate clear longitudinal associations, but rather are associated with valley confinement. For example, the dominants do become much less abundant in some confined reaches, while other plants, including horsetails (*Equisetum hymenale* and *E. arvense*) and Baltic rush (*Juncus arcticus*) become more important. These patterns reinforce the idea that riverine systems have properties of a continuum and fragmentation. As such, some longitudinal structure may be dictated to responses to substrate and confinement, but many species are common throughout the river.

Temporal Variation

This analysis observed a strong temporal pattern, as nearly all sites demonstrated increased relative cover of aquatic species (rice cut-grass, beggarstick, and cattails) that could have outcompeted or shaded out species that are important for streambank stability (three-square bulrush, spikerush, and knotgrass). Knotgrass and spikerush could have declined simply due to successional processes, given that both species are known to colonize bare sediments. However, three-square bulrush and horsetail have been observed to maintain dense stands even after several years without disturbance (Long and others 2003). The growth of aquatic plants appeared to increase cover and retain fine, organic sediments locally. However, many other cool-season species are largely unaccounted for and their contribution to vegetation patterns is unclear. Long-term personal observations support the premise that streamside vegetation is highly subject to hydrological influences, more so than other landscape factors. Coupled with the long-term grazing influence of riparian wetlands, some plants persist vigorously locally while others appear randomly distributed longitudinally and subject to local conditions, e.g., point bars.

The 1997 to 1998 data suggest more variation associated with the geologic-geomorphic classification. The 2001 data show greater similarity among the sites. Periods of stable flow can alter riverine dynamics such that biotic processes become dominant relative to abiotic influences (Gasith and Resh 1999). Therefore, this could account for the reduced association between streamside vegetation and abiotic features.

Stable baseflows, especially spring derived, appear more important in structuring plant communities in the long term. This is evidenced in the period pre-1993 when sedge-dominated wetland habitats were common and streambanks were populated with assemblages of rushes and sedges.

Management Implications

Land managers and researchers must account for temporal change, longitudinal variability, and the interactions between those two along the UVR. This variation may be particularly important in the UVR it is geomorphically fragmented and because its dynamics may shift during periods of quiescence following large floods. The temporal and longitudinal variability observed along the UVR during a period of stable baseflow cautions against attempts to strictly define "baseline" conditions. Instead, examinations of streamside vegetation need to account for locations along the river in relation to geologic structuring forces, as well as the time since the last major scouring event. Depending on purpose, assessment of long-term vegetation-hydrologic changes should compare conditions at the same intervals following major flood events (i.e., 1993 and 2005). Comparisons using repeat measurements or repeat photography are particularly useful for examing changes in species composition relative to land uses or other environmental changes. Emphasis on effects of land uses has been particularly contentious, and it's vitally important to not assume cause and effect relationships from only temporal vegetation data.

While increases in streamside vegetation are often assumed to be desirable, the particular shifts that were observed in this study may not be desirable, particularly in terms of sustaining native fishes in the presence of exotic predators. The increase in tall, weedy aquatic species (e.g., beggarstick and cattail) may crowd out native herbaceous species associated with long-term bank stability, increase hiding cover for predatory nonnative fish, induce narrowing and deepening of low-flow habitat, and retain fine organic substrates. Scientific testing is needed to elucidate the relationships between streamside vegetation and fish habitat. This analysis shows that some sites (e.g., Muldoon 13) shifted much more than others (e.g., Verde Ranch 2) (fig. 7.6). While inherent geomorphologic differences such as confinement may mediate the capacity for change, management actions such as grazing also influence streamside vegetation dynamics. As a consequence, research and management need to incorporate both types of factors into their design when evaluating the relationship of streamside vegetation to desired conditions. Many in-channel influences important to fish can occur independently of streambank dynamics. There is potential for assuming that changes between two points separated by long intervals represent long-term changes or that a lack of change between two periods represents a lack of change. Instead, particular reaches may exhibit rapid change as part of their nature, while other reaches may exhibit relatively little change.

Summary and Conclusions

This chapter examined patterns of vegetation in relation to major geomorphic and geologic attributes along the river. The analysis showed that, during a period of stable flows, streamside vegetation generally became more homogeneous, shifting toward several tall aquatic species and likely structuring the plant community in the long term. Evaluations of herbaceous streamside vegetation need to account for the influence of geologic structuring forces and flood dynamics. While increases in streamside vegetation are often assumed to be desirable, the particular shifts that were observed may not be desirable in terms of sustaining native fishes in the presence of exotic predators. Research and monitoring to test these hypotheses on the UVR must account for geomorphic variation as well as hydrologic dynamics that change rapidly. Another conclusion is that though substrate and channel confinement may initially dictate some vegetation structure longitudinally, many species are widely distributed throughout the river corridor. Lastly, across the various years many vegetation changes have been observed and docu¬mented. In this on-going dynamic situation, confined reaches are more likely than unconfined reaches to incur short-term changes, relative to major erosional changes of the current condition of stream channels and terraces, as well as encroachment of woody vegetation.

Chapter 8

A Preliminary View of Water Quality Conditions of the Upper Verde River

Alvin L. Medina

Introduction

Stream water temperatures are of general interest because of interactive effects among physical, biological, and chemical parameters of water chemistry (Langford 1990). Water temperature regimes dictate the types of aquatic flora and fauna present within the aquatic system, as well as influence the system's susceptibility to parasites and disease. These regimes are commonly noted in critical habitat designations as potentially limiting to native fish populations of Southwestern streams (Federal Register 2007). Temperatures that approach the upper thermal tolerances of Southwest native fishes have been noted in Arizona streams (Deacon and Minckley 1974; USDI Geological Survey 2005). Of particular interest are water temperatures for the UVR where spikedace (*Meda fulgida*) is imperiled. Recent fishery studies (Carveth and others 2006) suggest that native fishes are sensitive to annual and large temperature fluctuations. Reduced growth rates have been reported for some species (Widmer and others 2006). The relationships between desert fishes and water temperature are unclear, especially given the assumption that they should be capable of acclimating to hot and cold temperatures common to the Southwest.

State water managers rely on monitoring data to establish and validate water quality standards (Arizona Department of Environmental Quality 2002, 2007a, 2007b). Within the study area, the Arizona Department of Environmental Quality (Arizona Department of Environmental Quality 2007b) listed the headwater section of the UVR between Granite Creek and Hell Canyon as sufficiently high to support all uses attaining all uses, while the section between Perkinsville to below Camp Verde was listed as "impaired" because of sediment and turbidity. Arizona Department of Environmental Quality (2001) collected turbidity data between 1991 and 1995 to use in developing a Total Maximum Daily Load for turbidity using the "Aquatic and Wildlife Warm-water (A&Ww) Turbidity Standard" of 50 NTUs as defined in Arizona Department of Environmental Quality (1996, 2002). Anning (2003) synthesized National Water-Quality Assessment and other USDI Geological Survey monthly data for the Southwest and included the Clarkdale station located in the lower reach of the Verde River study area for the years 1981 to 1998. Aside from a few sample periods in which the A&Ww standards (Arizona Department of Environmental Quality 1996, 2002) were exceeded for pH, ammonia, total nitrogen, and total phosphorus, water quality was generally within accepted standards set by the State of Arizona (Arizona Department of Environmental Quality 1996, 2002).

In this chapter, the work of previous studies for water quality parameters, temperature, conductivity, dissolved oxygen, pH, turbidity, and total suspended solids are extended for April 2000 through April 2001 and for spring 2002. The purpose of this work was to establish a preliminary diagnosis of existing conditions for the purpose of identifying other research that could aid in identifying causal factors affecting native fishes. The data were collected using temporary monitoring stations installed in the UVR. This assessment reflects general conditions for the period of record and may not represent current conditions. Graphical contrasts of the statistical distributions of stream temperature for each station are provided.

Study Area

The UVR study area is defined as the perennial section of the river between Sullivan Dam downstream about 56 km (35 mi) to Tapco. It is described in detail in Chapter 2. Monitoring stations were established at two locations that aggregate various tributaries that contribute runoff to the main stem.

Most major historical influences, such as mining, livestock grazing, and vehicular travel, on the riparian zone have lessened over the last two decades (see Chapter 2). Grazing by livestock was modified from continuous-rotational to seasonal (winter) on most allotments in 1980, and then was entirely suspended in May 1998 (see Chapter 2. However, stray livestock graze some riparian areas intensively, as do elk. Wetland habitats are generally preferred grazing sites. Recreational impacts (e.g., off-road vehicles and camping) were also reduced through road closures, but the popularity of the river for off-road vehicles travel attracts many enthusiasts. No major fire or other off-site disturbances were noted. Potential sedimentation from rock quarries in the northern sections is possible, but not yet evident. The principal source of suspended sediments is from actively eroding paleoterraces and head cutting of tributaries adjusting to new base levels of the river (see Chapter 2).

Methods

Automated sampling stations using HydroLab* Datasondes with multi-parameter sensors were established in April 2000 at two locations on the UVR. Station 1 was located on the Prescott National Forest west boundary with the Verde River Ranch, and Station 2 was located at the Y-D Ranch in Perkinsville. Datasondes were suspended at a depth of 0.5 m (1.6 ft.), typically behind a boulder to protect sensors from large debris. Samples were taken at one-hour intervals and were obtained for continuous days where possible. Data were discounted if instrument calibrations drifted, hence making the period of record discontinuous. Data included storm- and flood-free days as determined from USDI Geological Survey Paulden flow gage records (USDI Geological Survey 2008). Additional data were collected in spring 2002 and were included in the period of record.

In addition, automated water samplers were used for determination of total suspended solids (TSS) as per Method 2540B in Clescerl and others (1998). Daily composite samples were created by collecting 50-ml aliquots every three hours. Three subsamples from each batch of 24 samples were analyzed for total organic carbon (TOC) as per Nelson and Sommers (1996). A total of 48 samples were collected in 2000. The intent was to ascertain the relative organic-inorganic fractions of about 10 to 12% of water samples.

Stations were established on or near private lands to provide security for equipment. Water quality parameters of interest included temperature, conductivity, dissolved oxygen (DO), pH, turbidity, TSS, and TOC. All data, except TOC, were summarized and graphed to display the variability for each parameter for the period of record.

Results

Temperature

Mean monthly water temperatures were virtually the same for Stations 1 and 2 (fig. 8.1). Slightly higher variability was observed at Station 1, probably owing to lesser water volume or influence from runoff emanating from high-elevation sub-watersheds. Seasonal changes in water temperature were observed, (maximum temperatures occurred in July), with a mean of 23 °C (73.4 °F) and low of 10 °C (50 °F) in January. Maximum and minimum temperatures at Stations 1 and 2 were 28.6 °C (83.5 °F) and 7.6 °C (45.7 °F), and 27.5 °C (81.5 °F) and 7.8 °C (46.0 °F), respectively. This temperature regime is consistent with the aquatic habitat criteria for native warm water fishes. Figure 8.2 illustrates and contrasts the diurnal variability in temperature across seasons. Aside from maximum and minimum values, there is great diurnal variability.

Specific Conductivity

Differences in specific conductivity were minor between Stations 1 and 2 (fig. 8.3). Both stations exhibited a similar trend through most of the year. Conductivity decreased at Station 2 in March 2001, probably in response to snowmelt runoff. This was not observed at Station 1 because there are no tributaries contributing snowmelt inflow (see watershed maps in Chapter 2). Winter precipitation in the upper headwaters (Station 1) is mostly in the form of rain, as snow rarely lasts beyond a few hours. In contrast, several tributaries that contribute to flow at Station 2 originate in the high country, where snow can last the entire season.

About a 15% increase in conductivity was observed at both stations during July. No observable difference in flow or rainfall occurred during this period so other factors could be at play. Water temperatures are noted near their highest in July, and it is possible the temperatures affected instrument calibrations for conductivity. General differences between Stations could be due to differences in location. Station 1 is located below the most spring sources for the Verde River, and baseflows derived from springs emanating from groundwater sources reportedly have different solution chemistry (Wirt and Hjalmarson 2000). Station 2 was subject to the flow and runoff influence from a vastly larger watershed, especially to those sub-watersheds from higher elevations and considerably larger drainages. The observed range of specific conductivity values are within the normal range (5 to 150 mS cm^{-1}) for potable waters (APHA-AWWA-WPCF 1989).

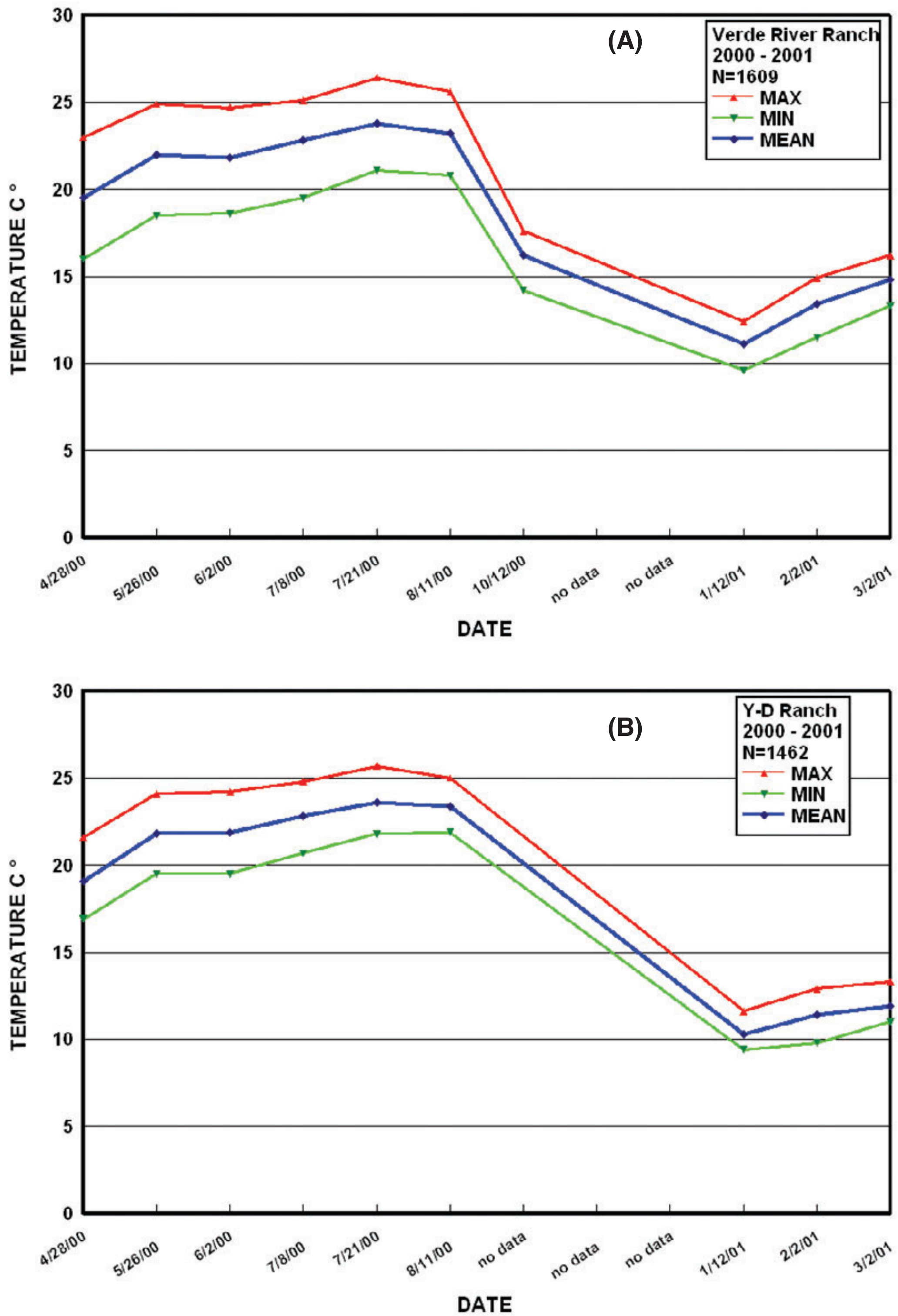


Figure 8.1—Monthly mean water temperatures at (A) the Verde River Ranch and (B) the Y-D Ranch sites, 2000 and 2001. High and low limits are equivalent to one standard deviation from the mean.

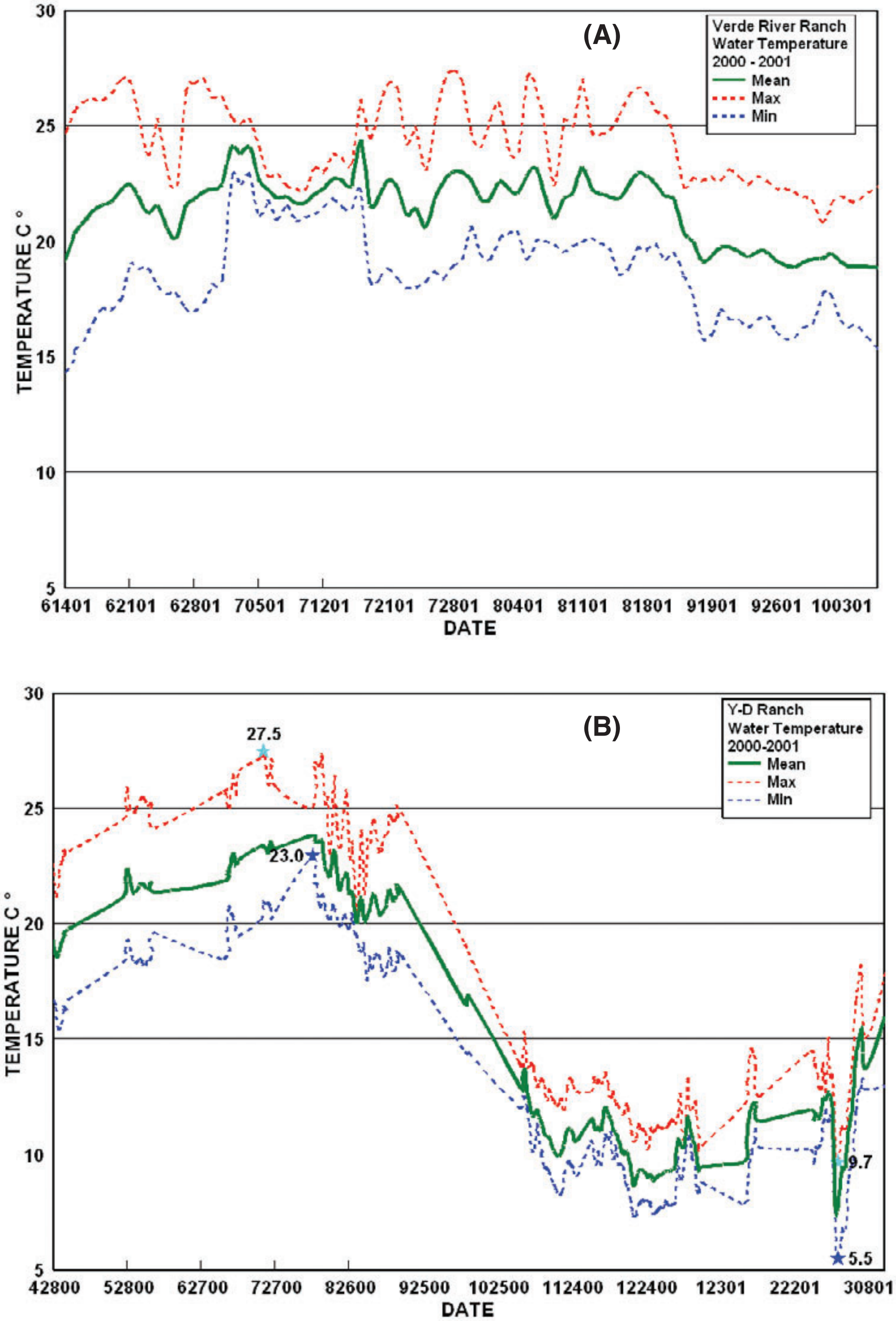


Figure 8.2—Comparison in diurnal variability in temperature between (A) the Verde River Ranch site (07/21/00 to 02/23/01) and (B) the Y-D Ranch site (04/28/00 to 03/08/01).

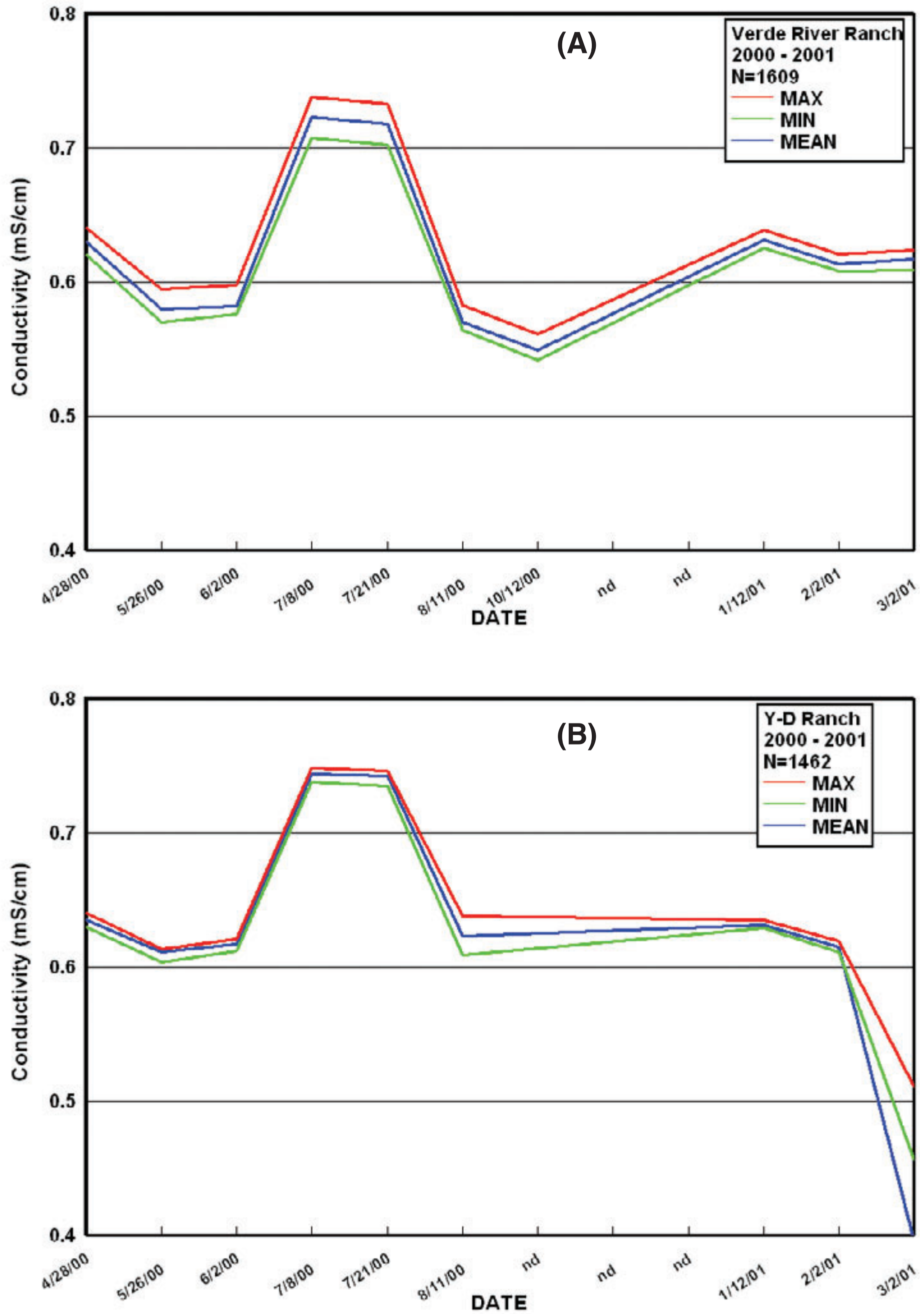


Figure 8.3—Contrasts in mean specific conductivity for (A) the Verde River Ranch and (B) the Y-D Ranch. High and low limits are equivalent to one standard deviation from the mean.

Dissolved Oxygen

Mean DO (fig. 8.4) saturation at Station 1 was above 90% (the suggested standard; Arizona Department of Environmental Quality 1996, 2002) in all cases, except for in early July when it dropped to a mean of 86% (± 26%). Mean DO (fig. 8.4) saturation at Station 2 was above 90% saturation for most of the year, except for brief periods in August and March, which coincided with the onset of macroinvertebrate production and algae algal blooms. The annual mean for both Stations combined was 97.2% ± 19%.

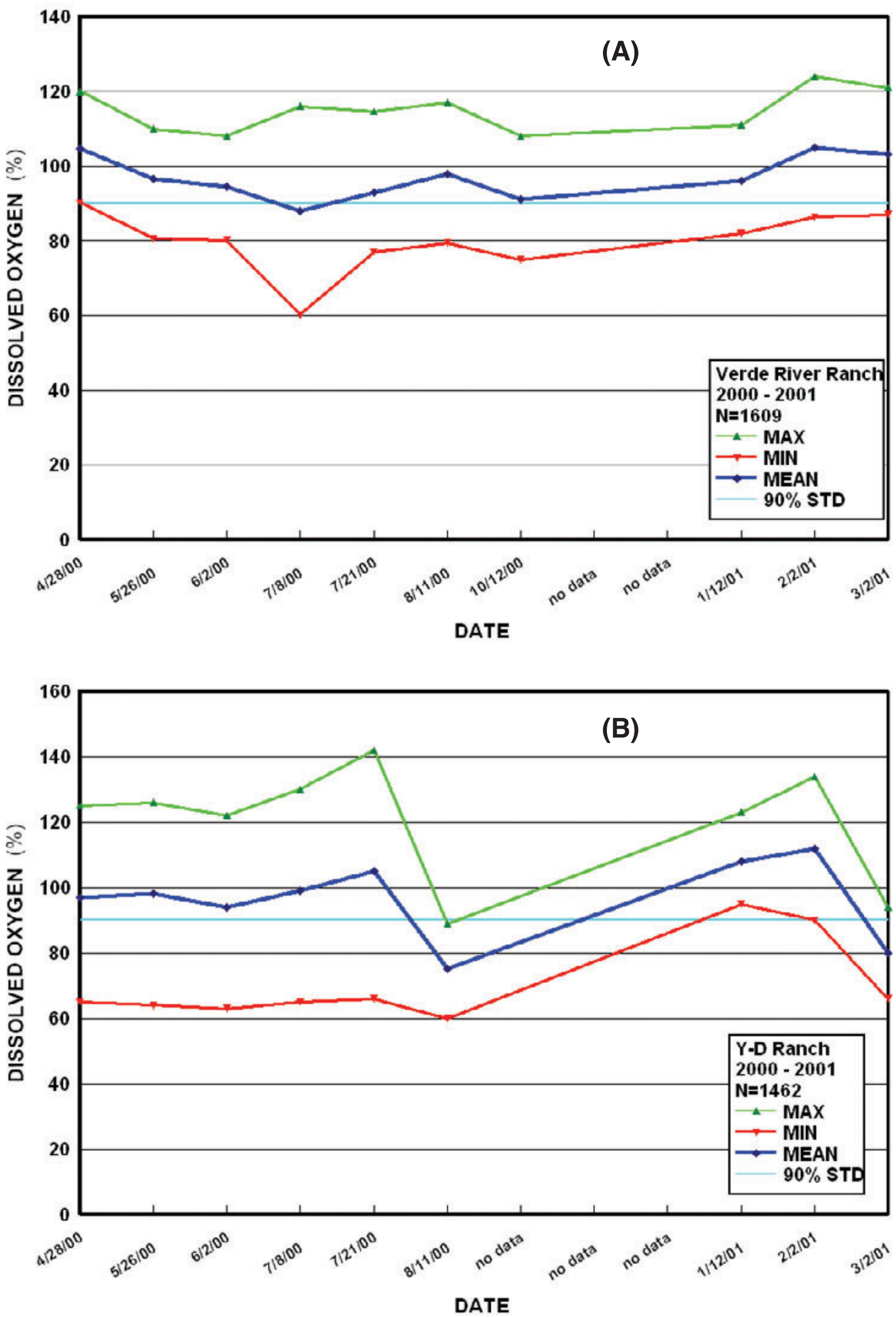


Figure 8.4—Contrasts in mean percent dissolved oxygen at (A) the Verde River Ranch and (B) the Y-D Ranch. High and low limits are equivalent to one standard deviation from the mean.

pH

Mean pH values for Station 1 were generally stable between April and late summer (fig. 8.5). An increase of 0.5 standard units was noted during the winter months, returning to pre-existing conditions in the spring. Mean pH levels at Station 2 were slightly lower than at Station 1 (7.7 and 8.1, respectively) (fig. 8.5). These levels are consistent with standards for warmwater streams (Arizona Department of Environmental Quality 1996, 2002) and do not pose a risk to water quality or aquatic habitats for native fauna.

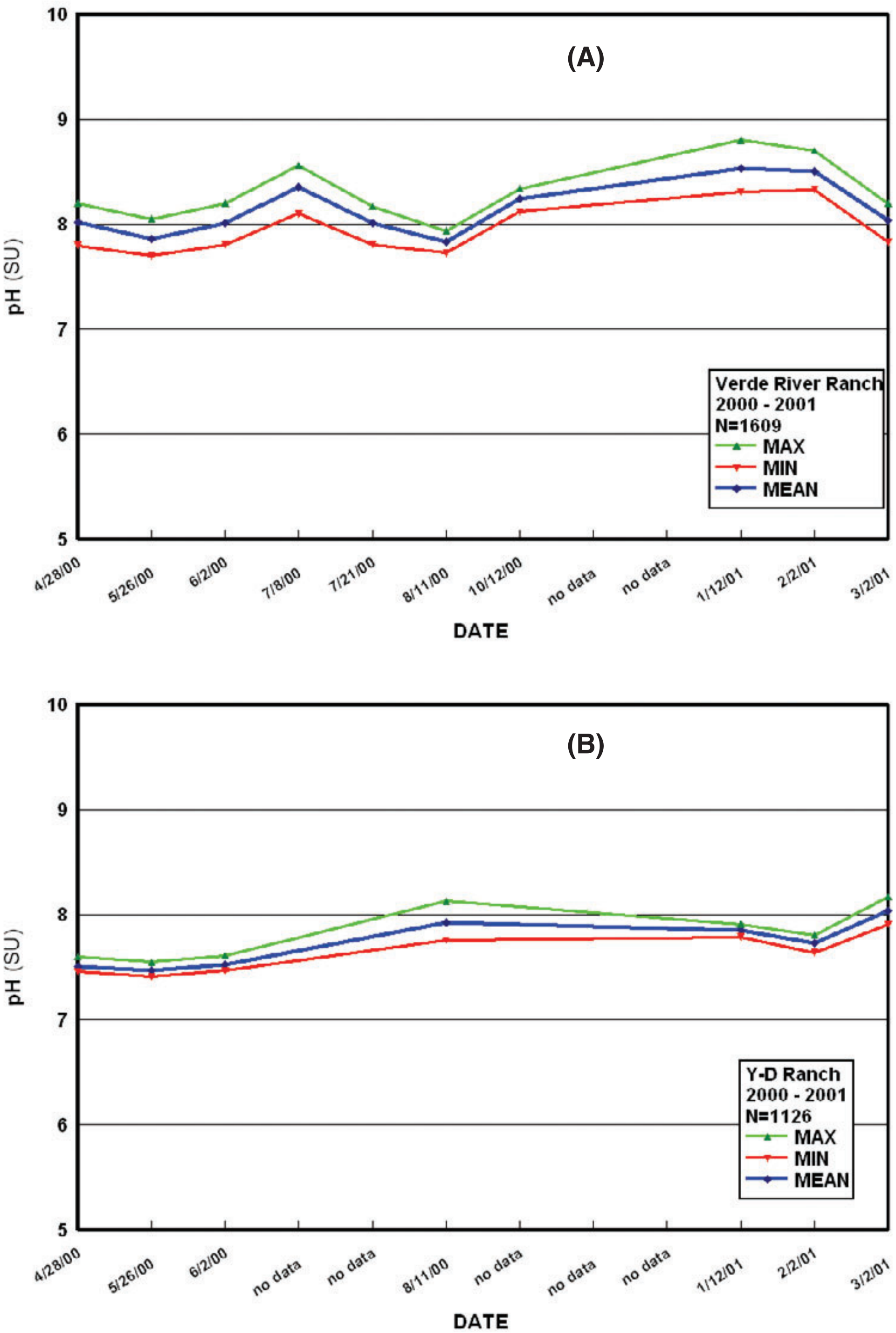


Figure 8.5—Contrast in mean pH values between (A) the Verde Ranch and the (B) Y-D Ranch. High and low limits are equivalent to one standard deviation from the mean.

Turbidity

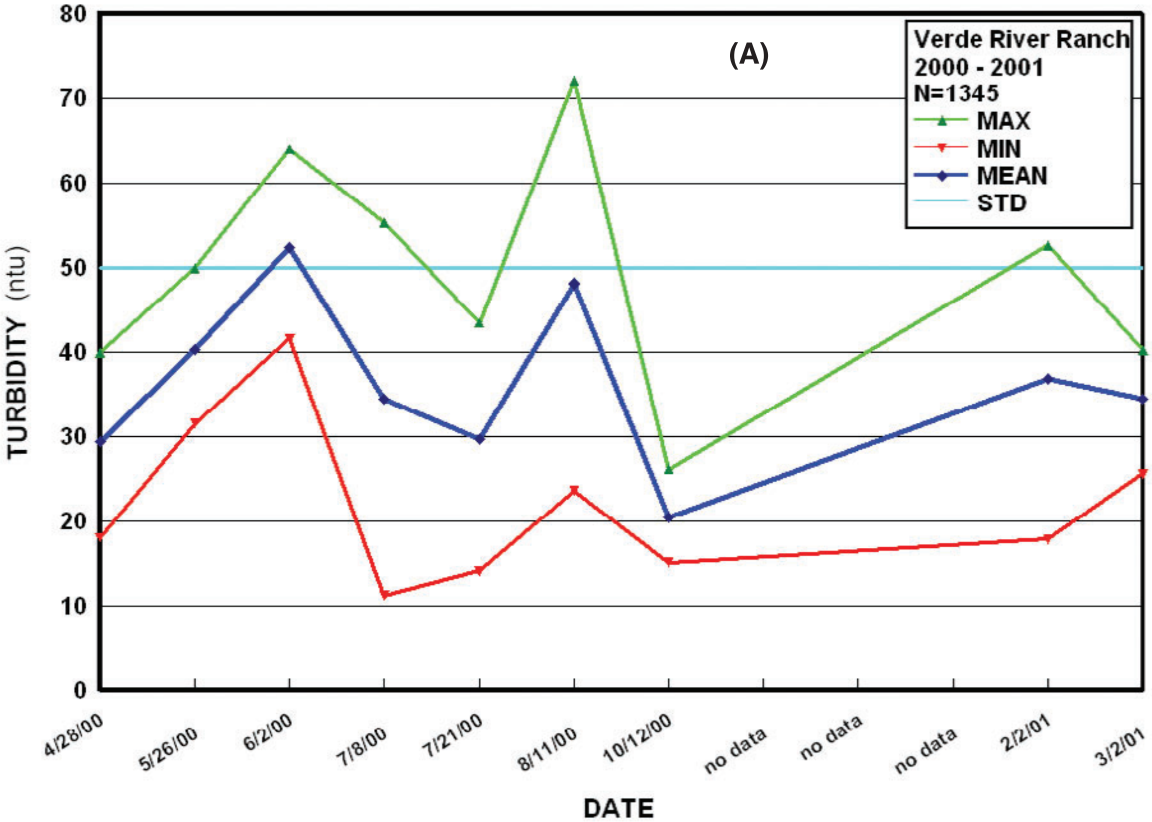
Turbidity levels fluctuated across time at both stations (fig. 8.6). Mean turbidity at Station 1 was below the 50 NTU standard (Arizona Department of Environmental Quality 1996, 2002) for all times except for June when mean turbidity reached 53 NTU ± 11. Mean annual turbidity for Station 1 was 35 NTU ± 17. Turbidity levels at Station 2 were always below the 50 NTU standard. Mean annual turbidity for Station 2 was 38 NTU ± 35. Turbidity proved to be unreliable estimates of suspended solids because of sensor fouling by detritus, diatoms, benthos, and algae. The effect of phytoplankton on turbidity sensors was most evident in the spring when various algae also became prevalent. Distinct patterns are evident between Stations and are attributed to actual water clarity. Station 1 was in a location with relatively little human disturbance but it was subject to biological growth owing to water clarity, especially algae. Station 2 was in a location where human disturbance occurred nearby as well as at a campground 1.6 km (1 mi) away. Crayfish and beaver were also abundant at Station 2 but were lacking at Station 1. The presence of these animals could account for additional differences either at specific times/seasons or in general.

There were notable differences in turbidity and water clarity observed for several years between the warm and cool seasons. During the summer water color approximated a gray-green in contrast to a clear color in the winter. Likewise high turbidity was most evident at locations where cattails abound and in pools and glides. Riffle areas tended to clarify turbid conditions.

TSS and TOC

Estimates of TSS are depicted in fig. 8.7. Greater variability was observed at Station 2. The data illustrate that suspended solids are relatively low and do not constitute an impairment to water quality. In this study, estimations of suspended solids are preferable to turbidity estimates because of the unknown effect of fouling of the turbidity sensor (see the "Turbidity" section). Hence, no correlation between TSS and turbidity was attempted. It is highly likely that the higher TSS for Station 2 at the Y-D Ranch was due to recreational disturbances from campgrounds and recreational vehicle travel on the floodplain and stream. These activities are common about 1 mile upstream of Station 2. It seems unlikely that livestock grazing contributed to the differences between Stations as both had grazing occurring above the collection site. However, livestock grazing at Station 2 was seasonal, while grazing was year-long at Station 1.

Analysis of 48 sediment samples from the TSS samples revealed that nearly 92% ± 4.6 of TSS was due to organic matter across all seasons. Organic fractions were highest during the growing season (96% ± 3.8)—May through September—and lowest during the fall-winter period 81% ± 5.7. There is an obvious change in turbidity and water color between these seasons, with turbid water evident during the summer. This is likely due to the activity of macroinvertebrates (shredders) during late spring and summer. No estimates of TOC were taken during flooding.



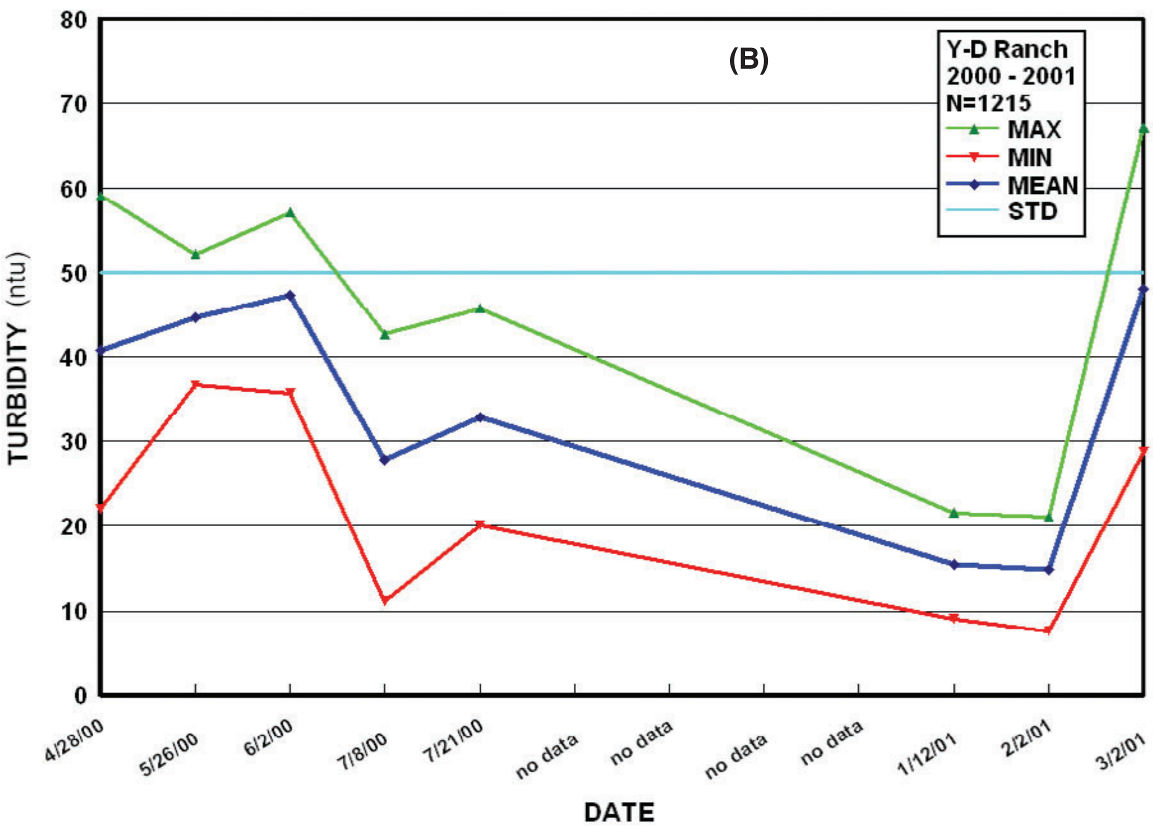


Figure 8.6—Contrast in mean turbidity values at (A) Verde Ranch and (B) Y-D Ranch. High and low limits are equivalent to one standard deviation from the mean.

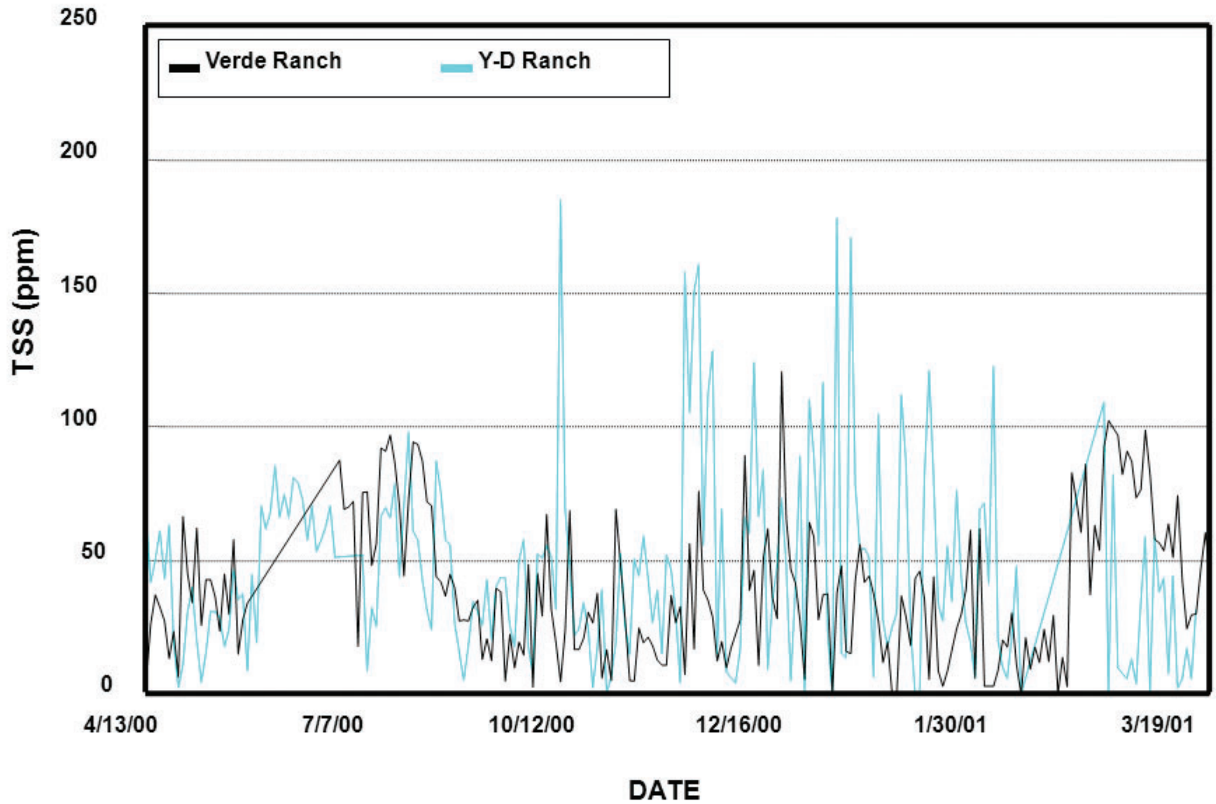


Figure 8.7—Contrast of TSS for the Verde River Ranch and the Y-D Ranch. Data are for non-flood days.

Discussion

Temperature

The temperature regimes identified in this study are consistent with results from other streams in Arizona (Barber and Minckley 1966; Barber and others 1970) and New Mexico (Propst and others 1986) for native warmwater fishes. Emphasis herein is placed on spikedace (*Meda fulgida*) because of its threatened status and its interest to management agencies, but the data apply to other important native fishes of the Verde River, including roundtail chub (*Gila robusta*), Sonora sucker (*Catostomus insignis*), speckled dace (*Rhinichthys osculus*), and longfin dace (*Agosia chrysogaster*). All these fishes are close associates of desert streams in Arizona and New Mexico. However, temperature regimes, including thermal maxima, can vary by several factors, including species, time of year, flow conditions, and local habitat conditions.

Barber and others (1970) reported habitat temperatures of occupied spikedace habitat to vary with time of year. In May, water temperatures at Aravaipa Creek, a stream system much like the Verde River, were uniformly 19 °C (66.2 °F). Summer water temperatures remained at no more than 27 °C (80.6 °F). On the Gila River, similar to the Verde River, in southern New Mexico in the Forks area in the Cliff-Gila Valley, summer temperatures reached a mean of 19.3 °C (66.7 °F) between June and November (Propst and others 1986). Winter water temperatures on Aravaipa Creek ranged between 20.6 °C (69.1 °F) in November down to 8.9 °C

(48.0 °F) in December (Barber and Minckley 1966). Rinne and others (2002) noted stream temperatures on the Verde River can exceed 30 °C daily and suggested some fish may survive temperatures near 35 °C but also noted that fish in the wild can move to cooler habitats and avoid temperature extremes.

These diurnal extremes are common on the Verde River, as evidenced in fig. 8.2. This variability is important and likely more common when considering habitat suitability for aquatic species. How this variability is apt to change with respect to major changes in vegetation (see Chapter 6) and channel conditions (see Chapter 5) is unknown but it is an important management consideration for warmwater fauna, especially TES species.

Carveth and others (2006) performed laboratory studies on temperature tolerances of spikedace from Aravaipa Creek and determined that no spikedace survived exposure of 30 days at 34 or 36 °C (93.2 or 96.8 °F) and that 50% mortality occurred after 30 days at 32.1 °C (89.8 °F). In addition, growth rate was slowed at 32 °C (89.6 °F) as well as at lower test temperatures of 10 °C and 4 °C (50 and 39.2 °F). The authors further observed multiple behavioral and physiological changes, indicating that fish became stressed at 30, 32, and 33 °C (86, 89.6, and 91.4 °F) treatments. The study concluded that temperature tolerance in the wild may be lower due to the influence of additional stressors, including disease, predation, competition, or poor water quality. Temperatures in the UVR during the monitoring never reached 30° C, much less the high temperatures tested in the University of Arizona study. Low temperatures briefly dipped below 10 °C (50 °F). The study concluded that 100% survival of spikedace at 30 °C (86 °F) in the experiment suggests that little juvenile or adult mortality would occur due to thermal stress if peak water temperatures remained at or below that level (Carveth and others 2006), accounting for genetic constraints that may be present among the various subspecies across the Gila River Basin, the Verde River included.

Carveth and others (2006) further compared the upper thermal tolerances of native and nonnative fish species of Arizona. Among the species acclimated to 25 °C (77 °F), desert pupfish (*Cyprinodon macularius*), western mosquitofish (*Gambusia affinis*), and Gila topminnow (P*oeciliopsis occidentalis*) were most tolerant to high temperature. The smaller native fishes—speckled dace (*Rhinichthys osculus*), spikedace (*Meda fulgid*a), and loach minnow (*R. cobitis*)—were least tolerant. Many native species demonstrated a limited ability to extend their upper temperature tolerances via acclimation. The Carveth and others (2006) study suggested that several native species may be sensitive to increasing annual and or large daily temperature fluctuations in Arizona's streams and rivers. Hence, the current changes in habitat conditions (see Chapters 2, 5, and 6) are increasingly important when defining management strategies, especially when their basis is limited or outdated. Although Southwest United States native fishes were previously believed to be tolerant to high temperature due to their evolution in desert environments, this may not be the case for some fishes.

Dissolved Oxygen

Warm water that is typically found in Southwest desert rivers and lakes contains decreased levels of DO, which can adversely affect aquatic animals such as fishes and amphibians not adapted to lower oxygen levels (Laws 2000). DO concentrations in the UVR were within the acceptable standards set by Arizona Department of Environmental Quality (1996, 2002) for warmwater streams. However, besides temperature, the high percentage of sampled organic matter is of concern with respect to potential decreased DO concentration. The UVR harbors a diverse aquatic plant flora; some such as cattails (*Typha* spp.), inhabit large areas of instream habitat (see Chapters 2 and 6). These dense stands of cattails, located primarily in the upper reaches, and associated herbaceous vegetation produce large amounts of detritus, which becomes part of the suspended load. Growth of these plants commences with the increase in ambient temperatures of spring and summer, as well as other growth of phytoplankton, macroinvertebrates, etc. These combined conditions produce a major change in water turbidity seasonally that is evidenced by a crystalline-clear to a murky gray-green appearance. In addition, the UVR in 1979 was a very different system compared to today. Channel habitat consisted mostly of wide and long riffles—a stark contrast to the more common pool-glide habitat present today (see Chapter 2). It's uncertain what the effects are of the combinations of temperature, organic loading, suspended silts/clays from eroding terraces, and changes in channel substrates and habitat (see Chapters 2 and 5) on productivity of the aquatic system. As noted elsewhere, these changes in vegetation and channel conditions are a recent condition. In some respects, one would expect primary and secondary production to increase, but this is not evident from fish population surveys conducted over the last 20 years.

Conductivity and pH

The data show nothing remarkable about conductivity or pH aside from some temporal anomalies that are difficult to explain. Specific conductivity and pH levels are consistent with standards for warmwater streams (Arizona Department of Environmental Quality 1996, 2002) and do not pose a risk to water quality or aquatic habitats for native fauna. Differences in specific conductivity between sampling locations is best attributed to differences in the size and origin of runoff for the lower location.

Turbidity and Total Dissolved Solids

Turbidity is a temporal problem on the UVR, most likely resulting from the abundant aquatic plant growth in the channel during the growing season. Estimates of organic matter content in water samples averaged 92% ± 4.6 across the sampling period in 2000 and accounted for increased concentrations of TSS. However, none of these was remarkable with respect to exceeding water quality standards (Arizona Department of Environmental Quality 1996, 2002). Today, better turbidity sensors are available to record this parameter across a continuous record.

Management Implications

Water quality data collected in this study were intended to provide land managers with a diagnostic reference about current conditions; the data were not intended for extrapolating cause-and-effect relationships of upland and riparian management activities. They are too limited in extent, duration, and flow range sampling to do so. At best, one can say that the water quality of the sampled reaches of the UVR is within the range of variability of warmwater standards for the Southwest and does not raise any particular concerns other than those discussed for organic loading. Sampling occurred under grazed and ungrazed conditions, which are inseparable, and no adverse effects can be attributed to such.

Since aquatic habitat conditions continue to change relative to 1979, it is recommended that a more extensive assessment of aquatic habitat suitability and availability be conducted before any major change in fish management occurs. This assessment should be conducted periodically—every three to five years—to establish trends and identify potential risk factors that could impair restoration efforts for riparian-aquatic habitats or aquatic fauna. Although there were no remarkable diagnostics for the parameters examined, recent studies have implicated the presence of chemical cocktails, e.g., pharmaceuticals, in aquatic fauna population studies (some conducted in Arizona rivers [Environmental Protection Agency 2009]). The concern has alarmed Environmental Protection Agency (2009) such that officials now include monitoring of "pharmaceutical and personal care products" as part of its National Rivers and Streams Assessment. This new concern is relevant to the UVR because of the potential for chemical contamination from the rural area above the dam. The rural area above Sullivan dam was once a sparsely populated community, until recently as the area is presently occupied by many homes, agricultural industries and other commercial business. A diagnostic approach to exclude chemical constituents is important to add to the status of knowledge of the UVR.

Summary and Conclusions

Water quality data collected on the UVR were not comprehensive or continuous and involved only two sites that were chosen for their ease of access and security, not for any scientific concern. However, the preliminary data collected for two stations on the UVR during the period April 2000 through March 2001 suggest that all parameters (temperature, DO, pH, conductivity, turbidity, and TSS) are consistent with warmwater standards for the Southwest. They are also well within the normal range of conditions for native fishes such as the spikedace.

Chapter 9

Fish and Aquatic Organisms

John N. Rinne

Introduction

The UVR of central Arizona, from its source at Sullivan Lake to the mouth of Sycamore Creek, 60 km (38 mi) downstream, is rare among the State's rivers because it still retains some of its native fish fauna. In 1994, six of the native fishes that were historically recorded in this reach of the Verde still occurred, along with at least seven nonnative species, and many other native species have been incidentally reported (Stefferud and Rinne 1995). The native fish fauna includes longfin dace (*Agosia chrysogaster*), speckled dace (*Rhinichthys osculus*), roundtail chub (*Gila robusta*), spikedace (*Meda fulgida*), desert sucker (*Catostomus clarki*), and Sonora sucker (*Catostomus insignis*) (figs. 9.1 to 9.6; Minckley 1973). The skeletal remains of razorback sucker (*Xyrauchen texanus*) and Colorado pikeminnow (*Ptychocheilus lucius*) have been found at an archaeological site near Perkinsville dated circa 1300 to 1400 A.D. (Minckley and Alger 1968). Both species have recently been stocked in this reach (Hendrickson 1993; Jahrke and Clark 1999). Nonnative species commonly found there include red shiner (*Cyprinella lutrensis*), western mosquitofish (*Gambusia affinis*), fathead minnow (*Pimephales promelas*), common carp (*Cyprinus carpio*), green sunfish (*Lepomis cyanellus*), smallmouth bass (*Micropterus dolomieu*), and yellow bullhead (*Ameiurus natalis*) (Minckley

Figure 9.1—Longfin Dace (*Agosia chrysogaster*). (Photo by John N. Rinne.)

Figure 9.2—Speckled Dace (*Rhinichthys osculus*). (Photo by John N. Rinne.)

Figure 9.3—Roundtail Chub (*Gila robusta*). (Photo by John N. Rinne.)

Figure 9.4—Spikedace (*Meda fulgida*) female (above) and male (below), Verde River, Arizona. (Photo by John N. Rinne.)

Figure 9.5—Desert Sucker (*Catostomus clarki*). (Photo by John N. Rinne.)

Figure 9.6—Sonora sucker (*Catostomus insignis*). (Photo by John N. Rinne.)

1973; Hendrickson 1993). Reasons for retention of this suite of the historic native fish fauna are unclear but may be related to the multiple influences of the geomorphic nature of the river, bed load composition, and its relatively unregulated flow that can scour the channel and dramatically change the physical and biological components, which, in turn, affect the dynamics of the fish assemblage (Brouder 2001; Rinne 2005).

Many independent studies and surveys of the fishes and aquatic ecology of the Southwest and UVR were conducted prior to 1994 (Minckley 1979). Results of some of these activities are available in the published literature and in scattered agency reports. However, not one study consistently investigated the long-term (10+ years) interrelationships of the fish assemblage with natural and/or anthropogenic disturbance events at multiple sites (Rinne 1985a). As of 1994, information was lacking on response of fish assemblages in the UVR to disturbance events such as drought, flooding, land use activities, and invasive species onset (Rinne and Rinne 1993). Research and monitoring were needed to document changes in species abundance and fish assemblages, occurrence through time and space, and fish densities relative to aquatic habitat types, hydrology and geomorphology. Lacking was any long-term and consistent monitoring of the fishery at multiple sites in the UVR.

In 1994, following multiple UVR flood events in winter of 1992/1993, RMRS initiated research and monitoring of a 60-km (38-mi) reach of the UVR between Sycamore Creek and Burnt Ranch (Arizona Game and Fish Heritage Property; Stefferud and Rinne 1995). The objective of the study (Rinne 1994) and monitoring was to determine the roles and relative influence of physical (hydrology and geomorphology) and biological (introduced fish population dynamics, native versus nonnative interactions, and reintroduction of native species) factors in the sustainability of native fishes in time (10 years) and through the space of seven sites over. Research and monitoring were designed to delineate the effects of flow regimes or hydrographs, local and broadscale geomorphology, and nonnative, invasive fishes on the native fish assemblage (Rinne 2005). From 1995 to present, numerous papers have been published on:

(1) Changes in fish assemblages over the entire Verde River (Rinne and others 1998, 2005a) and comparison with another Southwest desert river (Rinne and others 2005b);

(2) Fish-habitat relationships (Rinne and Stefferud 1996; Sponholtz and Rinne 1997; Rinne and Deason 2000);

(3) Status and habitat use of the threatened spikedace (Neary and others 1996; Rinne 1999a);

(4) Relationships between hydrology and geomorphology and fish assemblages (Rinne and Stefferud 1997; Neary and Rinne 1998, 2001b; Rinne 2001a, 2002; Rinne and Miller 2006; Rinne and others 2005b, 2005c);

(5) Stream channel and fish relationships (Rinne and Neary 1997; Rinne 2001d);

(6) Native fish biology (Rinne and others 2002) and native/nonnative fish interactions (Rinne 2001b, 2004, 2005; Rinne and others 2004); and

(7) Land use impacts on native fishes (Rinne 1998, 1999b, 2001c; Medina and Rinne 2000; Medina and others 2005; Rinne and Miller 2008).

UVR Study Area

The Verde River flows over 300 km (188 mi) from its headwaters in Big Chino Wash on the Prescott National Forest to its confluence with the Salt River northeast of Phoenix (see Chapter 1; figs. 1.1 and 9.7). The 60 km (38 mi) reach of UVR river corridor above Sycamore Creek or Reach 1 (Rinne and others 1998; Rinne 2001a, 2001b, 2001c, 2001d, 2005b, 2005c) is relatively undisturbed by humans and contains no flow-altering dams or major diversions. However, Sullivan Dam (fig. 9.8; figs. 2.14 through 2.18), constructed in the 1950s, has retained massive amounts of bed load materials from input downstream into the Verde River of over a half century. Primary uses of the river corridor are native fish conservation, general recreation, sport fishing, livestock grazing, and very limited irrigation for private land holdings. Current urbanization and that proposed in the headwaters, as well as the ever-increasing demand for water and groundwater mining, will have over arching impacts on these other river uses.

Methods

Methodologies for research and long-term monitoring are outlined in Rinne (1994) and Stefferud and Rinne (1995). Seven long-term monitoring and research sites were located primarily based on access and spatial disposition over the 60 km-long (38 mi-long) study reach (fig. 9.7). The first is located at Burnt Ranch, about 1.3 km (8 mi) downstream of Sullivan Lake and the last is at the confluence of the Verde River and Sycamore Creek. At each monitoring site, 200- to 300-m (656- to

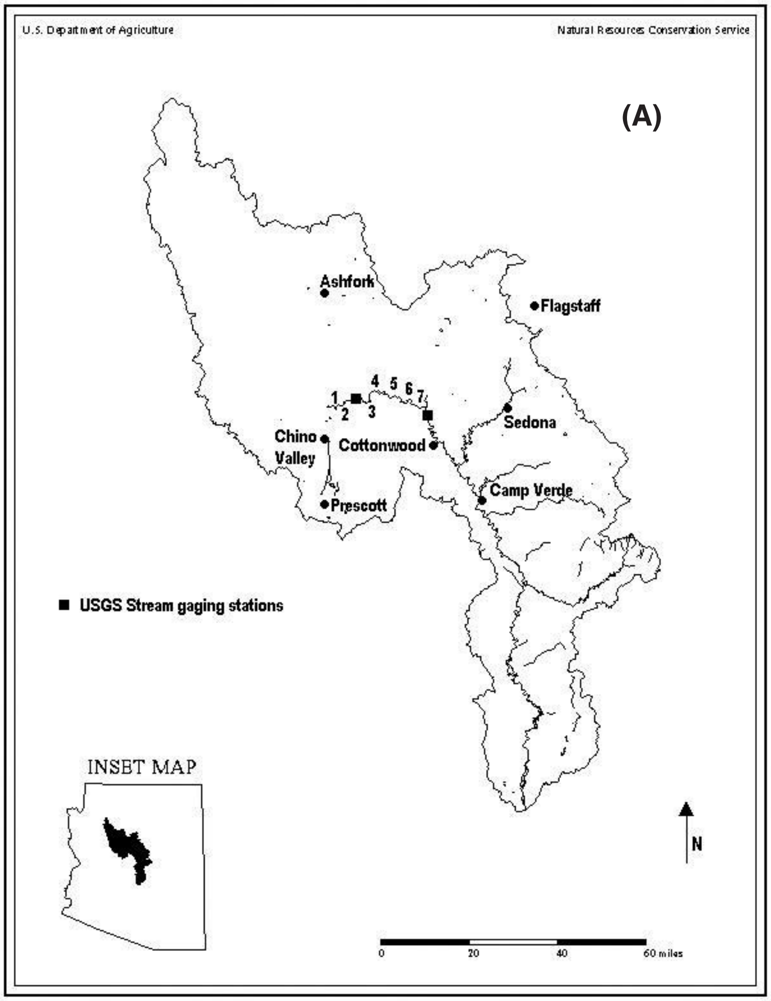


Figure 9.7—(A) UVR long-term fish sampling sites (1-7), local communities, and USDI Geological Survey stream gauge sites (Rinne 2005); and (B) mechanical removal sites at Burnt Ranch and 638 Road.

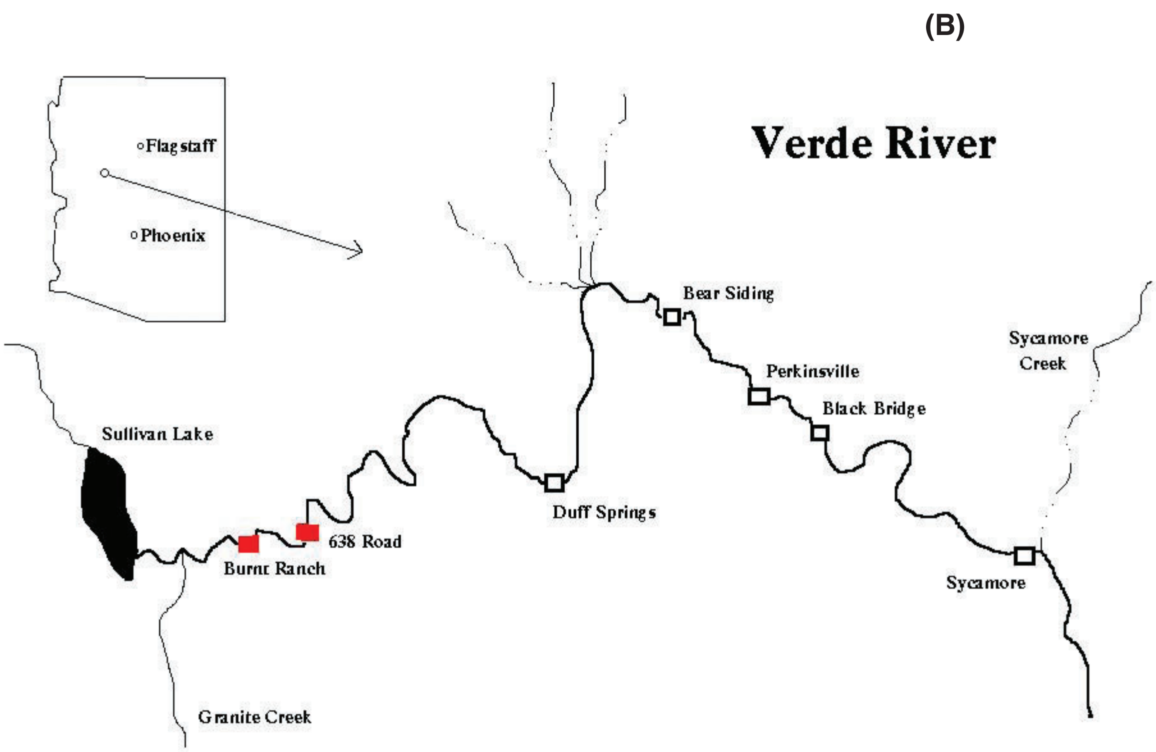


Figure 9.8—Flow over Sullivan Dam during spring runoff, 2005. (Photo by Alvin L. Medina.)

984-ft) reaches of stream were sampled depending on complexity of sites. The overall goal was to encompass the major aquatic habitat types (see the following discussion on macrohabitats) at each monitoring site (Rinne and Stefferud 1996). Habitats were sampled with both backpack, DC electro fishing gear and 3.2-mm (0.13-in) mesh seines that were used actively in glide runs and passively as block nets to capture electro-narcotized fish at the lower end of higher velocity riffles with currents of >40 cm s^{-1} (15.7 in s^{-1}) (fig. 9.9). All fish were measured (total lengths in mm), recorded, and returned alive to the stream. In the event of large numbers of individuals of a species in a respective habitat type, only 50 individuals were measured and the remainder were enumerated only. Lengths and widths of each sample reach were measured with metric tape and laser technology, depth was measured with a meter rule, gradients with laser technology, and substrate composition of each sub-reach (i.e., macrohabitat) within a monitoring area with pebble count methodology (Bevenger and King 1995). Monitoring sites were consistently maintained over the entire period of study, totaling 15 years as of spring 2008. Hydrologic data are from the USDI Geological Survey Paulden gauge in the upper reaches of the 60 km (38 mi) study area (figs. 9.7 and 9.10).

Mechanical removal of nonnative fishes was initiated at three 1.0 km (0.6 mi) stream reaches in 1999, two in the Burnt Ranch reach of the River and one in the 638 road reach (Site 1, fig. 9.7). This initial, pilot study was sustained until spring 2004 when it was terminated based on results of study and the multiple flooding events occurring in autumn 2004 and winter 2005; fig. 9.11). Methods are in Rinne (2001a, 2001b) and primarily consisted of electro-fishing for capture of fishes within treatment or removal reaches twice a year with single pass methodology. All fishes were measured, natives were returned alive to the stream, and nonnatives were disposed of on-site. Based on results of the original study (Rinne 2001a) and the 2004/2005 flood events that reduced the abundance of nonnative individuals and made marked changes in stream habitat, a modified study was instituted in 2006 and is ongoing (Rinne and others 2006a, 2006b).

Figure 9.9—(A) High-gradient riffle on the UVR downstream of Verde River Ranch, and (B) seining with mesh nets. (Photos by Alvin L. Medina.)

Figure 9.10—U.S. Geological Survey Paulden Gauging Station upstream of the Verde River Ranch near Paulden, Arizona. (Photo by Daniel G. Neary.)

Figure 9.11—2004 flood on the UVR at Perkinsville, Arizona. (Photo by Alvin L. Medina.)

Changes in Fish Assemblages 1994 to 2008

Fish Assemblage Changes

Fish assemblages in the study reach measured by Rinne (2001a, 2005; fig. 9.7) changed markedly over the 15-year period (fig. 9.12). For the first three years following marked, multiple increased instantaneous peak flow events in winter 1992/1993 (fig. 9.13), native species comprised over 80% of the total fish assemblage numbers. During baseflow, drought years between 1997 and 2004, fish assemblages were similar, but inverse, dominated by nonnative fish species that accounted for about 70 to 85% of the total fish assemblage at the seven long-term research/monitoring sites. All native species, including the threatened spikedace, declined substantially in samples during baseflow, drought years (Rinne 2005). All three smaller-sized species—speckled dace, longfin dace, and the threatened

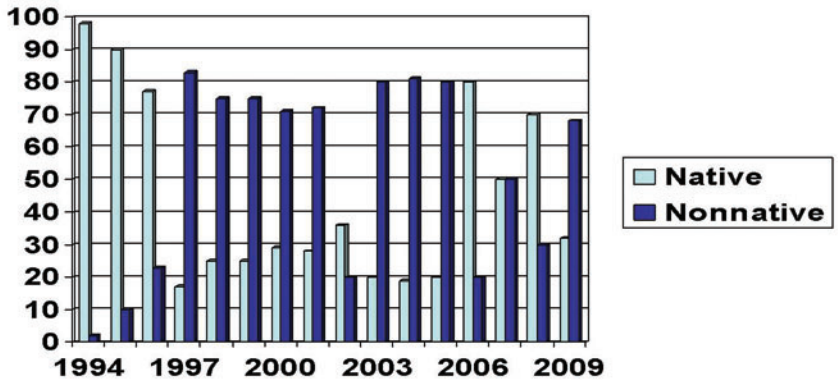


Figure 9.12—Changes in UVR native and nonnative fish assemblages (percentages), 1994 to 2009.

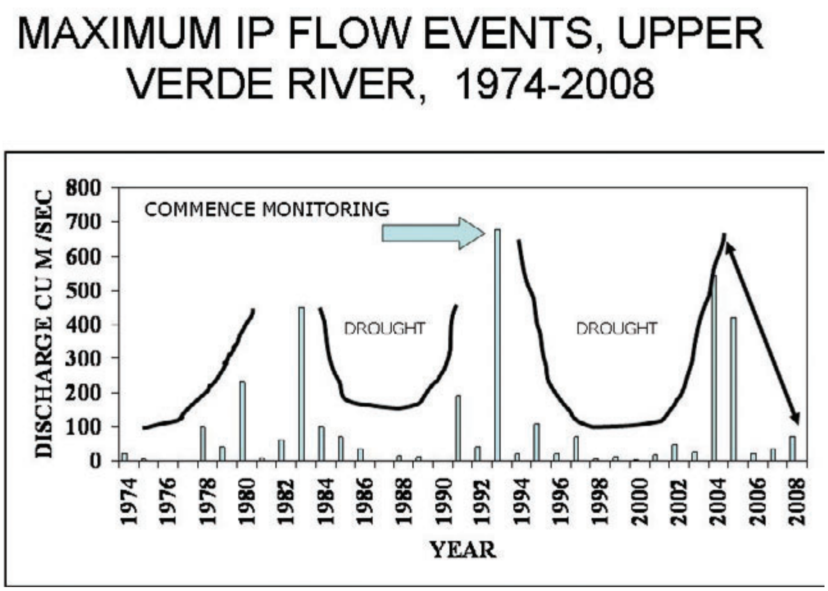


Figure 9.13—Maximum instantaneous peakflow in m^3 sec^{-1} measured at the Paulden gauge on the UVR, 1974 to 2008.

spikedace—became virtually absent. The spikedace has been absent from samples at all seven long-term sites since 1997 (Rinne 1999a). Although the three larger-sized, longer-lived species—desert sucker, Sonora sucker, and roundtail chub—were yet present, their numbers were likewise markedly reduced by 1996 (Rinne and others 2005c), and recruitment of all three of these species was reduced to absent (figs. 9.14A and 9.14B).

By contrast, nonnative species such as smallmouth bass, green sunfish, and red shiner oscillated in abundance from 1994 to 2008. The length of native species dominance after flood events differed between the 1992/1993 floods and the 2004/2005 floods. After the former events, native fishes dominated the fish assemblage in the UVR from 1994/1996. However, after the 2004/2005 floods, the total fish assemblage was native-dominated. But, by spring 2009, natives declined to <33% of the total fish assemblage (fig. 9.12).

In summary, fish assemblages responded markedly to flow regimes of the UVR over a 15-year period. However, flows do not appear to be the only operative factor affecting fish assemblages. That is, the response of fish assemblages post-flooding and prior to commencement of monitoring in 1994 was different from assemblages following recent, 2004/2005 flood events. The threatened spikedace, speckled and longfin daces—all short-lived, small-sized (<70 mm or <2.76 in) species—have virtually disappeared from samples in the uppermost reach of this desert river

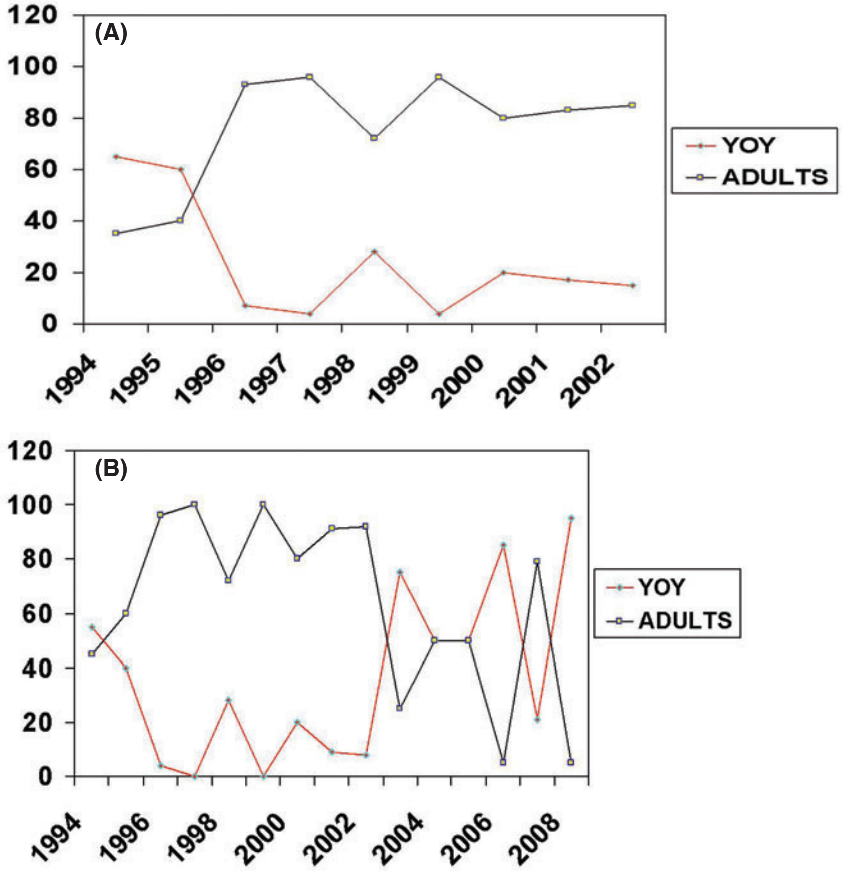


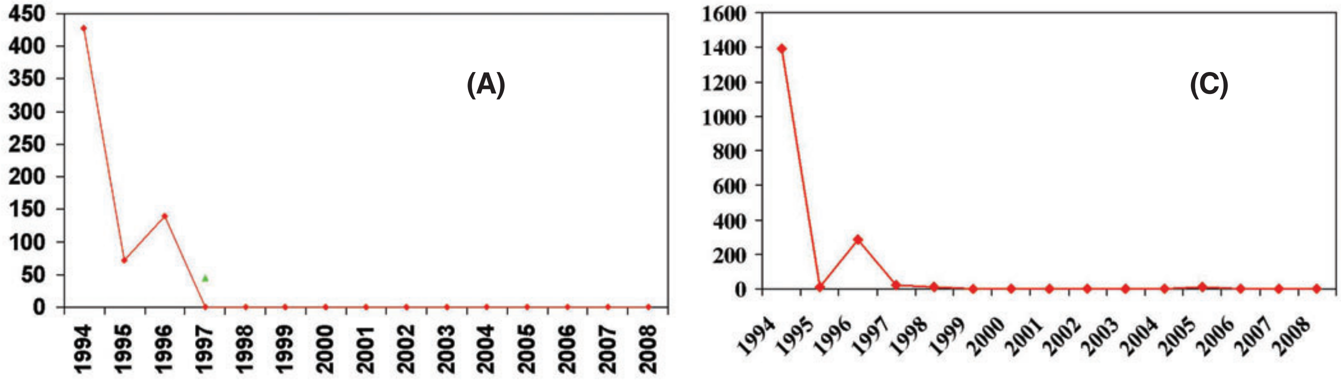
Figure 9.14—(A) Recruitment of sonora sucker in the UVR, 1995 to 2002, and (B) recruitment of roundtail chub in the UVR, 1995 to 2002 (YOY = young-of-the-year).

compared to 1994 samples (figs. 9.15A, 9.15B, and 9.15C). In spring 2006, only speckled dace increased in abundance in samples (n = 26). Spikedace and longfin dace were absent. The three larger-sized (>300 mm or >11.8 in), longer-lived (5 to 10 years) species also have become markedly reduced in numbers (figs. 9.16A, 9.16B, and 9.16C). The competitive and predatory influence of nonnative species on native species (Rinne and Minckley 1985; Rinne 1995b) have to be considered equally, or perhaps even more importantly than flow regimes. Most likely, the two factors are interactive and synergistic. There are ongoing efforts described in the following Mechanical Removal section to phsically remove nonnative fishes and to compare the response in treated reaches to that at contiguous control reaches at two of the long-term monitoring sites—Burnt Ranch and 638 Road—and at the other five long-term monitoring reaches.

At all seven sites, the native fish component dominated (82 to 86%) in numbers over the nonnative component (table 9.1, fig. 9.12). However, such predominance of native species was variable, comprising 54% of the total fish assemblage in autumn 1994 and increasing to 85% in the sampling reach by spring 1995. By autumn 1995, native species comprised 88% of the total fish assemblage. Similarly, sampling following the winter 1992/spring 1993 flood event, and, synchronous with data collected by RMRS personnel, indicated that natives comprised 96% of the total fish assemblage (Rinne and Stefferud 1997).

Changes in Species Abundance, 1994 to 2008

Numbers of most fish species decreased markedly between spring 1994 and 1995 sampling; only green sunfish increased (table 9.1). Native fish decreased from between 56 and 99% (mean of 83%) and nonnatives decreased by 11 to 100%. Yellow



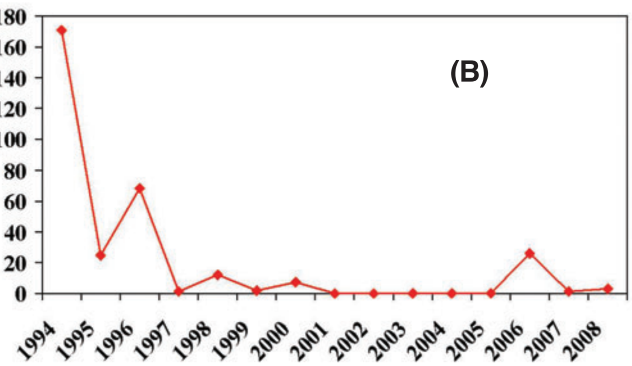
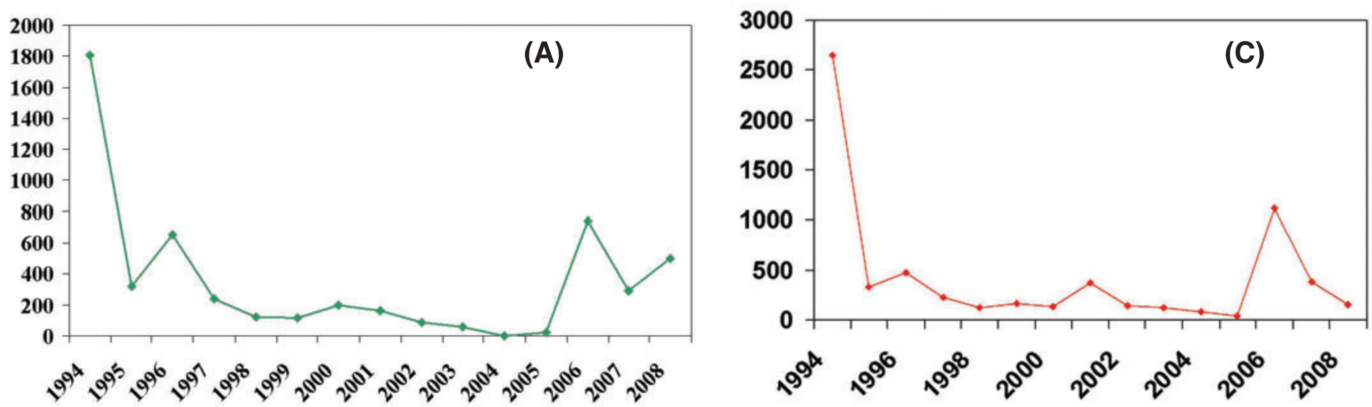


Figure 9.15—Total number of small-sized fish collected in the UVR seven-site sampling areas, 1994 to 2008: (A) spikedace, (B) speckled dace, and (C) longfin dace.



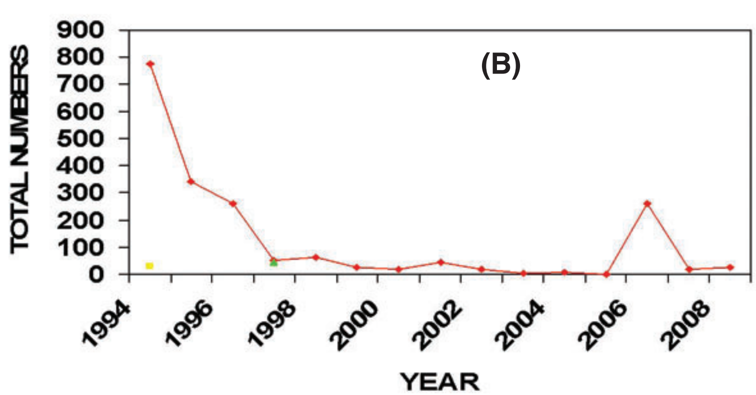


Figure 9.16—Total number of large-sized fish collected in the UVR seven-site sampling areas, 1994 to 2008: (A) sonora sucker, (B) roundtail chub, and (C) desert sucker.

Table 9.1—Fish community dynamics (number and percent change) in the UVR, spring 1994 to 1996. Values in ( ) are percentages of the total fish assemblage, and bold numbers are total numbers of sampled fish in the native and nonnative components. Species abbreviations are shown and are the same for tables 9.2 and 9.3.

Species	Species Abbreviation	Spring 1994 Fish	Spring 1995 Fish	Change[1]	Spring 1996 Fish	Change[2]
		Numbers	*Numbers*	*%*	*Numbers*	*%*
Native						
Desert Sucker	CACL	2644	247	-91	471	+91
Sonoran Sucker	CAIN	1810	322	-82	654	+103
Roundtail Chub	GIRO	776	341	-56	259	-24
Longfin Dace	AGCH	1319	12	-99	282	+2250
Spikedace	MEFU	428	72	-83	140	+94
Speckled Dace	RHOS	171	25	-85	68	+172
TOTAL		**7148**	**1019 (85%)**	**-861**	**1874 (85%)**	**+462**
Introduced						
Red Shiner	CYLU	1473	97	-93	275	+183
Common Carp	CYCA	23	6	-74	13	+117
Smallmouth Bass	MIDO	14	10	-29	32	+220
Green Sunfish	LECY	5	29	+580	6	-79
Yellow Bullhead	AMNA	36	32	-11	6	-81
Fathead Minnow	PIPR	6	0	-100	0	0
TOTAL		**1558**	**174 (15%)**	**-891**	**332 (15%)**	**+912**

[1] % change 1994 to 1995
[2] % change 1995 to 1996

bullhead was reduced by only 11% and smallmouth bass by 29%. Red shiner decreased by 93%, and no fathead minnows were found in spring 1995.

Biannual sampling at the upper- and lower-most sites in the river offers a more detailed picture of population dynamics (table 9.2). All native species, except roundtail chub, declined from spring 1994 to autumn 1994 at the Burnt Ranch site, decreased further by spring 1995, and increased in autumn 1995 and spring 1996 following flooding in spring 1995. Most nonnative species varied little between samples. The introduced red shiner population at Burnt Ranch held stable between spring and autumn 1994 and then declined markedly (>80%) by spring 1995 only to then increase markedly (95%) by autumn 1995. By comparison, at the Sycamore site, red shiner increased more than 100-fold between spring and autumn 1994 only to collapse (-99%) to very low population levels in 1995 and 1996. At Sycamore, common carp numbers were low from spring 1994 to spring 1996. Similarly, smallmouth bass numbers remained low during all sample periods, disappeared at Sycamore in spring 1995, and increased slightly by autumn 1995. Green sunfish were absent at these two sites in 1994, but were present and increasing at the Burnt Ranch site by autumn 1995. Numbers of yellow bullhead were generally low and declined steadily from spring 1994 to spring 1996.

Mechanical Removal: 1999 to 2003 and 2006 to 2009

1999 to 2003 Pilot Study

The marked decline of the native fish assemblage in the UVR mimics that presented for other stream and rivers in the generally reported negative impact of nonnative fishes on native fishes (Minckley and Deacon 1991; Rinne and Minckley

Table 9.2—Seasonal fish assemblage dynamics at Burnt Ranch (BR) and Sycamore Creek (SC), UVR, 1994 to 1996: (A) Spring 1994, Autumn 1994, and Spring 1995; and (B) Autumn 1995 and Spring 1996.

A

	Spring 1994			Autumn 1994			Spring 1995		
Species	**BR**	**SC**	**Total**	**BR**	**SC**	**Total**	**BR**	**SC**	**Total**
	Numbers			*Numbers*			*Numbers*		
Native Species									
CACL	339	379	718	31	93	124	15	29	44
CAIN	278	223	501	214	25	239	60	37	97
GIRO	15	165	180	50	17	67	3	104	107
AGCH	1072	1	1073	94	0	94	0	0	0
MEFU	257	92	349	93	0	93	33	17	50
RHOS	0	19	19	0	1	1	0	0	0
Nonnative Species									
Cylu	39	3	42	50	395	445	7	5	12
Cyca	1	4	5	67	1	68	0	2	2
Mido	2	3	5	2	3	5	3	0	3
Lecy	0	0	0	0	0	0	0	2	2
Amna	2	10	12	1	6	7	2	1	3
PIPR	0	0	0	5	0	5	0	0	0

B

	Autumn 1995			Spring 1996		
Species	**BR**	**SC**	**Total**	**BR**	**SC**	**Total**
	Numbers			*Numbers*		
Native Species						
CACL	44	77	121	79	38	117
CAIN	103	93	196	92	41	133
GIRO	40	6	46	23	25	48
AGCH	397	0	397	91	1	92
MEFU	290	0	290	33	51	84
RHOS	0	12	12	0	0	0
Introduced Species						
Cylu	151	7	158	88	9	97
Cyca	3	0	3	1	1	2
Mido	0	9	9	5	0	5
Lecy	7	0	7	1	0	1
Amna	5	8	13	1	0	1
PIPR	0	0	0	0	0	0

1991; Rinne 2003a) and suggests that nonnative species of fishes negatively, and often dramatically, impact native species of fishes. Such disturbing patterns in the UVR, when combined with the literature on the generally reported negative impact of nonnative fishes on native fishes in the western United States, infers the likely negative impact of both large (smallmouth bass, green sunfish, and yellow bullhead) and small (western mosquitofish and red shiner) fishes on young-of-the-year (YOY) native fishes (Carpenter and Mueller 2008). Because of this interaction, it was determined in autumn 1999 to treat several reaches of the UVR by mechanically removing nonnatives to determine the response of native species.

Nonnative species of fishes have been intensively and extensively introduced throughout the western United States over the past century (Minckley and Deacon 1991; Rinne 2003a; Rinne and others 2005a). Establishment of nonnative fishes assemblages has been a major impediment to the conservation and sustainability of native fishes in rivers and streams in the southwestern United States. A common method of removing nonnative species has been chemical treatment with piscicides to renovate streams to sustain and enhance native fish species (Rinne and Turner 1991; Finlayson and others 2000). However, this management tool is increasingly scrutinized by the public and often is subject to administrative delays. Further, the politics of managing sport fishes alongside native fishes is complex, usually contradictory, and most likely mutually exclusive (Rinne and others 2004; Marsh and Pacey 2003; Clarkson and others 2005).

Mechanical removal has recently been considered as an alternative tool to reduce/suppress nonnative fish species and restore native fish assemblages as it has increased in popularity recently. In some regions of the United States, substantial funds are being expended to implement these programs (Mueller 2005). The question becomes, "Is this approach a viable tool for the conservation and sustainability of native fishes?" Further questions that managers need answers to are:

(1) Does mechanical removal reduce nonnatives sufficiently to ensure sustainability of native populations?

2) What are the thresholds at which native species commence to respond to this treatment?

(3) What are the problems and probabilities of success, and how do politics and the public influence these probabilities?

(4) Does effectiveness relate to methods and approaches, species-specific response, stream size, and temporal-spatial aspects?

(5) Are these more often only "feel good" projects that expend considerable fiscal and human resources and really buy resource agencies little toward restoring and sustaining native fish assemblages?

Pilot Study: Mechanical Removal of Invasive Fishes

In 1999, because of the sustained loss of the native component of the fish assemblage, a pilot nonnative, mechanical fish removal project was initiated in the extreme UVR. The treatment involved removal of invasive fish species from three reaches of the river between September 1999 and February 2005. The response of the native fish component was estimated based on presence and recruitment of YOY and Age 1 individuals. Flooding that commenced in autumn 2004 and continued through winter of 2005 provided an opportunity to address some of the problems encountered in the pilot study (see the "Results" section).

Three experimental reaches, each approximately 1 km (0.6 mi) in length, were selected to be treated in the upper most reaches of the river. Two were established in the Burnt Ranch study area and one was placed at the 638 Road long-term study reach (fig. 9.7B). Commencing in autumn 1999 and ending in spring 2004, these sites were sampled in spring and autumn with a single pass approach and backpack DC electro-fishing units. All fishes were enumerated, and natives were returned alive to the stream. Captured nonnative fish were removed from the river. In sampling, YOY and age 1 native fishes were captured, measured, recorded, and returned alive to the stream. The relative numbers and percentages of these age class individuals were then compared to the percentage composition recorded at the Burnt Ranch and 638 Road long-term sampling sites to determine if a positive response in native fish recruitment resulted from mechanical removal of predatory fishes (Rinne 2001b). In June 2006, a modified approach was adopted that encompassed almost 8 km (5 mi) of the UVR. Previously treated reaches and long-term monitoring sites at Burnt Ranch and 638 Road were included in the study.

Results of the Pilot Study

Almost 4,000 invasive, nonnative potentially predatory fishes were removed mechanically from the river in the initial treatment period (fig. 9.17). In contrast to expectations, numbers of nonnative individuals removed increased with successive treatments. This was especially true at the Burnt Ranch sites. Overall, smallmouth bass were removed in the greatest numbers (fig. 9.18). Total numbers of smallmouth bass increased from 1999 to 2003 (fig. 9.19), but mean size of this species decreased from 160 to 180 mm (6.3 to 7.1 in) to about 120 mm (4.7 in) during that same time period (fig. 9.20).

Criteria for success of removal were based on comparative numbers of YOY and Age 1 of the three larger-sized native species (figs. 9.14A and 9.14B). The most positive response was at the 638 Road treatment reach (figs. 9.21A and 9.21B). There was no consistent, significantly positive response of YOY and Age 1 natives at removal reaches versus those same age classes at non-treated, long term monitoring sites.

Results of four years of Pilot Study removal reported by Rinne (2001b) indicated that:

(1) Native fishes did not respond consistently or positively.

(2) Nonnative species, especially smallmouth bass, increased in numbers although they were reduced in size.

(3) The single pass removal was not effective.

Conclusions from the study were:

(1) Intensity of single pass removal, once a year, was not sufficient to adequately reduce nonnative fish species. A three-pass system requires more effort but it is much more effective.

(2) Extensive streambank and in-stream vegetation reduced efficiency of removal.

(3) The limited spatial extent of 1-km (0.6-mi) treatment reaches did not preclude immigration into sites.

(4) Vegetation and increases in invasive fishes, combined with the marked reduction of all native species prior to study, precluded effective removal of nonnative species.

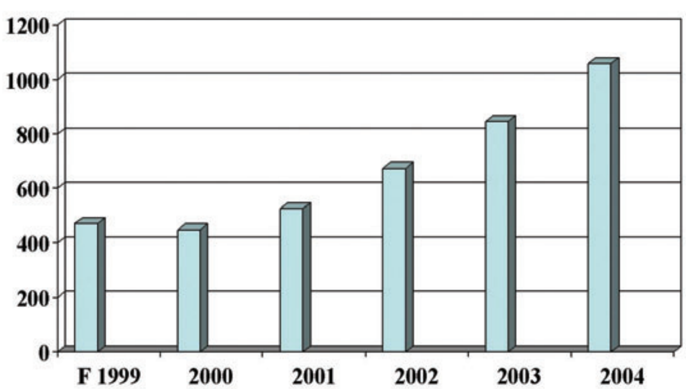


Figure 9.17—Total number of non-native fish removed by year during the fish removal study, UVR, 1999 to 2004.

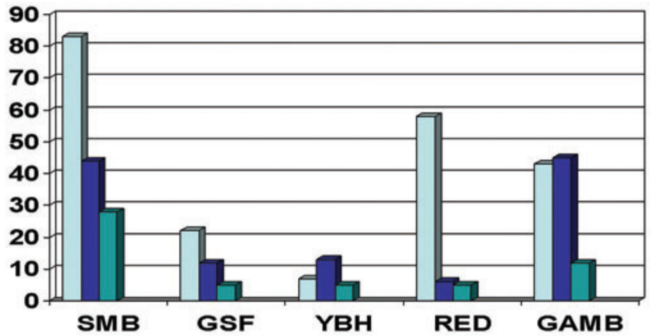


Figure 9.18—A one-time three-pass depletion on non-native fish species in the UVR in 2004 (SMB = smallmouth bass, GSF = green sunfish, YBH = yellow bullhead, RED = red shiners, and GAMB = western mosquitofish).

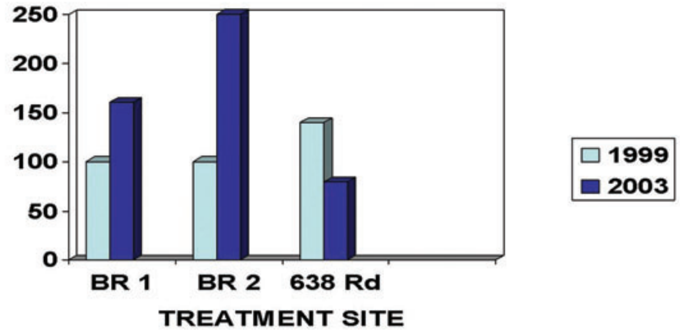


Figure 9.19—Change in total number of smallmouth bass at three treatment sites in the UVR, 1999 to 2003.

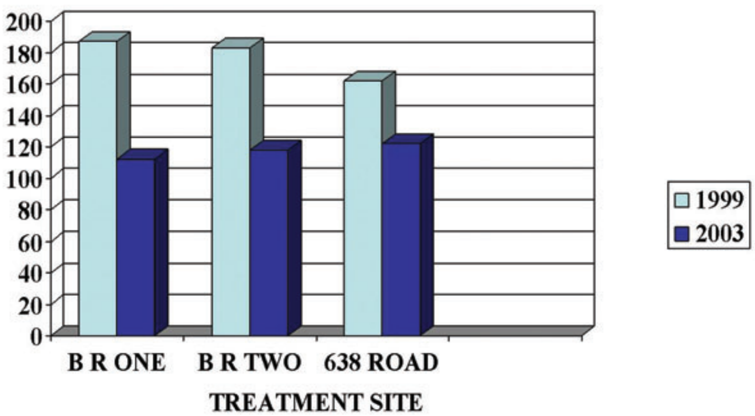


Figure 9.20—Change in mean size (mm) of smallmouth bass at Burnt Ranch and 638 Road, 1999 and 2003.

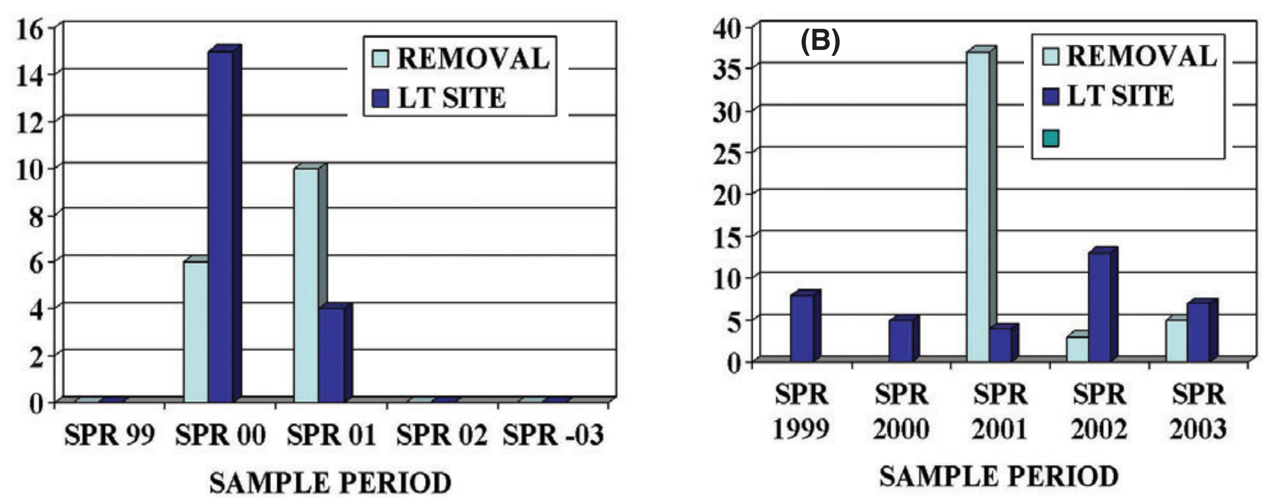


Figure 9.21—Percentage removals at removal study sites versus 638 Road long-term site, 1999 to 2003: (A) roundtail chub and, (B) sonora sucker.

Rationale for Lack of Success of Pilot Mechanical Removal

When studying natural systems, multiple, interactive factors are basic and either may be either antagonistic or synergistic. Both natural and anthropogenic activities were simultaneously occurring on the UVR and appear to have confounded and precluded achieving desired goals of the removal exercise. In summary, the four years of mechanical removal of nonnative fishes failed to invoke a consistent favorable response by the three larger-sized, longer-lived species. The conclusions here, based on removal between 1999 and 2004, are:

(1) Single pass electrofishing can remove only an average of 50% or less of the fish.

(2) Treatment twice a year was not sufficient to suppress nonnatives.

(3) Streambank and instream vegetation increase that was a result of livestock grazing cessation reduced efficiency of removal (see figs. 2.45 and 2.46).

(4) Populations of the three larger-sized native indicator species were reduced below a threshold (figs. 9.16A, 9.16B, and 9.16C) from which they could only slowly recover.

Further, these and other confounding factors potentially can, and likely did, have an influence on the outcome of this study:

(1) Livestock removal, in turn, resulted in denser riparian vegetation and increased hiding and avoidance cover during removal.

(2) Antagonistic management activities in the form of road closures and removal of sport fishing limits that reasonably reduce angling, even when anglers can take a greater number of nonnative, sport species, reduce depredation of nonnative fishes.

(3) Sustained drought and base flow regimes in absence of significant (>141.6 m^3 s^{-1} or >5,000 ft^3 s^{-1}) instantaneous peak flow events favored nonnative fishes (fig. 9.22).

No attempt was made to control the highly probable immigration of fishes into and out of treated reaches. Extensive and intensive flow events in winter 2004/2005 dramatically altered and reset in-stream and near stream habitat, and provided a window of opportunity to more effectively mechanically remove nonnative fishes from the UVR.

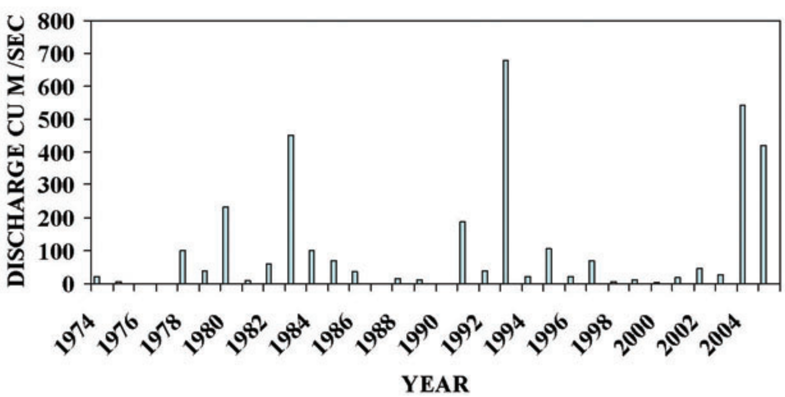


Figure 9.22—Maximum instantaneous peakflow events in m^3 sec^{-1} measured at the Paulden gauge, UVR, 1974 to 2005.

2006 to 2009 Modified, Ongoing Mechanical Removal

On September 19, 2004, the Verde River at the Paulden gage went from base flow of about 0.6 m^3 sec^{-1} (20 ft^3 sec^{-1}) to over 500 m^3 sec^{-1} (17,657 ft^3 sec^{-1}) (fig. 9.22) within hours as a result of heavy precipitation (10+ cm or 4+ in) in the upper Chino watershed (flow similar to fig. 9.8 and actually fig. 9.11). This event provided an opportunity to test the hypothesis of importance of the flood or the instantaneous peak flow component of the hydrograph on fish assemblages. More importantly, it presented a window of opportunity immediately post- flooding to further mechanically suppress the invasive component of the fish assemblages at both a larger and more intensive scale than previously possible (Rinne 2001a). Flooding reduced both the density of nonnatives and the in-stream and stream bank cover for the invasive species (e.g., smallmouth bass, green sunfish, and mosquitofish) which facilitated more effective, continued suppression of the nonnative fishes. Accordingly, with the likelihood of increased post-flood spawning and recruitment by native species in spring-summer 2005/2006, a more spatially and temporally robust experimental program of removal was launched that addressed apparent shortcomings and problems encountered in the initial 1999/2004 treatment efforts.

The on-going experimental effort started in April 2006 was comprised of eight 1.0 km (0.6 mi) contiguous units (fig. 9.23). The study area encompassed the three previously (1999 to 2004) treated long-term monitoring sites (Burnt Ranch and 638 Road) and was to be sampled two to three times a year (spring, summer, and autumn). One "frame of reference" for analyzing the effects of the mechanical removal treatment is the long term monitoring dataset at Burnt Ranch and 638 Road (figs 9.7A and 9.7 B; figs. 9.24A, 9.24B, and 9.24C).

Results of Post-Flood Treatments

The first post-flood treatment occurred from June 26 to 28, 2006, and indicated that native fishes were yet the major component of the fish assemblage (table 9.3). Desert sucker were most abundant, Sonora sucker ranked second in abundance, and roundtail chub were least abundant (table 9.3). Of the three smaller-sized

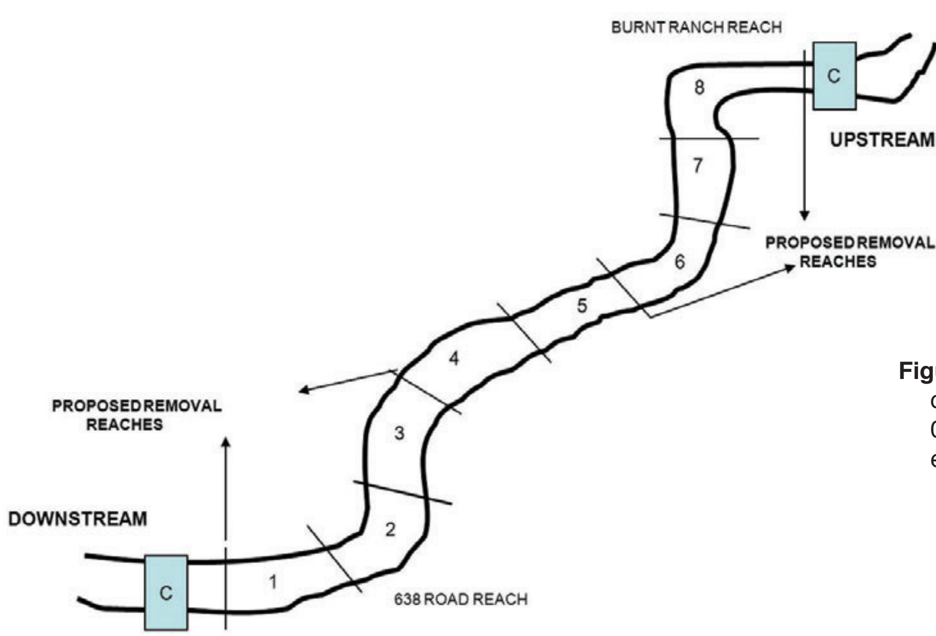


Figure 9.23—Diagrammatic illustration of positioning controls ("C") and 0.5 km (0.3 mi) sub-sample reaches established in summer 2006.

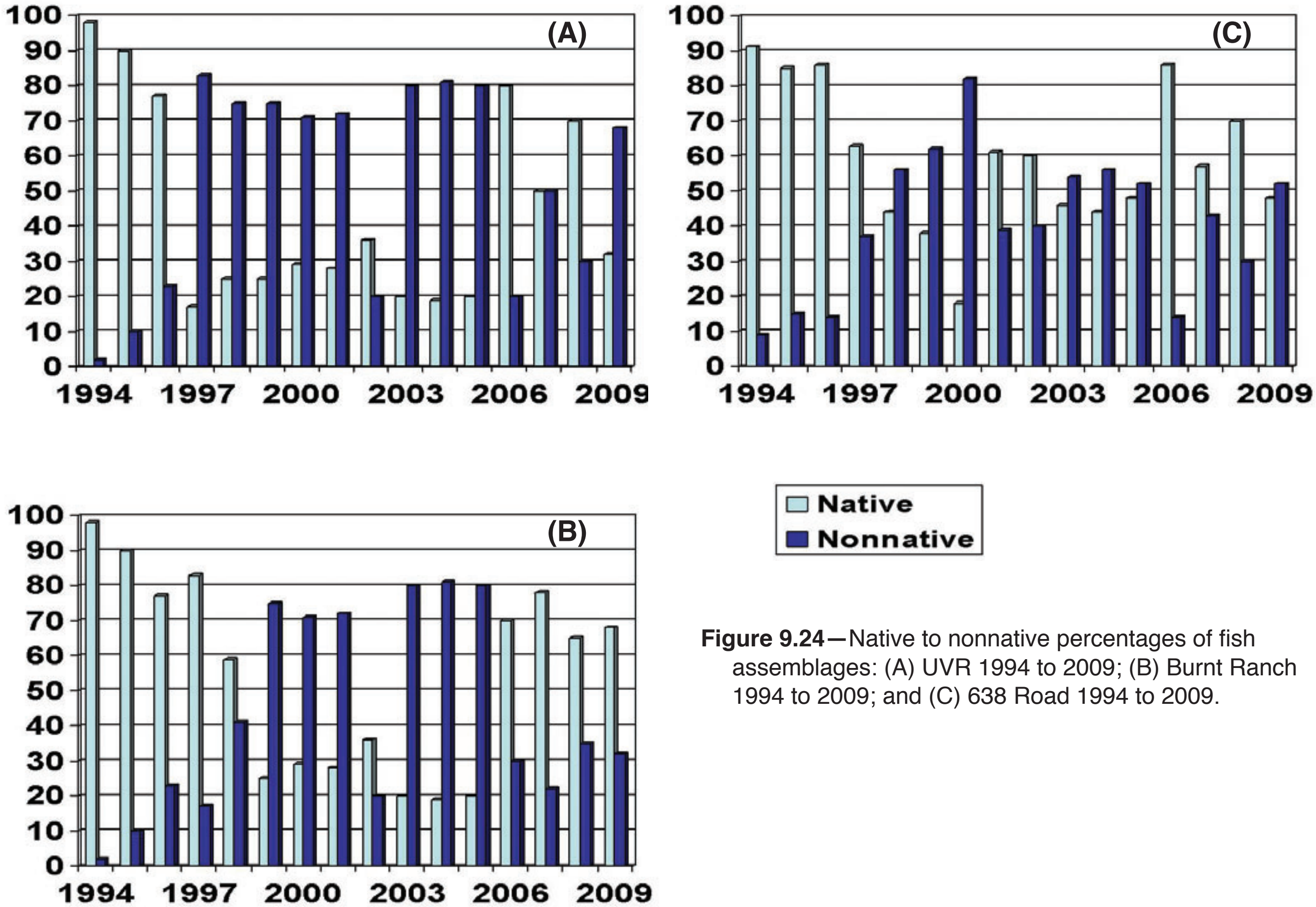


Figure 9.24—Native to nonnative percentages of fish assemblages: (A) UVR 1994 to 2009; (B) Burnt Ranch 1994 to 2009; and (C) 638 Road 1994 to 2009.

Table 9.3—Relative composition of fish species in the eight mechanical removal reaches, UVR, June 2006.

	Reach							
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Number							
Native Species								
Longfin dace	0	0	0	1	0	0	0	0
Desert sucker	409	247	302	163	215	305	333	62
Sonora sucker	450	214	159	352	308	236	294	75
Roundtail chub	23	19	19	30	21	34	19	18
Introduced Species								
Smallmouth bass	65	17	59	59	85	102	125	44
Green sunfish	1	2	6	0	0	4	0	0
Yellow bullhead	18	13	24	4	18	23	29	7
Red shiner	258	89	254	336	43	57	7	23
Fathead minnow	0	0	2	0	0	4	0	0
TOTALS	1229	612	830	946	690	811	809	229

native species, including the threatened spikedace, only a single longfin dace was encountered during the three-day effort. Additional removal treatments were performed in July 2006, April 2007, July 2007, April and June 2008, and April and June 2009.

Figures 9.25A and 9.25B depict native and nonnative components of the total fish assemblages in spring 2008 after two years of mechanical removal at the 0.5-km (0.3-mi) treatment sites in 2006 and 2007 are shown in figs. 9.25A and 9.25B). In the summer of 2008 (third year of treatment), all eight treated reaches contained 60 to 80% native individuals. By comparison, the lower control reach contained 63% nonnatives (fig. 9.26). These proportions were near the same as those at the eight treated sites and one control site in spring 2006. However, a year later, in April 2007, over half of the treated sites were trending toward a nonnative assemblage and four were still native-dominated (fig. 9.25B). By spring 2008, all treated sites were native-dominated (mostly by 70% or more; fig. 9.26). By contrast, the lower control reach was comprised of over 60% nonnative individuals. Finally, in spring 2009, the native fish component had again declined at three of the four sites in the 638 Road reach (fig. 9.27). All removal sites (R-5 to R-8) in the Burnt Ranch reach sustained native fish dominance, comprising 50 to almost 80% of the estimated total fish assemblage. Sampling two months later in June 2009 revealed a reversion of all sites to a native-dominated assemblage (fig. 9.27). However, the control site at the lower end of the 638 Road treatment reach also was estimated to have over 60% native fishes. By contrast, instituting sampling of an upstream control site (R-9) not previously sampled from 2006 to 2008, indicated over 60%

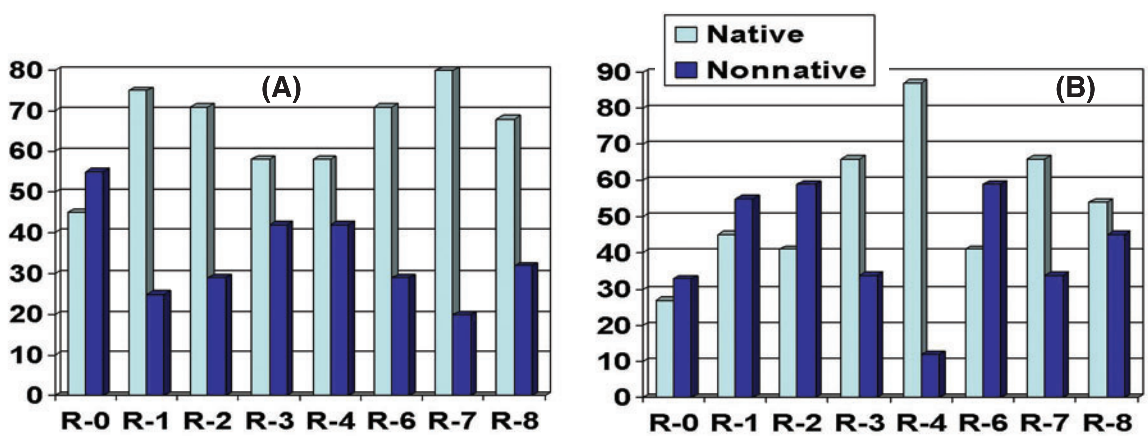


Figure 9.25—(A) Nonnative to native fish percentages at eight mechanical removal reaches (R-1 to R-8) and one control reach (R-0), UVR, 2006; and (B) native to nonnative fish percentages at eight mechanical removal reaches (R-1 to R-8) and one control reach (R-0), UVR, 2007.

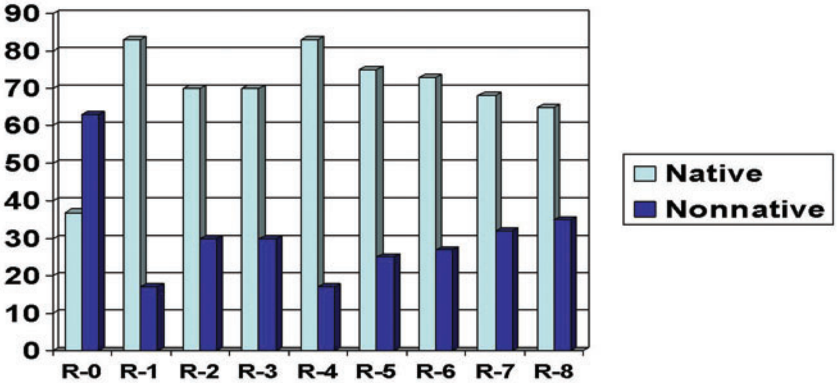


Figure 9.26—Native to nonnative fish percentages at eight mechanical removal reaches (R-1 to R-8) and one control (R-0), UVR, 2008.

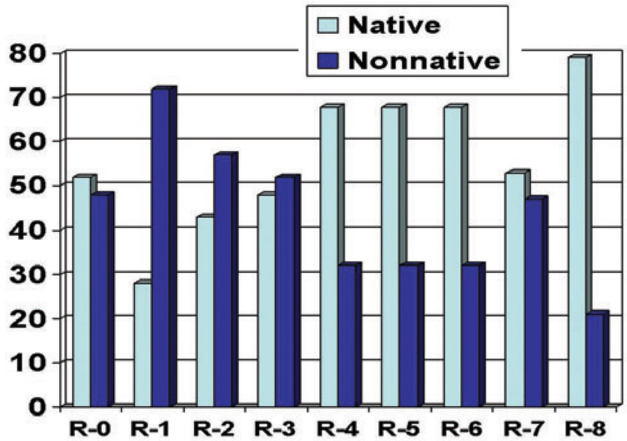


Figure 9.27—Native to nonnative fish percentages at eight mechanical removal reaches (R-1 to R-8) and one control (R-0), UVR, 2009.

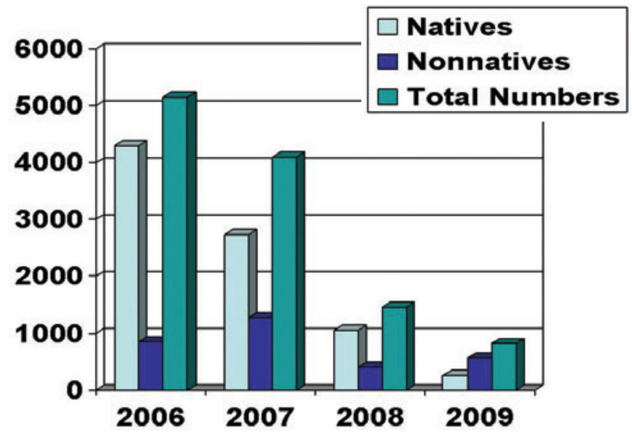


Figure 9.28—Total, native, and nonnative fish numbers in treatment sites, UVR, spring 2006 to 2009.

nonnative component. During this same time period total numbers of both native and nonnative fish declined (fig. 9.28). Of the nonnatives, red shiner numbers were depleted the most by mechanical removal (fig. 9.29).

Results of the most recent sampling in 2008 indicated that the two long-term monitoring sites (Burnt Ranch and 638 Road) within the treatment sites contained higher percentages (70 to 73%) of native fishes than did two contiguous down-steam sites, Duff Springs and Bear Siding (17 to 50%; fig. 9.30). In 2009, there was a substantial increase in nonnative species at the Duff Springs, Perkinsville, and Black Bridge sites. Nonnative species ratios at Bear Siding did not change much (fig. 9.31).

Comparative sampling at the seven long-term research/monitoring sites documented a marked, inverse decline in the native component of the fish assemblage from spring 2008 to 2009 (figs. 9.12, 9.30, and 9.31). This decline largely resulted from the continuing declines of the native component at those sites dominated by natives in spring 2008 and the reversal of dominance at the 638 Road, Perkinsville

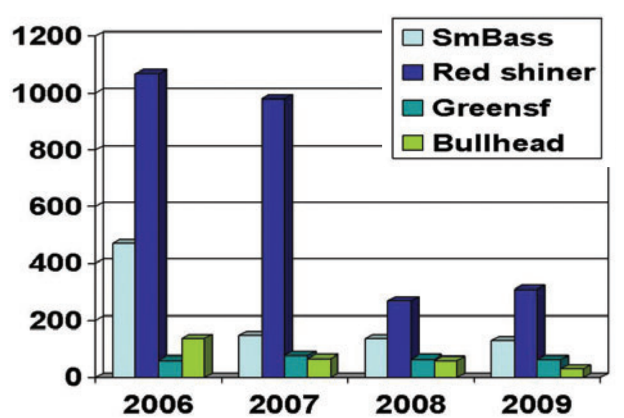


Figure 9.29—Temporal changes in nonnative fish species numbers in mechanical removal sites, UVR, 2006 to 2009.

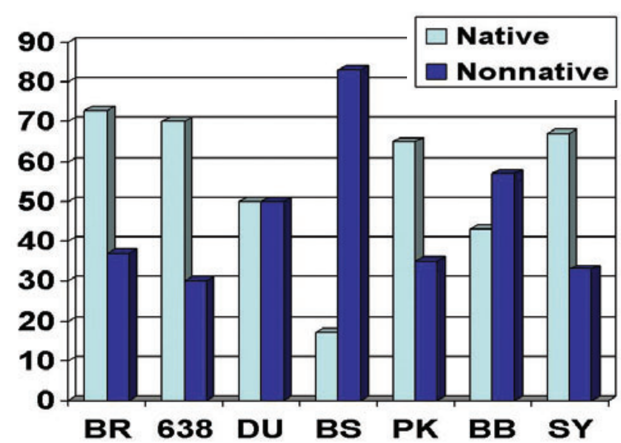


Figure 9.30—Comparative native to nonnative fish percentages at seven long-term sampling sites, UVR, spring 2008. Sites are left to right Burnt Ranch (BR), 638 Road (638), Duff Springs (DU), Bear Siding (BS), Perkinsville (PK), Black Bridge (BB), and Sycamore Canyon (SY).

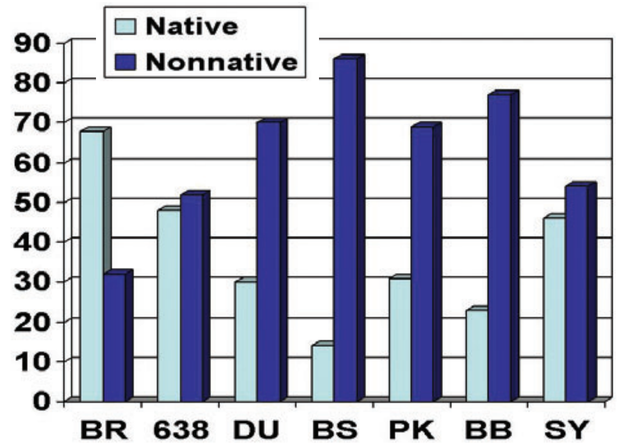


Figure 9.31—Comparative native to nonnative fish percentages at seven long-term sampling sites, UVR, spring 2009. Sites are left to right Burnt Ranch (BR), 638 Road (638), Duff Springs (DU), Bear Siding (BS), Perkinsville (PK), Black Bridge (BB), and Sycamore Canyon (SY).

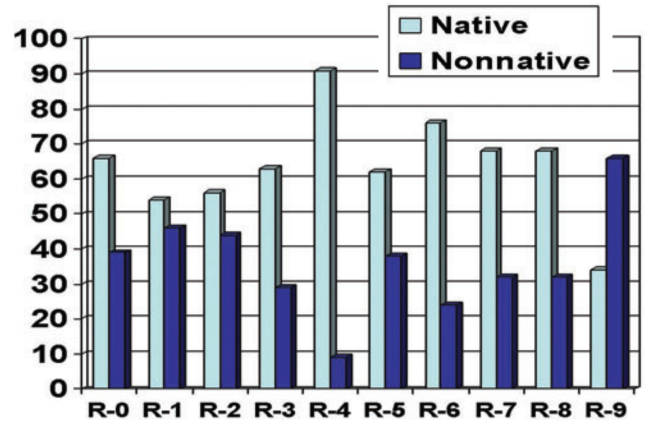


Figure 9.32—Native to nonnative fish percentages at eight mechanical removal reaches (R-1 to R-8) and two control reaches (R-0 and R-9) at Burnt Ranch, UVR, June 2009.

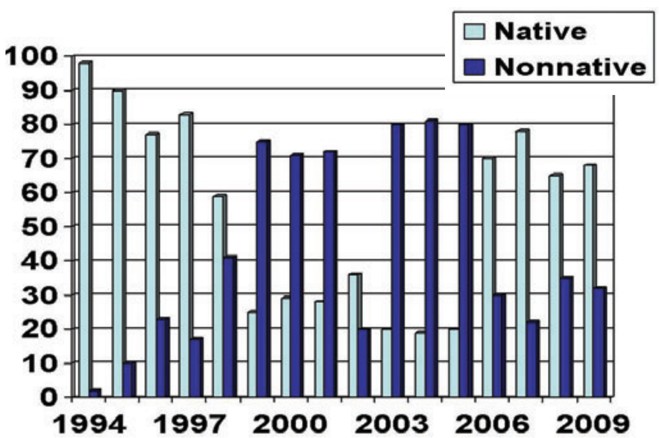


Figure 9.33—Native to nonnative percentages of fish assemblages, Burnt Ranch, UVR, 1994-2009.

and Sycamore sites (fig. 9.31). Sampling at the seven long-term sites (1994 to 2004) and at the Burnt Ranch and 638 Road sites prior to mechanical removal treatments provide, in part, a frame of reference (figs. 9.12 and 9.24A).

In general, following the 1992 to 1993 low recurrence, 75-year flood events (fig. 9.22), the proportion of native fish species in the total fish assemblage was sustained for two to three years (fig. 9.12). It should be pointed out that a smaller, five- to seven-year event occurred in March 1995 (fig. 9.22), and by 1997 the nonnative component of the total fish assemblage became dominant and remained so even into spring 2005 following flooding in winter of 2004/2005. Instantaneous peak flows in these recent flood events immediately prior to instituting the modified mechanical treatment in 2006 were somewhat lower than those that occurred in winter of 1992/1993 (fig. 9.22, Rinne 2005).

Similar to the initial years of long-term monitoring from 1994 to 1997, native fishes again became dominant (80% of total assemblage) by spring 2006 with increased recruitment of the three larger-size longer-lived suckers and chubs the previous summer (fig. 9.28). However, these proportions immediately dropped considerably by the spring 2007 sampling. An elevated winter flow event in February

2008 produced peakflows from 70.8 m^3 sec^{-1} (2,500 ft^3 sec^{-1}) at the Paulden gauge (fig. 9.22) to an estimated 169.9 m^3 sec^{-1} (6,000 ft^3 sec^{-1}) at the Sycamore Canyon site. These flows stimulated increased spawning and recruitment and resulted in natives again dominating when all sites were averaged, despite reduced numbers (fig. 9.28).

In summary, it appears that peak flow events dramatically impact the relative proportions of native and nonnative fishes in the total fish assemblage (Rinne 2005). However, two of the seven long-term sites—Burnt Ranch (treatment site 7) and 638 Road (treatment site 3)—sustained mechanical treatment in 2006. These two treatment reaches and the other five combined with the smaller peakflow events in late winter 2008 have contributed to the native component being sustained in the UVR from 2008 to 2009 (figs. 9.30 and 9.31).

Spring 2009 sampling and removal of nonnative species revealed: (1) nonnatives dominated the fish assemblages in three of four sites in the 638 Road reach and conversely; (2) natives dominated the fish assemblage at all sites in the Burnt Ranch reach (figs. 9.32 and 9.33). This inverse relationship very likely results from the lack of treatment at sites in the 638 Road reach in summer 2008. In addition, there was some channel disturbance at an estimated half of site 3 because of the installation of an underground gas pipeline. Removal efforts in June 2009 demonstrated both the impact of the absence of summer 2008 removal and the positive effect of the two months prior treatment in April 2009.

Mechanical removal efforts that were re-initiated in spring/summer 2006 and continued through June 2009 that employed a modified approach addressing shortcomings of the 1999 to 2003 pilot efforts (Rinne 2001b, 2006) appear to have a positive effect on the native fishes (figs. 9.26 and 9.27). It should be pointed out that only the two native suckers and the one native chub were represented in the samples. The smaller-sized, short-lived daces—longfin (*Agosia chysogaster*), speckled (*Rhinichthys ocsulus*) and threatened spikedace (*Meda fulgida*)—have not been represented in samples.

The initial removal efforts were started a year after the winter 2004/2005 flood events and all eight removal reaches revealed a predominance of natives (figs. 9.34 to 9.38). Native species dominated the fish assemblages in 2006 and 2008. However, nonnatives dominated at three to four of the eight removal sites in both 2007 and 2009. Nonnatives also dominated the fish assemblages at the control site (R-0) from 2006 to 2008. Overall, the native component in spring 2009 averaged 73% at sites where they were predominant as a result of flooding the previous year. Considering all sites, native dominance went from 58 to 89% in 2006 to 53 to 90% in 2009 (figs. 9.34 to 9.38). Nonnative fishes varied from 33 to 63% at control sites for the same period.

Total fish numbers captured during removal continued to decline as has occurred previously during drought periods at long-term monitoring sites (1997 to 2003, Rinne 2005; fig. 9.28). Total numbers fell below 1000 individuals in spring 2009, or less than 25% of the total numbers in 2006. Of the nonnative fishes, red shiner (*Cyprinella lutrensis*) continue to dominate (60%) (fig. 9.29). However, their numbers have declined to a third of those in 2006. It is obvious from figs. 9.28 and 9.29 that if red shiners were removed from the nonnative totals, the native compared to nonnative percentages presented above would change dramatically in favor of the native component.

Similar to the time period of 1994 to 2004, total fish numbers in the UVR at the eight mechanical treatment removal sites dropped 80% from 2006 to 2008 (fig. 9.28). The decline is largely reflective of the drop in native fish numbers from over 4,000 individuals captured in spring 2006 to 1,200 in 2008. By contrast,

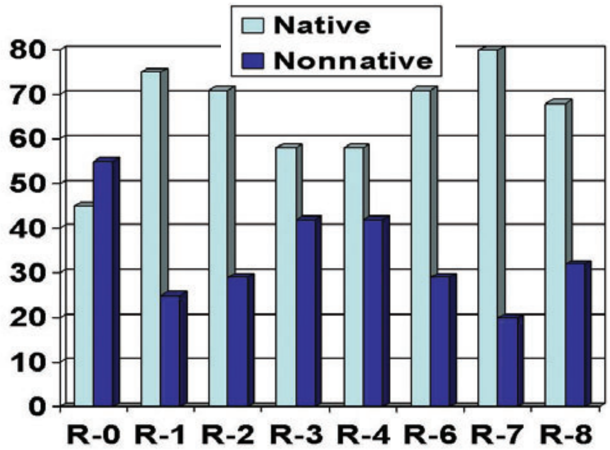


Figure 9.34—Native to nonnative percentages of fish at seven mechanical removal reaches (R-1 to R-8) and one control reach (R-0), UVR, 2006. (R-5 was not sampled).

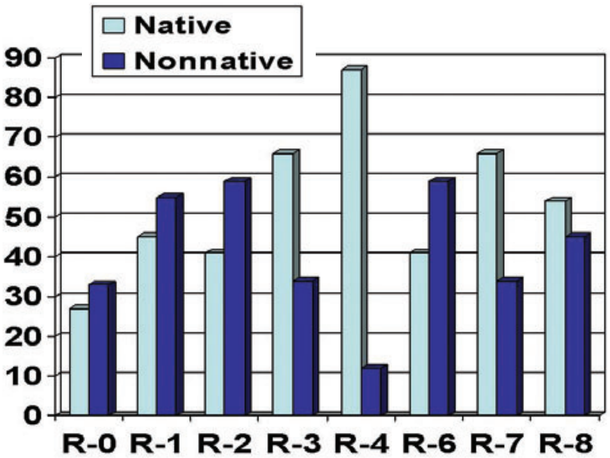


Figure 9.35—Native to nonnative percentages of fish at seven mechanical removal reaches (R-1 to R-8) and one control reach (R-0), UVR, 2007. (R-5 was not sampled).

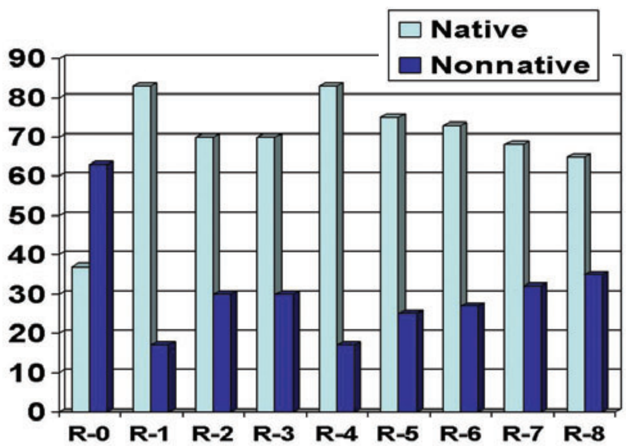


Figure 9.36—Native to nonnative percentages of fish at eight mechanical removal reaches (R-1 to R-8) and one control reach (R-0), UVR, 2008.

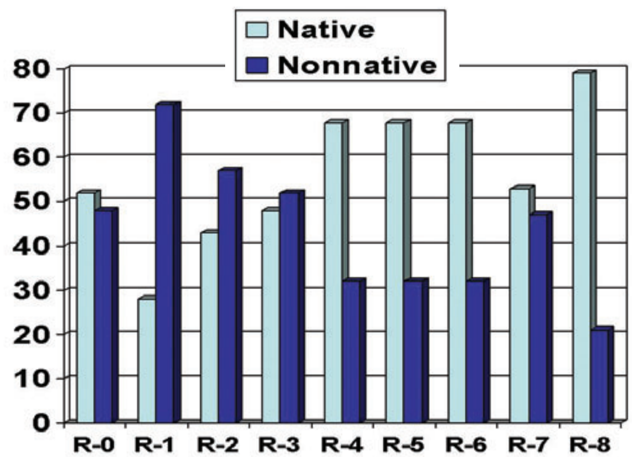


Figure 9.37—Native to nonnative percentages of fish at eight mechanical removal reaches (R-1 to R-8) and one control reach (R-0), UVR, April 2009.

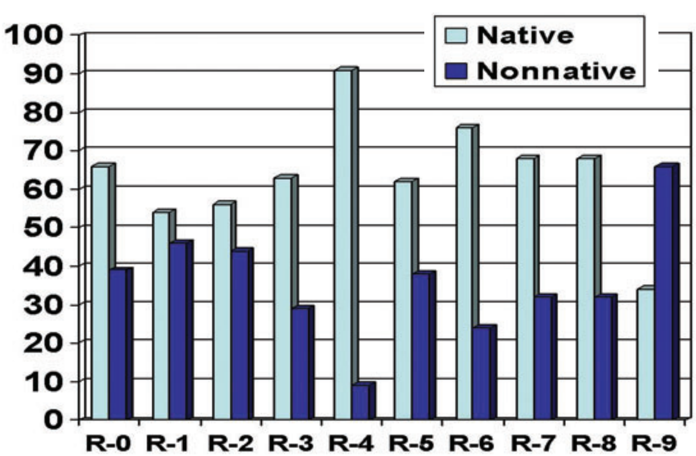


Figure 9.38—Native to nonnative percentages of fish at eight mechanical removal reaches (R-1 to R-8) and two control reaches (R-0 and R-9), UVR, June 2009.

nonnative species in removal sites were lowest (850) in 2006, increased to 1,270 in 2007 and then plummeted to around 400 in spring 2008 (fig. 9.28). Of the nonnative species, red shiner plummeted most (-75%) from 2006 to 2008, green sunfish dropped 74%, smallmouth bass 71% and yellow bullhead basically remained constant from year to year 59, 77, and 59% with no apparent response to mechanical removal (fig. 9.29).

Summary and Conclusions

In summary, native/nonnative ratios in the mechanically treated reaches are very similar to those resulting from large flow events. Instantaneous peak flows in September 2004 and again in early 2005 were 50% of those in 1992/1993 and produced similar results in ratios in native and nonnative fish assemblages. However, the drop within two years to a 50/50 ratio in spring 2007 and again in spring 2009 at the long term sites suggest that the fish assemblage was again rapidly returning to that dominated by nonnative fish species. Only with additional monitoring at the long-term sites and continual removal in all three seasons—spring (April), summer (June) and autumn (October)—and in absence of significant flooding will it be more to say that mechanical removal has a high probability of benefitting native fish sustainability, albeit only that of the larger sized, longer-lived suckers and the roundtail chub.

Data on fish assemblages over the past 15 years at long-term sites and fish assemblage response to mechanical removal and flow regimes indicate but do not confirm that mechanical removal is an effective tool to at least sustain the larger-sized, longer-lived native fishes between and in combination with instantaneous flow events. Red shiner, although numbers have been reduced three-fold since inception of treatment in 2006, appear to be the most difficult nonnative species to reduce to the levels of the other three larger-sized nonnatives (i.e., 50 to 100 in a total sample period at all eight treatment sites).

Accordingly, it is strongly recommended that both the long-term monitoring be continued for several years along with mechanical removal to determine if over the next few years. Perhaps, in absence of significant, influencing flow events, native fishes may dominate the fish assemblage again. Efforts should be made to assure that a third removal in autumn is effected at both the 638 Road and Burnt Ranch reaches. The latter has sustained only the spring treatment in 2007 and 2008 because of a lack of resources.

Hydrographs, Geomorphology, and Fish Assemblages

The current working hypothesis is: "Flooding is very important for sustaining native fish assemblages where nonnative fishes are present in Southwest rivers and streams." Minckley and Meffe (1987) first suggested this hypothesis for Southwest streams and Stefferud and Rinne (1995), Brouder (2001), Rinne and Stefferud (1997), and Rinne (2005) corroborated and advanced this hypothesis for the UVR. Minckley and Meffe (1987) contrasted differences in flood hydrology between Southwest arid lands and those of lowland mesic regions of the central and eastern United States. They reported that most of the annual water yield in Southwest systems was produced during high discharges in brief periods of time, whereas low discharges produced a far greater proportion of total yield from mesic systems. They suggested the differential effects of these patterns on fishes were significant to the native/nonnative mix of species now present in the Southwest. The authors concluded that native Southwest fishes were better adapted to withstand the effects of large floods than nonnative fishes. During severe floods, invasive fish species were either displaced or suffered mortality, whereas native species maintained position in or adjacent to mainstem channel habitats, persisted in micro-refuges, and rapidly re-colonized post-flood.

Building upon the Minckley and Meffe (1987) hypothesis, Rinne (2005) furthered this concept in the UVR. Rinne and Miller (2006) in a comparison of the Verde and Gila Rivers, documented that flow regimes are very basic to native fish sustainability and may have an overriding influence relative to human-induced activities, including fisheries and riparian management. Most recently, Propst and others (2008) further confirmed this hypothesis using 20 years of data at sites complementing those sampled by RMRS scientists since 1999 (Rinne and others 2005a, 2005c). The UVR is an example of a flood-dependent, disturbance-dependent ecosystem with a mixed native and nonnative fish assemblage.

In the UVR and other streams and rivers in the western United States, alteration of the natural hydrographs through natural climatic factors and human-induced impacts such as dams, diversions, pumping, and land use, and introduction of nonnative species of fish appear to interact to affect stability and integrity of native fish populations (Minckley and Deacon 1991). In all but a few streams in Arizona and the Southwest, these factors have dramatically reduced or eliminated native fish species and modified fish assemblage structure and dynamics, often within a few years after the action. Streams with purely native fish assemblages, or where the native component of the assemblage remains dominant, are a rarity in the region. The mechanisms that sustain native species in the presence of nonnative species are not well understood but are thought to be related, in part, to natural flow regimes characterized by extremes of drought and base flows and peak flow events and flooding. These climatic and hydrologic conditions characterize streams in the Southwest (Minckley and Meffe 1987), including the UVR (Rinne and Stefferud 1997; Brouder 2001). How flow regimes interact with the presence of competitive/predatory nonnative fishes is not well defined and merits further research. Clarification of this question is important at this time because of the ever increasing demand for water for a growing populace and the generally imperiled status of Arizona's native fish fauna.

Although a number of studies on fishes and their habitats have been undertaken in the Verde River as a whole, not one has investigated the long-term interrelationships of the native/nonnative fish assemblages relative to flood disturbance events and to each other. The relationship of base and instantaneous peak (flood) flows to sustainability of native fishes in the UVR is a prerequisite for inputs for water management plans for the system. The headwater Big Chino Valley aquifer is a major source of baseflow for the Verde River above Sycamore Creek; and there are proposals to extract its water to supply current municipal needs and future development in the watershed. Depletion of discharge from the aquifer could potentially alter base flow in the river and will dramatically and chronically affect sustainability of native fishes (Rinne 2001a, 2001b, 2001c, 2001d). However, the unresolved question of their effects on the native fish assemblage has deferred approval by resource agencies. Continued growth in the Verde River watershed will probably increase pressure for water development and diversion from the UVR. Resource management agencies must have reliable data in time and space to chart a course of action that will sustain native fishes in the UVR.

Relationships of Hydrographs and Fish in the UVR

Data from previous studies in the UVR indicated that following almost a decade (1984 to 1992) of drought and low flows (fig. 9.13), nonnatives only comprised 12% of the total fish assemblage (Marty Jackle, USDI Bureau of Reclamation, pers. comm.; USDI Fish and Wildlife Service 1989). Fishes were not sampled after the 1992/1993 flood events until spring 1994. Notwithstanding, following the massive flooding in winter 1992/1993, nonnatives were yet reduced in 1994 to only 4% of the total fish community. Therefore, Minckley and Meffe's (1987) hypothesis on the mechanism of interactions and control of the native and nonnative fish assemblages in the Southwest was partially correct. Not only the nonnative fishes are impacted by flooding, but the native fish are affected as well. However, immediately post-flood, native fish rebound rapidly; nonnatives also increase, but more slowly, and some ratio of the two is established. The ratio appears, in part, to be dependent on the subsequent annual hydrographs and relative native/nonnative fish response. For the first three years post-flood this ratio was consistently 85:15 (fig. 9.13), native to nonnative species. However, the fact that nonnative fish comprised only 12% of the total fish community in the late 1980s (see the previous section) after a four-year period of low flow suggests other mechanisms may influence the native/nonnative ratio in the UVR.

Based on the data from the Verde River following 75- (1992/1993) and 7-year (1995) flood events (fig. 9.13), it appears that floods of these magnitudes negatively impact and dramatically reduce both native and nonnative fish communities. The seven-year event that occurred in early spring (March) 1995 reduced the native fishes in the UVR by 86% and the nonnative community by 89% (tables 9.1 and 9.2). However, the native/nonnative fish assemblage composition ratio remained almost identical between years, respectively (82:18 and 85:15). Further, by spring 1996, the native fish component had increased, on average, by over 700%. In contrast, invasive fishes, despite marked increases in red shiner and smallmouth bass, increased by an average of only 71%.

Green sunfish was the only nonnative species to increase in absolute numbers in the UVR fish assemblage between 1994 and 1995 (5 to 29 individuals) (Rinne and Miller 2006), suggesting that it was a result of a differential magnitude of flooding over the entire study area. The flood in 1995, in contrast to that in 1993, affected mostly the reach of river downstream from Sycamore Creek that was not recorded by the Paulden gauge. The majority (26 of 29 individuals) of the increase in green sunfish numbers occurred in the upper reaches of the river (Sites 2 through 5). The peak discharge at these sites, as indicated by the Paulden gauge, suggests that flows were likely below the threshold to negatively impact this species. Similarly, the input of fathead minnow that originated in watershed stock tanks as a result of increased precipitation and runoff in spring 1994 may have been the reason for the appearance of this species immediately post-flood in the spring 1993 sample at Burnt Ranch (Sponholtz and others 1998). By autumn 1993, fatheads had disappeared and the native fish component reached 96% of the fish community.

Precipitation and stream hydrographs are stochastic and unpredictable in the Southwest and floods of significance (i.e., >400 $m^3 s^{-1}$ or 14,125.6 $ft^3 s^{-1}$) in the UVR appear to occur randomly. Cycles of flood and drought, however, are evident, and ensuing years of low flows were more probable following the 1993 and 1995 floods. Further, based on historic hydrographs, the probability for a period of low flows also increased after 1995.

Typical of desert streams and rivers, flooding can be significant in the Verde River. Larger floods, estimated to have recurrence intervals of 50 to 60 years (USDI Geological Survey 1992), appear to "reset" the channel morphology and aquatic habitats by eroding stream banks and restructuring and invigorating substrate materials (Rinne and Stefferud 1997; Rinne and Miller 2008). After each flood, total abundance of fish was reduced and the population structure of the various species was altered. Based on data collected after winter 1993 and 1995 flood events (both 75-year and 7-year return intervals), the floods reduced both native and nonnative species. Nevertheless, natives yet comprised 85% or more of the fish assemblage. Following these events, the natives rebounded quickly in numbers in response to the restructuring or invigorating of substrate materials (Mueller 1984; Rinne and Stefferud 1997; Rinne and Miller 2008). Spawning success and recruitment contribute to the quick re-establishment of native fish populations' biological and geo-morphological reference baseline. That is, riparian vegetation succession is set back to a base level, channel morphology is modified, and stream-bed materials are sorted and re-arranged.

Although spawning success and recruitment after floods probably contribute to the quick re-establishment of native fish populations, nonnative species begin to increase at the same time (table 9.2). Nonnative fish lowered numbers also would favor a rapid increase in native fish numbers because of the lack of competition and more probably predation (Minckley 1983; Rinne 1995b; Rinne and Alexander 1995). Further, recovery rates of nonnative fish populations were variable. Red shiner was markedly reduced by the seven-year flood event, common carp were less reduced, and smallmouth bass sustained their numbers.

As previously discussed, long-term (>five years) studies of native fish populations in low elevation desert rivers of similar or larger size are non-existent. Several long-term studies in smaller streams are ongoing: Aravaipa Creek, Graham and Pinal Counties, Arizona, is the subject of a 25-year record of fish community dynamics (W. L. Minckley, pers. comm.), and there are seven-year records of native fishes and habitat associations for several streams in the upper San Francisco and Gila River drainages in New Mexico (D. L. Propst pers. comm.; Rinne and others 2005b). Whereas these existing datasets may be useful for comparing effects of floods and droughts on native species, none of the studies are in a stream reach that sustains a significant nonnative fish component. Thus, the Verde River research and monitoring effort is unique in the Southwest and offers an excellent opportunity to test and refine current hypotheses relative to native/nonnative fish interactions, as influenced by drought and flooding over the long term.

Based on the data in the UVR (Rinne 2005) and from the upper Gila (Rinne and Miller 2006; Propst and others 2008), the native fishes of Southwest desert rivers and streams appear to be disturbance species. Disturbances can come in both natural and anthropogenic forms. Disturbance is defined here as a "specific, significant, and variable spatial/temporal event that dramatically alters structure and function of both physical and biological components of an ecosystem." Periodic instantaneous peak flow events in Southwest aquatic ecosystems certainly qualify as natural disturbance events. Further, as suggested above, the native fishes very likely can be considered "disturbance species" that directly and markedly are influenced by such periodic disturbance events to sustain populations through time. Too often, disturbance is considered to be anthropogenic or human-induced rather than natural. Major dams, diversions, and groundwater mining, for example, qualify as significant sustained disturbance events (Rinne and Minckley 1991). However, other less marked impacts imposed by intrinsic and extrinsic human-induced uses and impacts such as riparian/stream corridor and landscape or watershed uses are likely given more significance than they merit. Rinne and Miller (2008) suggested that overriding, natural hydrologic/geomorphic influences are likely more important in terms of creating habitat essential for sustaining fishes assemblages than is simple increase in riparian vegetation that may result from riparian restoration activities such as livestock grazing removal.

Verde River Hydrographs

A study of fish assemblages of the UVR relative to abiotic and biotic factors was conducted in 1997/1998 by RMRS personnel with Arizona Heritage Foundation funding (Rinne and others 1998). The primary objective of the research was to determine the relative influence of the hydrograph and introduced fishes in delimiting the relative native to nonnative composition of the total fish community. The results of the three years of study (Rinne and Stefferud 1997) showed that native fishes respond positively to flooding. Further, Rinne and others (1998) reported that the hydrograph and the lack of flooding over the entire Verde River have enhanced nonnative over native fishes (figs. 9.12 and 9.17). By spring 1998, after three years (1996 to 1998) of no significant (i.e., greater than bankfull) flow events, the relative abundance of native fishes (>70%) was reduced to the extent that nonnative fishes comprised this same relative percentage of the total fish community. Rinne and others (1998) concluded that flooding was essential for sustaining a native fish fauna in a river system such as the UVR with nonnative fishes present.

The threatened spikedace populations paralleled the overall population trend of native fishes in the UVR (Rinne and others 1998). The species was common in samples at four of the seven established sampling sites in the spring of 1994, rare by the spring of 1996, and absent in the spring of 1997 (fig. 9.15A). Therefore, flow regimes appear to be important to essential for sustaining not only native fishes in general but specifically populations of spikedace, especially in the presence of nonnative fishes.

Rinne and Stefferud (1997) concluded after three years of sampling that the river hydrograph was more influential than nonnative fishes for sustaining a native fish component in the UVR. Notwithstanding, it appears that the interaction of the two factors combine to legislate the relative native to nonnative composition of the overall fish community. The lack of any significant flooding and sustained base flow since 1996 resulted in nonnative fishes increasing significantly to comprise the majority (>70%) of the fish community (figs. 9.12 and 9.17). Accordingly, in the absence of significant flow events, nonnative fish species quickly and markedly became dominant. Only with the advent of flooding of at least the 1995 level (five+ year recurrence) can this hypothesized relationship of hydrograph and nonnative fish abundance be more completely defined. This relationship needs to be further research in the upper Verde and Gila rivers.

In summary, if RMRS studies had been conducted only during 1994 to 1996, flooding could be readily defended as the controlling factor in delimiting spikedace populations in the UVR. By contrast, studies during only 1997 to 1999 could lead to the conclusion that nonnative fishes are the controlling factor in delimiting spikedace numbers in the UVR. These data emphasize the importance of continual monitoring up to and following the next flood event (five-year recurrence or greater).

Aquatic Macrohabitats and Native Fishes

Methods

Analysis and description of aquatic macrohabitats in the UVR were delineated by Rinne and Stefferud (1996) and Rinne (2003b). These habitats were sampled for fishes in sequence, progressing in an upstream direction. Standard sampling methods were used including backpack DC electro fishing units, seines and dip and nets to sample macrohabitats. All fish captured within a macro-habitat were identified to species and counted. Total length of all specimens greater than 150 mm (about 6 in) was obtained. A sub-sample of individuals greater than 150 mm (6 in) were measured and weighed to define population demographics. Once measured, all fish except for periodic voucher specimens of nonnatives were returned alive to the stream.

Initially, each macrohabitat was numbered in sequence and subjectively classified based on ongoing fish-habitat studies in the upper Gila River, New Mexico, as lateral scour, mid-channel and backwater pools (POOL); glides (GLDs); runs (RUNs); glide-runs (GRUNs); low gradient riffles (LGRs); high gradient riffles (HGRs); and edge waters (Rinne and Stefferud 1995; Sponholtz and Rinne 1997) Length, width, depth, velocity, and substrate parameters for each macrohabitat were estimated and recorded. Gradients were measured with a laser level, substrates were measured using methodology outlined in Bevenger and King (1995), and velocity was measured with a direct readout digital current meter.

Sampling was designed to expeditiously gather data that would describe fish assemblages and characterize the habitat. With these data, it was possible to initially delineate relative, quantitative macrohabitats (mean length, width, depth, velocity, and substrate). However, refining the definition of aquatic macrohabitats was considered necessary. Accordingly, increased sampling intensity and rigorous statistical analyses resulted in greater potential accuracy in classifying aquatic macrohabitats in the UVR (Sponholtz and Rinne 1997). Further refinement of fish-habitat relationships needs to be researched at established study sites. Changes in habitat at study sites can conceivably be defined and then compared to fish assemblage dynamics.

Initially, aquatic habitats were visually and subjectively defined for sampling purposes (Stefferud and Rinne 1995). Aquatic macrohabitats in the UVR were more objectively defined based on physical measurement of gradient, velocity, depth, and substrate composition by Rinne and Stefferud (1996). Measurements were then statistically summarized by previous subjective classifications. Gradients successively paralleled subjective, lotic habitat classifications: glides ≤0.3%, runs ≥0.3 to 5%, low-gradient riffles 0.6 to 1%, and high-gradient riffles ≥1% (Rinne and Stefferud 1996). Velocities in pools displayed a high degree of variability (0 to 70 cm s^{-1} or 0 to 27.6 in s^{-1}), and velocity averaged the same as glide habitats suggesting shortcomings in subjective classifications. Pool classification difficulties are attributable to the many (>12) subjective types of pools (side channel, mid-channel, and scour pools; Stefferud and Rinne 1995) that were grouped within the pool category. Mean velocity increased as one moved up the lotic scale from glides and runs up through high-gradient riffle habitats (Rinne and Stefferud 1996; table 9.4, fig. 9.39). Similarly, substrate type changed from a greater percentage of small material (sand-gravel) in glides and runs in comparison to that in low- and high-gradient riffles (Rinne and Stefferud 1996).

Table 9.4—Substrate composition of macrohabitats as determined by pebble counts in the Gila (1999) and Verde (1996) rivers.

Habitat	Fines	Gravel	Pebble	Cobble	Boulder
	%	%	%	%	%
Gila River					
POOL	37	32	20	9	2
GRUN	27	51	15	6	1
LGR	10	48	28	12	2
HGR	6	35	37	20	2
Verde River					
GLIDE	30	55	10	5	0
RUN	25	30	25	20	0
LGR	20	30	25	25	0
HGR	0	15	30	50	5

Increased macrohabitat sampling was established in 1996 sampling by placing sample transects every 3 m (9.8 ft) within a habitat type (Sponholtz and Rinne 1997). Previously (1994/1995), habitat parameters were measured at only three transects/aquatic macro-habitat, irrespective of length of habitat type. Normally, four to six transects resulted from this more detailed 1996 sampling. As a result, data points for depth and velocity increased three-fold in terms of frequency. In addition, laser-generated gradients were measured at all habitats after initial results were recorded at only 14 random habitats in 1995 (Rinne and Stefferud 1996; fig. 9.7). Qualitative habitat descriptions in spring 1996 were used to delineate habitat type based on selected descriptors (Sponholtz and Rinne 1997). Pebble counts (Bevenger and King 1995) were performed in all habitats, with 30 "hits" used to estimate substrate type. Rigorous statistical analyses employing analysis of variance (ANOVA) and Classification and Regression Tree (CART) were performed on the data.

The ANOVA indicated higher variability in estimates of habitats among transects than among individual points; therefore, data were averaged for transects prior to statistics being calculated. Results of analysis suggested that depth and velocity were not sensitive enough to detect differences between either the high- and low-gradient riffle types or between run and glide habitats. Gradient was the only variable that most consistently (71% of the time) and clearly defined aquatic macro-habitat type. Further, when used with depth and velocity, gradient became an even more powerful tool, providing greater than 80% correct classification of aquatic macro-habitat types.

Aquatic Macrohabitat Comparisons in the Gila and Verde Rivers

The same fish and habitat sampling protocols were initiated on the upper Gila River in southwestern New Mexico. These waters have basically the same fish assemblage as that of the UVR. Therefore, comparisons of fish assemblage and habitat changes can be made.

Estimated velocities of 187 aquatic macrohabitats in the upper Gila River are shown in fig. 9.39. The mean velocity in POOLs was 20 cm s^{-1} (7.9 in s^{-1}) compared to 67 cm s^{-1} (26.4 in s^{-1}) for HGRs. GRUNs and LGRs displayed intermediate mean velocities of 38 to 52 cm s^{-1} (15 to 20.5 in s^{-1}). The mean depths of these same habitats were inverse to velocities, ranging from about 60 cm (23.6 in) for POOLs to 20 cm (7.9 in) for HGRs.

Gradients for these same habitats in the upper Gila were least for POOLs (mean = 0.3%), were greatest for HGRs (mean 2.22%; fig. 9.40), and were parallel to

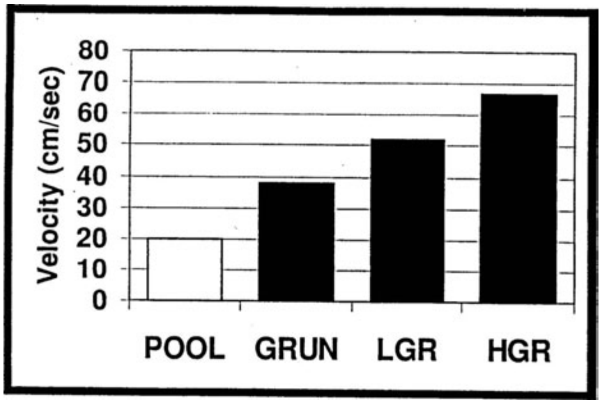


Figure 9.39—Streamflow velocities in cm sec^{-1} of habitats, Upper Gila River.

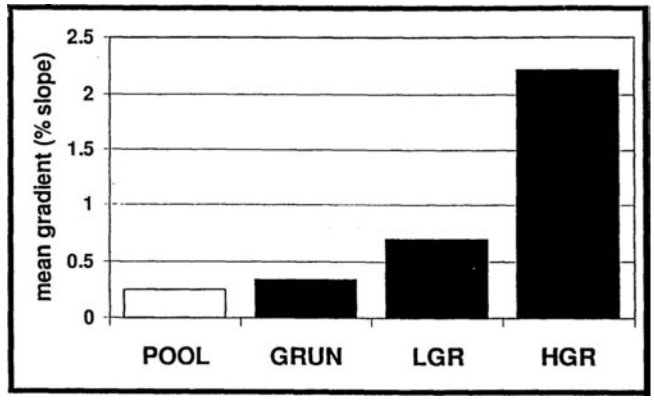


Figure 9.40—Slopes of POOL, GRUN, LGR, and HGR habitats in the Upper Gila River.

velocity and inverse to depth. Because gradients were suggested by Sponholtz and Rinne (1997) to be the best descriptors of aquatic habitat types in the UVR, Arizona, these data were analyzed for the upper Gila (fig. 9.40). Gradients of 49 HGR habitats ranged from 0.75 to 7% slope and averaged 2.22%. About 35% of all HGRs were greater than 2% slope, 18% were greater than 3% slope, and more than half (57%) were 1 to 2% slope. These values were very similar to gradients delineated for HGR in the UVR (Rinne and Stefferud 1996). Half of the HGR gradients in the UVR were between 1 and 2%, and 25% fell between 2 and 3% slope. By comparison, attempts at refinement of aquatic habitat definition in the UVR by Sponholtz and Rinne (1997) indicated that HGRs ranged from 0.56 to 4.39% and averaged 1.83% or near the mean (2.22%) for the upper Gila River. Accordingly, comparison of macrohabitat data between the Verde and Gila rivers is valid.

The 52 LGR samples ranged from 0.05 to 4% slope, averaging 0.70% (fig. 9.40). Only 20% of all estimated values were greater than 1% slope, and half were between 0.5 and 1%.

Forty percent (21) fell between 0.5 and 0.75% slope, and 33% were less than 0.5% slope.

Rinne and Stefferud (1996) reported that all estimated gradients for GRUNs (glide/run) in the UVR also were between 0.5 and 1% slope. Sponholtz and Rinne (1997) reported that LGRs in the UVR ranged from 0.72 to 2.38% slope and averaged 1.33% slope.

GRUN habitats ranged from 0.05 to 2.8% and averaged 0.35% slope in the upper Gila River (fig. 9.40). Only seven (12%) estimated slopes were greater than 1%. Thirty-eight percent of the estimated slope values for GRUNS were less than 0.25%; 48% (28) ranged between 0.025 and 0.5% slope. Rinne and Stefferud (1996) listed glide and run habitats separately, however one-third of their estimates fell between 0.25 and 0.5%. By comparison, Sponholtz and Rinne (1997) listed run habitats averaging 0.7% and glides 0.5%, or somewhat higher than the estimates from the upper Gila.

Finally, 28 pool habitats ranged from 0.0 to 0.2%, one-third was below 0.1%, and one-third was between these two values (fig. 9.40). Rinne and Stefferud (1996) listed no values for pools, but Sponholtz and Rinne (1997) listed pools ranging from 0.0 to 2.05% slope and averaging at 0.9% somewhat higher than in the upper Gila. Rinne and Stefferud (1996) and Sponholtz and Rinne (1997) found velocities of 22 and 18 cm s^{-1} (8.7 and 7.1 in s^{-1}), respectively. These data indicate and reflect that many pools in both the upper Gila and Verde commonly have slopes greater than zero and have positive current velocities.

Table 9.5—A comparison of percent availability of substrate category in the Gila and Verde Rivers and that used by spikedace.

Substrate	Spikedace Present	Spikedace Absent	Total substrates Gila River	Total substrates Verde River
	%	%	%	%
Sand	12	5	20	18
Gravel	39	19	43	40
Pebble	19	28	25	2

The HGRs consisted of gravel to cobble materials in both rivers. LGR habitats contained primarily pebble-gravel substrates in the Gila compared to gravel to cobble materials in the Verde. GRUNs in the Gila were almost 80% sand and gravel compared to sand- cobble in the UVR. Pools had sand-gravel substrates. Comparative substrates in the upper Gila and Verde for the respective habitat types are shown in table 9.5).

Rinne and Stefferud (1996) reported that HRGs in the UVR had a mean of about 50% cobble-boulder, 30% pebble, 15% gravel, and 0% sand. LGRs were about 25% cobble-boulder, 25% pebble, 30% gravel, and 25% sand. Finally, glides contained basically none of the cobble-boulder category, 10% pebble, 55% gravel, and 30% sand.

Macrohabitat Utilization by Native Species

Overall, native fishes were collected in pool habitats in the UVR (Rinne and Stefferud 1996. However, this association can be attributed, in part, to the predominance of two of the three large species (Sonora sucker and roundtail chub) which comprised 30 to 50% of the native fauna in 1994 and 1995, respectively (Rinne and Stefferud 1996) and were captured 11 and 61% of the time. Further, desert sucker (which comprised 25 to 30% of the native fauna) were captured in pools 20% of the time (Rinne and Stefferud 1996; fig. 9.41). Finally, the great variability in velocity of pool habitats that were comprised of multiple pool categories increased the probability that a greater number of individual fishes would be captured in pool habitat types. Longfin dace were captured primarily in low-gradient riffles and runs (fig. 9.42), spikedace in runs and glides (fig. 9.43; Neary and others 1996), and speckled dace in low- and high-gradient riffles (fig. 9.44).

Macrohabitat Utilization by Nonnative Species

Nonnative species primarily (29%) used glide habitat. Red shiner were collected mainly in GRUN habitat. Green sunfish, yellow bullhead, and smallmouth bass were taken in 91 habitats—comprised of 45% pools, 22% glides, 20% runs, and 13% riffles. Common carp was taken in pools over half the time. In addition, Rinne and Neary (1997) demonstrated that yellow bullhead and smallmouth bass frequently occupied streambank habitat that provided cover. Further, where these nonnatives were present, native species were reduced or absent. These studies are ongoing but suggest possible competition for habitat and/or predation effects of these two nonnative predatory species on the smaller-sized native species such as longfin dace and spikedace and YOY and juveniles of the desert and Sonora suckers and roundtail chub. Unpublished laboratory data using bullhead and smallmouth bass as predators and red shiners as a surrogate for both the small cyprinid

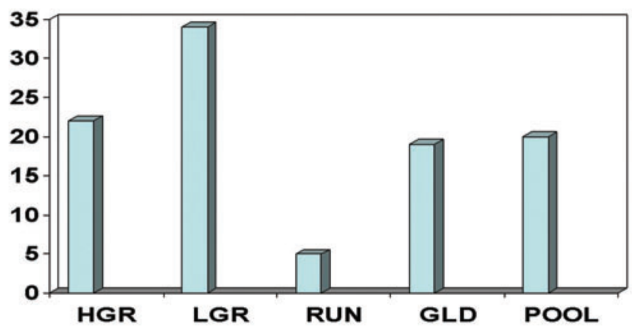


Figure 9.41—Macrohabitat utilization by desert sucker, UVR; number = 2,717.

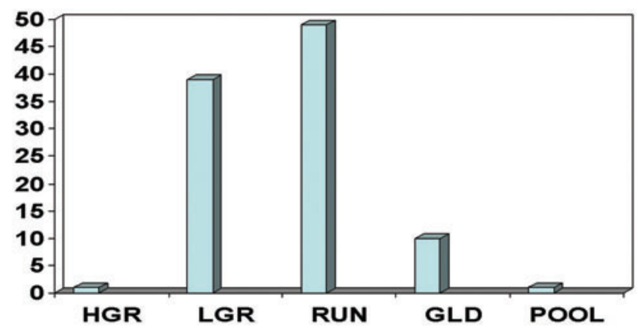


Figure 9.42—Macrohabitat utilization by longfin dace, UVR; number = 1,814.

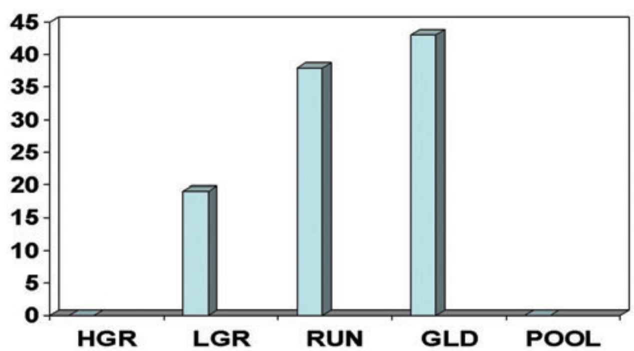


Figure 9.43—Macrohabitat utilization by spikedace, UVR; number = 1,177.

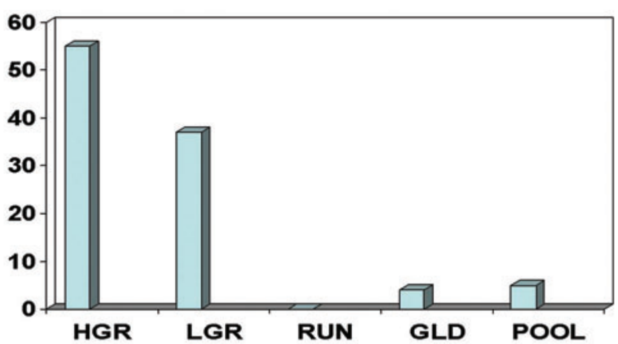


Figure 9.44—Macrohabitat utilization by speckled dace, UVR; number = 117.

species and YOY of the three large cyprinids suggest the predation effect on native species potentially could be substantial.

Stream Hydrology and Fish Habitat

Based on annual peak discharges and mean annual discharges over the past three decades, flows in the UVR, typical of Southwest rivers and streams, were highly variable (Stefferud and Rinne 1995; Rinne and Stefferud 1996). Neary and Rinne (1998) documented that base flow in the UVR has increased over the past two decades. Cycles of flood and drought appear to follow a 7 to 10 year periodicity. Although there are no specific data on channel morphology prior to the 1993 flood, morphology was observed to change dramatically after the 75-year event. The seven-year event in 1995 also altered channel morphology but to a lesser extent as evident in changes in the relative abundance of habitat types (see Chapter 5). Based on aquatic macrohabitat type, most of the major sample reaches change from year to year. A lack of significant flood events following 1995 sampling and ensuing (1996 to 2004) low, drought flows appear to have significant effects on macrohabitats (Sponholtz and Rinne 1997). Stream channels have narrowed and aquatic macrophytes have encroached from stream margins, reducing mean stream width. Depths of many macrohabitats also have been reduced because of a lack of scouring (Rinne and Miller 2008). The relationship of stream channels and flow events need to be further analyzed with data from the UVR and the very large dataset from the upper Gila River.

Status and Habitat of Spikedace

The threatened spikedace (*Meda fulgida*) was once widespread and locally abundant in streams and rivers of the Gila River Basin (fig. 9.4). It is a Federally-listed threatened species, occurring in four isolated stream and river systems in Arizona and New Mexico. Based on 15 years of study of the Verde River population, spikedace declined dramatically in abundance, even to the point of non-detection in samples since 1997 (Rinne 1999a). In 1999, calculated probabilities of extinction (0.8 to 0.9) suggest that the species is extirpated from the UVR. Based on current data, river hydrograph, habitat changes, and nonnative fish play interactive roles in this decline. Complicating determination of relationships and causal factors has been the removal of livestock grazing (see the "Grazing Management Changes" section) from the Verde River riparian stream corridor and the resulting changes in riparian stream habitat.

From an intra-stream perspective, monitoring for spikedace on the UVR should be continued and intensified. In the event of reappearance, local experimental suppression or reduction of nonnative fishes in these reaches should be considered to observe both the spikedace and the native fish assemblage response. Also, refugia streams should be identified and evaluated, culture techniques should be developed, and research priorities should be established. Research should be continued and should include comparative studies with the upper Gila River, to refine the level of understanding of the relationships and interactions of flow regimes, native/nonnative fish abundance, and land use activities.

Description and Biology

The spikedace is a slender, laterally compressed cyprinid. The dorsal surface is typically olive gray to brown, often mottled with silvery sides and the ventral region is whitened. Males become golden on their dorsal and lateral surfaces during breeding. The basic life history of the species has been studied primarily in one stream in Arizona—Aravaipa Creek (Barber and Minckley 1966, 1983; Barber and others 1970; Turner and Tafanelli 1983; Rinne and Kroeger 1988). In addition, Anderson (1978) and Propst and Bestgen (1986) have studied the biology of the species in the Gila-Cliff reach of the mainstream Gila River in New Mexico. However, most of the information collected on the species has been from survey and monitoring activities to assess the distribution and abundance of the species in time and space (LaBounty and Minckley 1972; Anderson and Turner 1977; Barrett and others 1985) and to provide limited information on the biology of the species.

Spikedace spawn in the spring and early summer (April to June) and are principally dependent upon streamflow and attendant water temperature, normally varying in time and space. In early March, 1999, extreme coloration of males and gravid females were noted in the Gila-Cliff valley of New Mexico (personal field observations). Eggs are expelled in the water column and are adhesive when fertilized, adhering to the substrates where spawning occurs. Sand to gravel-pebble substrates have been reported where reproductively ready individuals (based on coloration and gravidity) have been collected in the UVR (Neary and others 1996), Aravaipa Creek (Barber and others 1970), and the upper Gila River, New Mexico (Propst and Bestgen 1986). Spawning habitat was described by Neary and others (1996).

Historic Distribution and Current Status

The spikedace, is a diminutive, short- lived, stream-dwelling minnow endemic to the Gila River Basin of Arizona and New Mexico (Miller and Hubbs 1960; Minckley 1973). Although once widespread in the Gila River Basin (Rhode 1980; Propst and Bestgen 1986), the spikedace is now a Federally listed threatened species (USDI Fish and Wildlife Service 1986) and occurs only at intermediate elevations (1,070 to 1,830 m, or about 3,500 to 6,000 ft) of the upper Gila River in southwestern New Mexico (Propst and Bestgen 1986; USDI Fish and Wildlife Service 1990), Aravaipa Creek (Barber and Minckley 1966; Bettasco and others 1995), Eagle Creek (W. L. Minckley, unpublished data), and the UVR (Stefferud and Rinne 1995).

Historically, the spikedace was probably widespread and locally abundant in the Gila River Basin from low- to mid-elevation reaches of the San Pedro (type locality; Miller and Hubbs 1960), Salt, Verde, Agua Fria, San Francisco, and Gila rivers. Although present at upper elevations (1,525 to 1,830 m, or about 5,000 to 6,000 ft) of these same mainstream rivers, population numbers were likely lower. Gaps in quantified temporal-spatial information such as museum collections do not permit unequivocal assessment and delineation of historic distribution. Generally, the species was common throughout the basin and probably was locally abundant in preferred habitats. As with many western native cyprinids, fluctuations in both range and numbers of spikedace in response to regional environmental and climatic conditions are the norm (Minckley 1973). Another related, rare native cyprinid, the Little Colorado spinedace (*Lepidomeda vitatta*), ranges from abundant to rare in habitats of its native range and is extirpated from certain local stream systems (Minckley and Carufel 1967). For both species, extrinsic and intrinsic factors may likely be delimiting variations in range and abundance; however, specific factors have not been adequately defined. Further research is needed on the factors critical for sustaining this rare, threatened native fish species relative to intra- and interactive natural and human-induced factors in the Verde and Gila Rivers.

Verde River Spikedace—Recent Distribution and Abundance

As discussed previously, the UVR is a free-flowing stream with low base flows (0.57 m^3 s^{-1} or 20 ft^3 s^{-1}), only one perennial tributary (Granite Creek), and periodic extreme flood events (Stefferud and Rinne 1995). Although adapted to the vagaries of Southwest stream dynamics, over the past six years, spikedace populations have appeared to be affected dramatically by natural variations in the Verde River hydrograph (i.e., alternating floods and drought; Stefferud and Rinne 1995; Rinne and Stefferud 1997). In addition, introduced nonnative fishes such as the dimunitive red shiner (Rinne 1991b; Douglas and others 1994; Carpenter and Mueller 2008) and larger predatory species such as small mouth bass, green sunfish, and yellow bullhead appear to have negatively affected the species (Rinne 1991a, 1991b; Stefferud and Rinne 1995) through their proportional increase in the total fish community from 1997 to 2008.

In addition, it has been suggested that livestock grazing can negatively impact not only spikedace habitats and abundance, but native fishes in general (Rinne 1999b, 2000). Notwithstanding, no reports or published accounts are available that document the nature and extent of this impact in the UVR or elsewhere in Southwest riparian stream systems (Rinne and Miller 2008). The only information implicating this land use activity as negatively affecting spikedace habitat and populations was a draft biological opinion (administratively withdrawn) on one grazing allotment on the UVR. In general, information is lacking on the relationships between native

Southwest cypriniform fishes and livestock grazing. This relationship is in dire need of additional, well-designed, objective, and replicated research (Rinne 1999b).

Although historically present in the Verde River, the spikedace was not rediscovered in samples until the early 1970s from the mouth of Sycamore Creek (Anonymous 1974). Large numbers of spikedace were collected by the USDI Bureau of Reclamation in the mid-1980s in the UVR while examining instream flow needs of native fishes (Barrett and others 1985). Spikedace were common in samples comprising up to 11% of the native fish fauna.

As previously stated, RMRS in Flagstaff, Arizona, commenced study of fish populations in the UVR in 1994 following major flooding (75-year recurrence event) in the winter of 1992/1993 (Stefferud and Rinne 1995). Spikedace were most abundant in the most upstream reaches of the UVR in spring 1994 (table 9.1; Stefferud and Rinne 1995; Rinne and Stefferud 1997). Fewer were collected downstream at the Perkinsville and Black Bridge sites and at the mouth of Sycamore Creek. A reduced level of flooding (seven-year recurrence event) occurred again in March 1995. Spikedace populations pulsed once more in 1996 (Rinne and Stefferud 1997), only to decline in subsequent samplings and became absent from samples at the seven established sites by spring 1997 (Rinne 1998). Additional sampling along the entire course of the UVR in 1997 and 1998 also indicated that the spikedace population had declined markedly. In the spring of 1999, sampling in the most upstream reaches of the Verde (Bear Siding upstream) again indicated no spikedace presence. Based on these data, the species presently is very rare in the UVR. Spikedace has not been collected despite extensive efforts by RMRS and Arizona Game and Fish Department efforts for a decade (Rinne 2001a, 2001c, 2005).

Grogan and Boreman's (1998) approach was applied to assess and address more specifically the rarity and probability of extirpation of spikedace from the UVR. This methodology uses years and last year of collection versus total years of surveys to arrive at a probability that a species, based on historic collection, is extirpated. A probability (P) of 0.873 that spikedace were gone from the UVR was calculated using U.S. Forest Service data collected since 1994 and a last date of collection of 1996. A more robust data set from Arizona State University that commences with collections in 1980 and has a last date of collection of 1997 resulted in a lower but similar probability ($P = 0.832$) of extirpation of this species from the UVR above Sycamore Creek. Employing that methodology with the continued absence of the species between 1997 and 2008 results in a $P = 0.93$, or 93 chances out of a 100 that the species has been lost from the UVR.

Bahm and Robinson (2008) reported on a recent Arizona Game and Fish Department spikedace survey in the UVR from Burnt Ranch to Perkinsville (fig. 9.45). Fish biologists did not capture any individuals, making this the ninth consecutive year that spikedace have not been detected during sampling by Arizona Game and Fish Department. However, the Department survey was a general fisheries surveys (electrofishing) and did not specifically target spikedace. Although they could not conclude that the species is extirpated in the UVR, Bahm and Robinson (2008) recommended that another survey should be done specifically for spikedace in 2009 to 2010 and beyond.

Comparison of Spikedace Habitat—Verde and Gila Rivers

Spikedace occupy lentic habitats of varying depths (<1 m or <3.3 ft) over gravel and pebble substrates. The species is often found in greater abundance in shear zones where two riffle areas converge to form eddying currents (Rinne 1985b, 1991a, 1991b, 1992). In larger rivers, the species is most common in

Figure 9.45—Arizona Game and Fish Department 2008 fish survey in the UVR from Burnt Ranch to Perkinsville. (Photo by Arizona Game and Fish Department.)

GRUN habitat of moderate velocities (30 to 50 cm s^{-1} or 11.8 to 19.7 in s^{-1}) and gradient (0.5 to 1.0%; Neary and others 1996) over gravel-pebble substrates. Boulder substrates may infrequently provide alteration or reduction of current velocity and create eddying currents that appear to attract the species. Habitat associations may vary both in time and space as well as ontogenically (Anderson 1978; Rinne 1985b, 1991b; Propst and Bestgen 1986; Rinne and Kroeger 1988).

More extensive analyses of spikedace habitat occupation have been completed in the upper Gila River (Rinne and Deason 2000). The overall objective of almost a decade of study was to delineate factors that strongly influence fish assemblage structure and through monitoring and research compare with studies conducted in the UVR, Arizona (Rinne and Stefferud 1997; Rinne 1999b; Rinne and others 2005c). In spring and early summer (March to July) of 1999, fish community structure was estimated at 18 sites (Rinne and others 2005c) from the headwaters of the Gila River, New Mexico, into Arizona near the Arizona and New Mexico border. The primary objective of the study effort in the upper Gila was to establish long-term monitoring sites. A secondary objective was to compare results of sampling in both rivers in 1999 and other years, and also to contrast and compare fish assemblages in the two river systems based on temporal and spatial changes in the native and nonnative components, especially the abundance of two threatened species. Of special interest was the abundance and distribution of spikedace and loach minnow (*Rhinichthys [Tiaroga] cobitis*) (Vives and Minckley 1990; Propst and Bestgen 1991). Because of persistence of the species in the upper Gila, these studies provide a more robust database of habitat use by spikedace than that provided by studies of the species in the UVR (Neary and others 1996; Rinne and Stefferud 1996).

In the upper Gila River, five major, pre-designated study reaches were sampled between March and July of 1999, generally ranging in length from 150 to 300 m (492 to 984 ft) (Rinne and others 2005a, 2005b). Reaches were selected based on the primary objective of including a diversity of aquatic macrohabitats that have been demonstrated to be occupied by the native fish assemblage in the UVR (Rinne and Stefferud 1996; Sponholtz and Rinne 1997). These habitats were HGRs, LGRs, GRUNs, and POOLs of varying types. Initial physical descriptors of these habitat types are contained in Rinne and Stefferud (1997) and Sponholtz and Rinne (1997). Habitat types were initially designated qualitatively; however, a direct readout digital flow meter, meter rule, and laser transit were used to define these units quantitatively after fish sampling. Only specific habitat data relative to spikedace and loach minnow abundance and distribution are reported herein. The other members of the native and nonnative fish assemblage and their habitats need additional analyses.

Fishes were collected in the upper Gila River by the same multiple sampling techniques that were used in the UVR. Direct-current, backpack electrofishing units were used to sample under debris, banks, and in HGR and LGR habitat. Normally, these two habitat types were sampled from up to downstream into a 5-m (16.4-ft), 3-mm (0.1-in) mesh bag seine. The GRUNs were normally sampled by seining from up- to down-stream with the same 5-m (16.4-ft) bag seine. All fishes collected in each unit were enumerated, measured, and returned alive to the same reach of stream. In the event of large numbers of individuals of a species, after 50 or more were measured, individual fish were enumerated only.

Depths were measured with a meter rule at 5-m (16.4-ft) interval transects in each macrohabitat. Velocities were estimated with a direct readout current meter at these same sites. Gradients were measured with a laser unit, and substrate was quantified by pebble count methodology (Bevenger and King 1995). Presence and absence data for the two species were compared and analyzed by nonparametric, Mann-Whitney tests to determine if a significant difference was present between these two data sets for both species.

Spikedace primarily (80%) occupy GRUN habitats in the UVR (Neary and others 1996; Rinne and Stefferud 1996) and secondarily in LGRs over gravel-pebble substrates. The species is often found on the UVR in greater abundance in "shear zones" where two riffle areas converge and form eddying currents (Rinne 1985b, 1991b, 1992, 1999a). Rinne and Deason (2000) reported the same habitat occupation by spikedace in the upper Gila River. The species was most common in average gradients of 54%. In 1994 in the UVR, GRUN habitats comprised about 40% of all habitats sampled. This percentage is near identical to that in the upper Gila in 1999 (Rinne and Deason 2000). Presently, only about 25% of habitats sampled in the UVR are GRUNs. Accordingly, there has been a about a 40% reduction in the well-documented optimal habitat for the species in the UVR over the past decade. Spikedace occupied waters that averaged 25 cm (9.8 in) deep with about 47 cm s^{-1} (18.5 in s^{-1}) current velocity over gradients of approximately 1%. The gradients where spikedace were present and the habitat occupied provided the only significant ($P = 0.014$) physical habitat descriptor, as determined by a Mann-Whitney test. This rare species occupied substrates of sand-gravel composition in the upper Gila River (table 9.5). Availability of substrate components was nearly identical in the two rivers.

Spikedace appear to be broadly adaptable or perhaps broad in their habitat utilization. For example, mean water column velocity and depth where spikedace were present and absent were not statistically different ($P>0.05$). The pelagic behavior of spikedace has previously suggested that mobility (Propst and others 1988) may be a rationale for a lack of habitat fidelity. Habitat use by this species does appear, however, to be delineated best by gradient or slope estimates. Most spikedace in the upper Gila were captured in GRUN and LGR habitat types over sand-gravel substrates. Rinne and Stefferud (1996) reported that 90% of all spikedace ($N = 904$) occupied GRUN habitats (mean velocities of 22 and 48 cm s^{-1} [8.7 and 19.9 in s^{-1}], respectively) in the UVR. Similarly, Neary and others (1996) documented that 80% of spikedace that were captured in the UVR occurred in GRUN habitats, and the remaining 20% occupied LGR habitat containing 20 to 50% sand substrates.

Fish sampling in the upper Gila River in 1999 revealed gradients of respective aquatic macrohabitats that were very similar to those recorded for the UVR. Spikedace were most commonly collected in GRUNs (80%) and LGRs (20%, mean gradients = 0.54%; Rinne and Deason 2000). Spikedace were found in gradients ranging from 4.3 to 78 cm s^{-1} (mean of 47 cm s^{-1} or 18.5 in s^{-1}) and were most commonly found over sand-gravel substrates. There was a significant difference ($P = 0.0139$) in gradient between habitats where spikedace were present and absent, but this was not the case for depths and velocities.

Grazing Management Changes—UVR Corridor

Changes in grazing management on the river corridor confounded the question of which factor—flooding or nonnative fishes—was most influential in determining the status of all native fish, and specifically spikedace (Rinne 1985a, 1988). Since the spring of 1997, following continuous reductions in animal unit months over the previous decade, livestock grazing has been totally eliminated from the UVR corridor. As a result, riparian vegetation diversity and density have increased dramatically on the river corridor (Medina and others 2005). Neither native fishes nor the spikedace specifically have so far responded positively to this change in management although nonnative fishes have directly paralleled the increases in vegetation both on streambanks and within aquatic habitats. These correlations need additional study.

Conversely, there has been an inverse relationship between decreases in native fish populations, livestock numbers, and flooding and corresponding increases in nonnative fishes (Rinne 1999b). There are several factors interacting here (i.e., fishes, livestock, flooding, and vegetation). Lack of flooding has apparently been positive to vegetation distribution and abundance and to nonnative fishes, and it has been unfavorable to native fishes, including the spikedace. The dramatic increase in vegetation since 1997 due to the removal of grazing parallels an increase in nonnative fish abundance. The marked increase in two predatory nonnatives—smallmouth bass and green sunfish—may be a response, in part, to greater in stream cover associated with increased near stream and streambank vegetation density. These correlations and relationships could be coincidental; they have not yet been adequately studied or statistically tested. Rinne and Miller (2008) suggest that river and stream hydrographs characterized by periodic, variable instantaneous flow events are equally, and very likely more important, to native fish sustainability than is differing livestock grazing activity that results in variable changes in riparian/stream form and function. More research is needed to refine and delineate the relationship between native fish and grazing relationship (Rinne 1988, 1999b, 2000).

Interactive Factors and Management to Sustain Native Fishes

Notwithstanding known cycles of abundance (Minckley 1981; Propst and Bestgen 1986), the status of the spikedace and the entire fish assemblage in the UVR is perilous at best. Spikedace have declined in just a few years from 6 or 7% (1994 and 1996, respectively) of the native fish community to a level of non-detection. This decline coincided with an increase in base flow over the past two decades (Neary and Rinne 1998), and with a period of no flooding from

1996 to 2004. The combination of the predominance of nonnative fishes, the probability of entering a drought cycle, and the change in riverine habitat resulting from grazing management changes could lead to extirpation of one of only two large river populations of spikedace in the Southwest. Although statistically non-significant, the high probability that spikedace is extirpated from the UVR is cause for concern.

Of the three potentially interactive factors of flooding, nonnative fishes, and habitat change, only two can be addressed by management. Flood events are subject to the vagaries of the Southwest climate. Alternating cycles of drought and flood are the rule, not the exception. Data from the UVR (Stefferud and Rinne 1995; Rinne and Stefferud 1997; Brouder 2001) and the upper Gila River (Propst and Bestgen 1986, Propst and others 2008) and the conclusions of other documented effects of flooding on fishes (Minckley and Meffe 1987) show that native fish populations, including spikedace, appear to be positively correlated to flooding. In the UVR, spikedace have gone from common to very rare to absent from samples in just a few years during a period with no flood events and a drought or base flow condition (Rinne and Stefferud 1997; Rinne and others 1998).

Of equal importance in the UVR, as elsewhere in the West (Minckley and Deacon 1991) and Southwest (Rinne and Medina 1996; Rinne 1994, 1996), is that nonnative fishes consistently have resulted in a negative impact on native fishes. Whether by displacement or replacement (Douglas and others 1994), nonnatives apparently outcompete and prey upon native species (Minckley 1983; Meffe 1985; Rinne 1995b; Blinn and others 1993). Predation may indeed be the primary factor of replacement of native fish species by nonnatives (Clarkson and others 2005). At present, almost half of the individual fish inhabiting the UVR are nonnative. Combined with the lack of collection of spikedace for the past 12 years, this is cause for both concern and focused management by State and Federal agencies. In place, ongoing mechanical removal research should be continued. In addition, there should be consideration for experimental introduction of spikedace from the upper Gila within an adaptive management/research paradigm.

Finally, livestock grazing is a manageable land use activity. Anecdotally and coincidentally, livestock removal from the UVR in 1997 paralleled both the lack of flooding and the decline of spikedace in the river (fig. 9.15A). The indirect impact of livestock grazing on the watershed of the UVR presents a possible threat to spikedace sustainability. Although not discountable, the relative extrinsic impact of livestock grazing on the watershed, when compared to the predominance of an intrinsic, competitive, and predatory nonnative fish fauna in the UVR, becomes a moot point in the near term for management alternatives. Administrative/research collaboration should be attempted on selected reaches of river where both mechanical removal of nonnative fishes is ongoing and where it is absent.

Although complete removal of nonnative fishes using piscicides from the UVR is a highly improbable near-term management alternative, the objective of continually reducing and suppressing nonnative fishes should be the highest priority for management at present. Although immediate, complete removal of nonnative fishes is not administratively or logistically feasible, any efforts to suppress or reduce their abundance should be considered as a timely management alternative. Waiting for the next flood event to reduce nonnatives as a management alternative is not an appropriate strategy because of the time factor, the status of the spikedace, and the dominance of nonnative fishes in the UVR. However, continuing and synchronizing future nonnative fish suppression with natural reduction in numbers by flooding (Rinne and Stefferud 1997) may be a viable management alternative.

Flooding is a natural disturbance event and, as previously discussed, may indeed be a prerequisite for native fish sustainability in the presence of nonnative fishes. Historically, floods and droughts have caused extreme fluctuations in the numbers and ranges of native fish, including the spikedace. After reduction of the entire fish community, re-colonization from refugia reaches has been possible historically in the absence of nonnative fishes and without many of the current mainstream dams and their alteration of flow regimes (Rinne 1994, 1995a, 1995b) and removal of fluvial connectivity.

The UVR has no significant mainstream impoundments or diversions below the start of perennial flow, only a nonnative fish assemblage. Further, with recent low drought flows and the removal of livestock, the riparian stream ecosystem of the UVR has become stabilized for the near term. Such stable aquatic conditions appear to be more favorable to nonnative fishes than natives in this river system. Even if nonnatives were absent in the UVR, the stability characterized by adequate and perhaps enhanced baseflow and the absence of floods (Neary and Rinne 1998) would promote increased instream and streambank vegetation and probably would be more favorable to native fishes. Nevertheless, until the next significant peak flow event occurs, nonnative fishes will continue to impact the spikedace—an impact that could result in extirpation of this threatened species from the Verde River system. If this happens, it would probably be favorable to attempt to experimentally restore spikedace and native fishes in general.

Even if a residual spikedace population exists and even if spawning does occur annually, the probability of survival of YOY spikedace is low given the excessive numbers of nonnative, predatory species present in the river (Stefferud and Rinne 1995; fig. 9.15A). An appropriate management alternative should be continued suppression of nonnative fish populations in the most upstream reaches of the UVR. Such action could help sustain native fishes and the spikedace locally (if present in future surveys) until the next flood event. Removal of grazing from the watershed or imposing limits on sport fishes are commendable extrinsic management strategies. However, both are cosmetic at best and pale in significance to intrinsic mechanical reduction in abundance of nonnative fishes, especially when coordinated with natural hydrologic reduction. Although mechanical, partial suppression of nonnative fish is not entirely effective, its continuation should be of high management priority in the total fish community (Rinne and Stefferud 1997).

Because of genetic considerations, the introduction of spikedace from other river systems has not been considered a viable management alternative (Tibbets and Dowling 1996). Isolation of the spikedace in the UVR from spikedace of the Gila River and Aravaipa Creek dates at least to completion of the Horseshoe and Bartlett dams on the Verde in the 1930s. Analyses of spikedace populations in the Gila River system (Tibbets and Dowling 1996) suggest that the population of spikedace in the UVR is genetically distinct. Accordingly, no translocation of spikedace should occur unless there is unequivocal evidence that the spikedace has been extirpated from the UVR drainage. At what point does one reach an unequivocal conclusion—extirpation of the species? Despite extensive sampling in Eagle Creek, Arizona, spikedace were not collected for more than two decades, but the species was recently confirmed with great effort at a disturbed road-crossing site in this stream. However, none of these situations justify adopting a non-action, non-progressive, or pro-active approach to management.

Three major additional management strategies should be strongly considered and instituted immediately. The first is intensification of survey and monitoring activity to search for spikedace. Secondly, locating and evaluating possible natural refugia streams or artificially establishing such in the Verde Basin should be considered. Lastly, culture techniques must be developed immediately for the species. These last two items should be in place when the next flood event occurs, which is presumably when spikedace will reappear in samples.

As discussed at the outset of this synthesis, RMRS in Flagstaff, Arizona, commenced study of fish populations in the UVR in 1994 following major flooding (figs. 9.11, and 9.13). Spikedace were most abundant in the most upstream reaches of the UVR during initial sampling in 1994 when 428 individuals were collected at the seven long term monitoring sites (Stefferud and Rinne 1995; Rinne 1998). Total catch in 1995 following less marked flooding dropped to 72 individuals, increased in 1996 to 140 individuals total captured. The species disappeared from samples at all seven sites in 1997 and has not been captured in the last 11 years of sampling. The species was common at four of the seven sites in 1994, rare by spring 1996 and absent in 1997 to present.

A dozen individuals were captured in the vicinity of the Black Bridge site in 1997. Reports of a single individual being captured by an Arizona Game and Fish Department Survey in the vicinity of the 638 Road site, however, no photographs or a specimen are available to document the record. Accordingly, the species has been absent from samples for over a decade (1996 to 2008) and has an ever-increasing probability of being extirpated from the river. The recent 2004/2005 floods greatly modified and improved habitat for spikedace (Rinne and Miller 2006, 2008) and reset many reaches of the river to that of 1993 flooding. However, three years of sampling at the seven sites, surveys by (60% of all spikedace captured in 1994) have failed to collect the species. Because of the high probability of the extreme reduction, and perhaps extirpation from the Verde River, and the aquatic ecosystem fragmentation of rivers and streams in the Southwest (Rinne and Calamusso 2006), experimental stocking of spikedace should be strongly considered in selected reaches of the UVR in the context of Sedell and others (1990).

Research and Management Implications

Long-term databases on temporal and spatial fish assemblage distribution and abundance in Southwest rivers and stream are wanting. Aravaipa Creek is likely the most lengthy (25 years) and robust in Arizona. In New Mexico, the upper Gila River has the most lengthy (10 to 20 years) database of this nature (Rocky Mountaun Research Station database, Propst and others 2008). The database spanning 15 years and 60 km (37.5 mi) of the UVR is the most robust and sustained in time and space in Arizona. Almost two dozen publications have been produced since 1995 on not only fish distributions but also habitat use, interactions, flow regimes and fish assemblages, mechanical removal to sustain native species, and summary papers on fish assemblages (Rinne and others 2005a). Several cycles of flood and drought flows have been studied and their relative impacts on both aquatic and riparian corridor habitats and fish assemblages are documented. Continued reduction of native fishes and the disappearance of a threatened fish species, the spikedace, have been documented. Further, these physical and biological dynamics in the UVR have been contrasted and compared to the upper Gila River with the same native fish fauna, but different flow regimes (Rinne and Miller 2006).

The data collected and publications printed over the 15-year time span suggest that it is important at this point to assess results and suggest some specific research and management activities that should be undertaken to build on with the objective to both sustain and enhance the native fish resource in the UVR. Some of the main themes of research/management that should be investigated:

(1) The relative roles of nonnative fishes, flow regimes, and management activities such as fisheries and grazing management in the riparian corridor and extrinsic land use activities on the watershed on native fish sustainability.

(2) The efficacy and effectiveness of mechanical removal techniques of nonnative, invasive fishes for sustainability of native fishes.

(3) The relative roles of predation/competition by nonnative fishes and other invasive species such as crayfish, Asiatic clams, and bullfrogs on native fish sustainability.

(4) The relative roles of primary and secondary production levels in native fish sustainability.

(5) Experimental restoration of spikedace to the UVR though introduction of stock from the Gila River.

Long-Term Monitoring/Research of Fish Assemblages

The fish/habitat data base for the UVR is the largest of its kind in Arizona on a major river. Data have spanned three flood cycles, a substantial drought, base flow cycle, marked changes in fish species and assemblages, and stream channel habitats, disappearance of the threatened spikedace, and livestock grazing removal. A similar database of 10 years duration is extant for the upper Gila River. Continued monitoring and future research should be put in place to build on, compare, and further analyze these databases in light of the differential response of fish and species assemblages in these two river systems comprised of the same native and nonnative fish assemblages. A prerequisite to sound management is the best data and science on which to base it. Of critical importance is the restoration of the one threatened species—spikedace—to the UVR.

Mechanical Removal of Nonnative Fish Species

Mechanical removal on the UVR has been in place for almost a decade. In this time the factors responsible for success and or the lack of it in terms of response of native fishes have been well defined. Modified and intensified effort was instituted in 2006 and continues to present. The response of native fishes in spring 2008 at two of the long-term sites within removal treatments indicates a positive response to removal efforts. Therefore, it is highly recommended that these efforts be continued in out years. Further, land managers, RMRS scientists, and fish resource management agencies should strongly consider collaborative efforts to test the response of these efforts relative to the presence and or absence of management activities such as livestock grazing. Removal efforts should be considered as prerequisite to possible future chemical removal of nonnative fishes in the uppermost reaches of the Verde River.

Predation, Competition, and Primary/Secondary Production

Because of the ever-increasing literature on the impact of direct predation by nonnative fishes and other aquatic invasive species this impact should be examined in the UVR. Laboratory studies such as those of Carpenter and Mueller (2008) suggest that juveniles of even smaller-sized nonnative fishes can have a potentially negative impact on native fishes. Studies have been conducted by the University of Arizona (Schade and Bonar 2004, 2005) to lay groundwork for future studies. Primary and secondary production studies have not been a component of the past 15 years of study. Their role as related to flow regimes have not been studied intensively enough to determine their role in the sustainability of native fishes in the UVR.

Spikedace Monitoring and Restoration

The threatened spikedace disappeared from samples at the seven long-term monitoring sites within a few years after floods in 1992/1993 and 1995. The species has not been collected in the UVR since 1996 at the long term sites and 1997 below the Black Bridge long-term site. There should be a continued effort to monitor upper reaches of the river for the presence of this rare, threatened species. Large populations of this species yet occur in the upper Gila River in New Mexico. There should be an increased emphasis on consideration and implementation of restoring the species to the UVR, as is a component of the Recovery Plan (USDI Fish and Wildlife Service 1990). Restoration efforts must be coordinated with mechanical removal efforts and land management activities. Calculations suggest that the spikedace species has a high probability of being already extirpated from the UVR. The combined monitoring of RMRS, Arizona Game and Fish Department, and the U.S. Fish and Wildlife Service over the past decade and over the upper 60 km (38 mi) of river have failed to collect the species. Collaborative efforts should be initiated and pursued by these same agencies to experimentally introduce the species in the Burnt Ranch and Black Bridge long-term study site reaches.

Summary and Conclusions

The primary intent of this chapter is to summarize these works and then offer plausible management implications and research recommendations of this voluminous information into a state-of-the-art publication delineating management implications on fishes, fish assemblages, fish habitats and biology, and hydrology and geomorphology in the UVR based on monitoring and research from 1994 to 2008. In summary, the intent is to delineate for land managers: (1) what is known, (2) what is not known, and (3) what are the future research needs to facilitate management to sustain native fishes in the UVR.

Fish have been collected at seven long-term sites on the UVR since 1993. There has been a distinct decline in native fish species since the year after the 1993 flood and a parallel rise in nonnative fish species. Mechanical removal of nonnative fishes was not of sufficient intensity to have a significant effect with only an annual approach. Extensive streambank and in-stream vegetation reduced efficiency of removal, and limited treatment reaches (1 km or 0.6 mi) did not preclude emmigration of nonnatives into other sites.

The threatened spikedace disappeared from samples at the seven long-term monitoring sites within a few years after floods in 1992/1993 and 1995. The species has not been collected in the UVR since 1996 at the long-term sites, and since 1997 below the Black Bridge long-term site. Calculations suggest that the spikedace species has a high probability of being already extirpated from the Verde.

Chapter 10

Research Recommendations

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Introduction

This chapter contains a number of research recommendations that have developed from the 15 years of research on the UVR conducted by the Southwest Watershed Science Team, as well as from insights from key cooperators and contacts. It is meant to be our best insight as to where efforts should go now. Achieving these recommendations will depend on a number of factors, including agency budgets of the USDA Forest Service, USDI Geological Survey, USDI Fish and Wildlife Service, and Arizona Game and Fish Department. A key to future success in marshalling resources to conduct research on the UVR is partnerships with other Government agencies at the Federal, State, and local levels and with non-Government organizations and private individuals. Rocky Mountain Research Station will need to work with cooperators such as private landowners, the USDA Forest Service's Prescott National Forest, USDI Geological Survey, USDI Fish and Wildlife Service, USDI Bureau of Reclamation, Arizona Game and Fish Department, Arizona Department of Water Resources, Arizona Department of Environmental Quality, University of Arizona, Northern Arizona University, The Nature Conservancy, and the Verde Watershed Association.

Research Recommendations

Hydrology

- The main hydrologic data gathering is done by USDI Geological Survey at the Paulden gauge. This effort is sustained through a cooperative agreement with the USDI Geological Survey, the Prescott National Forest, and the local landowner. The USDI Geological Survey analyzes and reports the data and the Prescott National Forest funds the operation and maintenance of the gauging station. Access is provided by an agreement between the USDI Geological Survey and the Verde River Ranch. **It is important for the USDA Forest Service to provide assistance in maintaining this work, including access and site protection.**
- The influence of Sullivan Dam as a sediment and chemical source and sink is unknown. Many hydrological physical processes are affected by the structure. When completed in 1939, the dam was filled with bedload within two years. This bedload is necessary to sustain the dynamic equilibrium of the system downstream and has been held in check for 70 years. All evidence suggests that deprivation of this bedload has resulted in the channel degradation, erosion of historical terraces, loss of the critical hyporheic zone, aquatic habitats for fish, and disturbance of once productive streamside habitats and wetlands. **A Rosgen level IV assessment (Rosgen 1994) is needed to determine the**

sediment-bedload relationships, and stream stability, and to ascertain the benefits to society and the UVR of removing the dam for the purpose of restoring the physical processes to the system.

Groundwater

- The chemical attributes of accumulated sediments in Sullivan Dam and upstream for several miles should be determined. Of specific interest is the presence of chemical “cocktails” commonly referred to by the U.S. Environmental Protection Agency as Pharmaceuticals and Personal Care Products (PPCPs). In 2009, tests were conducted across the United States and it was determined that water bodies and other sources, e.g., soils, contain varying quantities and products that may pose harm to humans or the environment. The basin above Sullivan Dam has historically been used commercially for agricultural production of forage products and industrial business (such as gravel mining); more recently, it has become a dense urban community. **It is important to determine if PPCPs are present and potentially contributing to water pollution in the UVR downstream in such a manner that disrupts biological processes, e.g., reproduction.**
- All of the groundwater research has been done by USDI Geological Survey as well as the State of Arizona. **No USDA Forest Service involvement is needed, but some material support may be needed for future work if research budgets continue to be cut at the State and Federal level.**

Vegetation

- Considerable effort has been invested in implementing a riparian monitoring program (1996 to 2010) that includes permanent vegetation stations. These stations provide trend information that is useful for management of the riparian habitats. The stations provide specific information about composition, density, frequency and structure that is useful for examing changes in regards to land uses or climate change. Point photos provide real-time contrasts of habitat changes and alert managers of riverine conditions. **The vegetation monitoring program instituted for the Prescott National Forest should be continued and the database should be archived. A repeat measurement interval of three to four years is suggested, depending on major floods or other management needs.**
- Vegetation studies have permitted the development and implementation of invasive plant treatments, e.g., removal of tamarisk, for the Prescott National Forest. This information is being used locally by other agencies and private enterprises to development similar treatments in the middle Verde Valley. Preliminary studies have also revealed the presence of many other invasive plants of importance to the Prescott National Forest. **Additional vegetation surveys should be conducted to identify management options for the array of invasive herbaceous and woody species. It is important to identify maintenance programs for the control of nonnative plants, treated and untreated, for the purpose of sustaining plant communities for a variety of wildlife, especially TES species.**
- Grazing still remains a practical and economical tool to control and manage vegetation, including invasive species. New grazing programs, such as “targeted grazing” (American Sheep Industry 2006) have proven successful under various

scenarios. Livestock grazing of the UVR can provide additional resource protection from unwanted vegetation and reduce risks to aquatic habitats. **Research on the effectiveness of different weed management strategies, including biological, weed control, and operational techniques in the UVR is needed.**

- UVR has incurred major changes in woody plant species and densities. It is uncertain how woody plants affect the productivity of wetland communities. It is also uncertain how woody plants affect site productivity, streambank stability, and other erosional processes. **Studies are needed that address the relationships among woody plants, channel dynamics and site productivity. These are useful for management of key habitats for willow flycatcher, amphibians, and other aquatic-dependent wildlife.**
- Overstory canopy of deciduous trees can influence the chemistry of water in the stream. **Evaluation of water chemistry influenced by overhead vegetation canopy closure and its effects on the relative roles of primary and secondary production levels in native fish sustainability needs to be examined.**

Geomorphology

- Considerable effort has been invested in implementing a riparian monitoring program that includes permanent geomorphic stations where Rosgen "type" level II assessments are completed (Rosgen 1994). **These stations are important to maintain and measure at two to three year increments (more so after major floods) to ascertain the relative stability of the channel, as well as to corroborate associated changes to terrestrial and aquatic habitats, especially for TES species.**
- Permanent geomorphology transects provide a means of clearly documenting changes in the UVR over time and between climatic events. Changes in agency personnel at the Prescott National Forest, Rocky Mountain Research Station, USDI Geological Survey, etc., might result in future misunderstandings of the dynamics of the UVR. **A set of geomorphology transects was established in the 1997 to 2000 time period. These transects should be re-measured periodically to follow future trends in the river.**
- Fish are directly affected by habitat changes in the UVR. There has been a history of misinterpretations of fish response to land management activities and changes in the UVR geomorphology and vegetation. **Additional studies are needed to refine the fish-habitat linkages that are important to native fish survival in the UVR.**
- The geomorphology of the UVR is strongly influenced by episodic flood events. Floods pre-dating European settlement of the Verde Valley have had major impacts on the current geomorphology and aquatic habitats. **Any future large-magnitude floods that reset the UVR's geomorphology should be documented to better understand geomorphic changes after long return-interval floods.**
- Climate change, urbanization of the Chino Valley, and groundwater withdrawals for the cities of Prescott and Prescott Valley have been implicated in regional aquifer declines and reduced streamflow in the UVR. **The influence of declining streamflows on stream geomorphology and aquatic habitats must be evaluated. This work can be a part of the riparian monitoring program.**

- Videography of the UVR has been historically used to assist in research site selection and identification of changes in conditions. **Additional remote sensing data, e.g., LiDAR, should be conducted used to provide a current and more portrayal of riverine conditions, and the database archived.**

Fishes

- Despite efforts to repatriate native fish (spikedace and loach minnow) into the upper headwaters above Perkinsville, nothing is known of the suitability and availability of habitat for these species. **It is imperative that surveys/assessments be conducted to establish these criteria before the projects are implemented.**
- It is useful to establish permanent stations (e.g., vegetation, channel, and fish data collected) where pre- and post-treatment data can be collected for the purpose of assessing success of fisheries, vegetation, and land management projects. Proposed monitoring station segments are not being grazed by livestock and as such would provide additional insight about no-grazing effects on fish and their habitats. **Additional studies should be initiated to understand the relationships between nonnative fishes, flow regimes, and management activities, such as fisheries and livestock grazing management in the riparian corridor and extrinsic land use activities on the watershed on native fish sustainability.**
- The relative roles of predation/competition by nonnative fishes and other invasive species such as crayfish, Asiatic clams, and bullfrog and their effects on native fish sustainability are poorly understood. **Research should be conducted to better understand inter- and intra-species relationships of nonnative aquatic species.**
- Spikedace have not been collected in periodic time-constrained surveys since 1997. These surveys have focused on habitats favored and those avoided by the fish. Surveys have included fixed sites as well as complete perennial channels in the river corridor. **An assessment should be conducted to determine the benefits of restocking UVR with spikedace from stock of the Gila River.**
- There is considerable controversy over the role of and need for woody debris in UVR channels. Woody debris became much more prevalent in UVR channels in the latter few decades of the Twentieth Century and has been implicated in proving habitat for predatory nonnative fish. **The role woody debris plays in sustainability of native fish species and riparian habitats needs to be researched for the UVR and other Southwestern streams.**
- The native fish fauna of the Southwest has evolved with drought and flood disturbance regimes. **The precise role of disturbance in the restoration and sustaining of native fish species and their habitats needs to be better understood for the UVR and other Southwestern streams.**
- Fish populations and communities on the UVR have been studied at seven fixed sites since the flood of 1993. This is a valuable resource because of its long-term nature, and it is probably the most complete environmental database for any river in the Southwest. **Continued monitoring and research relative to the long-term fish/habitat database on the UVR is needed.**

- Mechanical removal of nonnative fish has proven to be a promising method for reducing predatory nonnative fishes. Prescott National Forest managers, Rocky Mountain Research Station scientists, and fish resource management agencies should strongly consider collaborative efforts to test native fish response to the removal of nonnative fish efforts relative to the presence and or absence of management activities such as livestock grazing. **Studies of the mechanical removal of nonnative fish be continued in out years is highly recommended.**

- Chemical removal of nonnative fishes is not fish population specific and has the potential to adversely affect macroinvertebrates that are crucial to the native fish food supply, as well as potential human health issues. **Physical removal efforts should be a prerequisite to considering chemical removal of nonnative fishes in the uppermost reaches of the Verde River.**

- Laboratory studies such as those of Carpenter and Mueller (2008) suggest that juveniles of even smaller-sized nonnative fishes can have a potentially impact on native fishes. **Because of the ever-increasing literature on the impact of direct predation by nonnative fishes and other aquatic invasive species, this impact should be examined in the UVR by new studies.**

- Although studies have been conducted by the University of Arizona that lay a groundwork for future studies, primary and secondary production studies have not been a component of the past 15 years of study. **Primary and secondary production as related to flow regimes should be studied intensively enough to determine their role in the sustainability of native fishes in the UVR.**

- Spikedace restoration efforts must be coordinated with mechanical removal efforts and land management activities. On-going monitoring indicates that there is a high probability that the spikedace species has already been extirpated from the UVR. The combined monitoring efforts of the Rocky Mountain Research Station, Arizona Game and Fish Department, and the USDI Fish and Wildlife Service over the past decade and over the upper 60 km (38 mi) of river have failed to collect the species. Collaborative efforts should be initiated and pursued by these same agencies to experimentally introduce the species in the Arizona Game and Fish Department property and Black Bridge long-term site reaches. **There should be a continued effort to monitor the UVR for spikedace, as well as an increased emphasis on restoring the species to the UVR, as is a component of the Recovery Plan (USDI Fish and Wildlife Service 1990).**

Aquatic Ecology

- There are many key interactions with native and nonnative aquatic species for which we have little information. **The whole arena of aquatic ecology of the UVR needs to be explored.**

- The combination of warm temperatures, abundant sunlight, and organic matter inputs from a well-developed riparian zone have created a high potential for aquatic productivity in the UVR. **Primary production in the UVR relative to the food chain for native and nonnative fishes needs to be thoroughly investigated to more clearly define its role in the fish ecology of the river.**

- Macroinvertebrates commonly provide an important part of the ecology of fish populations in streams like the UVR. However, very little is known about this component of the UVR ecosystem. **Characterization of macroinvertebrate**

populations, their genetics, and their ecology in the UVR is needed to assess the sustainability of native fish populations.

- Changes in the hydrology of the UVR have the potential to adversely affect macroinvertebrate populations and their food sources. **The relationships between macroinvertebrate populations and flows in the UVR need to be examined.**

Water Quality

- Water quality data collected at the Verde Ranch and Y-D Ranch sites were not intended to guide land management actions or determine cause-and-effect relationships of upland management activities—they are too limited in extent, duration, and flow range sampling. At best, one can say that the water quality of the sampled reaches of the UVR is within the range of variability of warm water standards for the Southwest and does not raise any particular concerns. **However, a water quality monitoring program should be developed to assist in interpreting cause and effect relationships from integrated studies listed elsewhere. This program should be consistent with Arizona Department of Environmental Quality protocols.**
- Water quality is a key component of the UVR ecosystem but its role in sustaining or deteriorating aquatic productivity is poorly understood. **There should be a major expansion of water quality studies to compliment the fish, aquatic ecology, and geomorphology studies that may be done on the UVR.**

Database Management

- Many years have been invested in developing long-term databases for vegetation, hydrology, fishes, water quality, and photo point monitoring. The design of this archival system is applicable to historic databases as well and can set the example for archival of all other studies for the UVR. **These databases require a curator to organize and archive the data for retrieval and access to other scientists and managers. This is an important task to be completed as soon as possible, before personnel familiar with the data move or retire.**
- The photo point database is rich in content and is well organized, but will require periodic repeat photos in order to sustain a consistent temporal timeline. **Repeat photos should be taken at four- to five-year intervals, and more frequently in the event of major floods or other events.**

Management Opportunities

- The UVR Adaptive Management Partnership (UVRAMP) demonstrated its capacity to function as collaborative group for promoting science-based decisions to invoke management of the multiple resources at risk in the UVR. Vested parties from agencies and private landowners had opportunities to actively participate in dialogue about management issues and direct emphasis toward problem solving in a collaborative atmosphere. This type of award winning partnership is highly encouraged to assist the Prescott National Forest in long-term planning. **UVRAMP should be reactivated and used to promote holistic community-based resource management strategies for the UVR.**

- This synthesis of the UVR has provided many options for guiding management opportunities aimed at restoration of critical habitats, e.g., wetlands, fishery. **A comprehensive management strategy should be developed that incorporates various multiple aspects of the ecology of the UVR and integrates them with the socio-economic needs of the communities and the UVR ecosystem. Restoration plans and strategies need to be made part of this effort.**

Funding Sources

Research and monitoring documented in this report have been funded from a variety of resources including Federal government appropriated funds for the U.S. Forest Service and USDI Geological Survey. State government funds and University grants have also been used. In the current economic environment, these sources of funding are becoming increasingly constrained or eliminated. Future research will require partnerships of Federal, State, and University scientists to obtain funding from sources such as the National Science Foundation, special Federal appropriations like climate change, non-government organizations such as The Nature Conservancy, and private foundations. Limited amounts of land management agency funds can be directed toward monitoring, practical questions, and data needs, but these funds are generally not available for research.

Chapter 11

Summary and Conclusions

Daniel G. Neary, John N. Rinne, Alvin L. Medina

Introduction

Summaries and conclusions of each chapter are compiled here to provide a "Quick Reference" guide of major results and recommendations for the UVR. More detail can be obtained from individual chapters.

Summaries and Conclusions

Chapter 1. Introduction

A number of management issues which were raised in this chapter that were addressed in the rest of the report. Specifically, the research and monitoring documented here were conducted on behalf of the Prescott National Forest to assess the impacts of grazing on the watershed condition of the uplands and on the channels of riparian corridor of the UVR. This has been the primary land use issue on Prescott National Forest lands. Of particular concern to the Prescott National Forest is the impact of land management activities on the spikedace (*Meda fulgida*), a small fish species that is part of the native fish fauna of the UVR. The spikedace is a Federally listed threatened species, occurring in only four isolated stream and river systems in Arizona. Despite the lack of definitive evidence of any direct links between current grazing activities and stocking levels and declines of spikedace populations, the focus of regulatory and environmental concern has continued to be grazing and its potential impacts on watershed condition. Thus, one focus of the monitoring and research reported in this publication is watershed condition and immediate channel impacts.

Chapter 2. Historical and Pictorial Perspective of the Upper Verde River

Repeat photography was used to display the vivid texture of the UVR's vegetation, channel, and valley landscapes and to contrast the historical with current conditions. These contrasts are interpreted within the context of plant ecology and hydrogeomorphology to provide a comprehensive understanding of the changes that have occurred in the past century. In some cases, additional photographs provide greater breadth for understanding the larger perspective of the area and its habitats. A principal objective was to provide a broad understanding of historical influences that are necessary to comprehend the various physical and biological processes that govern present-day conditions on the UVR. Climate and land uses undoubtedly have affected the streamflow and sediment regimes, which in turn influenced such factors as riparian vegetation and aquatic wildlife.

Paleo-reconstruction studies of historical environmental conditions are utilized to put forward alternative descriptions of the Verde River for the period of record (1890 to present). Paleoecological data are useful for discriminating environmental changes between natural and cultural influences (Swetnam and others 1999). The introduction of livestock circa 1890 is an important event that is often cited as crucially influential on present-day conditions. However, many descriptions have been extrapolated from general sources that did not recognize climatic conditions during this period that may have had long lasting consequences on the evolution of riparian and aquatic habitats in the UVR.

Chapter 3. Verde River Hydrology

In this chapter, the geology and hydrology of the UVR were examined with special reference to the peak flows that form river geomorphology and habitat, and baseflows that support the aquatic fauna and riparian vegetation. Research is being conducted by a number of non-governmental organizations, as well as state, and Federal agencies to improve understanding of the UVR. Flows in the river are mostly stable baseflows due to steady contributions of groundwater flow from the Big Chino and other aquifers making this river unique in Arizona. Like other stream systems in Arizona, the UVR is subject to rare, episodic flood flows that rise three to four orders of magnitude above its baseflows. While drought can have an impact on the steady baseflows of the river, the overwhelming future impact on the sustainability of UVR perennial flow is urbanization of the Prescott and Chino Valley areas.

Chapter 4. Watershed Condition

When examined at a coarse scale of analysis, the TES discussed in this chapter can suggest which sub-watersheds may be contributing unusually high amounts of fine sediment. Such information can direct field monitoring to validate whether or not tributaries are inducing sedimentation of the main river. A comparison of current sediment yields relative to natural yields suggests that priority areas for reducing soil loss lie in the lower portions of the UVR watershed (Grindstone Wash/UVR hydrologic unit), the lower portion of Sycamore Creek watershed, and the Williamson Valley. Because the differences in soil losses calculated using the Universal Soil Loss Equation under current and hypothesized "natural" conditions are largely attributable to differences in ground cover, it is important to validate the relationships between ground cover and soil erosion for particular areas rather than relying on questionable assumptions.

The watershed assessment prepared by the Prescott National Forest suggested that the Tri-Canyon area (Hell Canyon HU) represented the greatest departure from potential, in contrast to this analysis. The impaired rating for the Hell Canyon HU was apparently based on the high percentage of unsatisfactory/impaired soil condition ratings as well as the abundance of very coarse substrates in the tributary channels. Historical watershed degradation that induced a flashier watershed condition would account for the geomorphic condition of the channels and the widespread occurrence of unsatisfactory soil conditions. Because historical accounts of flash flooding in the UVR watershed and its tributaries extend to an early date, the potential to improve watershed conditions, particularly in steep, rocky, and relatively arid areas, may be naturally quite limited.

The upland soil units of the UVR watershed have a range of watershed conditions that reflect the geology and semi-arid nature of the Prescott National Forest.

There are units that have very skeletal and unproductive soils and that show evidence of significant erosion in the geologic past. However, linkages between these erosion processes, land management, and channel geomorphology are tenuous at best.

Chapter 5. Channel Morphology

Measurements of channel morphology and application of channel classification have become a common tool for describing variation in rivers. The Rosgen (1996) classification system was applied to geomorphic data collected at 138 locations on the UVR from 1997 to 2000. The results showed that this segment of the river is dominated by gravel-bedded alluvial channels (B-, C-, and E-type) across a continuum of entrenchment. While channel typing in itself is not a sufficient basis for evaluating channel stability, the lack of braided channels (D-type) is consistent with more detailed studies that describe the UVR as hydrogeomorphically stable. Channel typing reveals that the river has a distinctive combination of low slope and low sinuosity. Due to the river's distinctive qualities, changes in riparian vegetation and aquatic habitat will occur at scales that are finer than that used for channel classification. Managers and researchers should adapt their sampling methods to focus on understanding such fine-scale changes in the river.

Chapter 6. Woody Vegetation of the Upper Verde River: 1996-2007

This chapter presents a quantitative description of the woody vegetation of the UVR based on 56 permanently established and monumented sampling sites. The UVR contains a large diversity of woody species (62) and plant associations. The plant associations found in the UVR contain species that are common to other streams of the Mogollon Rim region of the Southwest. However, one notable difference is the relatively high frequency and abundance of upland woody species found in close association with obligate riparian species on the Verde River. The presence of many facultative and upland species is attributed to the general absence of obligate species until circa 1980. Large cottonwood stands or willow thickets were absent until post-1993. Essentially, nearly all woody obligate (e.g., cottonwood) and facultative (boxelder) species established within the floodplain can be dated to 1993. Mature stands of velvet ash, Arizona walnut, and netleaf hackberry are common along the historical high water mark, in and amongst talus boulders. Brock (1987) characterized the riparian vegetation as a shrub community dominated by seepwillow, with interspersed species of velvet ash, Arizona walnut, Gooding's willow, Utah juniper, velvet mesquite, and desert willow.

Webb and others (1991, 2007) demonstrated that historically, many Southwestern riparian habitats including the Verde River, were largely devoid of typical gallery forests. They attributed floods as a principal agent in limiting the expansion of woody vegetation in Southwestern rivers (Turner 1974; Turner and Karpiscak 1980; Webb and Baker 1987; Turner and others 2003). Evidence from climate and hydrologic reconstruction studies is strongly linked with photographic evidence to conclude that woody vegetation is a recent Twentieth Century phenomenon in the UVR. Similarly, vegetation data from this study and photographic data (see Chapter 2) do not support the popular belief that gallery forests were prevalent in the Twentieth Century or earlier on the UVR. Cottonwoods and similar woody species were present in open valleys like Perkinsville but in very limited numbers. Arizona ash was more likely the dominant tree, as mature trees remain in greater abundance on terraces.

Chapter 7. Spatial and Temporal Variation in Streamside Herbaceous Vegetation of the Upper Verde River: 1996-2001

In this chapter, patterns of vegetation are examined in relation to major geomorphic and geologic attributes along the river. Specifically, this analysis examines how streamside vegetation in different reaches changed during the period of stable flows. A clearer picture of the ecology of the river is provided by better understanding longitudinal and temporal vegetation variation, and plant interactions within highly dynamic areas of the river, Along most reaches, the UVR is only moderately confined by valley walls, which allows low-gradient B- and C-type channels to develop (see Chapter 5). This analysis showed that some confined reaches with B- and C-type channels experienced considerable changes in streamside vegetation (e.g., Muldoon 13), while sites in the unconfined E-type channels of Verde Ranch were relatively stable. These changes may be undesirable for several reasons. Weedy aquatic species tended to increase while species associated with stable streambanks decreased. The weedy aquatic species crowd out native herbaceous plants and may provide increased cover for predatory nonnative fish. The changes may also induce channel narrowing retention of organic sediments that decrease the quality of habitat for native fishes.

Chapter 8. A Preliminary View of Water Quality Conditions of the Upper Verde River

Water quality data collected on the UVR were not comprehensive or continuous, and involved only two sites chosen for their ease of access and security, not for any scientific concern. However, the preliminary data collected for two stations from April 2000 to March 2001 suggest that all parameters (i.e., temperature, dissolved oxygen, pH, conductivity, turbidity, and total suspended solids) are consistent with warm water standards for the Southwest. The parameters are also well within the normal range of conditions for native fish such as the spikedace.

Chapter 9. Fish and Aquatic Organisms

The primary intent of this chapter was to summarize for land managers: (1) what is known, (2) what is not known, and (3) what the future research needs are to facilitate management to sustain native fishes in the UVR. Fish have been collected at seven long-term sites on the UVR since 1993. There has been a distinct decline in native fish species since the year after the 1993 flood, and there has been a parallel rise in nonnative fish species. Mechanical removal of nonnative fishes was not of sufficient intensity to have a significant effect with only an annual approach. Extensive streambank and in-stream vegetation reduced efficiency of removal, and limited treatment reaches (1 km or 0.6 mi) did not preclude movement of nonnatives into other sites.

The threatened spikedace disappeared from samples at seven monitoring sites within a few years after floods in 1992/93 and in 1995. The species has not been collected in the UVR since 1996 at the long-term sites and 1997 below one of the long-term sites at Black Bridge. Monitoring results demonstrate that the probability is high that spikedace species has already been extirpated from the UVR.

Chapter 10. Research Recommendations

Chapter 10 summarizes the research recommendations formulated by the authors based on their experience and the information presented in this volume. The main topics are needs related to general hydrology, groundwater, vegetation, geomorphology, fishes, aquatic ecology, and water quality. Aside from topics such as aquatic ecology, where there has just been a minimum effort, the most important recommendation relates to fishes. Continued monitoring and research relative to the long-term fish/habitat database on the UVR is needed. The fish population database is a valuable resource because of its long-term nature, and because it is probably the most complete for any river in the Southwest. Specific research methods are not discussed since those decisions are left to the study plans of individual investigations. The chapter concludes with a brief discussion of funding sources for future research.

Chapter 12. Information Sources

Information on the hydrology, geology, ecology, and management of the UVR can now be obtained from a number of web sites that are introduced in this chapter. The Southwest Watershed Science Team's web site provides reciprocal links to all of these sites (http://www.rmrs.nau.edu/awa/).

Chapter 12

Information Sources

Daniel G. Neary, John N. Rinne, Alvin L. Medina

Introduction

The main information sources for the UVR consist of several web sites with general information and bibliographies. RMRS has publications on its Air, Water, Aquatic Environments (AWAE) Program Flagstaff web site. Another RMRS and University of Arizona website on semi-arid and arid watersheds contains a large, searchable bibliography of supporting information from the Beaver Creek watersheds, in the Middle Verde River area. The Verde Watershed Association has a website on the river and normally supports a bibliography of publications. Northern Arizona University also supports several websites on the Verde River as does The Nature Conservancy.

Rocky Mountain Research Station Web Site

RMRS' Verde River web site is: http://www.rmrs.nau.edu/awa/verde/.

The Southwest Watershed Team of the AWAE Program has been involved in research on the UVR since 1993. The Team's predecessor, Research Work Unit RMRS-4302, Watersheds and Riparian Ecosystems of Forests and Woodlands in the Semi-Arid West, researched fish populations, riparian vegetation, channel geomorphology, invasive aquatic and plant species, and stream flows. This work resulted in over 62 publications (see the Verde River bibliography), and one of the most comprehensive riparian databases in any of the National Forests in the Southwest. RMRS has invested over $8 million since 1993 in developing comprehensive information about hydrology and ecology of UVR. Part of the Station's database is an extensive photo collection of on-going work and legacy photography.

Working with its cooperators in the UVR Adaptive Management Partnership (UVRAMP), the Team has been able to provide up-to-date science to help guide the Prescott National Forest's land management decisions. This has been very valuable to the Forest in terms of foregone appeals and litigation. Prescott National Forest staff estimated that the savings to the Forest have been over $5 million. UVRAMP consisted of the Prescott National Forest, RMRS, and several grazing permittees from allotments along the river. The partnership was open to any organization or agency interested in furthering the understanding of the Verde River ecosystem. UVRAMP was disbanded in 2011.

The objective of the AWAE Team's research has been the understanding of the physical, chemical, and biological influences affecting the native fauna and flora of this important river ecosystem. Current projects include the ongoing seven-site fish monitoring, aquatic non-native predator removal, and invasive plant control and removal.

Verde River Bibliography

The Verde River Bibliography consists of the publications produced by the AWAE Southwest Watershed Team. Publications originating from other entities such as USDI Geological Survey and State of Arizona Universities are being assembled and will form the second part of the bibliography at a later date. Copies of all the publications can be obtained electronically off of the Flagstaff AWAE web site or in hard copy by calling (928) 556-2001, by faxing (928) 556-2130, or by sending regular mail to:

Science Team Leader
Southwest Watersheds Research
Rocky Mountain Research Station
2500 South Pine Knoll Drive
Flagstaff, AZ 86001

Publications and up-to-date information on the status of the UVR Program can also be obtained by calling (208) 373-4351, faxing (208) 373-4391, or by sending regular mail to:

Program Manager
Air, Water, and Aquatic Environments Research Program
Rocky Mountain Research Station
Aquatic Sciences Laboratory
322 East Front Street, Suite 401
Boise, ID 83702

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Rocky Mountain Research Station and University of Arizona Web Site

The Southwest Watershed Team supports a web site that was developed in cooperation with the University of Arizona, Office of Arid Lands Studies, titled "Semiarid and Arid Watershed Management." It is available at: http://www.rmrs.nau.edu/awa/watershed/.

The web site contains 302 bibliographic entries of the 800+ article bibliography that deal with the Verde River. Descriptions of vegetation of the Verde River ecosystems and other features on past watershed management research by RMRS are also available. Actual watershed data from the Beaver Creek Experimental Watersheds, within the Middle Verde River reach, can be downloaded.

Verde Watershed Association

The Verde River Watershed Association web site contains information on the UVR and hosts a bibliography of UVR publications. It is available at: http://www.vwa.org/.

UVR Watershed Issues Web Site

The UVR Watershed Issues web site is available at: http://upperverdewaterissues.org/.

The purpose of the organization and web site is to analyze and present objective information about water resources and water resource issues in the UVR watershed. Several reports of interest are available for download.

UVR Issues Reports

Meyer, W.; Wolfe, E.W. 2007. How we know that ground water in the Big Chino Valley flows into the Verde River. 2 p.

Meyer, W.; Wolfe, E.W. 2007. Why Big Chino pumping threatens the Verde. 2 p.

Meyer, W.; Wolfe, E.W. 2006. A plan to mitigate the effect of Prescott's proposed pumpage from Big Chino Valley on the flow of the Upper Verde River—What needs to be considered. 4 p.

Wolfe, E.W.; Meyer, W. 2006, Water-resource issues in the Upper Verde Watershed. 5 p.

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UVR Watershed Project Bibliography

This bibliography was compiled by Jim Byrkit who was assisted by Bruce Hooper. It is available at: http://www.vwa.org/documents/verdebib.pdf.

Of the 1,369 entries in the bibliography, a few that are pertinent to this report follow:

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Arizona Geological Survey

The Arizona Geological Survey serves as a primary source of geologic information in the state to enhance public understanding of Arizona's geological character and resources. It provides technical advice and assistance to Federal, state, and local government agencies. Publications are available at: http://azgs.az.gov/publications.shtml.

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U.S. Geological Survey

Web-Based Information

USDI Geological Survey has several publications about the UVR available at: http://pubs.er.usgs.gov/.

A few pertinent publications are:

Anderson, M.T.; Woolsey, L.H., Jr. 2005. Water availability for the western United States—Key scientific challenges: U.S. Geological Survey Circular 1261. 85 p.

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Paulden Gauge

USDI Geological Survey operates the river gauging station at Paulden, Arizona. Its real time and record information can be accessed at: http://waterdata.usgs.gov/az/nwis/uv/?site_no=09503700.

The Nature Conservancy

Since purchasing property in the UVR headwaters, The Nature Conservancy has become much more active in sharing information on the UVR and in supporting conservation activities on the River. Information on The Nature Conservancy activities on the UVR is available at: http://azconservation.org/downloads/data/ecological_implications_of_verde_river_flows/.

Northern Arizona University

Northern Arizona University has been an active participant in UVR research and advocacy through the Ecological Monitoring and Assessment Program and the Watershed Research and Education Program of the Merriam-Powell Center for Environmental Research. Information on these programs can be found at: http://emaprogram.com/Verde River.asp and http://mpcer.nau.edu/.

Summary and Conclusions

Information on the hydrology, geology, ecology, and management of the UVR can be obtained from a number of web sites that are introduced in this chapter. The Southwest Watershed Science Team, AWAE Program, RMRS web site will contain reciprocal links to all of these sites to provide easy access to UVR information.

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Glossary

Sources

BIO—(Biology On-Line)
CNP—(California Native Plant Society)
DEC—(New York Department of Conservation)
ECO—(Sinauer Associates Ecology Textbook Companion Glossary)
ECO2—(Craig Chalquist Ecological Glossary)
FAO—(United Nations Food and Agriculture Organization Glossary)
FOR—(U.S. Forest Service Glossary)
GEO—(Geotech.org Dictionary)
GWB—(Garden Web Botanical Glossary)
NOAA (National Oceanographic and Atmospheric Administration Fisheries Glossary)
NWS—(National Weather Service Glossary)
PG—(Physical Geography.net Glossary)
ROS—(Rosgen Fluvial Geomorphology Glossary)
SRM—(Society for Range Management Glossary)
SSSA—(Soil Science Society of America Glossary)
STAT—(Stat Soft On-Line Statistical Text)
SWGTR (RMRS-GTR-42, Volume 4)
USGS—(U.S. Geological Survey Water Science Glossary, Geologic Glossary)
WEB—(Merriam-Webster's New Collegiate Dictionary)

Web Sites

BIO—(http://www.biology-online.org/dictionary/)
CNP—(http://www.cnps.org/cnps/vegetation/)
DEC—(http://www.dec.ny.gov/animals/7468.html#M)
ECO—(http://www.sinauer.com/ecology/glossary.html#E)
ECO2—(http://www.terrapsych.com/ecology.html)
FAO—(http://www.fao.org/fi/glossary/)
FOR—(http://forestry.about.com/blforgls.htm)
FWS—(http://www.fws.gov/sandiegorefuges/new/ccp/final/Volume%20II/Appendix%20A%20-%20C.pdf)
GWB—(http://glossary.gardenweb.com/glossary/)
NOAA (http://www.st.nmfs.noaa.gov/st4/documents/FishGlossary.pdf)
PG—(http://www.physicalgeography.net/physgeoglos.html)
ROS—(http://www.fgmorph.com/showglossary.php)
SRM—(http://extension.usu.edu/rangelands/htm/intro-rangelands/range-terms/)
STAT—(http://www.statsoft.com/textbook/)
SWGTR (http://www.fs.fed.us/rm/pubs/rmrs_gtr042_4.html)
USGS—(http://www.nature.nps.gov/geology/usgsnps/misc/glossary.html)

SSSA—(https://www.soils.org/publications/soils-glossary/#)

WEB—(http://www.merriam-webster.com/dictionary/)

Definitions

A

Acclimation: A reversible physical change in an adapting organism in response to environmental pressures. (ECO2)

Age Class: A group of individuals of the same age range in a population. The age 0 group are the fish in their first year of life. A fish born in April of a given year remains in the age 0 group until April of the following year. The term usually refers to a year class in long-lived annually breeding species. (NOAA)

Aggradation: Readjustment of a stream profile where the stream channel is raised by the deposition of bed load. (PG)

Allotment: An area of Federal lands designated for the grazing use of a designated number and kind of livestock under a specific plan of management. (SRM)

Alluvial: Referring to deposits of clay, silt, sand, gravel, or other particulate material that has been deposited by a stream or other body of running water in a streambed, on a flood plain, on a delta, or at the base of a mountain. (USGS)

Alluvium: Sediment transported chiefly by water and often sorted into similar size classes. (ROS)

Aquatic: Pertaining to water, in contrast to land. (FWS)

Aquic habitat: Habitat that is persistently wet; similar to aquatic. (ECO2)

Aquifer: A geologic formation(s) that is water bearing. A geological formation or structure that stores and/or transmits water, such as to wells and springs. Use of the term is usually restricted to those water-bearing formations capable of yielding water in sufficient quantity to constitute a usable supply. (USGS)

Arroyo: Spanish term for watercourse, gully, or channel, often dry. (WEB)

Artesian water: Groundwater in aquifers between layers of poorly permeable rock, such as clay or shale, may be confined under pressure. If such a confined aquifer is tapped by a well, water will rise above the top of the aquifer and may even flow from the well onto the land surface. (USGS)

Assemblage: 1. An association of coexisting species, in space and time, with similar environmental tolerance, possibly trophic relationships, but not totally interdependent; 2. A collection of species inhabiting a given area, the interactions between the species, if any, being unspecified. (NOAA)

B

Bankfull: This stream stage is delineated by the elevation of incipient flooding, indicated by deposits of sand or silt at the active scour mark, break in streambank slope, perennial vegetation limit, rock discoloration, and root exposure. (ROS)

Basalt: A dark, fine-grained, extrusive (volcanic) igneous rock with a low silica content (40% to 50%), but rich in iron, magnesium and calcium. Generally occurs in lava flows, but also as dikes. Basalt makes up most of the ocean floor and is the most abundant volcanic rock in the Earth’s crust. (USGS)

Baseflow: Streamflow sustained by subsurface flow and groundwater flow between precipitation events. (SWGTR)

Bedload: Portion of a stream's sediment load that is carried along the streambed without being permanently suspended in flowing water. (USGS)

B Horizon: The second layer of soil or soil material approximately parallel to the land surface and differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics such as color, structure, texture, consistency, kinds and number of organisms present, degree of acidity or alkalinity, etc. (SSSA)

Biological Diversity: 1. The variety and variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems. Diversity indices are measures of richness (the number of species in a system) and may reflect ecosystem stresses (such as those due to high fishing intensity); 2. Includes genetic diversity (within species), species diversity (within ecosystems), and ecosystem diversity. (NOAA)

Biological Opinion: A scientific assessment issued by the National Marine Fisheries Service or U.S. Fish and Wildlife Service, as required by the Endangered Species Act (ESA) for listed species. Determines the likelihood of an action to jeopardize the existence of a species listed under the ESA. (NOAA)

Biome: A terrestrial biological community shaped by the regional climate, soil, and disturbance patterns where it is found, usually classified by the growth form of its most abundant plants. (ECO)

Biota: The plant and animal life of a region. (FWS)

Boulders: Large rock fragments having diameters greater than 256 mm (10 inches). (PG)

Braided streams: Shallow stream channels that are subdivided into a number of continually shifting smaller channels separated by sediment bar deposits. (PG)

C

Channel types: Rosgen stream classification system (categories A-G) based on water surface slope, entrenchment ratio, width/depth ratio, and sinuosity further divided into categories 1 through 6 based upon dominant channel materials sizes (D50). (ROS)

Chaparral: A dry land plant formation of impenetrable thickets, composed of stiff, thorny, small-leaved shrubs. (GWB)

Cluster analysis: This is a statistical term that encompasses a number of different operations or procedures and methods for grouping objects of similar kind into respective categories. (STAT)

Cobble: A rounded rock fragment found in streams between 64 and 256 mm in diameter (2.52 and 10.08 inches). (PG)

Code of Federal Regulations (CFR): A codification of the regulations published in the Federal Register by the executive departments and agencies of the Federal government. The CFR is divided into 50 titles that represent broad areas subject to Federal regulation. (NOAA)

Co-dominant: A tree that extends its crown into the canopy and receives direct sunlight from above but limited sunlight from the sides. One or more sides of a co-dominant tree are crowded by the crowns of dominant trees. (FOR)

Community: The terrestrial and aquatic populations that live and interact physically and temporally in the same area. (NOAA)

Conifer: Cone-bearing tree of the pine family, usually evergreen. (GWB)

Control section: A physical feature(s), either sectional, channel, or flood plain, that directly defines the slope of the stage-discharge relation at the streamgage. The control section defines the relative hydraulic stability of a stream bed, channel, or flood plain. At low flows the sectional control is usually at or immediately downstream from the measurement section of the gage. A typical stable natural control is bedrock or consolidated alluvium that is not subject to scour or deposition. (USGS)

Cross-section: Surveyed line across a stream channel. (USGS)

D

Degradation: Readjustment of a stream profile into a lower slope where the stream channel is lowered by the erosion of the stream bed. Usually associated with high discharges. (USGS)

Dendrogram: A tree diagram frequently used to illustrate the arrangement of the clusters produced by hierarchical clustering. (FOR)

Detritus: Decomposing organic matter such as leaves, insects, woody material, roots, bugs, etc. (ECO2)

Discharge: The volume of water that passes a given location within a given period of time. Usually expressed in cubic feet per second or cubic meters per second. (USGS)

Disturbance: Significant alteration of habitat structure or composition. May be natural (e.g., fire, drought, landslides, etc.) or human-caused events (e.g., logging, urbanization, etc.). (FWS)

E

Ecosystem: A geographically specified system of organisms, the environment, and the processes that control its dynamics. Humans are an integral part of an ecosystem. (NOAA)

Ecosystem function: An intrinsic ecosystem characteristic related to the set of conditions and processes whereby an ecosystem maintains its integrity. Ecosystem functions include processes such as decomposition, production, nutrient cycling, and fluxes of nutrients and energy. (NOAA)

Ecosystem health: A measure of the stability and sustainability of ecosystem functioning or ecosystem services that depends on an ecosystem being active and maintaining its organization, autonomy, and resilience over time. Ecosystem health contributes to human well-being through sustainable ecosystem services and conditions for human health. (NOAA)

Ecotone: The transitional zone between adjacent biotic communities, often with unique nutrients and ecological relationships. (ECO)

El Niño: Also known as the Southern oscillation, this is a warming of the ocean current along the coasts of Peru and Ecuador that is generally associated with dramatic changes in the weather patterns of the region; a major El Niño event generally occurs every 3 to 7 years and is associated with changes in the weather patterns worldwide. (NWS)

Entrenchment ratio: The channel width at two times the bankfull depth divided by the channel width at bankfull. (ROS)

Environmental Assessment (EA): As part of the National Environmental Policy Act (NEPA) process, an EA is a concise public document that provides evidence and analysis for determining whether to prepare an environmental impact statement (EIS) or a finding of no significant impact (FONSI). (NOAA)

Environmental Impact Statement (EIS): As part of the National Environmental Policy Act (NEPA) process, an EIS is an analysis of the expected impacts resulting from a proposed Federal action on the environment. An EIS is required for all Federal management plans as well as significant amendments to existing plans. The purpose of an EIS is to ensure that the proposed Federal action gives appropriate consideration to environmental values in order to prevent harm to the environment. (NOAA)

Ephemeral flow: Streamflow within a normally dry channel, occurring inconsistently or infrequently and seasonally. (USGS)

Erosion: The process by which particles of rock and soil are loosened, as by weathering, and then transported elsewhere, as by wind, water, ice, or gravity. (ROS)

Escarpment: A long, high, steep face of rock forming a cliff. (WEB)

Evaporation: The process of liquid water becoming water vapor, including vaporization from water surfaces, land surfaces, and snow fields, but not from leaf surfaces. (USGS)

Evapotranspiration: The sum of evaporation and transpiration (USGS)

Extrinsic factors: Causative agent outside of a biological or physical system. (WEB)

F

Facultative plant: Species that can occur both in wetlands and uplands. (WEB)

Fine sediment: Sediment consisting of sand, silt, and clay particles <0.5 mm (0.2 inches) in diameter. (USGS)

Fish assemblage: An association of co-existing fish species with similar environmental tolerance, possibly trophic relationships, but not totally interdependent. (FAO)

Flash flood: Sudden, temporary overflow of water outside of a stream's bankfull depth. (USGS, ROS)

Flashy storm runoff: See Flash flood.

Floodplain: A strip of relatively flat and normally dry land alongside a stream, river, or lake that is covered by water during a flood. (ROS)

Flora: Plants (WEB)

Flow duration curve: Cumulative curve of the percent of time streamflow is at a range of flows from peakflow to lowest baseflow. (USGS)

Fluvial: Pertaining to a river. (FWS)

Finding of No Significant Impact (FONSI): As part of the National Environment Policy Act (NEPA) process, a FONSI is a document that explains why an action that is not otherwise excluded from the NEPA process, and for which an environmental impact statement (EIS) will not be prepared, will not have a significant effect on the human environment. (NOAA)

G

Gallery forest: A stretch of forest along a river in an area of otherwise open country. (PG)

Geomorphology: The field of knowledge that investigates the origin of landforms on the Earth and other planets. (WEB)

Glide: A third general habitat category possessing attributes of both riffles and pools. Glides are characterized by moderately shallow water (10-30 cm or 3.94-11.81 inches) with an even flow that lacks pronounced turbulence. Although they are most frequently located at the transition between pool and the head of a riffle, glides are occasionally found in long, low gradient stream reached with stable banks and no major flow obstructions. The typical substrate is gravel and cobbles. (USGS)

Graben: An elongate block of rock down-dropped along roughly parallel faults. (USGS)

Gradient: Slope. (SSSA)

Gravel: All sediment particles larger in diameter than 2 mm (0.08 inches) is called gravel. Gravel is subdivided into pebbles, cobbles, and boulders. (USGS)

Grazing allotment: An area of federal lands designated for the grazing use of a designated number and kind of livestock under a specific plan of management. (SRM)

Groundwater: 1. Water that flows or seeps downward and saturates soil or rock, supplying springs and wells. The upper surface of the saturated zone is called the water table. 2. Water stored underground in rock crevices and in the pores of geologic materials that make up the Earth's crust. (USGS)

Gully: A very small channel formed by running water. Gullies hold water for brief periods of time after a rain storm or snow melt. (USGS)

Gully erosion: Erosion occurring at the head of or inside a gully system. (SSSA)

H

Habitat: The place or conditions where specific organisms (plants and animals) live. (ECO)

Herbaceous species: Plants with little or no woody tissue that die back to their roots each year during winter. (GWB)

Herbaceous vegetation: See Herbaceous species.

Herbivore: An organism that eats the tissues or internal fluids of living plants or algae. (ECO)

Holocene: An epoch of the Quaternary Period beginning 10,000 years ago and continuing today. (USGS)

Hydrograph: A graphical relationship of streamflow discharge in ft3/sec or m3/sec to time.

Hydric habitat: Habitat that is characteristically wet most of the year. (SSSA)

Hydrologic Unit Code (HUC): Unique 2-8 digit numbers that classify United States stream locations into regions, subregions, accounting units, and cataloging units. (USGS)

Hydrology: Field of physical geography that studies the hydrosphere. (PG)

Hydrosphere: The hydrosphere describes the waters of the Earth. Water exists on the Earth in various storage areas including the atmosphere, oceans. Lakes, rivers, glaciers, snowfields, and groundwater. Water moves from one area to another by way of evaporation, condensation, precipitation, deposition, runoff, infiltration, sublimation, transpiration, and groundwater flow. (PG)

Hydrophytic vegetation: Plants living in wholly or partially in water. (ECO)

I

Intrinsic factors: Causative agents within a biological or physical system. (WEB)

Introduced species: With respect to a particular ecosystem, any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem. Introduced species often compete with and cause problems for native species. Introduced species are also called exotic, nonnative, and alien species. (NOAA)

Invasive species: An introduced species that out-competes native species for space and resources. (NOAA)

L

La Nina: La Niña, a phase of the El Niño-Southern Oscillation, is a periodic cooling of surface ocean waters in the eastern tropical Pacific along with a shift in convection in the western Pacific further west than the climatological average. These conditions affect weather patterns around the world. The preliminary definition of La Niña is a phenomenon in the equatorial Pacific Ocean characterized by a negative sea surface temperature departure from normal. (NWS)

Legacy impacts: Ecosystem impacts from historical land uses or disturbances such as floods, fires, droughts, earthquakes, etc. (ECO)

Limestone: A sedimentary rock made mostly of the mineral calcite (calcium carbonate). Limestone is usually formed from shells of once-living organisms or other organic processes, but may also form by inorganic precipitation. (USGS)

Lithology: Refers to sediment type. (SSSA)

Lithologic: Pertaining to the physical character of a rock. (SSSA)

Longitudinal association: Association of plants along the length of a stream rather than across it as in a transect association. (ECO)

M

Macrohabitat: An extensive habitat presenting considerable variation of the environment, containing a variety of ecological niches, and supporting a large number and variety of complex flora and fauna. (ECO2)

Macroinvertebrates: A small animal generally visible to the unaided eye, usually larger than 0.5 mm (0.02 inches). These animals do not have a backbone. (DEC)

Marsh: A wet area, periodically inundated with standing or slow moving water, that has grassy or herbaceous vegetation and often little peat accumulation. The water may be salt, brackish or fresh. Sometimes they are called wet prairies, swamps, tidal flats, and wetlands. (USGS)

Meander: Sinuous shaped stream channel usually found in streams flowing over a very shallow elevation grade. (PG)

Mesic habitat: Habitat intermediate between wet and arid. (ECO)

Metric ton: 1,000 kilograms (kg), equivalent to 2,204.6 pounds, 1 Megagram (Mg). (NOAA)

Microhabitat: a small, specific habitat, like under a log or in a bush. (ECO2)

Microphyllous: Small leaved plant. (WEB)

Monsoon: A regional scale wind system that predictably changes direction with the passing of the seasons. Monsoon winds blow from land to sea in the winter, and from sea to land in the summer. The latter are often accompanied with heavy precipitation. (PG)

Mudstone: A very fine-grained sedimentary rock formed from mud. (USGS)

N

National Environmental Policy Act: Passed by Congress in 1969, NEPA requires Federal agencies to consider the environment when making decisions regarding their programs. Section 102(2)(C) requires Federal agencies to prepare an environmental impact statement (EIS) before taking major Federal actions that may significantly affect the quality of the human environment. The EIS includes the environmental impact of the proposed action, any adverse environmental effects which cannot be avoided should the proposed action be implemented, alternatives to the proposed action, the relationship between local short-term uses of the environment and long-term productivity, and any irreversible commitments of resources which would be involved in the proposed action should it be implemented. (NOAA)

Native species: Plant or animal species naturally residing in an area or habitat. (NOAA)

Nonnative species: Plant or animal species introduced into a habitat from another location. (NOAA)

O

Obligate: Species that occur only in selected habitats, such as wetlands, or uplands. (WEB)

Ordination: In multivariate analysis, ordination is a method complementary to data clustering, and used mainly in exploratory data analysis rather than in hypothesis testing. Ordination orders objects that are characterized by values on multiple variables (i.e., multivariate objects) so that similar objects are near each other and dissimilar objects are farther from each other. These relationships between the objects, on each of several axes (one for each variable), are then characterized numerically and/or graphically. (STAT)

Overland flow: Also called surface runoff, this is water flow that has not infiltrated into the mineral soil and flows along the surface to a stream channel. (SWGTR)

P

Paleo-ecological: Refers to the characteristics of ancient environments and their relationships to ancient plants and animals. (WEB)

Paleoflood: Prehistoric flood. (USGS)

Peakflow: The maximum instantaneous or time-related stream discharge for a given event or time period. (PG)

Parameter: A “constant” or numerical description of some property of a population (which may be real or imaginary). (NOAA)

Pebble count: Method for determining stream sediment size in streams developed by Wolman (1954) utilizing random sampling within a grid system. This method was further developed into a field procedure by Bevenger and King (1995). The pebble count is a systematic method of sampling and measuring the diameters (b-axis) of a sufficient number of pebbles (and possibly other rounded rock fragments of smaller and larger size) to attain a significant representation of the range of sizes and median size of a deposit of coarse sediment. (ROS)

Pedestalling: Process of forming soil erosion pedestals by the removal of soil material around resistant artifacts such as rocks, pieces of woody debris, or compacted soil. (SSSA)

Perennial flow: Continual year round streamflow. (NWS)

pH: Water quality parameter that is the negative logarithm of the hydrogen ion concentration.

Phreatophyte: Plant that can endure periodic flooding or saline conditions (GWB)

Phytoplankton: Small photosynthetic organisms, mostly algae and bacteria, found inhabiting aquatic ecosystems. (PG)

Plant abundance: The number of individuals in a plant species that are found in a given area. Abundance is often measured by population size or population density. (ECO)

Plant associations: A grouping of plant species, or a plant community, that recurs across a landscape. Plant associations are used as indicators of environmental conditions such as temperature, moisture, light, etc. (BIO)

Plant community: A group of interacting plant species that occur together at the same place and time. (ECO)

Plant cover: Percent of the soil surface occupied by plants. (ECO)

Plant density: Plant numbers or biomass per unit area. (ECO)

Plant dominance: A plant species that has large, community-wide effects by virtue of its size or abundance, its strong competitive ability, or its provision of habitat or food for other species, also called a foundation species. (ECO)

Plant constancy: The tendency for plants to be perceived as unchanging despite variations in the positions in and conditions under which the plant species are observed. (BIO)

Population: All the members of a single species coexisting in one ecosystem at a given time. (FWS)

Precipitation: Rain, snow, hail, sleet, dew, and frost. (USGS)

Predation: Relationship between two species of animals in which one (the predator) actively hunts and lives off the meat and other body parts of the other (the prey). (NOAA)

Q

Quadrat: A small area set aside for ecological measurements and study. (ECO2)

Quaternary: The most recent Period of the Cenozoic Era. Encompasses the time interval of 1.6 million years ago through today. (USGS)

R

Regolith: Any solid material lying on top of bedrock. Includes soil, alluvium, and rock fragments weathered from the bedrock. (GEO)

Recruitment: The annual increase in a population as determined by the proportion of surviving offspring produced during a specific period (usually expressed per year). (FWS)

Relevé: The relevé method of sampling vegetation was developed in Europe and was largely standardized by the Swiss ecologist Josias Braun-Blanquet. The use of relevé in the United States has not been extensive with the exception of the U.S. Forest Service. The relevé is particularly useful when observers are trying to quickly classify the range of diversity of plant cover over large units of land. In general, it is faster than the point intercept technique. The relevé is generally considered a "semiquantitative" method. It relies on ocular estimates of plant cover rather than on counts of the "hits" of a particular species along a transect line or on precise measurements of cover/biomass by planimetric or weighing techniques. (CNP)

Return interval: A return period or return interval is an estimate of the interval of time between climatic events of a certain intensity or size. It is a statistical measurement denoting the average recurrence interval over an extended period of time, and is usually required for risk analysis (i.e. whether a project should be allowed to go forward in a zone of a certain risk) and also to dimension structures so that they are capable of withstanding an event of a certain return period (with its associated intensity). It is calculated as RI = n + 1/m where n is number of years on record; m is the rank of the event being considered. (USGS)

Riffle: Sediment deposit found on the bed of streams. Associated with these deposits are glides, runs, and pools. (PG)

Rill: A very small steep sided channel carrying water. This landscape feature is intermittent and forms for only a short period of time after a rainfall. (PG)

Rill erosion: Small scale erosion on a landscape. (PG)

Riparian: Areas that are situated in the interfaces between terrestrial and aquatic ecosystems that can be found along open bodies of water, such as the banks of rivers and ephemeral, intermittent, and perennial streams, and around lakes, ponds, springs, bogs, and meadows. (SWGTR)

Risk: 1. In general, the possibility of something undesirable happening, of harm or loss. A danger or a hazard. A factor, thing, element, or course involving some uncertain danger; 2. In decision-theory, the degree or probability of a loss; expected loss; average forecasted loss. This terminology is used when enough information is available to formulate probabilities; 3. The probability of adverse effects caused under specified circumstances by an agent in an organism, a population, or an ecological system. (NOAA)

Risk assessment: A process of evaluation including the identification of the attendant uncertainties, of the likelihood and severity of an adverse effect(s)/event(s) occurring to man or the environment following exposure under defined conditions to a risk source(s). A risk assessment comprises hazard identification, hazard characterization, exposure assessment, and risk characterization. (NOAA)

River continuum concept: A holistic view of rivers, first proposed by Robin L. Vannote and others in 1980, which permits a broad zonation of river systems based on the utilization of energy through the orderly processing of organic matter by the resident biota. The theory is based on the concept of dynamic equilibrium in which streamforms balance between physical parameters, such as width, depth, velocity, and sediment load, also taking into account biological factors. (USGS)

Run: Stream reach with uniform flow. (USGS)

Runoff: 1. That part of the precipitation, snow melt, or irrigation water that appears in uncontrolled surface streams, rivers, drains or sewers. Runoff may be classified according to speed of appearance after rainfall or melting snow as direct runoff or base runoff, and according to source as surface runoff, storm interflow, or ground-water runoff. 2. The total discharge described in (1), above, during a specified period of time. 3. Also defined as the depth to which a drainage area would be covered if all of the runoff for a given period of time were uniformly distributed over it. (USGS)

S

Sample: A proportion or a segment of a biological population or the physical environment that is removed for study, and is assumed to be representative of the whole. The greater the effort, in terms of both numbers and magnitude of the samples, the greater the confidence that the information obtained is a true reflection of the status of the object of study. (NOAA)

Sand: Loose particles of rock or mineral (sediment) that range in size from 0.0625-2.0 mm (0.002-0.08 inches) in diameter. (USGS)

Sandstone: Sedimentary rock made mostly of sand-sized grains. (USGS)

Sclerophyllous: Small plants that have hard, thickened leaves and have a relatively short distance along the stem between the leaves (short internodes). Sclerophyllous plants are often from dry areas. (SRM)

Sediment: Eroded soil or geologic parent material that is transported from watershed surfaces to stream channels by overland flow, and then through stream systems in streamflow. It is the product of erosion. (SWGTR)

Sedimentation: The process of deposition of sediment in stream channels or downstream reservoirs. (SWGTR)

Shear stress: Stress caused by forces operating parallel to each other but in opposite directions. (PG)

Shrub: A plant that has persistent woody stems and a relatively low growth habit, and that generally produces several basal shoots instead of a single bole. It differs from a tree by its low stature and nonarborescent form. Usually shrubs are less than 4.9 m (16 ft) tall at maturity. (FOR)

Siltstone: A sedimentary rock made mostly of silt-sized grains. (USGS)

Sinuosity: As applied to stream-channel pattern, is a non-dimensional ratio, generally expressed in meters per meter or kilometers per kilometer, of the length of the channel thalweg to the length of the stream valley, measured between the same points. (USGS)

Site/soil productivity: The capabilities of a site, soil, or watershed to support sustained plant growth and plant communities, or the natural sequences of plant communities. (ECO)

Skeletal soils: Poorly developed soils. (SSSA)

Soil classification: The systematic arrangement of soils into groups or categories on the basis of their characteristics. (SSSA)

Soil compaction: Increasing the soil bulk density, and concomitantly decreasing the soil porosity, by the application of mechanical forces to the soil. (SSSA)

Soil erosion: The dislodgement and transport of soil particles and small aggregates of soil by the actions of water, wind, ice, and gravity.

Soil texture: The relative proportions of the various soil separates in a soil as described by the classes of clay, clay loam, loam, loamy sand, sand, sandy cay, sandy clay loam, sandy loam, silt, silt clay, silt clay loam, and silt loam. The textural classes may be modified by the addition of suitable adjectives when rock fragments are present in substantial amounts; for example, "stony silt loam." The sand, loamy sand, and sandy loam classes are further subdivided on the basis of the proportions of the various sand separates present. (SSSA)

Southern Oscillation: Also known as ENSO. See El Niño and La Niña.

Species richness: The number of species in a community. (ECO)

Specific conductivity: Electrical conductivity is a measure of water's ability to conduct electricity, and therefore a measure of the water's ionic activity and content. The higher the concentration of ionic (dissolved) constituents, the higher the conductivity. Conductivity of the same water changes substantially as its temperature changes. This can have a confounding effect on attempts to compare this feature across different waters, or seasonal changes in this parameter for a particular body of water.

Stream gage: Structure with known hydraulic properties used to measure water flow in a stream. (PG)

Streambank: The sides of a stream channel. (PG)

Streamflow: The water discharge that occurs in a natural channel. A more general term than runoff, streamflow may be applied to discharge whether or not it is affected by diversion or regulation. (USGS)

Stormflow: The sum of channel interception, surface flow, and subsurface flow during a precipitation or snowmelt event. (SWGTR)

Substrate: 1. That which is laid or spread under an underlying layer, such as the subsoil. 2. The substance, base, or nutrient on which an organism grows. 3. Compounds or substances that are acted upon by enzymes or catalysts and changed to other compounds in the chemical reaction. (SSSA)

T

Terrace: An abandoned floodplain due to river incision or downcutting, etc. (ROS)

Total suspended solids: Sum of mineral and organic particles in a water column. (USGS)

Transect: Environmental measurement method using a straight line across vegetation, soils, streams, etc. (ECO)

Turbidity: A measure of suspended fine mineral or organic matter that reduces sunlight penetration of water, and influences photosynthesis rates and water quality. (SWGTR)

V

Vegetation: The composition of plant species, their frequency of occurrence, density, and age classes at a specified scale. (NOAA)

W

Water quality: Refers to the physical, chemical, and biological characteristics of water in reference to a particular use. (SWGTR)

Water table: The top of the water surface in the saturated part of an aquifer. (ROS)

Watershed: The areas which supply water by surface and subsurface flow from precipitation to a given point in the channel network.

Watershed condition: A subjective term to indicate the health (status) of a watershed in terms of its hydrologic function and soil productivity. (ROS)

Wetlands: Areas that are saturated by surface water, groundwater, or combinations of both at a frequency and duration sufficient to support a prevalence of vegetation adapted to saturated soil conditions. (SWGTR)

Width/depth ratio: Numerical ratio of stream width to stream depth. (ROS)

Woody vegetation: Plants with predominantly wood (xylem) tissue. (FOR)

X

Xeric habitat: Habitat that is characterized by predominantly arid or dry conditions. (SSSA)

Y

Young of the year: Refers to fish <1 year old.

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