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Status of the Upper San Pedro River (United States) Riparian Ecosystem

TWENTY

Introduction

Because rivers are products of their watersheds, riparian preserves can be affected by off-site activities that alter the hydrologic cycle (Pringle 2000, 2001). We explore this issue of off-site effects for the San Pedro Riparian National Conservation Area (SPRNCA) (fig. 20.1). The U.S. Bureau of Land Management (BLM) strives to protect and enhance this desert riparian ecosystem and has filed for federal reserved water rights to maintain it (see chap. 22). Groundwater pumping, floodplain agriculture, off-road vehicle use, and mineral development have been halted within the SPRNCA, and a moratorium has been placed on livestock grazing (Yuncevich 1993). However, much of the upper San Pedro watershed is under state and private ownership and is steadily urbanizing (Steinitz et al. 2003). About 70,000 people live in the Sierra Vista subwatershed, with each using a portion of the basin's groundwater resources. Fewer people live in the Benson subwatershed, but considerable water is used in that area for agricultural purposes, and the population is growing rapidly (Kepner et al. 2004). There are concerns that the riparian ecosystem is being affected by human actions, notably groundwater pumping, occurring beyond the conservation area borders (Arias 2000; and see chap. 21).

Scientific studies play an important role in determining workable solu-

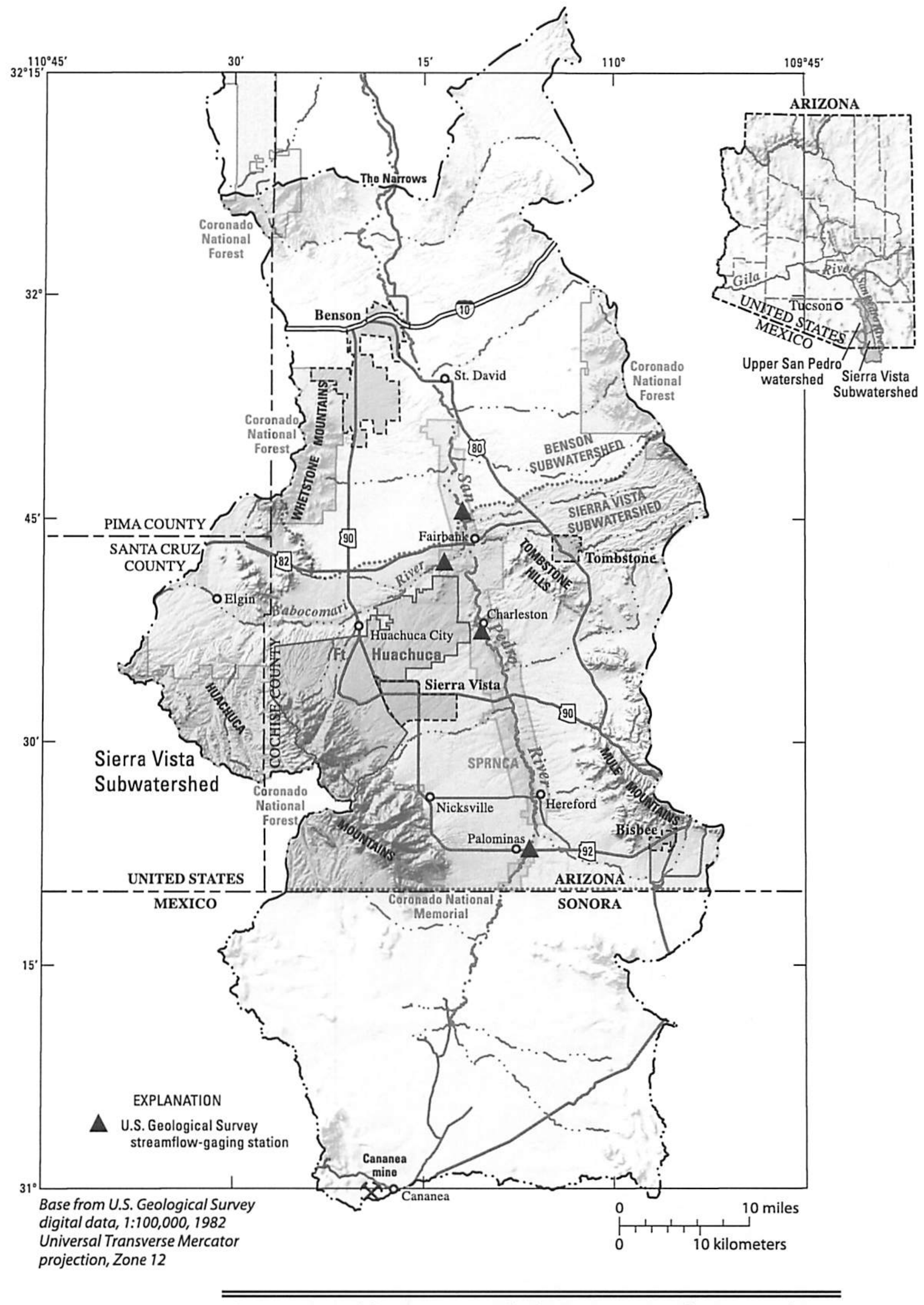


Fig. 20.1. Map of the upper San Pedro basin. Courtesy of James Leenhouts.

tions to water management challenges (Naiman et al. 2002, B. D. Richter et al. 2003) and are of value to stakeholders in the upper San Pedro watershed who are working towards the goal of sustainable groundwater management (see chap. 21). In this chapter we review some of the ecological issues that underpin the San Pedro conservation challenge. We discuss recent findings regarding water needs of the San Pedro riparian vegetation, explore the factors driving observed changes in San Pedro streamflows and riparian vegetation, and review ecological aspects of some management actions implemented to achieve sustainable water use.

How Much Water Does the San Pedro Riparian Ecosystem Need?

FLOW REGIMES

Various approaches can be taken to determine the amount of water, as well as the temporal and spatial patterns of water flow, that sustain aquatic and riparian biotic communities (Richter et al. 1997, Nilsson and Svedmark 2002, Postel and Richter 2003). A useful approach for determining environmental flow needs is the Building Block Methodology (King et al. 2003). For this, a recommended streamflow regime is constructed, on a month-by-month basis, by combining components of the flow regime that sustain different biotic elements or ecosystem functions. If the biotic components are selected judiciously, with each serving as a multi-species umbrella (Lambeck 1997), the composite flow regimes will encompass the processes and conditions that sustain a wide diversity of species and functional types.

Streamflow regimes can be characterized by their magnitude, timing, frequency, duration, and rate of change (Poff et al. 1997), with these applying both to the high-flow (floods) and low-flow (baseflow) components, and to surface (stream) and subsurface (groundwater) flow. The first building blocks of the flow regime are the low-flow conditions that provide water for survivorship of many organisms throughout seasonal dry periods. The second are small, annual floods for channel and habitat maintenance and for stimulating reproduction and growth of some aquatic and riparian organisms. The third are large, less-frequent floods that structure the channel, inundate the floodplain, recharge the floodplain (i.e., stream) aquifer, distribute nutrients and seeds across the floodplain, and create opportunities for establishment of riparian plants.

Table 20.1 portrays streamflow building blocks for the aquatic and riparian biota of the upper San Pedro River. Fish and other aquatic biota require surface flows in the channel year-round. Wetland plants along the channel edge depend upon saturated soils throughout the growing season, a condition associated with perennial streamflow (see chap. 1). Shallow groundwater (less than approximately 3 m below ground surface and with no more than

TABLE 20.1. Relationship of biota on the upper San Pedro River to components of the surface water/groundwater flow regime.

Seasons include the warm spring dry season (April through June), warm summer wet season (July through September), and the cool fall-winter (October through March) season.

Flow component	Frequency, magnitude, or fluctuation	Season	Function
Baseflows	Perennial (100%)	Cool and warm	Sustain riverine marsh vegetation; sustain fish and other aquatic organisms; provide drinking water for wildlife
Riparian groundwater	Depth of <3 m; inter-annual fluctuation <1 m	Cool and warm	Sustain dense, multi-age cottonwood/willow forests and seepwillow shrublands
Riparian groundwater	Depth of <3 m	Cool	Sustain high productivity of sacaton grasslands
Small floods	<5 yr return interval	Warm-wet	Increase productivity and diversity of warm-season plants
Small floods	<5 yr return interval	Cool	Increase productivity and diversity of cool-season plants
Large floods	>5 yr return interval	Warm-wet	Stimulate establishment and increase productivity of warm-season plants
Large floods	>5 yr return interval	Cool	Stimulate establishment of cottonwood/willow and other cool-season germinants; increase plant productivity; drive floodplain patch dynamics

1 m intra-annual fluctuation) maintains dense forests of Fremont cottonwood (*Populus fremontii*) and Goodding's willow (*Salix gooddingii*) and also maintains high productivity of big sacaton (*Sporobolus wrightii*) grass. Winter floods of suitable magnitude (sufficient to scour vegetation and mobilize sediment) and timing (with draw-down during the spring germination season) trigger the establishment of new generations of cottonwood and willow trees. Floods also play a role in the establishment of many other riparian and aquatic organisms, including certain fish. Summer floods provide pulses of productivity in riparian grasses, forbs, and trees, with cascading effects on insects, birds, and other animals. A range of small to large floods, in summer, fall, and winter, create spatially and temporally heterogeneous environments and maintain high diversity in the riparian zone. In concert, perennial streamflows, shallow groundwater, and seasonal rains and floods of varying intensity sustain a diverse and productive community of plants and animals.

GROUNDWATER QUANTITIES

Although many plant species in the San Pedro riparian corridor are sustained by floodwater or rain, the dominant overstory species, including cot-

TABLE 20.2. Groundwater use by major[1] vegetation types along the San Pedro River within the San Pedro Riparian National Conservation Area as measured in 2003.

Vegetation type	Total canopy area in SPRNCA (ha)	Groundwater use per unit area of canopy (mm yr^{-1})	Total estimated groundwater use in SPRNCA (1000 m^3 yr^{-1})	Percent of ET from groundwater
Cottonwood/willow, perennial reach	253	966[2]	2444[2]	100
Cottonwood/willow, intermittent reach	177	410	726	84
Mesquite	1154–1456[3]	689	7953–10035	75
Sacaton (<3 m to groundwater)	113–168	575	650–967	68
Saltcedar	72–108[3]	689	496–744	NA
Open water	73	1156	884	100
TOTAL IN SPRNCA	1842–2235		13113–15759	

Source: Leenhouts et al. 2006.

[1]Minor vegetation types not included in the table are seepwillow, and herbaceous types such as Johnson grass and Bermuda grass.

[2]Values are reported to the nearest millimeter, per convention in the water use literature, but this does not represent their level of certainty or accuracy.

[3]Range reflects uncertainty in percent canopy cover values in the vegetation map.

tonwood, willow, and mesquite (*Prosopis*), are sustained wholly or in part by groundwater. From a perspective of groundwater consumption, the question, "How much water is needed to support the current riparian vegetation?" can be reduced to a single number, with associated variance, for various desired river conditions (table 20.2). A suite of studies conducted along the San Pedro River has estimated the evapotranspiration (ET) rates for the common riparian plant associations. The area of each vegetation type has been mapped from aerial photographs, allowing for landscape-scale estimation of ET and the total consumptive water use of the riparian vegetation (Leenhouts et al. 2006; and see chap. 2).

These landscape-scale estimates of groundwater use have considerable variance. The variance arises because of measurement error (e.g., mapped patch area, ET rates per patch), but also because there is true spatial variance in ET rates among patches of a given type (due to differences in plant age, plant density, and groundwater levels) and true variance between years in water availability, temperature, and other factors that affect plant water use. The fraction of transpired water derived from groundwater (vs. soil water from rains or floods) also varies between vegetation types, as well as among sites and years, particularly for facultative phreatophytes such as mesquite.

Longer-term measurements, and better quantitative linkages of climate, water availability, and evapotranspiration, will be required to more precisely bracket this annual range of variance in total evapotranspiration and the fraction derived from groundwater.

The total water use by phreatophytes along the San Pedro varies spatially among river reaches, depending in part on local hydrogeomorphic conditions. Total riparian water use also undoubtedly has changed temporally over the past century, as dominance shifted from wetlands and grasslands to forests and woodlands, as cottonwood forests and floodplain area expanded in the decades following river entrenchment, and as forests and grasslands were replaced by irrigated and then abandoned fields. The water needs and water use of the riparian vegetation will continue to change in coming decades, as the forests, grasslands, and marshlands are influenced by ongoing successional processes, ever-changing flood and fire regimes, changing climate, and the activities of beaver (see chaps. 1 and 3).

Spatio-temporal Changes in Streamflow

Only a small percent of the rain that falls in the upper San Pedro watershed flows to the river; most evaporates from the soil or is transpired by upland vegetation (see chap. 15). Some of this rainwater recharges the regional aquifer (although rates and processes of such are still poorly understood; Hogan et al. 2004), and then slowly discharges to the San Pedro floodplain aquifer and then to the stream (fig. 20.2). However, most of the annual streamflow in the upper San Pedro River derives from summer stormwater runoff, with some of the stored floodwater contributing to streamflow during dry seasons. Although the portion of the streamflow that is derived from the regional aquifer is but a small percentage of the total streamflow, this baseflow discharge is ecologically important in that it sustains surface water in the channel and a high water table in the floodplain aquifer during dry seasons of non-flood years.

Since about the 1940s, the total annual flow volume of the upper San Pedro River has declined (reflecting significant reductions in summer flows) as has its baseflow discharge (Pool and Coes 1999, Thomas and Pool 2006; and see chap. 15). There are few long-term data sets for groundwater levels in the San Pedro floodplain alluvium, but water levels in wells near Palominas (southern end of SPRNCA) are known to have declined by about 1 m from the 1950s through 1980s, sufficient to convert this stream reach from perennial to intermittent (Pool and Coes 1999). This particular hydrologic shift is largely attributable to historic agricultural pumpage from the floodplain aquifer (see chap. 15).

Presently, about half of the river in the SPRNCA has perennial flow, although greater lengths of the river have year-round flow during wet years.

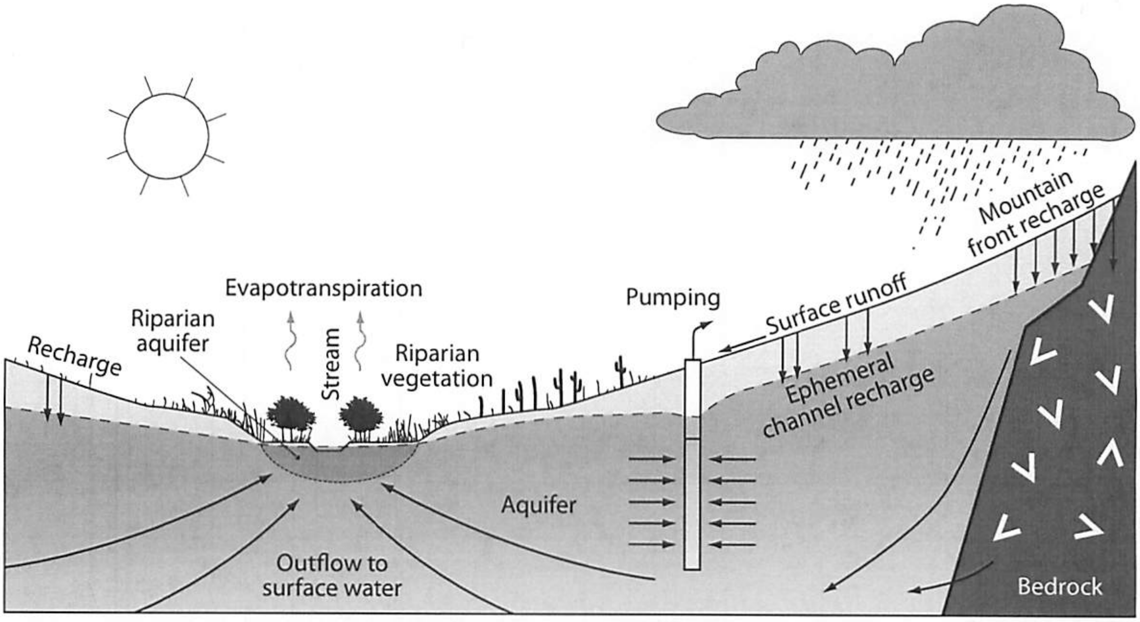


Fig. 20.2. Key hydrologic processes influencing streamflows in the San Pedro River. Illustration credit: Mike Buffington (as modified from U.S. Geological Survey Fact Sheet 086-00).

In 2001, for example, 75 percent (47 of 62 km) of the river in the SPRNCA had surface flow during the June dry season compared to 55 and 57 percent in 2002 and 2003 (fig. 20.3). The greater surface flow in 2001 was a result of discharge from the floodplain aquifer of recharge associated with a large flood in October 2000 (Leenhouts et al. 2006).

The consistently perennial reaches in the SPRNCA are concentrated in the south-central portion (Hereford to Fairbank). Here, year-round flow is maintained by shallow or exposed bedrock which forces groundwater up into the floodplain aquifer, discharging it into the stream. The late-1800s to early-1900s episodes of channel entrenchment may have contributed to perennial flows in this area by replacing alluvial sediments of moderate permeability with more permeable sands and gravels, thereby improving hydraulic connectivity between the regional aquifer and the river (Pool and Coes 1999).

Streamflows are intermittent in the northern tier of the SPRNCA. This is partly because of geologic features: the low permeability of the St. David Formation (a 300-m-thick layer of clays and silts) results in a poor hydraulic connection between the river and the regional aquifer near St. David and Benson (Goode and Maddock 2000). Additionally, San Pedro streamflow has been diverted seasonally into the St. David and Pomerene irrigation canals for over a century. These diversions, together with groundwater pumping, contribute to stream intermittency in the northern tier of the SPRNCA and in areas downstream (Vionnet and Maddock 1992; and see chap. 15).

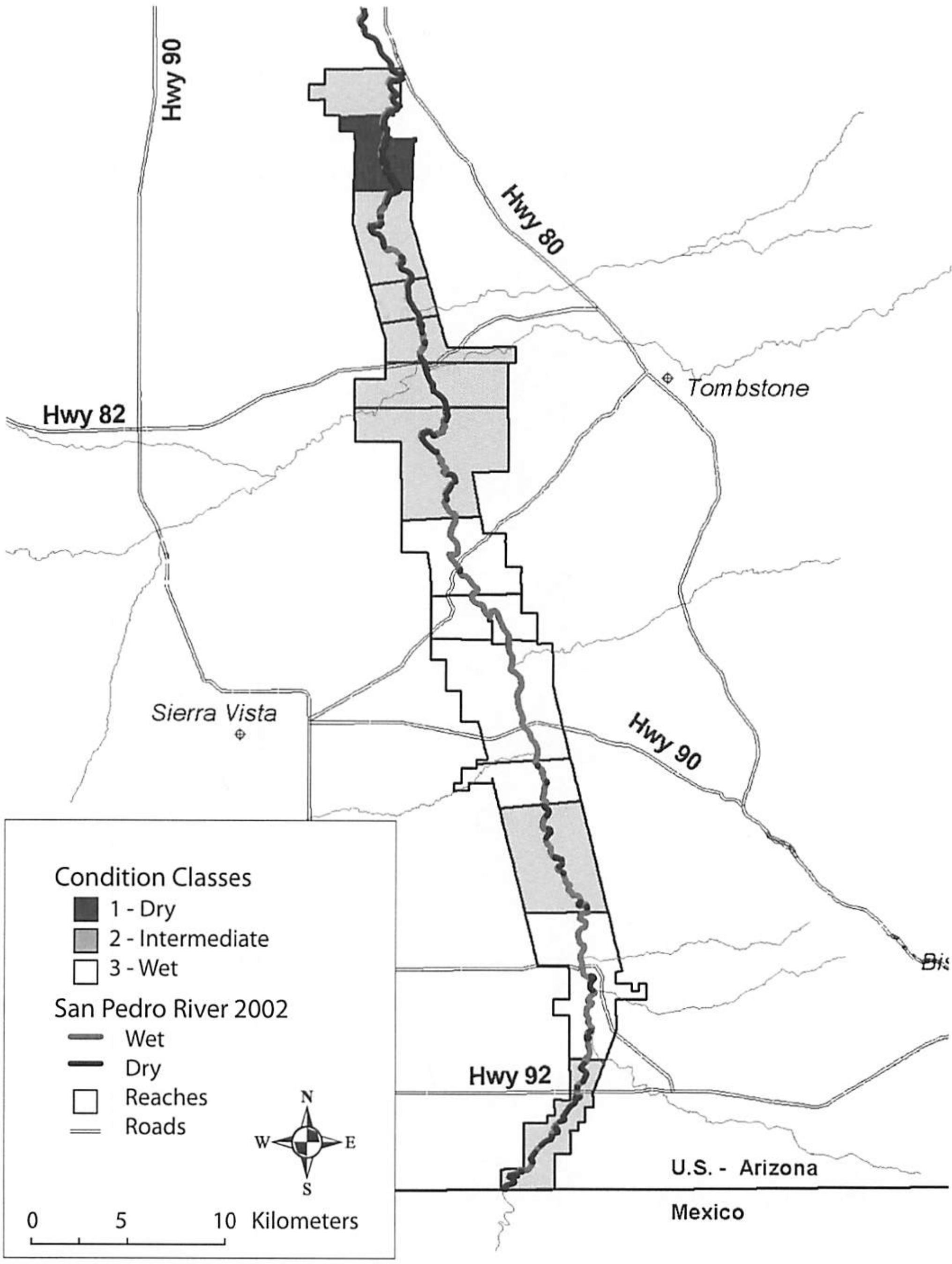


Fig. 20.3. Map indicating riparian condition class for 14 reaches within the San Pedro Riparian National Conservation Area (see Stromberg et al. 2006 for details). Also shown is the location of the stream channel in 2002. Illustration credit: Lainie Levick.

Drivers of Hydrologic Change

Riparian water tables and streamflow rates can be influenced by groundwater pumping from the floodplain aquifer (a more rapid and direct effect) and from the regional aquifer (a slower effect). Pumpage from the upper San Pedro floodplain aquifer mainly supplies irrigation water for row crops and pasture grasses, while pumpage from the regional aquifer supplies most of the urban water used throughout the basin. Both the amount of pumping and its location are influential.

Groundwater extraction in the upper basin, inclusive of that from the near-stream area, began to increase sharply in the 1940s (see chap. 15). However, pumpage rates from the near-stream area declined considerably in the Sierra Vista subwatershed after 1988 due to retirement of some irrigated agricultural land associated with designation of the SPRNCA. In recent decades, agricultural pumping from the floodplain aquifer in the upper basin has been limited mainly to areas near St. David and Benson, private inholdings near Palominas, and parts of Sonora, Mexico.

Urban population growth and municipal water use in the Sierra Vista area are increasing due to a variety of factors, including the nearby army base, attractiveness as a retirement community, and ecotourism. As of 2002, about 7,900,000 more cubic m of water were pumped annually from the Sierra Vista subbasin of the upper San Pedro River than were recharged from rainfall (see chap. 15). Most of this urban pumping has taken place between the mountain-front recharge zone and the river. Cones of groundwater depression have developed in the regional aquifer near Cananea (Sonora), near Sierra Vista (to depths in excess of 25 m), and near St. David and Benson (see chap. 15). Contour maps of regional groundwater levels suggest widespread declines over the past 50 years in many areas of the basin. This has reduced or reversed hydraulic gradients, thereby slowly reducing the amount of groundwater flowing from the regional to the stream aquifer. In addition, by converting stream reaches from perennial to intermittent or ephemeral, groundwater pumping (even when ceased) can continue to reduce streamflow rates by increasing rates of infiltration. Lag effects of past pumping on groundwater flow paths and streamflow rates can persist for centuries (Filippone and Leake 2005).

Streamflow rate and floodplain groundwater level are influenced by many factors other than extraction of water, including climate, riparian vegetation abundance and type, and watershed land cover and soil conditions. Determining the relative magnitudes of these various influences on historic streamflow declines is challenging. A decline in summer precipitation began about 1960 and contributes to declines in summer flood peaks and streamflow rates (Pool and Coes 1999, Thomas and Pool 2006). The recent drought (Gray et al. 2003) may be influencing low-flow conditions, but precipitation changes alone do not fully explain the long-term changes in streamflow (Thomas and Pool 2006).

Plants that use groundwater have a significant influence on daily and seasonal groundwater fluctuations, and as of 2002 accounted for about half of the total groundwater use in the Sierra Vista subwatershed. The post-entrenchment expansion of the high-water-use riparian cottonwood

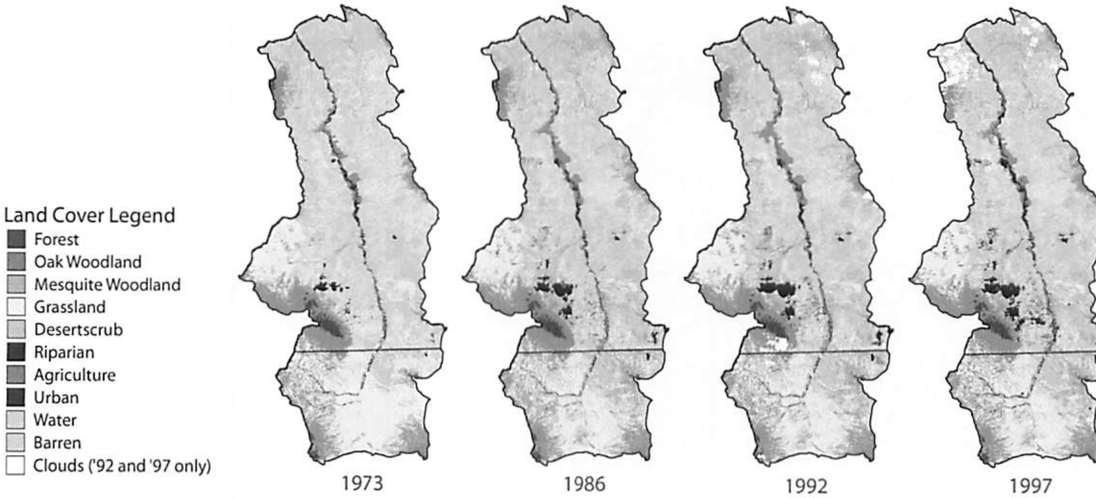


Fig. 20.4. Land cover of the San Pedro River watershed from headwaters in Mexico to Redington during four years, based on LANDSAT data. Figure courtesy of William G. Kepner, U.S. Environmental Protection Agency; report details are available at http://www.epa.gov/nerlesd1/land-sci/pdf/sw-watershed.pdf.

forests (see chaps. 1 and 12) may be contributing to the observed declines in streamflow rates (B. Thomas and Pool 2006), but the extent of this influence remains unknown in the absence of quantitative values for change in acreage of riparian cover types through time. Efforts are underway to reconstruct historic patterns of water use by riparian vegetation, and this information will be of value in refining understanding of feedbacks between vegetation and stream hydrology.

Range conditions throughout the watershed began to improve in about the 1930s and 1940s, following historic degradation of upland grasslands, and this may have reduced summer runoff amounts and flood size (Bahre and Shelton 1993; and see chaps. 11 and 12). Of the more recent land-cover changes in the upper San Pedro watershed (fig. 20.4), many—including the expansion of mesquite woodland, continued declines in grassland, and increases in urban and barren areas—are producing a more rapid or flashy watershed response to rainfall, with greater runoff rates, increased flood magnitude, and greater sediment erosion but less infiltration (Kepner et al. 2000, S. N. Miller et al. 2002). However, although the surface paving that accompanies urbanization is associated with increased surface runoff, it also may lead to increased aquifer recharge, by causing stormwater runoff to concentrate in ephemeral channels (Hernandez et al. 2000, Kepner et al. 2004). Effects of urbanization on hydrologic processes in the San Pedro watershed remains an area of active investigation.

Modeling Efforts

Researchers have been developing models of the relationship between regional groundwater, riparian zone water levels, and riparian vegetation abundance along the upper San Pedro for decades. These groundwater flow models show that the rate of flow between the regional aquifer and stream has changed over time because of groundwater pumping. They also suggest that the current levels of groundwater discharge into the San Pedro River may be only 30 percent of levels prior to 1940 (Goode and Maddock 2000; and see chap. 15). The groundwater models also have been used to predict groundwater level and streamflow changes under scenarios of population growth and water management in the Sierra Vista subbasin (Steinitz et al. 2003). The scenarios examined span a range from Open, which projects high population growth with no constraints on land development and no retirement of irrigated agriculture, to Constrained, with lower population growth than is anticipated, retirement of all irrigated agriculture, and growth concentrated in the existing urban areas. In the Open scenario, increased rates of pumping from the regional aquifer cause water levels to decline throughout the basin and cause streamflows in the San Pedro River to diminish. The Constrained scenario predicts a continued lowering of groundwater levels near the cities, but to a lesser degree than for the Open scenario, and also predicts rising stream water levels and riparian expansion in certain areas in response to retirement of irrigated agriculture. The reality likely will fall somewhere between these two extreme scenarios, depending on future management decisions.

Outputs from modeling scenarios can be used to guide planning (King et al. 2003, Tharme 2003). For the upper San Pedro River, a Decision Support System has been developed that allows policy makers and other stakeholders to use the model outputs to evaluate the potential economic and environmental impacts of different amounts and spatial distributions of groundwater pumping (McPhee and Yeh 2004; and see chap. 21). The output, of course, is only as good as the input. Development of a spatially explicit model that incorporates bi-directional linkages and feedbacks between stream hydrology and riparian vegetation (Baird et al. 2005, Loheide and Gorelick 2007), and that is calibrated using long-term data sets for hydrology and vegetation, will be necessary to provide the next iteration for more accurately predicting interactions between basin-fill groundwater levels, floodplain groundwater levels, and riparian vegetation over the length of the San Pedro River.

Effects of Streamflow Changes on Upper San Pedro Riparian Vegetation

Changes in San Pedro streamflow regimes over past decades have affected upper San Pedro riparian vegetation in many ways. Decadal variations in winter flood patterns have influenced population age structure of cottonwood and willow trees, with some decades being more favorable for establishment than others (see chap. 1). Effects of changing summer flood patterns on the riparian vegetation are less well understood. We know that small sum-

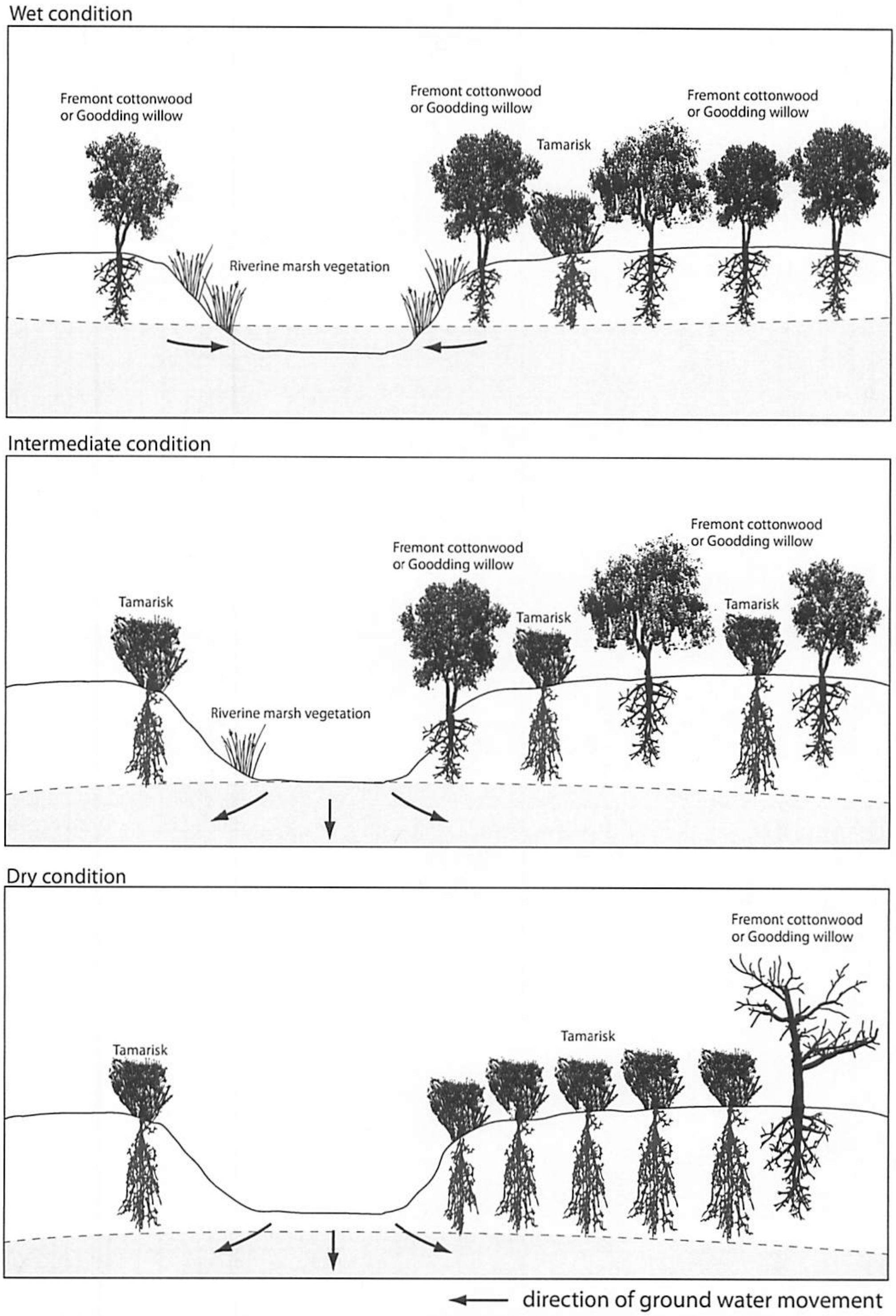


Fig. 20.5. Schematic of changes in riparian vegetation that occur as streams such as the San Pedro lose perennial flow and undergo declines in groundwater in the floodplain aquifer. In reaches with perennial flow and shallow groundwater (top panel), the vegetation is in a wet condition class (Stromberg et al. 2006), characterized by abundant cottonwood and willow trees in the floodplain and wetland plants along the low-flow channel. As the stream becomes increasingly intermittent, and as groundwater deepens and shows more inter-annual and intra-annual fluctuation, the moisture tolerance ranges for riparian plant species are sequentially exceeded and the vegetation shifts into intermediate and then dry condition classes.

mer floods create pulses of primary productivity and species diversity in the floodplain (see chap. 5), but vegetation response to the larger summer floods that typified some past decades has not been described.

Changes in low-flow conditions also undoubtedly have influenced vegetation. Shifts from perennial to intermittent flows, such as occurred in the Palominas area, likely were accompanied by declines in riverine marsh plants along the low-flow channel, but changes remain undocumented, given that focused monitoring of vegetation began only recently. Dendrochronology studies provide a small window to the past and provide evidence of some increase in saltcedar (*Tamarix*) in intermittent portions of the upper San Pedro over the past few decades (Stromberg 1998b, Leenhouts et al. 2006). These changes may be indicative of stream drying.

To provide a baseline for future monitoring, the riparian vegetation in the SPRNCA was assessed from 2001 to 2004 with a riparian condition model (Stromberg et al. 2006; figs. 20.3, 20.5). This analysis shows that about 40 percent of the San Pedro River in the SPRNCA is in a wet condition characterized by perennial flow, shallow groundwater, and an abundance of hydroriparian plant species. Most of these wet areas are in the south-central section. Floodplains in these areas support tall, dense, multi-aged cottonwood/willow forests, with intermixed areas of sacaton grassland and mesquite, seepwillow (*Baccharis salicifolia*), and rubber rabbitbrush (*Ericameria nauseosa*) shrublands. The stream channel is lined by wetland graminoids such as cattail (*Typha*) (fig. 20.6).

Another 55 percent of the SPRNCA, including reaches at the southern and northern ends, is in an intermediate-moisture condition, characterized by intermittent streamflows and low to no cover of wetland plants along the stream channel. Water stress effects, including leaf yellowing, reduced stem growth, and reduced evapotranspiration rates, are routinely observed on cottonwoods and willows in reaches of the San Pedro River with intermittent flow and summer declines in groundwater levels.

Six percent of the SPRNCA, in the reach downstream of the St. David diversion dam, is in a dry condition characterized by intermittent streamflows and floodplain groundwater conditions insufficient to sustain dense cottonwood/willow forests (figs. 20.3, 20.6). Saltcedar is the dominant pioneer plant. Survey data on vegetation condition are not yet available for portions of the upper San Pedro River outside of the SPRNCA boundary, but much of the riverbed downstream of the SPRNCA, near Benson, is dry.

Ecosystem monitoring will continue along the SPRNCA, mandated by federal legislation (see chap. 22). At varying intervals, there will be monitoring of stream surface flows, groundwater levels in the stream aquifer and regional aquifer, area of various vegetation types, and abundance of hydrologically sensitive biota. Downstream of the SPRNCA boundary, riverine

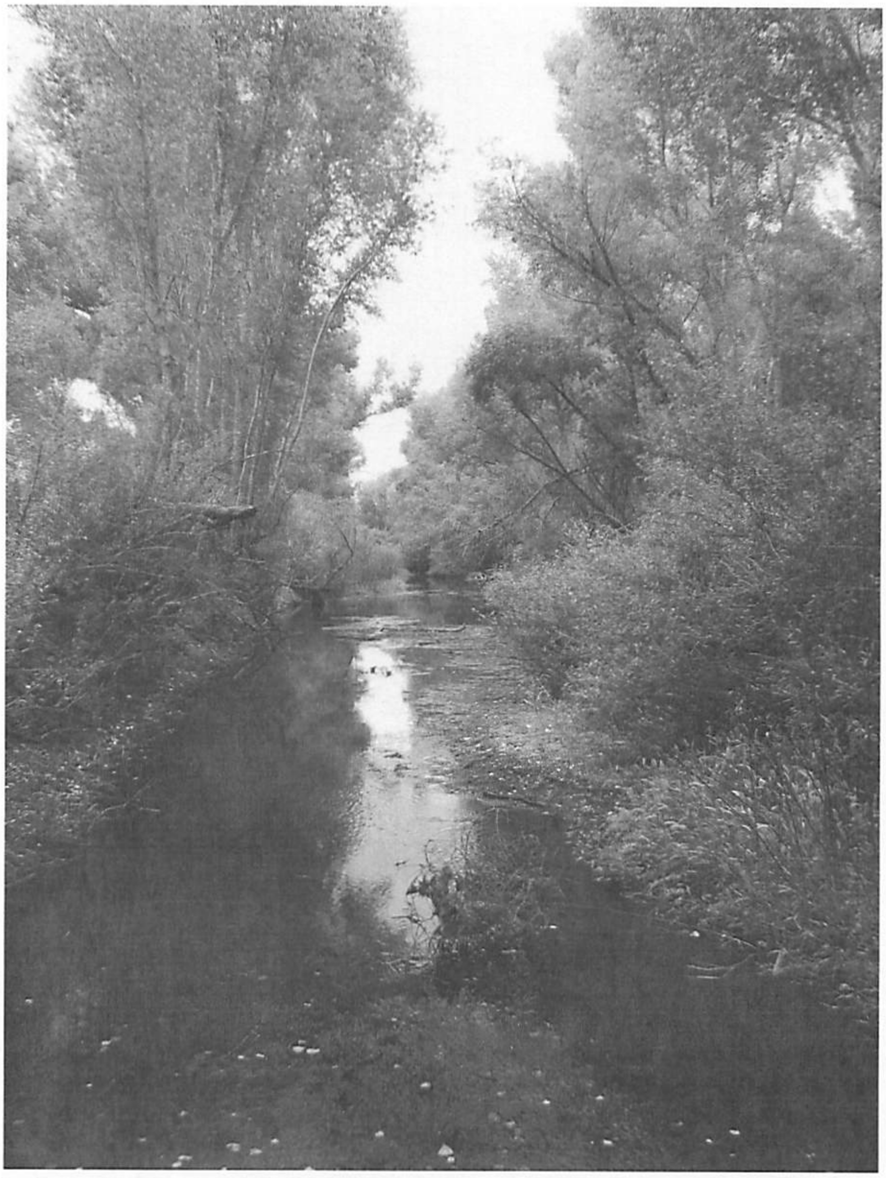
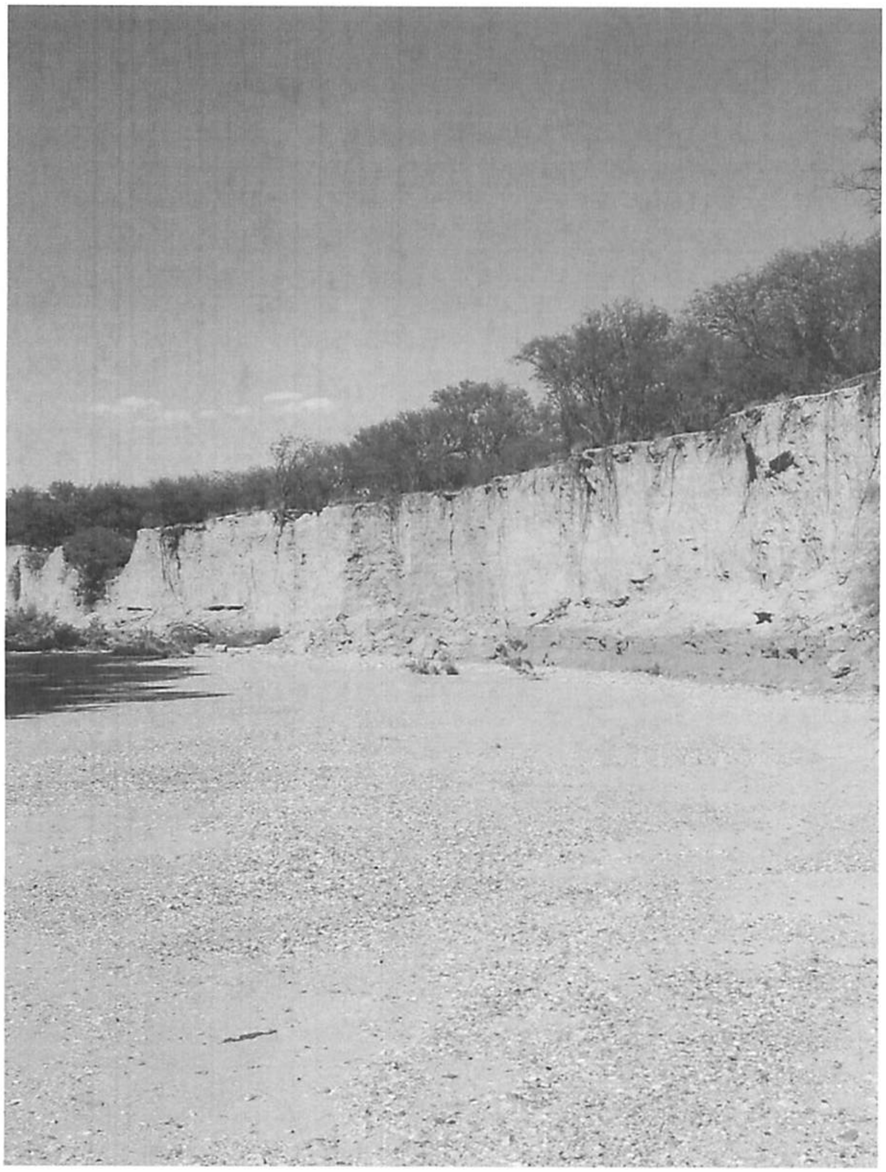


Fig. 20.6. Perennial-flow (above; 20.6a) and intermittent-flow (right; 20.6b) reaches of the upper San Pedro River. The photo of the perennial-flow site shows the low-flow channel, lined by *Populus/Salix* forests. The photo of the intermittent-flow site shows an unvegetated portion of the floodplain and *Prosopis* forests on the terrace. Photo credits: Elizabeth Makings.

ecosystem monitoring has been initiated by a local watershed group, the Community Watershed Alliance.

How Sensitive Is the Riparian Vegetation to Hydrologic Change?

Small changes in riparian groundwater levels and stream low-flows can have significant effects on the riparian community if values are near threshold levels for vegetation change. For example, in the northern tier of the SPRNCA,



water table levels in the stream aquifer are near the lower threshold for cottonwood and willow survivorship. Small declines in the water table (on the order of 0.5 m relative to levels measured in the floodplain in 2002) in this dry northern tier would drive shifts from the intermediate condition class to the dry condition class, with cascading effects across trophic levels (see chap. 8). In much of the central portion of the SPRNCA, in contrast, water tables are not approaching this particular threshold. Shifts between perennial and intermittent streamflow constitute another hydrologic threshold for riparian vegetation change. Restoration of perennial flows in reaches that are presently intermittent, such as those near Palominas, would restore riverine marsh communities and drive shifts from the intermediate condition class to the wet condition class.

Ecological Perspective on Management Options

To address the basin-wide groundwater overdraft, and balance the water budget, managers and policy makers in the Sierra Vista subwatershed of the upper San Pedro basin are taking actions both to increase the groundwater supply to the riparian corridor and to reduce demand by the riparian vegetation for groundwater (see chap. 21). Among these efforts are water conservation and re-use, recharge of municipal effluent, construction of stormwater retention basins, reduction of agricultural groundwater pumping, construction of watershed check dams, and burning of mesquite.

Scientific studies have been initiated to address the effects of many of these actions on water budgets. Studies also are needed to address their effects on ecological functions, to insure that potential consequences are understood. For example, stormwater retention basins have been constructed on washes in the upper San Pedro watershed to offset flow peaks resulting from upstream development and to increase percolation of water into the regional aquifer. While studies have been initiated to document the ensuing hydrologic changes, studies also are needed to determine how the retention basins will influence biotic processes, such as flows of plant seeds between the tributaries and main-stem river.

Another example of a project that could benefit from multidisciplinary research is the prescribed burning of mesquite and other shrubs by BLM personnel in the SPRNCA. The burning is intended to reduce riparian water use, reduce fuel loads, and restore riparian and desert grasslands. GIS-based models indicate that riparian groundwater use rates will decline in response to replacement of mesquite by sacaton, a species that uses less groundwater than mesquite, or by upland grasses, that use no groundwater (see chap. 21). However, many uncertainties remain. Burning of mesquite could create a shrubby growth form that no longer provides habitat for forest-affiliated birds, while allowing the plants to continue to transpire at high rates due to their well-established root system. Reduction in mesquite cover could reduce soil fertility (see chap. 14) or shallow soil moisture (see chap. 2), thereby affecting productivity and habitat quality of post-fire vegetation. Further study is warranted to determine how this management action would influence a range of riparian functions.

Summary and Conclusions

Do we know how much water is needed to sustain the San Pedro riparian ecosystem? The answer to this is a qualified "yes." Landscape-scale evapotranspiration rates, and the groundwater-derived component thereof, have been determined as one index of riparian vegetation water needs. Although there is high variance and although values will change given the dynamic nature of riparian ecosystems, it provides a measure of the amount of water that is needed to flow to the river to sustain the current levels of water use by the riparian vegetation. Further, hydrologic thresholds for plant-community maintenance have been quantified, thus determining groundwater levels and streamflow permanence needed to sustain various vegetation types.

Will these flows be maintained? This is a more difficult question to answer. The San Pedro case is different from some in that there is not a point source for management, such as a regulating dam for which the requisite flow releases can be prescribed (Richter et al. 2003). Rather, there are multiple groundwater wells distributed throughout the watershed and multiple land use changes taking place. Stream-groundwater interactions are complex and variable over time and space, and there remain unresolved issues regarding rates and extent of groundwater storage changes and the rate and extent of their impacts on San Pedro River flows and riparian biota in the basin. It does seem evident, however, that groundwater pumping beyond the SPRNCA borders has affected regional groundwater levels and groundwater flow paths, and thus streamflow and riparian condition. It also seems clear that there are unavoidable lag effects, with past human actions reverberating in the present landscape; just as vegetation trajectories have been set by past geomorphic events, groundwater flow paths will be affected for decades to come by past pumping. It also seems apparent that certain actions, such as retirement of irrigated agriculture, can be taken that will cause local increases in groundwater levels and streamflows. Results of the recently initiated ecosystem monitoring along the upper San Pedro will be a test of whether thriving urban-agricultural centers can co-exist with thriving riparian ecosystems, a challenge that can be difficult to meet (e.g., Logan 2002).