Ciénegas—Vanishing Climax Communities of the American Southwest

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Abstract

The term *ciénega* is here applied to mid-elevation (1,000–2,000 m) wetlands characterized by permanently saturated, highly organic, reducing soils. A depauperate flora dominated by low sedges highly adapted to such soils characterizes these habitats. Progression to ciénega is dependent on a complex association of factors most likely found in headwater areas. Once achieved, the community appears stable and persistent since paleoecological data indicate long periods of ciénega conditions, with infrequent cycles of incision. We hypothesize the ciénega to be an aquatic climax community. Ciénegas and other marshland habitats have decreased greatly in Arizona in the past century. Cultural impacts have been diverse and not well documented. While factors such as grazing and streambed modifications contributed to their destruction, the role of climate must also be considered. Ciénega conditions could be restored at historic sites by provision of constant water supply and amelioration of catastrophic flooding events.

Introduction

Written accounts and photographs of early explorers and settlers (*e.g.*, Hastings and Turner, 1965) indicate that most pre-1890 aquatic habitats in southeastern Arizona were different from what they are today. Sandy, barren streambeds (Interior Strands of Minckley and Brown, 1982) now lie entrenched between vertical walls many meters below dry valley surfaces. These same streams prior to 1880 coursed unincised across alluvial fills in shallow, braided channels, often through lush marshes. The term *ciénega*, applied to riparian marshlands by Spanish explorers, has since attained acceptance in cartographic and public vocabularies of the region.

These unique aquatic and semiaquatic habitats have been reduced in recent times from a formerly widespread distribution to small, scattered remnants (Hastings, 1959; Dobyns, 1981). Stabilization of flow by upstream dams, channelization, and desiccation by diversion and pumpage have greatly reduced natural stream communities in the desert Southwest (Brown *et al.*, 1981; Minckley and Brown, 1982). Ciénega habitats persist in headwaters, reduced in size, variously modified, or artificially maintained. In light of their continuing disappearance, cultural histories, and importance to aquatic faunas and floras, these dwindling, valuable, as yet little-understood ecosystems constitute a resource which merits further investigation. The geographic area considered is that of greatest known past and present abundance of ciénegas in the American Southwest—Arizona south of the Gila River and east of, but including, the Avra-Altar Valley (Fig. 3).

We do not claim comprehensiveness in this work. Dobyns (1981) pointed out the need for a multidisciplinary approach to the topic of environmental change in our region, and we being biologists admit many biases. We undoubtedly have overlooked archaeologic, anthropologic, geologic, and historic literature. However, we provide a review from diverse, relevant sources. Our objectives are to present an historical data base, which may motivate others to further delineate these communities and aid in

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[1] *Minckley's affilation through the Summer of 1985 is with the U.S. Fish and Wildlife Service, Dexter National Fish Hatchery, Dexter, New Mexico 88230.*

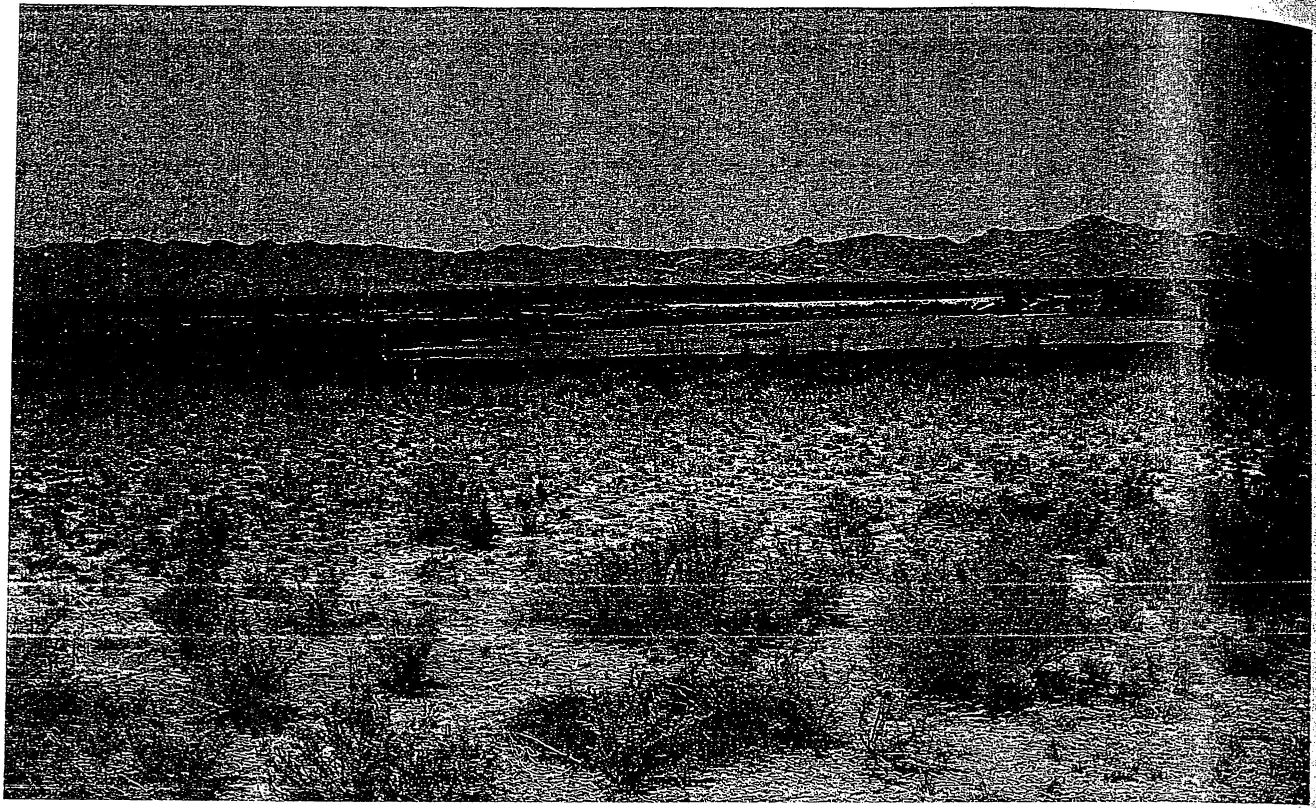

Figure 1. San Simon Ciénega, Arizona-New Mexico, after artificial protection by impoundment and deepening. Photograph 1981.

Figure 2. Arroyo walls downstream from San Simon Ciénega. Photograph 1981.

their perpetuation and management. We document cultural activities that influenced these habitats and review historical accounts of riparian conditions. We have attempted to evaluate historical statements critically by employing criteria of Forman and Russell (1983). Relationships of hydrology and succession theory to the ecology of ciénegas are discussed, and we end with a commentary on biological significance of ciénega habitats within the framework of Southwestern ecosystems.

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Ciénega Definition

The term ciénega (or ciénaga) is applied to a diversity of aquatic habitats throughout areas of Hispanic influence. In South America the term is most commonly applied to floodplain lakes (Welcomme, 1979). These lakes often have vast expanses of open water, but are only a few meters deep and support substantial littoral emergent or floating vegetation. In North American areas with Hispanic histories, the term has been applied to a broad spectrum of marshy and swampy habitats at any elevation. In Arizona, we propose that three basic types of marshy wetlands are present.

Numerous "ciénegas" at >2,000 m elevation are marshy to bog-like Alpine and Cold Temperate meadowlands surrounded by Petran Montane (= Rocky Mountain) Conifer Forest (Patton and Judd, 1970; Judd, 1972; Brown *et al.*, 1980; Minckley and Brown, 1982). These wetlands may occur in depressions and thus be lentic, fed by seepage or precipitation, or they may be lotic habitats, bordering headwater streams. They are dominated by low, semiaquatic and terrestrial grasses (Gramineae, *e.g., Glyceria* spp.), cold-resistant rushes (Juncaceae) and sedges (Cyperaceae), and often support low woody shrubs such as Alder *(Alnus tenuifolia)*, Currant (*Ribes* spp.), and Willows *(Salix bebbiana, S. scouleriana)*. For much of the year these communities are frost-inhibited or lie beneath snow, and surface waters are subject to a succession of freezing and thawing in winter and drying in summer.

At elevations <1,000 m, subtropical marshes in oxbows, behind natural levees, and along margins of major streams comprise a different riverine community. Sharply delimited shoreward by desertlands and riverward by water depth and scouring, such marshes support stands of large reeds *(Phragmites australis* and *Arundo donax)*, Cattail *(Typha domingensis)*, Bulrush *(Scirpus californicus)*, and Three-square *(S. americanus, S. acutus)*, which thrive in fluctuating water levels and relatively well aerated hydrosoils. Goodding and Coyote Willows *(Salix gooddingii, S. exigua)*, Seep-willow *(Baccharis salicifolia)*, and Cottonwood *(Populus fremontii)* form galleries along drier alluvial terraces, and vast stands of Arrowweed *(Tessaria sericea)* and diverse Chenopodiaceae *(Atriplex lentiformis, etc.)* occupy saline areas adjacent to these swamps. All such habitats are transitory. They develop rapidly only to be removed by channel-straightening floods, or proceed toward a xeric community after drying (Grinnell, 1914; Ohmart *et al.*, 1975; Ohmart and Anderson, 1982).

At mid-elevations of 1,000 to 2,000 m in Semidesert Grassland, and more seldom in Madrean Evergreen Woodland, a third marshland community is associated with perennial springs and headwater streams. These Warm Temperate habitats were most often termed ciénegas by Hispanic and later explorers and settlers, and appear distinctive. We restrict use of the term in following text to this habitat type. Ciénegas are perpetuated by permanent, scarcely-fluctuating sources of water, yet are rarely subject to harsh winter conditions. They are near enough to headwaters that the probability of scouring from flood is minimal. The system is controlled by permanently saturated hydrosoils, within which reducing conditions preclude colonization by any but specialized organisms. Many meters of organic sediments have often been deposited. Most plant components restricted to such communities (Table 1) are monocotyledonous taxa such as low, shallow-rooted, semiaquatic sedges (Cyperaceae, such as *Eleocharis* spp.), rushes, some grasses, and only rarely cattails. Dicotyledonous taxa such as Watercress *(Rorippa nasturtium-aquaticum)* and Water-pennywort *(Hydrocotyle verticillata)* may be locally common. Dense stands of sedges and charophytes fill shallow, braided channels between pools, or deeper, narrow, vertical-walled channels may be heavily vegetated with *Rorippa nasturtium-aquaticum, Ludwigia natans*, and other macrophytes. Pools often have vertical walls of organic sediments and undercuts below root systems. Submerged macrophytes are commonly rooted in local, gravelly substrates.

Trees are scarce, limited to Goodding, Coyote, and Swamp Willow *(Salix lasiolepis)*, that can tolerate saturated soils. Immediate surroundings of ciénegas often are rendered saline through capillarity and evapotranspiration. Halophytes such as Salt Grass *(Distichlis spicata)*, Yerba-mansa *(Anemopsis californica)* and numerous species of Chenopodiaceae and Compositae thus live along salt-rich borders of these riparian marshlands. Extensive stands of Sacatón *(Sporobolis airoides)* also are common on adjacent flatlands. Upslope, and where soil aeration and salinities allow, broadleaved deciduous woodlands often develop (Minckley and Brown, 1982). Typical riparian species of the region (Seep-willow, Fremont Cottonwood, Arizona Sycamore [*Platanus wrightii*], Arizona Ash [*Fraxinus pennsylvanicus* var. *velutina*], Walnut [*Juglans major*], *etc.*) border such saturated areas, replaced in more xeric places by Mesquite *(Prosopis velutina, P. glandulosa).*

Ciénegas act as traps for organic materials and nutrients in the aquatic ecosystem, and also must be remarkably productive. Indeed, freshwater macrophyte communities are among the most productive in the world (Westlake, 1963, 1965). The availability of water and resultant luxuriance of forage in this semi-arid region results in concentration of herbivore populations, a factor to be discussed later that may have contributed to the demise of these habitats. Vast quantities of materials are transported *via* herbivores to surrounding terrestrial habitats.

Description of the Study Region

The study region lies within the Basin and Range Geomorphic Province (King, 1977). Roughly parallel, north-south trending ranges formed by block faulting are separated by broad valleys filled with Tertiary and Quaternary sediments eroded from adjacent mountain slopes (Nations *et al.*, 1982). Faults along mountain fronts provide egress for springs, and deep valley alluvium serves as an aquifer for groundwater storage, contributing two important prerequisites for ciénega formation and maintenance.

Relevant aspects of the study area are most easily discussed by drainage sub-basins. Structural troughs from east to west are the San Simon, Sulphur Springs, San Pedro, and Santa Cruz (including Avra-Altar) valleys. With exception of the second, all drain north to the Gila River *via* rivers of the same names. The northern Sulphur Springs Valley is drained to the Río San Pedro by Aravaipa Creek through a channel that likely predates Basin and Range orogeny (Melton, 1960; Simons, 1964). Its central portion is endorheic (Pluvial Lake Cochise or Willcox Playa) while the southern regions drain south to the Río Yaqui *via* Whitewater Draw. Both divides within this basin are low. Adding the mainstream Gila River gives a total of seven hydrographic regions (Fig. 3).

Climate is characterized by a bimodal summer and winter rainfall pattern, alternating with spring and autumn drought (Sellers and Hill, 1974). Rainfall during the hottest months of July–September grades from <50% of the annual total in the northwestern corner to >70% in south and southeastern parts of the study area. A second peak in precipitation occurs in December–January. Annual precipitation varies from 13 to 48 cm, increasing along the same axis as relative importance of summer rains (Hastings and Turner, 1965).

Temperatures also show considerable variation, not necessarily correlated with elevation (Turnage and Hinckley, 1938). Cold air drainage from adjacent mountains often makes valleys colder than higher areas. Record lows at stations near ciénegas range to about −10°C, and record highs to >40°C (Sellers and Hill, 1974). Most stations have mean values of less than half a day per year during which temperature does not rise above freezing (Hastings and Turner, 1965; see however, Bowers, 1981, and Glinski and Brown, 1982).

Terrestrial vegetation was mapped and described for this region by Brown and Lowe (1980). Upland vegetation of most of the San Pedro, San Bernardino, and San Simon valleys is characterized by zones of Chihuahuan Desertscrub interdigitating with Semidesert Grasslands. In certain valleys, such as the broad upper Santa Cruz and upper Sonoita Creek, a Plains Grassland Formation lies between Semidesert Grassland and Madrean Evergreen Woodland. In most of Arizona the transition is more direct, with no development of Plains Grassland. Density of Evergreen Woodlands increases with elevation, eventually giving way to insular Petran Montane (= Rocky Mountain) Conifer Forests on high peaks. At highest extremes of the Chiricahua and Pinaleño mountains, relict stands of Subalpine Conifer Forests persist. Brown *et al.* (1980) provided photographs of these communities, and Hastings and Turner (1965) presented matched photographs of the region's Desert, Desert Grassland, and Oak Woodland, which illustrate vegetation changes between the late 19th Century and the 1960s. Lowe (1967), Gehlbach (1981), Crosswhite and Crosswhite (1982), and Brown (1982) also published plates and provided descriptions of vegetation and dominant species of these communities.

Cultural History

Four major cultural forces have influenced the Sonoran Desert Region. Least is known of early aboriginal populations who left no written records, but knowledge of subsequent cultural influences increases through time. Written documentation dates from 16th Century explorations, through nearly three centuries of Spanish occupation into early 19th Century colonization by Mexicans, and shortly thereafter the Angloamerican invasion.

Prehistoric cultures had long inhabited parts of the region when Spaniards arrived and began describing their lifestyles. Only inferences based on archaelogical data may be made about their relationships with the environment, but some populations modified or manipulated aspects of their surroundings. The Hohokam of central Arizona valleys constructed extensive canal systems for crop irrigation, which, in modified form, are still in use today (Masse, 1981). They also engineered large, complex irrigation systems in the vicinity of Casa Grande on the Gila River (Haury, 1976). These peoples mysteriously disappeared and were unknown to tribes inhabiting the region when the Spanish arrived.

By about 1600, Spanish contacts with Indians were sufficient to allow recognition of at least eight major cultures in the Sonoran Desert Region (Sauer, 1934). Spicer (1962) grouped these into economic categories, which provide a basis for discussion of their impact on the environment. Of special interest are some of his "band peoples" and "*rancheria* peoples."

The Apache, apparently unknown in Arizona prior to the 17th Century (Walker and Bufkins, 1979), were band people who came from what is now Texas. They originally inhabited montane areas north of the Gila River, but also used the Chiricahua Mountains and other southern

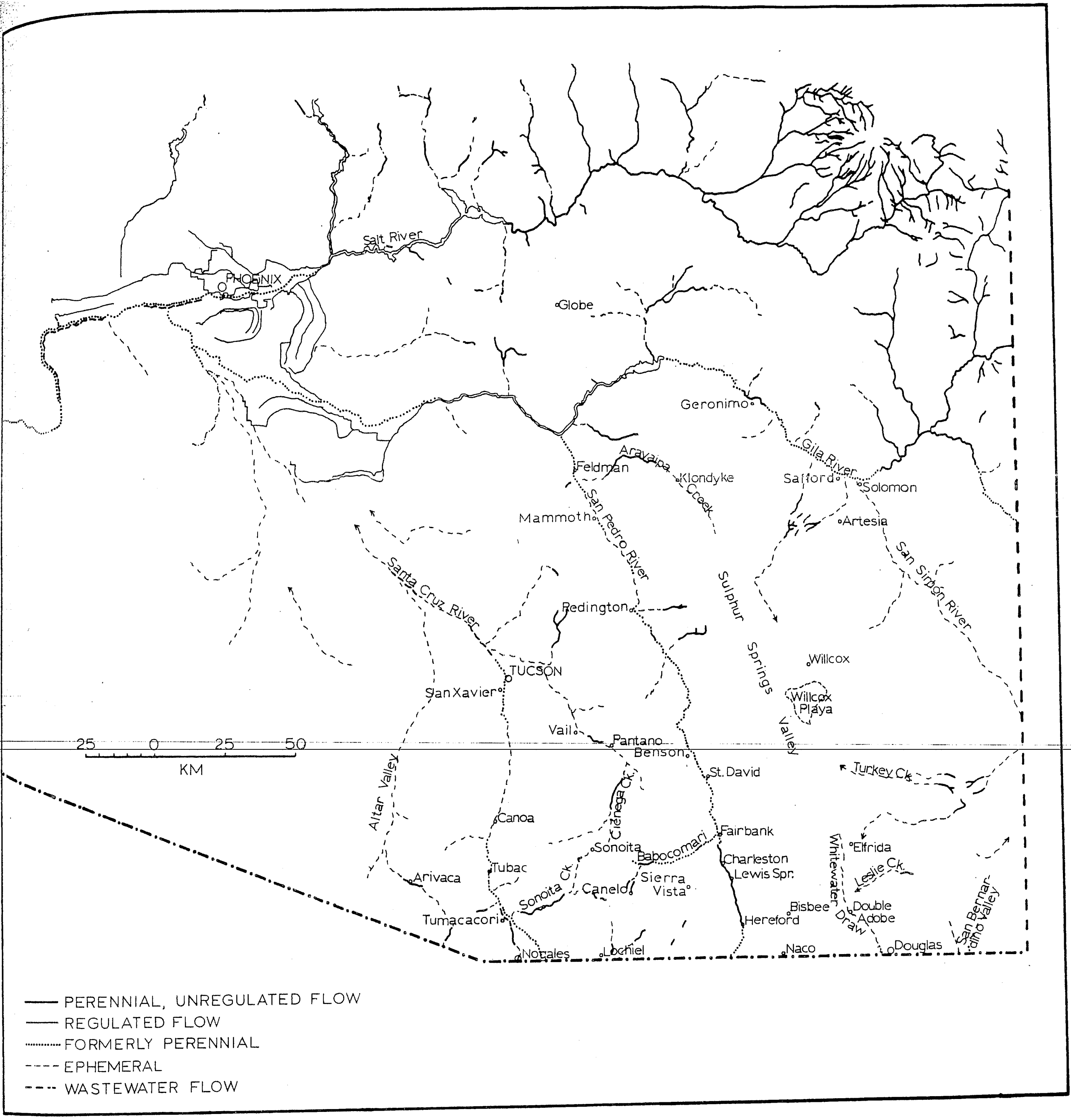

Figure 3. Sketch map of southeastern Arizona, with some place names mentioned in the text. Historical and present status of surface streamflows are indicated as adapted from Brown, Carmony, and Turner (1981).

ranges. Mostly hunters and gatherers, these groups practiced little agriculture.

Older residents were the Pimas Altos of the Santa Cruz and San Pedro valleys. These rancheria peoples lived in semi-permanent settlements wherever perennial surface water was available. They subsisted primarily by floodplain and irrigated farming (Bryan, 1929, 1941), supplemented with wild food gathering. Adjacent rancheria peoples were the Opatas who lived on northern Río Yaqui tributaries in the area of Rancho San Bernardino and the upper Río Sonora drainage in México, and the Pimas Bajos who occupied lower reaches of these same drainages. Papagos inhabited more arid deserts west of the Pimas Altos, and they were bordered on the west by Yumans of the lower Gila and Colorado rivers (Sauer 1934; Crosswhite, 1981). Size of these Indian populations 4 to 8 centuries ago was larger than the total European and Indian population of 1880 (Hastings and Turner, 1965).

Spanish colonization brought new impacts on the environment. However, descriptions of their missionary settlements are rare and provide few data for comparison with recent landscapes. A major impact of Spanish conquest on aboriginal populations predated that culture's arrival in the study region. Smallpox, introduced in 1520

Table 1. Preliminary list of macrophytic plant taxa recorded from ciénega habitats and environs in southeastern Arizona. Compiled from various literature sources and herbarium records (see Acknowledgments). Taxonomy for vascular plants follows Lehr (1978) and Lehr and Pinkava (1980, 1982). Additional detailed plant lists for some specific ciénegas are available from Arizona Natural Heritage Program, Tucson.

	Distribution		
Taxa	**Aquatic**	**Semiaquatic**	**Riparian**
Characeae,Stonewort Family (non-vascular, but important floral components)			
Chara sp.	X	–	–
C. braunii Gm.	X	–	–
Nitella clavata Bertero	X	–	–
Equisetaceae, Horsetail Family			
Equisetum laevigatum A. Br.	–	X	X
E. x. ferrisii Clute	X	X	X
Salviniaceae, Water Fern Family			
Azolla filiculoides Lam.	X	–	–
Marsileaceae, Pepperwort Family			
Marsilea vestita Hook. & Gray.	X	–	–
Polypodiaceae, Maiden-Hair Fern Family			
Adiantum capillus-veneris L.	–	–	X
Typhaceae, Cattail Family			
Typha domingensis Pers.	X	–	–
Potamogetonaceae, Pondweed Family			
Potamogeton foliosus Raf., var. *marcellus* Fern.	X	–	–
P. nodosus Poir.	X	–	–
P. pectinatus L.	X	–	–
Ruppiaceae, Widgeon Grass Family			
Ruppia maritima L.	X	–	–
Zannichelliaceae, Horned Pondweed Family			
Zannichellia palustris L.	X	–	–
Najadaceae, Naiad Family			
Najas guadalupensis Morong.	X	–	–
N. marina L.	X	–	–
Alismataceae, Water Plantain Family			
Alisma triviale Pursh	X	–	–
Sagittaria longiloba Engelm.	X	–	–
Graminae, Grass Family			
Agrostis exarata Trin.	–	X	X
A semiverticillata (Forsk) C. Chr.	–	X	X
A. stolonifera L., var. *palustris* Huds. (Farw.)	–	X	X
Arundo donax L.	–	X	–
Bouteloua gracilis (H. B. K.) Lag.	–	–	X
Bromus marginatus Nees.	–	X	X
Chloris virgata Swartz	–	–	X
Cynodon dactylon (L.) Pers.	–	X	X
Distichlis spicata (L.) Greene, var. *stricta* (Torr.) Beetle	–	–	X
Echinochloa colonum (L.) Link.	–	X	X
E. crusgalli (L.) Beauv.	–	–	X
Eragrostis cilianensis (All.) Mosher.	–	X	X
E. lutescens Scribn.	–	X	X
E. megastachya (Koel.) Link.	–	–	X
Eriochloa lemmoni Vasey & Scribn., var. *gracilis* (Fourn.) Hitchc.	–	X	X
Heteropogon contortus (L.) Beauv.	–	X	X
Muhlenbergia asperifolia (Nees & Mey) Parodi	–	X	X
Panicum obtusum H. B. K.	–	X	X
Paspalum dilatatum Poir	–	X	X
P. distichum L.	–	X	X
P. paspaloides (Michx.) Scribn.	–	X	X
Phalaris caroliniana Walt.	–	X	X
Phragmites australis (Cav.) Trin.	–	X	X
Polypogon, cf. *interruptus* H. B. K.	–	–	X
P. monspeliensis (L.) Desf.	–	*X*	*X*
Sitanion hystrix (Nutt.) J. G. Smith	–	–	X
Sorghum halapense (L.) Pers.	–	–	X
Sporobolus airoides Torr.	–	–	X
S. wrightii Munro ex Scribn.	–	–	X
Cyperaceae, Sedge Family			
Carex agrostoides Mack.	–	–	X
C. alma Bailey	–	–	X
C. bolanderi Olney	–	X	–
C. lanuginosa Michx.	–	X	–
C. praegracilis W. Boott.	–	X	X
C. senta Boott.	–	–	X
C. subfusca W. Boott.	–	–	X
C. thurberi Dewey	–	–	X
Cladium californicum (Wats.) O'Neill	–	X	X
Cyperus acuminatus Torr. & Hook	–	–	X
C. aristatus Rottb.	–	X	–
C. esculentus L.	–	–	X
C. fendlerianus Boeckl	–	–	X
C. niger R. & P.	–	X	–
C. odoratus L.	–	–	X
C. parishii Britt.	–	–	X
C. pringlei Britt.	–	–	X
C. rusbyi Britt.	–	–	X
Eleocharis acicularis (L.) R. & S.	–	X	–
E. caribaea (Rottb.) Blake	X	X	–
E. macrostachya Britt.	X	X	X
E. montevidensis Kunth.	–	X	X
E. parishii Britt.	–	X	X
Scirpus acutus Muhl.	X	X	–
S. americanus Pers.	X	X	–
S. pungens Vahl.	X	X	–
Lemnaceae, Duckweed Family			
Lemna gibba L.	X	–	–
L. minor L.	X	–	–
L. minima Phil.	X	X	–
L. valdiviana Phil.	X	–	–
L. trisulca L.	X	–	–
Pontederiaceae, Pickerel Weed Family			
Heteranthera limosa (Swartz) Willd.	X	X	–
Juncaceae, Rush Family			
Juncus balticus Willd., var. *montanus* Engelm.	–	–	X
J. ensifolius Wikstr., var. *brunnescens* (Rydb.) Crona	X	X	X
J. mexicanus Willd.	–	X	X
J. tenuis Willd.	–	X	X
J. torreyi Coville	–	X	X
Iridaceae, Iris Family			
Sisyrinchium demissum Greene	–	X	–
Orchidaceae, Orchid Family			
Spiranthes graminea Lindl.	–	X	X
Saururaceae, Lizard-Tail Family			
Anemopsis californica (Nutt.) H. & H., var. *subglabra* Kelso	–	X	X
Salicaceae, Willow Family			
Populus fremontii Wats.	–	X	X
Salix exigua Nutt.	–	X	X
S. gooddingii Ball	–	–	X
S. laevigata Bebb	–	–	X
S. lasiolepis Benth.	–	X	X
S. taxifolia H. B. K.	–	–	X
Juglandaceae, Walnut Family			
Juglans major (Torr.) Heller	–	–	X
Polygonaceae, Buckwheat Family			
Polygonum aviculare L.	–	–	X
P. coccineum Muhl.	–	X	X
P. pensylvanicum L.	–	X	X
P. persicaria L.	X	X	X
Rumex conglomeratus Murr.	–	–	X
R. crispus L.	–	X	X
R. violascens Rech. F.	–	–	X
Nyctaginaceae, Four-O'clock Family			
Mirabilis longiflora L.	–	–	X

Table 1. *(Continued)*

Taxa	Distribution		
	Aquatic	Semiaquatic	Riparian
Aizoaceae, Carpetweed Family			
Mollugo verticillata L.	–	–	X
Ranunculaceae, Crowfoot Family			
Ranunculus macranthus Scheele	–	X	X
Thalictrum fendleri Engelm.	–	–	X
Papaveraceae, Poppy Family			
Argemone pleiacantha Greene	–	–	X
Cruciferae, Mustard Family			
Rorippa nasturtium-aquaticum (L.) Shinz & Thell.	X	X	–
Saxifragaceae Saxifrage Family			
Ribes aureum Pursh.	–	–	X
Platanaceae, Plane Tree Family			
Platanus wrightii Wats.	–	–	X
Leguminosae, Pea and Bean Family			
Amorpha fruticosa L., var. *occidentalis* (Abrams) K. & P.	–	–	X
Cologania angustifolia H. B. K.	–	–	X
Medicago lupulina L.	–	–	X
Melilotus albus Desr.	–	–	X
Trifolium arizonicum Greene	–	–	X
Trifolium repens L.	–	–	X
Oxalidaceae, Wood-Sorrel Family			
Oxalis stricta L.	–	–	X
Callitrichaceae, Water-Starwort Family			
Callitriche heterophylla Pursh	X	–	–
Anacardiaceae, Sumac Family			
Rhus radicans L., var. *rydbergi (Small) Rehder*	–	–	X
R. trilobata Nutt.	–	–	X
Rhamnaceae, Buck-Thorn Family			
Sageretia wrightii Wats.	–	–	X
Vitaceae, Grape Family			
Vitis arizonica Engelm.	–	–	X
Malvaceae, Mallow Family			
Anoda cristata (L.) Schlect.	–	–	X
Sidalcea neomexicana Gray	–	X	X
Tamaricaceae, Tamarix Family			
Tamarix chinensis Loureiro	–	–	X
Elatinaceae, Water-Wort Family			
Elatine brachysperma Gray	–	X	–
Violaceae, Violet Family			
Viola nephrophylla Greene	X	X	–
Lythraceae, Loosestrife Family			
Ammannia auriculata Willd., var. *arenaria* (H.B.K.) Koehne	–	X	X
A. robusta Heer & Regel	–	X	X
Lythrum californicum T. & G.	–	X	–
Rotala ramosior (L.) Koehne	–	X	X
Onagraceae, Evening-Primrose Family			
Epilobium californicum Hausskn.	X	X	X
Gaura parviflora Dougl.	–	–	X
Ludwigia palustris (L.) Ell.	X	X	–
Ludwigia repens Forst	X	X	–
Oenothera rosea Ait.	–	X	X
Umbelliferae, Parsley Family			
Berula erecta (Huds.) Corille	X	X	X
Eryngium heterophyllum Engelm.	–	–	X
Hydrocotyle verticillata Thunb.	X	X	–
Lilaeopsis recurva A. W. Hill	X	X	–
Primulaceae, Primrose Family			
Centunculus minimus L.	–	X	X
Samolus parviflorus Raf.	–	–	X
S. vagans Greene	–	–	X
Plumbaginaceae, Plumbago Family			
Limonium limbatum Small	–	X	X
Oleaceae, Olive Family			
Fraxinus pennsylvanica Marsh, ssp. *velutina* (Torr.) G. N. Miller	–	–	X

Table 1. *(Continued)*

Taxa	Distribution		
	Aquatic	Semiaquatic	Riparian
Gentianaceae, Gentian Family			
Centaurium calycosum (Buckl.) Fern.	–	X	–
Eustoma exaltatum (L.) Griseb.	–	X	X
Apocynaceae, Dogbane Family			
Apocynum suksdorfii Greene	–	–	X
Asclepiadaceae, Milkweed Family			
Asclepias subverticillata (Gray) Vail	–	–	X
A. tuberosa L., ssp. *interior* Woods.	–	X	X
Cynanchum sinaloense Woods.	–	–	X
Labiatae, Mint Family			
Marrubium vulgare L.	–	–	X
Mentha arvensis L., var. *villosa* (Benth.) S. R. Stewart	–	X	X
M. spicata L.	–	X	–
Solanaceae, Nightshade Family			
Physalis hederaefolia Gray, var. *cordifolia* (Gray) Waterfall	–	–	X
Solanum americanum Mill	–	–	X
S. rostratum Dunal.	–	–	X
Scrophulariaceae, Figwort Family			
Bacopa rotundiflora (Michx.) Wettst.	X	–	–
Limosella aquatica L.	–	X	–
Lindernia anagallidea (Michx.) Penn.	–	X	–
Mimulus guttatus DC.	–	X	X
Bignoniaceae, Bignonia Family			
Chilopsis linearis (Cav.) Sweet	–	–	X
Lentibulariaceae, Bladderwort Family			
Utricularia vulgaris L.	X	–	–
Acanthaceae, Acanthus Family			
Anisacanthus thurberi (Torr.) Gray	–	X	X
Plantaginaceae, Plantain Family			
Plantago lanceolata L.	–	X	X
Caprifoliaceae, Honeysuckle Family			
Lonicera, cf. *arizonica* Rehd.	–	–	X
Campanulaceae, Bellflower Family			
Lobelia cardinalis L., ssp. *graminea* (Lam.) McVaugh	–	–	X
Compositae, Sunflower Family			
Ambrosia aptera DC.	–	X	X
A. confertiflora DC.	–	–	X
A. psilostachya DC.	–	X	X
Artemisia dracunculus L.	–	–	X
Aster exilis Ell.	–	–	X
A. pauciflorus Nutt.	–	X	–
A. subulatus Michx.	–	X	–
Baccharis salicifolia (R. & P.) Pers.	–	X	X
Bidens ferulaefolia (Jacq.) DC.	–	X	X
B. laevis (L.) B. S. P.	–	X	X
Centaurea rothrockii Greenm.	–	X	X
Chrysothamnus nauseosus (Pall.) Britt.	–	X	X
Conyza canadensis (L.) Cronq.	–	X	X
C. coulteri Gray	–	X	X
Cosmos parviflorus (Jacq.) Pers.	–	–	X
Erigeron canadensis L.	–	–	X
Gnaphalium chilense Spreng.	–	X	X
G. purpureum L.	–	X	–
Helianthus annuus L.	–	X	X
Heterotheca psammophila Wagenkn.	–	X	X
Pyrrhopappus multicaulis DC	–	X	X
Senecio douglasi DC., var. *longilobus* (Benth.) L. Benson	–	X	X
Sonchus asper (L.) Hill	–	X	X
Taraxacum officinale Weber	–	X	X
Xanthium strumarium L.	–	X	X
Zinnia peruviana (L.) L.	–	X	X

at Vera Cruz, México, spread through the region by 1524 with devastating Indian mortality (Crosby, 1976). This disease was followed shortly by measles (1531) and another unknown pathogen (1535) also introduced by the Spanish. These epidemics reduced aboriginal populations at the time of the first Spanish settlements to less than three-fourths of the 1519 level (Dobyns, 1981).

The 1531 epidemic was introduced to Texas by a member of a shipwrecked party led by Alvar Nuñez Cabeza de Vaca, who in 1534 escaped from Indian servitude and proceeded west, perhaps crossing the southeast corner of Arizona enroute to Culiacán. His stories of the rich "Cities of Cíbola" to the Viceroy of New Spain stimulated future expeditions through Arizona in search of wealth. Fray Marcos de Niza led the first party down the Río San Pedro and northeast into New Mexico in 1539. Francisco Vasquez de Coronado followed the same valley in 1540. Spanish explorations were few and little reported until Jesuit missionary activity began with *entradas* to Pimeria Alta by Padre Francisco Eusebio Kino from 1695 until his death in 1711. Working from missions established as much as 50 years earlier in the ríos Yaqui, Sonora, and Magdalena basins, Kino and other missionaries had profound influence on Indian cultures and their environments. As early as 1687, Pima Indians at Remedios, Sonora, were complaining that the Spanish pastured so many cattle that watering places were drying. This, and other Spanish impacts, precipitated the Pima uprising of 1751 in Arizona and Sonora (Ewing, 1941, 1945). Kino's accounts allow population estimates, evaluation of the extent of surface water, and assessment of possible impacts of Piman agricultural, food gathering, and livestock herding activities, but he was notably disinterested in natural history (Bolton, 1916, *et seq.*; Kino, 1919). Although accounts of Jesuit activities are available, it is the rare exception that provides details on the region's natural landscape.

Spanish missionary activity decreased after Kino's death. Spanish political problems in Europe coupled with Indian dissatisfaction and increasing Apache depredations ushered in an era of Spanish military control with establishment of *presidios*. By the mid-1760s a peaceful situation had been attained, but expulsion of the Jesuits by King Charles III in 1767 and their replacement by Franciscans produced deterioration of Indian-Hispanic relationships. Apache raids continued, but there were hints of general paranoia among the Spanish population and exaggeration of Apache impacts (Hastings and Turner, 1965). It is clear, however, that Spanish livestock-raising activities were maintained at high levels throughout much of the 18th Century (Bolton, 1948; Pfeffercorn, 1949; Wagoner, 1952).

By the early 19th Century, Spanish activities in Neuva España were decreased by diversion to more pressing problems in Europe. Decreased attention to her colonies eventually led to revolt, which gained México independence from Spain in 1821. Domestic problems almost immediately began in northern parts of the new country, with disagreements over state boundaries and revolt of the previously peaceful Opatas and Yaquis in Sonora. This unrest pushed the Sonoran cattle industry north into what is now southern Arizona, where Apaches were still peaceful (Bancroft, 1962). Large land grants along major drainages were made to private individuals. Expansion of the cattle industry was, however, cut short by renewed Apache depredations in 1831 (Mattison, 1946), which caused virtual abandonment by Mexican ranchers and miners. Accounts of the first large Angloamerican expeditions in 1846 and 1851 are replete with references to deteriorating haciendas and encounters with immense herds of abandoned cattle (Bartlett, 1854; Cooke, 1878, 1938; Bieber, 1937; Goetzmann, 1959). Thus ended the brief period of Mexican government in the region. The 1848 boundary treaty allotted lands north of the Gila River to the United States; the border was extended south to its present position by the Gadsden purchase of 1854.

The 1846 march of the Mormon Battalion was well chronicled by many of its participants. They provided descriptions of the land as did reports of Bartlett's surveying party and journals of numerous "49ers" enroute to gold fields in California. These were not, however, the first Angloamericans. Beaver trappers illicitly exploited the Gila River in the 1820s (Weber, 1971), and Pattie (1833) left a written chronicle of his adventures.

Basic documentation of natural conditions and cultural development is good from 1846 to present. The major impact of Angloamerican invasion was growth of the cattle industry. Suppressed first by Apaches and later the Civil War and economic depression, its expansion did not really begin until establishment of railway transportation in the 1880s (Wagoner, 1952). Herds built rapidly until overgrazing coupled with two years of drought brought disaster in 1893 with livestock mortalities reaching 50–75% (Wagoner, 1960).

Near the onset of severe overgrazing, the well-documented cycle of arroyo cutting began destroying ciénegas (Bryan, 1925b, 1926, 1928, 1940; Schumm and Hadley, 1957; Hastings, 1959; Hastings and Turner, 1965; Cooke and Reeves, 1976; Dobyns, 1981). Other forms of economic development, principally mining and irrigated agriculture, also were increasing by this time, and our general account of the region's history may end. More recent information is better detailed and our discussion becomes more specific.

Ciénegas of Individual Basins

San Simon Valley. This drainage (Fig. 4) is separated by an inconspicuous divide (1,400 m elevation) from the south-flowing Arroyo San Bernardino of the same structural trough. The valley is broad and shallow, ranging in width from 16 km in the south to 40 km at its mouth (elevation 914 m) (Schwennesen, 1917). The Peloncillo Mountains bounding the valley on the east average about 1,500 m high, with peaks to 1,800 m. The Chiricahua, Doz Cabezas, and Pinaleño mountains on the west are higher, with several peaks reaching to >2,400 m and Mt. Graham, the most northerly, exceeding 3,000 m.

Quaternary stratigraphy was described by Schwennesen (1917) as stream-gravel deposits overlain by clay-sand lake beds, which are in turn covered by younger stream gravels. The older stream deposits outcrop in only a few places. Younger stream deposits that surface two-thirds of the valley are thin near the Gila River, but thicken south-

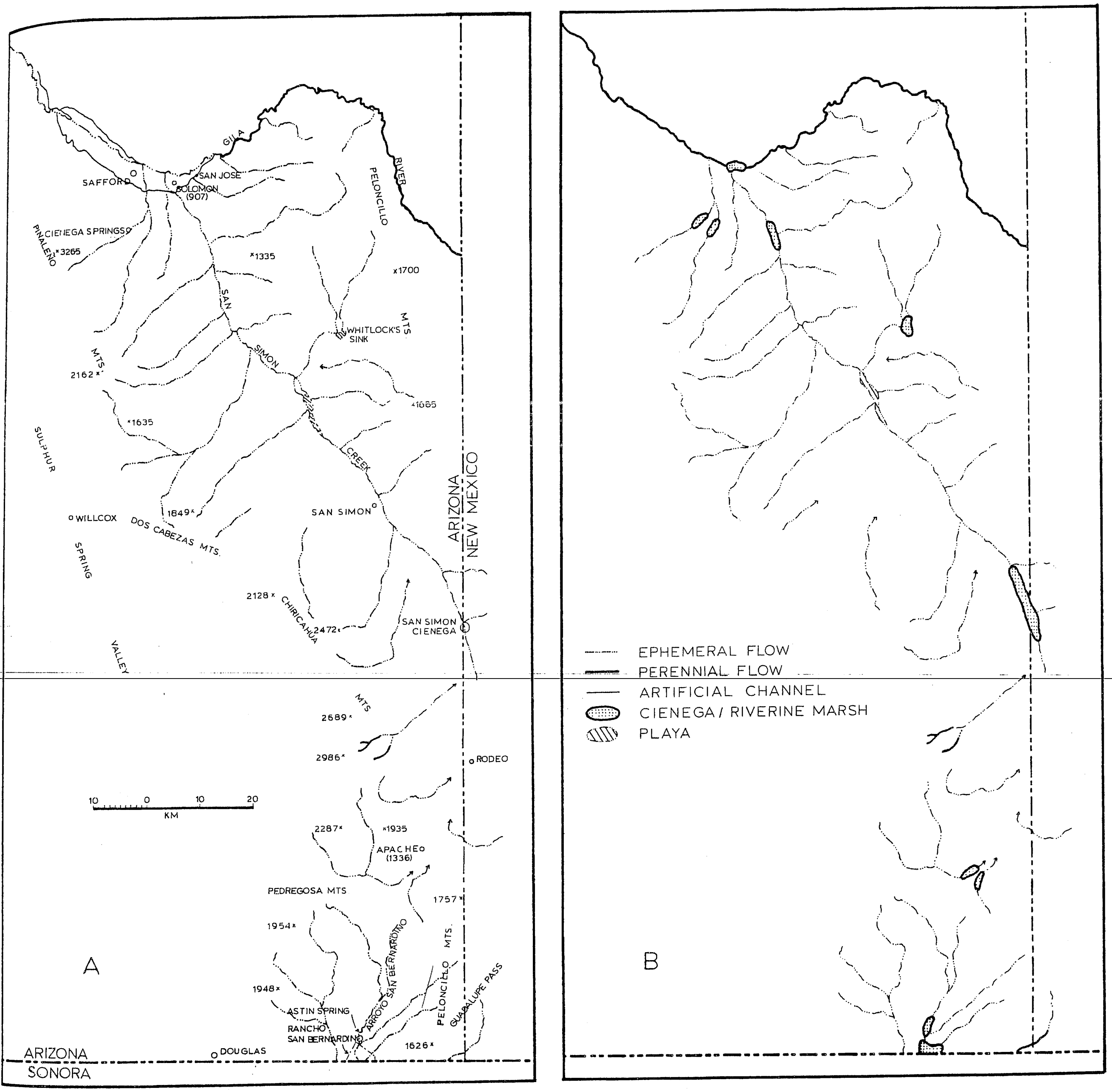

Figure 4. Sketch map of the San Simon Valley, Arizona: with place names mentioned in the text and present-day aquatic and semiaquatic habitats (excluding stock tanks) (A); and, map of San Simon Valley, with aquatic and semiaquatic habitats before 1890 as inferred from historic records (B). Elevations are in meters.

ward to 90–120 m. Lacustrine deposits >300 m thick are widely exposed in the lower valley, but are covered elsewhere by the younger stream gravels. Small, scattered lava beds are insignificant features near the San Bernardino divide. Schwennesen (1917) thoroughly surveyed wells in the valley and concluded that all groundwater resulted from infiltration of direct precipitation. Stream-gravel deposits are the water-bearing strata, the deeper one being artesian.

The San Simon Valley was inhabited by indigenous peoples who had disappeared by the time of Spanish explorations (Antevs, 1962). The valley was well known to Spaniards who christened it Río de Sauz (River of Willows), or, as Capitán Zuñiga referred to it in 1795, La Ciénega Salada (Hammond, 1931). Accounts of luxuriant vegetation prior to 1885 abound in the literature (Hinton, 1878; Barnes, 1936; Peterson, 1950). San Simon Ciénega, which lies across the present Arizona-New Mexico Border (Figs. 1, 2, 4), was a famous, well-described watering stop for pioneers, military, and surveying expeditions (Parke,

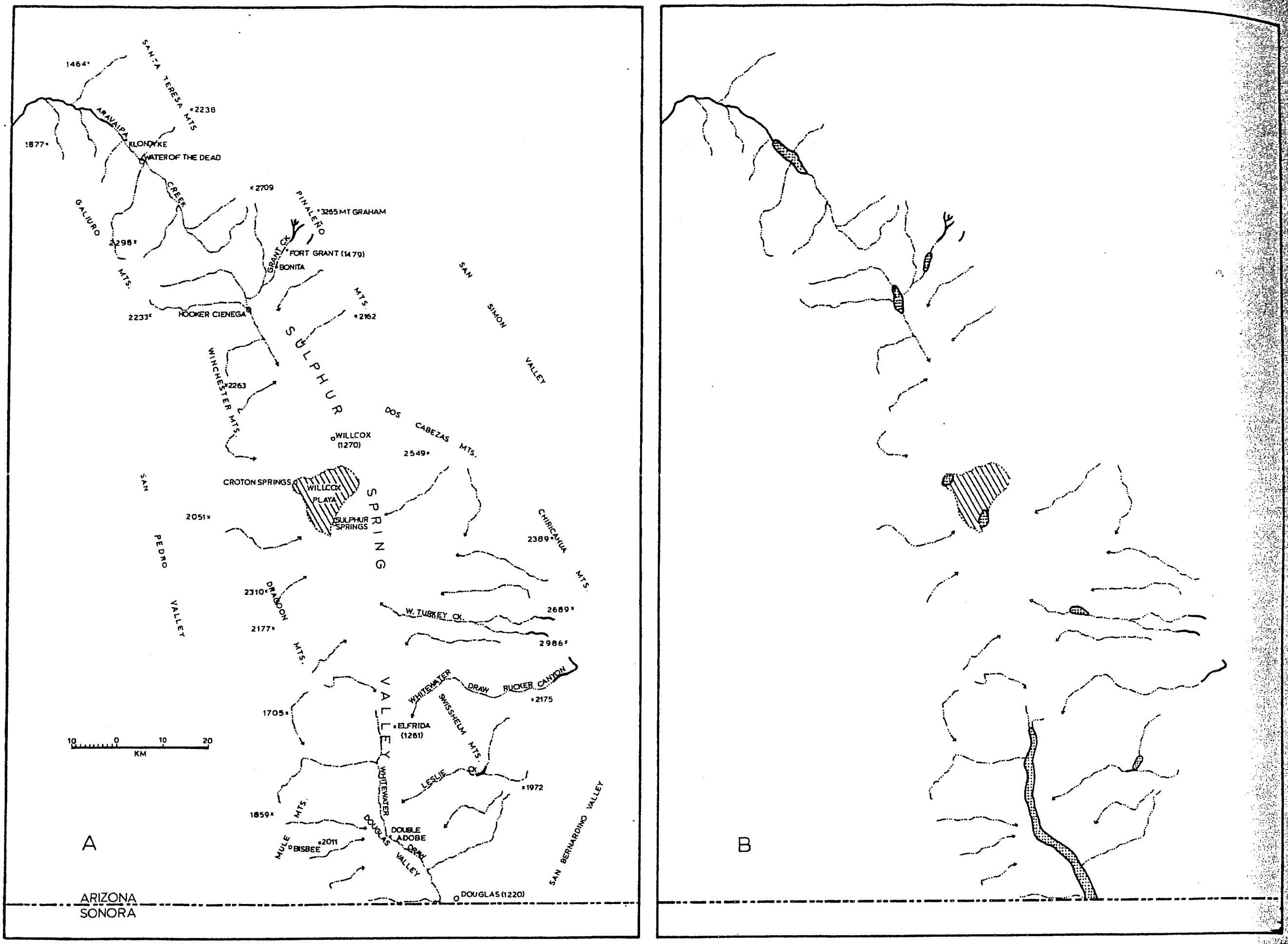

Figure 5. Sketch map of the Sulphur Spring Valley, Arizona: with some place names mentioned in the text and present-day aquatic and semiaquatic habitats (excluding stock tanks) (A); and, map of Sulphur Spring Valley, with aquatic and semiaquatic habitats before 1890 as inferred from historic records (B). Elevations are in meters. Symbols are as in Figure 4.

1857; Bell, 1869; Box, 1869; Eccleston, 1950; Peterson, 1950; Gray, 1963). The general picture was one of a grassland, with widely scattered Mesquite. The stream flowed through braided channels between low or virtually non-existent, marshy banks (Parke, 1857). Martin's (1963a) pollen data indicated that such ciénega conditions date well into prehistoric times.

The San Simon Valley changed rapidly after about 1885. Disappearance of grasses and beginning of severe erosion corresponded with heavy grazing pressure exerted by large cattle herds. Peterson (1950) proclaimed: "Today's picture of the valley... is one of devastation," and Olmstead (1919) and Barnes (1936) emotionally decried environmental destruction that had taken place.

Historical and scientific literature on arroyo cutting in this valley was reviewed by Cooke and Reeves (1976). Initiation of incision was often at points of streambed modification. A channelization project near Solomonville resulted in drastic incision during July floods of 1890. It also is clear that the present arroyo closely follows a former wagon road, which was implicated as the initiator of gullying. Cattle trails and the Gila, Globe, and Northern Railway embankments also were implicated. The result is an eroded valley with greatly improverished vegetation (see figures and descriptions in Jordan and Maynard, 1970).

San Simon Ciénega (Fig. 1), although now artificially maintained, represents the only extant ciénega in the drainage. Schwennesen (1917) reported it to cover 486 ha. In 1952 its discharge was 9.9×10^6 m^3/yr (DeCook, 1952). In 1953 a concrete retention dam was erected by the U.S. Bureau of Land Management (BLM) to prevent further incision. Immediately below the dam, remnant organic deposits remain in 3–4 m, vertical arroyo walls. Groundwater, which once intersected the surface to form the ciénega (Schwennesen, 1917), has been depressed. BLM now artificially maintains surface water by pumping, and water level is allowed to fluctuate. Expanses of open water are large and deep, creating a lentic, reservoir-like system.

Other areas in the basin formerly referred to as ciénegas are Whitlock's in Whitlock Sink (Granger, 1960), Munson's near San Jose (Hodge, 1877; Granger, 1960), Ciénega

Springs east of Cactus Flat in the lower valley (Knechtel, 1938), and unnamed ciénegas in the upper valley near the divide to the San Bernardino drainage (Riecker, 1879; Schwennesen, 1917).

Sulphur Springs Valley. This valley consists of an endorheic basin (Willcox Playa) bounded by two through-flowing drainage systems (Fig. 5). Aravaipa Creek drains the northern valley to the Río San Pedro *via* a deep canyon crossing between the Galiuro and Santa Teresa mountains, while the southern valley drains through Whitewater Draw to México. Each drainage is considered singly, although land use that affected aquatic systems was not confined by hydrographic divides.

Willcox Playa Basin.—All runoff in this middle drainage terminates in the Willcox Playa just south of the town of Willcox (Fig. 5). This barren, nearly level alkali flat covers about 130 km² and retains surface water following rainy seasons (Meinzer and Kelton, 1913). The present Willcox Playa is but a small remnant of Pleistocene Lake Cochise, which, as evidenced by remnant beach ridges, formerly covered 307 km² to depths >14 m (Meinzer and Kelton, 1913; Schreiber *et al.*, 1972).

Groundwater pumpage in the basin has increased from 2.5×10^6 m³ year^{-1} or less during the first four decades of this century, to an average of about 3.7×10^8 m³ year^{-1} for 1967 to 1975 (Mann *et al.*, 1978). Direction of groundwater movement has changed toward agricultural pumping centers. While Meinzer and Kelton (1913) reported a 320 km² area in which water was <5.0 m below the surface, Mann *et al.* (1978) mapped a similar area as having water at >30 m in 1975.

Permanent surface water is scarce throughout the approximately 3,840 km² drainage area (Mann *et al.*, 1978). Headwaters at high elevations on Mt. Graham and the Chiricahua Mountains, tributaries of Grant Creek and West Turkey Creek, respectively, collect snowmelt, rainfall, and springs to produce surface flows that rarely reach the valley floor (Brown *et al.*, 1981).

Croton Springs on the west edge of the playa and Sulphur Springs to the south both formerly produced surface flows evidently used by Indians (Meinzer and Kelton, 1913). Each had associated ciénega habitat. Eccleston (1950) described Croton Springs in October, 1849 as "springs of fresh water [that] build up here and lose themselves in the sand." Hinton (1878) referred to Croton and Sulphur springs as being among "several springs of good water in the valley." Another was Eureka Spring in upper Aravaipa Valley. At Croton Spring, Meinzer and Kelton (1913) found water within 0.3 m of the surface of a spring mound[1], and seepage from its base. A 1946 surface photograph and a 1958 aerial photograph of Croton Spring reveal ample water (R. M. Turner, U.S. Geological Survey, pers. comm., 1982). Hastings (1959) remarked that Croton Springs "has an excellent flow still . . . no significant difference is apparent between conditions there in 1850 and 1959." Hevly and Martin (1961), however, found no seepage anywhere and water more than a meter below tops of the mounds after a particularly wet winter. Wells near both Croton and Sulphur springs in 1975 had water at 9 to 13 m (Mann *et al.*, 1978). No surface water was present when we visited Croton Spring in 1981. Not as much historical information was found on Sulphur Springs, but a 1932 photograph (No. 5198, Arizona Pioneer Historical Society [APHS], Tucson) depicts an unmistakable marshy area that was ditched and thus probably drained by 1941, as indicated in another APHS photograph (No. 9006).

Croton Spring sediments and a 42-m core from the Willcox Playa have provided materials for palynological studies, from which major vegetation and thus climatic changes during and since Pleistocene have been inferred (*e.g.*, Hevly and Martin, 1961; Martin, 1963b; Martin and Mosimann, 1965). These studies demonstrated a higher proportion of *Pinus* pollen during Pluvial times than in modern pollen rains. A downward displacement of pine forests of 900 to 1,200 m was indicated, thus bringing them to the shores of Lake Cochise during Wisconsin time (20,000 to 23,000 years before present [ybp]) (Martin, 1963b). Relatively short-term vegetational shifts between Pine parklands and Juniper-Oak woodlands surrounding the lake during Wisconsin time were also inferred from their data (Martin and Mosimann, 1965). Sedimentologic data (Schreiber *et al.*, 1972) indicate Pluvial conditions previous to 13,000 ybp and desiccation followed by return to Pluvial conditions from 11,500 to 10,500 ybp. Increasing aridity to present has caused drying of the lake and a shift in surrounding vegetation to Desert grassland.

The largest ciénega in the basin is Hooker Ciénega (Fig. 6) at 1,350 m on the historic Sierra Bonita Ranch settled by Henry C. Hooker in 1872 (Granger, 1960). Pattie (1833) described ". . . a rich, black soil, with heavily timbered groves" in the vicinity. The ciénega has been essentially dry at times within the last 20 years, but after 4 of the last 5 years having abundant winter precipitation, is presently (1982) well watered (D. E. Brown, Arizona Game and Fish Department, pers. comm., 1982). Water was less than a meter below the surface in 1975 (Mann *et al.*, 1978). At its lower end the ciénega has been impounded resulting in artificially maintained habitat with large water-level fluctuations. Yatskievych and Jenkins (1981) surveyed the diverse flora at 8 transects across the 8-km-long ciénega area. Forty-six aquatic and semiaquatic taxa were documented. They noted that plants had been collected in the Area by J. J. Thornber in the first decade of this century, but did not discuss differences or similarities between the two collections.

Other references to ciénegas in this drainage were given by Granger (1960). Robert's Ciénega about 10 km from the mouth of West Turkey Creek was the site of a temporary military camp in the 1880s. In 1878, not far away, Pat Burn gave his name to another small, spring-fed ciénega near which he settled. Present status of these is unknown. Typically dark sediments and a peripheral stand of mature cottonwoods also occur near Bonita at the point where water from Grant Creek must have formerly surfaced onto the valley floor.

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[1] Spring mounds result from accumulation of organic materials, entrapment of wind-blown sand and dust, and lateral accretion of salts, and may rise to heights of >2.0 m where seeps rise to the surface in arid areas.

Aravaipa Valley.—This valley remains relatively remote and sparsely inhabited and appears to have always been so. Surface drainage from the east is from the northwest end of the Pinaleño Mountains and southern slopes of the Santa Teresa Mountains. The Galiuro Mountains form the western and southern boundaries of the basin (Fig. 5).

Permanent surface water on the valley floor presently flows only in the canyon which bisects the Galiuro range (Minckley, 1981). However, Hutton (1859) reported a large ciénega about 8.0 km above the canyon and Bell (1869) presented a lithograph illustrating such a marsh. Parke (1857) mentioned a ciénega in the same vicinity. Dobyns' (1981) mapped a marsh near the same location, calling it "Water of the Dead." Few other written historical descriptions exist and no viable remnants remain today. Hastings (1959) found reference in a government report to the use of mowing machines to cut hay for the cavalry at old Fort Grant (near the mouth of Aravaipa Creek) in the 1870s and 1880s. Cooke and Reeves (1976) pointed out that such harvesting might still be possible during wet years. An earlier reference is that provided by Dobyns' (1981) translation of the report of Capitán Don Antonio Comadurán who visited "Water of the Dead" on 27 May, 1830, but failed to describe it. The next day he observed near the head of the canyon "...that the Indians caused a large fire that had been burning for five days." Then mention of "thick pieces of wood still burning" is evidence of a mature riparian gallery forest. Such a forest, also described by Bell (1869), persists today (Minckley, 1981).

Douglas and San Bernardino Valleys.—Although San Bernardino Valley occupies the southern part of the San Simon structural trough, it is related hydrographically and geologically to the south-flowing lower Sulphur Springs or Douglas Valley. Arroyo San Bernardino receives its water from the south and east slopes of the Chiricahua Mountains and the southwest end of the Peloncillo Mountains. The Douglas Valley drains western slopes of the Chiricahua Mountains, principally *via* Rucker Canyon, which enters Whitewater Draw and flows around the north end of the Swisshelm Mountains before turning south crossing the border just west of Douglas (Fig. 5). Drainages from the Mule Mountains are tributary to Whitewater Draw from the west. South of the border the stream is known as Río de Agua Prieta (River of Dark Water), an often confusing situation in light of its name just north of the border and the presence of nearby Black Draw (also known as Arroyo San Bernardino). Tamayo (1949) attributed the Spanish name for Whitewater Draw to its severely polluted nature below the Douglas copper smelter, although use of the name long predates the smelter (Parry, 1857). The Sulphur Springs and San Bernardino valleys join in Sonora to continue south to the Río de Bavispe, which then joins the Río Yaqui.

The San Bernardino and Douglas valleys are geologically similar. Both, like other basins discussed here, are dominated by fluviatile valley fills, and include deeply buried lake beds (Meinzer and Kelton, 1913). Volcanic activity has been recent in both, but more extensive and surficially evident in the San Bernardino Valley (Sauer, 1930). Buried surface flows as well as injected lavas in Douglas Valley correlate with those of San Bernardino Valley (Meinzer and Kelton, 1913). The two are tectonically connected; both experienced extensive movements in the May, 1887 Sonoran earthquake (Dubois and Smith, 1980). In spite of many similarities, however, groundwater aquifers of these two basins are independent (Wilson, 1976; Mann and English, 1980).

Some evidence is available of prehistoric human occupation and ecological conditions in the Douglas Valley. Prehistoric ciénegas along Whitewater Draw near Double Adobe were studied palynologically by Martin *et al.* (1961) and Martin (1963a) from samples at archeological sites investigated by Sayles and Antevs (1941). These data, correlated with radiocarbon dates, show dominance of Compositae pollen indicating local ponding or ciénega habitat in a mesic environment between 800 and 4,000 ybp. During that time climate was similar to present. This period was preceeded by an "altithermal" period, 4,000 to 8,000 ybp, during which ciénegas with Ash-Willow riparian zones were along Whitewater Draw. Sayles and Antevs (1941) found evidence of arroyo cutting during this period, but thought conditions were arid (see also Antevs, 1962; Solomon and Blasing, 1982). Ciénega conditions along Whitewater Draw have nonetheless long existed.

Earliest human inhabitants of this region in historic time were Chiricahua Apaches, whose warlike nature precluded settlement by other Indians and Europeans. They occupied the Chiricahua Mountains at least as early as the first Spanish explorations (Guiteras, 1894; Kino, 1919). Springs at Rancho San Bernardino were used by Spanish travelers as early as 1697 (Bolton, 1936), and at least as late as 1795 when Don Manuel de Echeagaray spent time there writing letters after a long Apache campaign (Hammond, 1931). In 1822, Ignacio Perez received the 297 km^2 land grant including these springs from the Mexican government (Granger, 1960). Apache activity restricted development, and the hacienda was in ruins when members of the Mormon Batallion camped there on 2 December, 1846. Members of the batallion were aware that the ranch's owner was a Señor Elias of Arizpe: "...said to have been proprietor of above two hundred miles square extending to the Gila, and eighty thousand cattle."

Cooke's road through Guadalupe Pass to San Bernardino Valley and its springs, and continuing across Douglas Valley to the Rio San Pedro, quickly became a major cross-country route. Some descriptions of the San Bernardino Valley that shed light on ecological conditions at the time (1846–55) follow (brackets ours):

> *...encamped near the old houses and a remarkably fine spring fifteen paces in diameter (Bieber, 1937).*
>
> *...to the small and boggy valley of San Bernardino...and here we found a splendid spring of cold and clear water (Evans, 1945).*
>
> *It has the appearance of being a large town originally. A flat bottom beneath the ruins bears traces of having once been under good cultivation. Saw a large bear prowling through the ruins (Aldrich, 1950). [It may be noteworthy that Aldrich makes no mention of difficulties, such as a deeply incised arroyo, after having crossed the Río San Bernardino downstream a total of 69 times in 2 days enroute to the spring.]*

> *Adjoining this rancho [San Bernardino] are numerous springs, spreading out into rushy ponds, and giving issue to a small stream of running water. The valley is covered thickly with a growth of coarse grass, showing in places a saline character of soil. The timber growth is confined to a few lone cotton-wood trees scattered here and there (Parry, 1857).*

About 35 km west of the ruins at San Bernardino, Cooke and the Mormon Batallion found "...a large spring, which, as usual, loses itself after running a hundred yards....It is thought that as many as five thousand cattle water at this spring" (Cooke, 1938). Bliss (1931) thought it to be 10,000 cattle, but both he and Cooke agreed that there was Walnut-Ash riparian forest. Evans (1945), a 49er, found "an abundance of water for all" at this same place. Bartlett (1854) visited a spring much like that described by Cooke in May, 1851, and in August, 1852 returned to find it "filled with a dark, muddy water, whence it derives its name" (Agua Prieta). Emory (1857) noted large herds of feral cattle in 1855, and his geologist Parry (1857) provided one of the more informative descriptions of this valley:

> *The descent on the opposite (western) side of the ridge to the alluvial bed of the Aqua Preito is over a long, tedious slope, the gravelly table-land giving place to extensive tracts of clay or loam, supporting a patchy growth of coarse grass. The "Black Water" valley, at its lowest depression at this point, contains no constant running stream, its course being mainly occupied with low saline flats or rain-water pools. Extensive lagoons are said to occur in this valley a short distance south of where the road crosses.*
>
> *The main tributary to this valley comes from the west, and is followed to its head on the line of wagon-road. Its bed consists of a wide ravine, coursing through pebbly strata, variously marked by the washings and drift deposits, caused by the occasional strong current derived from local rains. At other times its bed is entirely dry. The timber growth along its borders consists of hackberry and walnut.*
>
> *At its source there is a fine spring, issuing from ledges of stratified porphyritic rock, identical in character with that noticed at the foot of the Guadalupe Pass. The stratification is inclined to the northeast, and along the line of its tilted ledges the spring issue forms frequent pools of limpid water.*

During the second U.S. and Mexican Boundary Survey in 1892, E. A. Mearns collected data for his "Mammals of the Mexican Boundary..." in which he (1907) wrote:

> *The San Bernardino River...is wooded with willow, cottonwood, boxelder, ash and mesquite; a few red junipers grow on adjacent hills; and the creosote bush, mesquite, acacia and ocotillo occupy the stony mesas and arroyos which constitute the major portion of that region. The broad meadows below the San Bernardino Springs are now covered by grazing herds; but at the time of Emory's survey they were occupied by a dense growth of cane which has since entirely disappeared. Waterfowl were abundant along the San Bernardino River and on the marshy meadows and pools below the springs.*

Apaches led by Cochise and Geronimo prevented settlement by Angloamericans until about 1872. At that time a treaty was made with Cochise, and a Chiricahua Reservation established. Geronimo remained active, however, and continued troubles were cause for removal of the Apaches to the San Carlos Reservation in 1876 upon dissolution of the Chiricahua Reservation. Construction of the Southern Pacific Railroad through Willcox in 1880 and Geronimo's surrender in 1886 provided supplies and security (Bancroft, 1962). Cattle ranching grew with rapidity at the same time mining activities in Bisbee provided impetus for development. The railroad through Douglas from Bisbee opened in 1902, and smelters located on Whitewater Draw for its groundwater provided an economic base for rapid growth (Ransome, 1904).

On 3 May, 1887, this area was shaken by a major earthquake, the epicenter of which was not far south in the San Bernardino Valley near Batepito, Sonora (now known as Colonia Morelos) (Goodfellow, 1888; Bennett, 1977; Sumner, 1977; Dubois and Smith, 1980; Herd and McMasters, 1982). Groundwater equilibria were disturbed throughout the Río Yaqui basin and elsewhere. A widely publicized occurrence was alteration of groundwater conditions at Abbott Ranch in Douglas Valley. The following quotations extracted from Dubois and Smith (1980) (compiled from Goodfellow [1888], Bennett [1977], and newspaper accounts shortly after the event) serve to illustrate these phenomena:

> *In one place far up the mountainside a stream of pure water 10 inches in diameter is belching forth, and at present shows no sign of ceasing.*
>
> *The stream which was 10 inches in diameter created a shallow lake a mile wide.*
>
> *Water came bubbling from the hillsides, from where water has never been seen.*
>
> *One and a half mi. from C. S. Abbott's house the water shot up into the air to a considerable height, about 4 or 5 ft. in width, and extended fully 100 ft. in distance. Today the flow was decreasing very fast, but for miles the plains were covered with water.*

Flow in the Río Yaqui in Sonora increased greatly, but this as well as Abbott's windfall, said to be sufficient to water 100,000 cattle, returned to former conditions within a few days.

Agriculture started in the Douglas Valley in 1910 with drilling of the first wells (Coates and Cushman, 1955), and expanded rapidly to 202.5 km^2 by 1965 (White and Childers, 1967). The history of groundwater exploitation is well known, starting with a comprehensive study by Meinzer and Kelton (1913), followed by Coates and Cushman (1955), White and Childers (1967), and recently, Mann and English (1980). Groundwaters of San Bernardino Valley have not been so extensively exploited. However, wells constructed by J. H. ("Texas John") Slaughter on Rancho San Bernardino in Arizona tap a warm artesian aquifer also drained by wells in Sonora. This aquifer is distinct from that which produces natural springs on the property (Wilson, 1976).

Permanent, natural surface waters in the Río Yaqui drainage in Arizona currently consist only of springs on Rancho San Bernardino, and short reaches in Leslie Creek and upper Rucker Canyon in the Douglas Valley drainage (Hendrickson *et al.*, 1980; Brown *et al.*, 1981). A few references mention high groundwater and sometimes marshy areas along Whitewater Draw west and southwest of Elfrida (Parry, 1857; Meinzer and Kelton, 1913; Coates and Cushman, 1955; Cooke and Reeves, 1976). The lower 3.2

km of Whitewater Draw and Astin Spring on the Arroyo San Bernardino have become ephemeral only within the last few decades (Coates and Cushman, 1955; Minckley, 1973; McNatt, 1974; Hendrickson *et al.*, 1980).

Springs at Rancho San Bernardino produced extensive ciénegas, still largely intact although artificially maintained by artesian wells (Fig. 8). Vegetation and flora were detailed by Marrs-Smith (1983). As reviewed above, its historical importance to human activity was considerable. However, despite frequent mention in journals, a definitive description of its historic vegetation more detailed than "a boggy valley with scattered cottonwood trees" cannot be made. Higher ground definitely supported mesquite, but the valley bottom seemed devoid of it and dominated by grasses where not "rushy" (Cooke, 1938). Mesquite now forms dense *bosques* over a wide area along Arroyo San Bernardino (Marrs-Smith, 1983).

A Sacatón meadow persists on the site of an old ciénega above a low dam on Leslie Creek. Below the Sacatón extends a 1.0-km reach of permanent water, with dense Cottonwood-Ash-Willow riparian forest bordering a narrow stream dominated by Watercress (Fig. 7). This small reach of permanent flow was proposed as a Natural Area by Smith and Bender (1974a).

Ciénegas were apparently scarce elsewhere in the Río Yaqui drainage in Mexico. Hendrickson *et al.* (1980) reported none, but an anonymous essay translated by Guiteras (1894) mentions ciénegas during Spanish times in what is now Sonora at Cuchuta, Teuricachi, and west of Cuquiarachi.

San Pedro Valley. Flowing north from Oak-Grassland hills of the Sonoran copper mining area of Cananea (40 km south of the International Boundary), the Río San Pedro drains more than 16,635 km^2 (Cooke and Reeves, 1976). The stream enters Arizona at 1,303 m elevation and flows 200 km to enter the Gila River at Winkelman (588 m) (Fig. 9). Eastern rim of the basin is formed from south to north by the Mule, Dragoon, Winchester, and Galiuro mountains, which range to peaks >2,300 m high, separated by 1,525–1,650 m passes. The western divide is higher, with peaks to 2,885 m in the Huachuca Mountains north of the border, to 2,259, 2,641, and near 3,000 m in the Whetstone, Rincon, and Santa Catalina mountains, respectively, as one proceeds north. Passes of 1,220 to 1,650 m divide these major ranges.

Geologically, structure and composition is much like that of other valleys in the Basin and Range Province (Roeske and Werrell, 1973). Valley fill consists of two basic parts, the upper (younger) ranging from 90 to 240 m thick with greatest depth in mid-valley and consisting of clay and silty gravel beds along margins and silt and sandy silt in the center. Below these strata are older gravels, sandstones, and siltstones, thin peripherally, but exceeding 300 m thick centrally. Over valley fill at the surface along drainages is a 12- to 46-m thick floodplain alluvium of gravel, sand, and silt. Bedrock outcrops restrict the valley's width near Charleston, at "The Narrows," at Redington, and again near the Gila River (Wilson *et al.*, 1960). These restrictions, producing surface flows in places, have resulted in unequal depths of valley fill between sub-basins and increased longitudinal surface slope in each successive sub-basin (Haynes, 1968; Cooke and Reeves, 1976).

Human occupation of this valley dates to as early as 1500 as indicated by excavations of Di Peso (1951) along the lower Babocomari River. The Babocomarites, with affinities to more southern cultures in Sonora, established at least four agricultural communities along eastern foothills of the Huachuca Mountains. They may have been ancestral to the Sobaipuri Indians found along the Río San Pedro by early Spanish explorers, but evidences of relationship are ambiguous (Di Peso, 1951).

The Sobaipuris were visited by Padre Kino and other missionaries from 1692 to 1697 (Kino, 1919). They were censused at 2,000 "souls" distributed along the San Pedro in 14 villages. The most populous of these was Quiburi about 2.0 km north of Fairbank, with 500 inhabitants, and La Victoria de Ojio near the mouth of Aravaipa Creek, with 380. That the river was unincised and marshy, at least at village sites, is attested to by mention of extensive *acequias* (ditches) for irrigation of squash, bean, maize, and cotton fields, and statements that houses were constructed of poles and "reeds." The Sobaipuris were provided livestock by Kino in the late 17th Century (Kino, 1919). They pursued an agricultural lifestyle until fleeing Apache depredations in 1762 (Guiteras, 1894), leaving the valley unirrigated until Mormon settlers arrived 125 years later.

During the next 70 years, variations in intensity of Apache raids allowed sporadic development of Spanish cattle industries. Mexican land grants in 1822 deeded most riparian bottomlands to wealthy cattlemen, who heavily stocked their ranges (Mattison, 1946). By the time Angloamericans began exploring, intensified Apache hostilities from 1828 to 1843 had caused the Mexicans to abandon their operations (Haskett, 1935). Clarke (1852) mentioned evidence of Mexican irrigated farming, but all that remained were ruined haciendas and plentiful feral cattle. Cooke (1938), upon reaching the Río San Pedro in 1846, remarked that "There is not on the prairies of Clay County, Missouri, so many traces of the passage of cattle and horses as we see every day." Wild herds appeared to dwindle rather quickly, possibly due to hunting by Apaches, military expeditions, and 49ers (Browne, 1869; Bell, 1932).

American cattle ranching attempts began in the late 1860s, but problems with Apaches thwarted them until the late 1870s when J. H. Slaughter brought a herd to Hereford (Haskett, 1935). By the early 1880s herds grew rapidly, peaking just before a disasterous drought of 1891–93.

During this same time irrigated farming was developing, especially near St. David where a thriving Mormon colony established (McClintock, 1921). By 1899, 1,400 ha were being irrigated (Roeske and Werrell, 1973). Mining concurrently became important, especially near Tombstone beginning in 1878 (Hamilton, 1881; Gilluly, 1956). A rip-rap dam across the river in 1879 diverted water into a 2.4-km ditch to supply an ore mill operating at Charleston by 1881. This was short-lived, however, and the mining boom that so quickly made Tombstone a population center soon died. By 1890, Charleston was deserted, and Tombstone nearly so. Agriculture continued

Figure 6. Hooker Ciénega, Arizona, after partial impoundment. Photograph 1981.

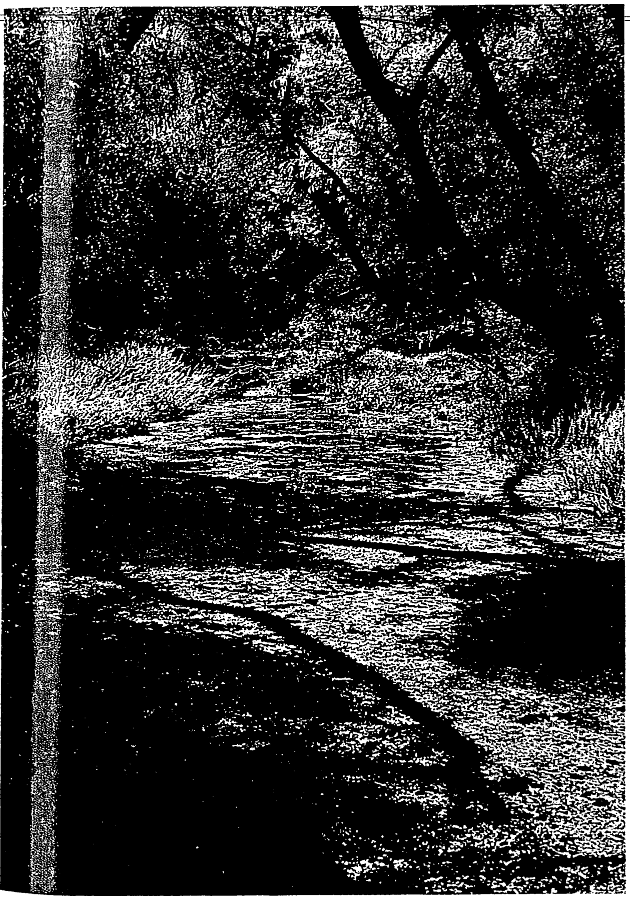

Figure 7. Leslie Creek, Arizona: narrow ciénega habitat bordered by dense riparian gallery near middle of 1.0-km, permanent reach. Photograph 1982 by G. K. Meffe.

to grow, reaching 5,000 irrigated hectares by 1966, but decreasing to 3,900 ha by 1970. Groundwater pumpage roughly paralleled changes in area irrigated (Roeske and Werrel, 1973).

As recently as a century ago the Río San Pedro was unincised and marshy along much of its length (reviewed by Hastings, 1959 and Hastings and Turner, 1965). Earliest descriptions are vague, but Padre Kino (1919) in the late 17th Century described the valley as lush, with much irrigation. The Mormon Batallion first camped in the valley "...in a marshy bottom with plenty of grass and water" (Cooke, 1938). Here and for two days travel downstream conditions remained the same. Cooke (1938) and Bliss (1931) both mention an abundance of fishes, "...salmon trout, up to three feet long" (Cooke, 1938), taken by members of the Batallion along this reach[2]. Eccleston (1950) reported such fish at Tres Alamos in 1849. Tyler (1881) described the boggy nature of the stream at "Bull Run" (presently Lewis Springs) in 1846: "A kind of cane grass grew in this region, from four to six feet high, being very profuse and luxuriant in the bottom near the stream." Cooke (1938) was impressed by the valley, and apparently referred to *Sporobolis airiodes* when he mentioned "...bottoms having very high grass and being lumpy" near Lewis Springs. The next day he wrote "the bottom grass is very tall and sometimes difficult to pass through. These bottoms average above a mile and are good land." Evans (1945), found "...our road winding through miry bottoms of a small stream which was kept alive by the water of marsh and springs" as his party crossed Río San

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[2] Such fish could only have been Colorado squawfish, *Ptychocheilus lucius*, the largest native North American cyprinid, formerly abundant in the Colorado River basin, but now approaching extinction.

Tucson. Members of the Mormon Batallion (Cooke, 1938) expressed surprise that water existed as far as 11.2 km downstream from that presidio in 1848, and numerous other travelers attested to aridity of lands between Tucson and the Gila River. There is no evidence that the Río Santa Cruz extended as surface flow to its confluence with the Gila River in historic time. However, subsurface waters rose to the surface near the southern terminus of Sierra Estrella (Rea, 1983) producing marshlands to be discussed later along with Gila River habitats.

Beginning with a history of continuous habitation and agriculture predating the late 17th Century, this basin is distinguished from others in many ways. A consequence of continuous human habitation is not only better documentation of land use, but significant differences not seen in other valleys. Like the San Pedro, this valley was irrigated by *acequias* at least as early as Padre Kino's first visit in 1689, and surely much earlier (Bolton, 1936). Many Sobaipuri Indians who abandoned the San Pedro Valley in 1762 moved to the Río Santa Cruz near Tucson, where a continuous history of irrigation has been maintained to present.

Spanish mission activity in Arizona was centered in the upper Santa Cruz Valley, which was a principal regional thoroughfare, and nothing exceeding visita status was established outside that valley (Bolton, 1936). The extent of livestock grazing was consequently of greater intensity and duration than elsewhere (Wagoner, 1952). Padre Kino brought cattle to San Xavier del Bac in 1700 (Kino, 1919). Early floodplain alterations related to urban development in Tucson, such as infiltration galleries, mills, and mill ponds, also were unlike river modifications in other drainages (Cooke and Reeves, 1976). Early agricultural development near Tucson was substantial (Fergusson, 1862). More recently, groundwater pumpage for irrigation, especially near Eloy, has been extensive. Total annual pumpage in this hydrologic basin has often exceeded that of any other in the study region by nearly an order of magnitude (Babcock, 1980). Schwalen (1942) and Schwalen and Shaw (1957) provided rainfall, runoff, and groundwater data for the basin.

Unlike the Río San Pedro, the Santa Cruz was well documented as only locally perennial (Browne, 1869; Bourke, 1891; Bieber, 1937; Durivage, 1937; Cooke, 1938; Harris, 1960; Way, 1960). The trough through which the river passes is deeply alluviated and lacks shallow structural dikes or "narrows" which force groundwaters to the surface. Perennial flow now is absent except in short reaches above Lochiel, below Nogales in Potrero Creek, through Arivaca, and above Vail in Pantano Wash (Brown *et al.*, 1981). Longer reaches in tributaries at mid-elevations are a 10-km-flow along Ciénega Creek on the Empire and Ciénega ranches, and about 19 km in Sonoita Creek downstream from Patagonia (Brown *et al.*, 1981). Marshlands formerly occurred in present-day perennial reaches, and local remnants persist.

Private ownership of a large part of the San Rafael Valley dates to 1825 when the land grant of San Rafael de la Zanja was deeded to Ramon Romero. Valuations of the *sitios* in 1821 indicate that 3 of the 4 had permanent surface water (Mattisòn, 1946). Permanent surface flow is present today only in a short reach of the mainstream and in spring systems above Lochiel. Springs near the perennial reach in the mainstream connect to it *via* surface flows only during flood.

Each of two springs described by Meffe (1983) and Meffe *et al.* (1982, 1983) in the San Rafael Valley consist of similar, well-developed, but areally-restricted ciénega conditions (Figs. 17, 18). Both have long, narrow, vertical-walled pools, often exceeding a meter in depth, separated by shallow, reticulate channels flowing through sedges and other macrophytes. Sharp Spring Ciénega (Meffe, 1983; Meffe *et al.*, 1983) appears younger than Sheehy Spring Ciénega. The latter system has associated large Cottonwood trees, while younger trees predominate at the former. Sharp Spring is bounded by vertical banks often exceeding 3.0 m in height. No evidence of arroyo cutting is apparent at Sheehy Spring, where hillsides slope evenly to the valley floor ciénega. Incision of Sharp Spring has been followed by hydrologic and climatological conditions appropriate for aggradation and vegetational succession toward the present condition. Each is situated in gently rolling, Plains Grassland (Brown and Lowe, 1980). Both are grazed, sometimes heavily during drought.

Upstream, another spring persists at Bog Hole. Recently (1975) impounded by Arizona Game and Fish Department to provide Mexican Duck *(Anas platyrhynchos diazi)* nesting habitat, what surely was once a natural ciénega is now an open-water reservoir several meters deep. *Typha* sp. has invaded littoral areas and small islands, but a few remnant patches of ciénega persist.

Although not well documented, ciénegas elsewhere in this valley in Arizona and in Mexican portions of the drainage were formerly more widespread than at present. Black ciénega deposits outcrop in walls of most arroyos. Parry (1857) mentions an abundance of water near the Mexican town of Santa Cruz. Browne (1869) and his party killed enough ducks there in 1864 to last them for several days. Today the mainstream is incised along most of its course through México (Hastings, 1959).

It seems well documented that there was locally perennial surface flow in the 1800s in the upper mainstream Río Santa Cruz in Arizona from the U.S.-Mexican border to about Tubac (Brown *et al.*, 1981), and that intermittent conditions existed downstream as far as Tucson (Mowry, 1864; Browne, 1869; Bell, 1932; Bieber, 1937; Durivage, 1937). Today it is ephemeral along this reach, and virtually no marshlands exist. Historic references to marshy bottomlands near the mouths of Calabasas and Sonoita creeks, where Brown *et al.* (1981) mapped a former wetland, are in Allison (undated) and Browne (1869). Hastings (1959) reported on 1870 newspaper and government document references to problems with malaria, also mentioned by Wheeler (undated) at Calabasas. The Pete Kitchen Ranch on Potrero Creek about 9.6 km north of Nogales overlooked a ciénega (Bourke, 1891). Small remnants of ciénega associations still exist in Calabasas Creek where crossed by U.S. Highway 89, and in Potrero Creek near its mouth. Powell (1931) mentioned "...bunchy swamp grass" near Guevavi in 1849.

Although not frequently visited by early explorers, the few journal reports on Sonoita Creek are valuable. Bartlett

(1854) was impressed by the "head-high" grass and giant Cottonwoods, with an understory of dense Willows and vines, that he found in a "swamp" near headwaters of Sonoita Creek. He noted that the gallery forest and understory became dense and impossible to negotiate without axes below present-day Patagonia, where an impressive riparian gallery forest persists today (Glinski, 1977). The "large swamp" upstream, thought by Irwin (1859) to be the source of malaria at Fort Buchanan, is gone. Irwin described the marsh as follows:

> *This* ciénega *consists of alluvial deposits and extensive beds of decaying organic matter, the result of the rank, forced vegetation of the hot season. Here several warm and cold springs pour forth their contents, which run over the surrounding level surface, forming a* peat *marsh of considerable extent, wherein there are several stagnant, filthy pools, in which vast herds of swine may be seen constantly basking in the mud or rooting up the foetid and miasmatic soil of the adjacent quagmires.*

Two small, ciénega-like remnants, Monkey and Cottonwood springs, have persisted in this area.

Cottonwood Spring, immediately downstream from ruins of Fort Buchanan, is sporadically diverted below its source. Its waters have deposited no recent travertine. The spring issues from a hillside adjoining Sonoita Creek and flows into it, unless diverted, after crossing a short reach of boggy, organic ciénega deposits dominated by low sedges.

Monkey Spring formerly deposited large amounts of travertine downstream from its source. An extensive natural lake and later an artificial pond were impounded by these deposits until its seal was broken by heavy machinery (Minckley, 1973). All that remains today is an often-dry, artificial impoundment, and the now-dry travertine (Fig. 19). Despite proximity of the area to Fort Buchanan, which thrived in the 1870s, only one account of this spring was found. Pumpelly (1870) remarked that he did a morning excursion with Lieutenant Evans "...to see some springs which were forming a heavy deposit of calcareous tufa..." Today the springhead and approximately 20 m of run are fenced against cattle. Below the fence, flow is diverted into a concrete flume leading to an impoundment, from which water is drawn for irrigation. Virtually all natural habitats outside the short spring run (Fig. 20) have been destroyed, with no documentation of their structure and composition.

The geologic map of Wilson *et al.* (1960) reveals a rhyolite-andesite intrusion into the Sonoita Creek bed in the area of Cottonwood Spring that must have forced groundwater to the surface near Fort Buchanan. Faults in this intrusion presumably help produce both the thermal Cottonwood and Monkey springs.

Marshlands along Río Santa Cruz near San Xavier del Bac and Tucson formerly occupied what is now one of the most extensive examples of arroyo cutting in the region, and consequently have long since disappeared. Progression of this incision was observed by Tucson residents during floods of 1890–92, and thoroughly discussed by Cooke and Reeves (1976). Erosion initiated at man-made structures and progressed upstream. Marshes existing around Tucson just prior to the floods were recalled by Allison (undated) and incision of those near San Xavier del Bac was documented by Olberg and Schanck (1913) and Castetter and Bell (1942).

Historical descriptions again go scarcely beyond documentation of the existence of marshes. References to lush grasslands abound. Vegetational composition is rarely mentioned except when species provided feed for livestock. Allison (undated) described what was almost certainly a stand of Common Reed *(Phragmites australis)* along the river at the next ranch below Pete Kitchen's. He and Wheeler (undated) also remembered similar marshy areas at the base of "A" Mountain in Tucson.

The history of woody riparian vegetation is confusing, although more frequently described in journals. Bartlett (1854) was impressed by dense gallery forests along Sonoita Creek and near its mouth, where he measured a Cottonwood 8.5 m in circumference 1.5 m above the ground. Browne (1869) was especially impressed with grass cover in the valley, but often mentioned abundance of cottonwood and found an abundance of "mesquit (sic), cotton-wood, willow and walnut" at Calabasas. Evans (1945) found "towering cottonwoods" along the river. Durivage (1937), another gold seeker, noted Cottonwoods marking the dry river course below Tumacacori to Tucson. Parke (1857), however, thought Cottonwood, Willow, and Mesquite scarce near Tucson, and certainly Bahre and Bradbury's (1978) rephotography of boundary survey sites document deciduous riparian galleries near Lochiel and east of Nogales where none existed in 1892.

The now dry bed of Rillito Creek passes through the northern suburbs of Tucson, past ruins of Fort Lowell where it was perennial in the 1880s (Condes de La Torre 1970), to its confluence with Río Santa Cruz northwest of the city. East of there on Pantano Wash and its tributary Ciénega Creek may have formerly been the most extensive ciénega system in the basin. Small remnants persist today. The wagon road established along this drainage by Captain Cooke and his Mormon Batallion became an important cross-country route for gold seekers. Later the Butterfield Overland Stageline connected with it over the same pass across the north end of the Whetstone Mountains, skirted the south edge of the Rincon Mountains across lower Ciénega Creek, then followed Pantano (Spanish for "swamp") Wash and Rillito Creek to Tucson (Conkling and Conkling, 1947). The Southern Pacific Railroad subsequently replaced the stageline along the same route. Marshy conditions may well have existed along all those watercourses and they were collectively known as "Ciénegas de los Pimas." This extensive system was obviously known to indigenous peoples and was used by the Zuñiga party in 1748 (Hammond, 1931), as well as Comadurán's Mexican anti-Apache campaign (Dobyns, 1981). Eccleston (1950) followed the stream 8.0 km downstream from where he first entered Ciénega de los Pimas in 1849 before it sank into its bed and marsh vegetation ended. In his words "The water was in marshes, coming from springs and a little brackish....The grass, or rather cane, was some 6 feet high..." This vegetation was accidentally ignited by Eccleston's party, who barely managed to save their teams and wagons. Way (1960), in the diary of his 1858 stagecoach trip, described the water as "...clear and beautiful, but slightly alkaline." He added

Figure 14. *Ciénega Creek, Arizona: uncut, impounded ciénega adjacent to stream channel. Photograph 1980.*

Figure 15. *Ciénega Creek, Arizona: ciénega and riparian gallery formation on floor of incised stream. Photograph 1980.*

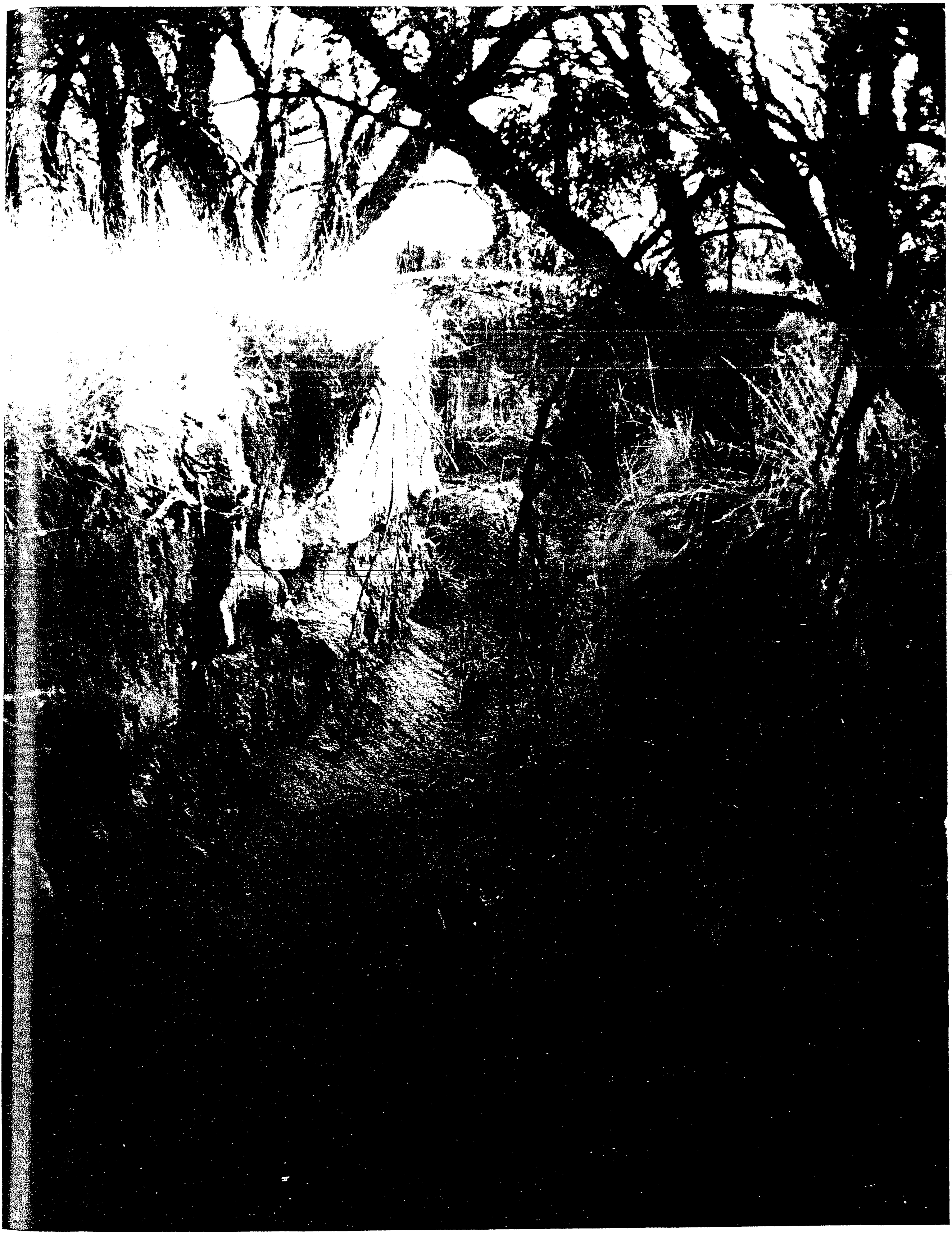


Figure 16: Ciénega Creek, Arizona: arroyo incision with subsequent Mesquite invasion. Photograph 1980.

that "The valley is a delightful looking place and its cool water, green foliage and scrubby trees look like paradise to the weary traveler over the hot and parched up plain."

Approximately a 5.0-km perennial surface flow persists today in Pantano Wash (Condes de La Torre, 1970; Brown *et al.*, 1981) above a basaltic dike (Davidson, 1973) at the railroad crossing. It infiltrates into streambed alluvium immediately below this structure, apparently near where Eccleston (1950) noted its disappearance in 1849. It thus seems likely that this same dike brought groundwater to the surface for marsh formation and maintenance. Nothing remains of the wetland today and an average annual discharge of 6.3 x 10^7 m^3 (Condes de La Torre, 1970) flows through a sandy bed, deeply incised into surrounding alluvium and bordered by mesquite.

Ciénega Creek probably took its name from Ciénega de Los Pimas. Smith (1910) referred to the entire lower Ciénega Creek Valley as:

> *...an unbroken forest, principally of mesquite, with a good growth of gramma and other grasses between the trees. The river course was indefinite,—a continuous grove of tall cottonwood, ash, willow and walnut trees with underbrush and sacaton and galleta grass, and it was further obstructred by beaver dams.... Such portion [of rainfall] as found its way to the river channel was retarded and controlled in its flow, and perhaps not oftener than once in a century did a master flood erode and sweep the river channel.*

He described a major flood in 1881 that spread out over the valley, but later floods (1890s) which incised. The 1869 General Land Office Map of the Arizona Territory went so far as to extend "Ciénegas Las Pimas" from Tucson upstream to the town of Pantano. Granger (1960) cited another earlier map that did the same. The 1875 War Department Surgeon General's Office report on Army hygiene (U.S. Army, 1875) mentioned perennial flow ending about 1.6 km below Fort Lowell and stated that near the post Rillito received underground flow from the ciénega "...about twenty-three miles distant from this camp."

Another important marshland is still represented by remnants 16 km upstream along Ciénega Creek. While not reported as early in historical literature, inferences about prehistoric ecological conditions have been made by Schoenwetter (1960). Martin *et al.* (1961), and Martin (1963a), using palynological analyses. Their data indicate the ciénega as prehistorically more extensive, but with evidence of alternating periods of degradation and aggradation. At the northern (downstream) edge, where a deep incision now exists, a 13th Century cut may also have occurred and subsequently filled. Upstream, where ciénega habitat is actively rebuilding within an incision, evidence of the 13th Century arroyo was not detected, but later dissection was indicated during historic time. A long interval of predominately undissected ciénega conditions (dominated by ragweed pollen, *Ambrosia trifida* and *A. psilostachya*) over the last 3,500 years was, however, indicated. An absence of sediments older than 4,000 years was interpreted by Martin (1963a) as indicative of an older, extended period of erosion. It is significant that corn (*Zea* sp.) pollen was present. This, plus Eddy's (1958) study of cultural time spans contemporaneous with Martin's pollen stratigraphy, indicate the ciénega as an important resource to prehistoric cultures.

In historic time, ranches developed on upper Ciénega Creek became widely known. Hinton (1878) mentioned abundant springs, which furnished a large volume of water. It may have been here that Graham (1852) found abundant grass and a valley "quite boggy in the middle," which forced them to keep to the western side. Wagoner (1960) reported the Empire Ranch was grazing 5,000 head of cattle in the 1880s, and there were 1,000 cattle and 23,000 sheep on the adjacent Ciénega Ranch. Reminiscences of Vail (undated), one of three joint owners of the Empire Ranch in 1880, described the land as a succession of meadows thickly covered with Sacaton and Salt Grass. Mesquite grew only in gulches.

The Sacaton flats are presently invaded by Mesquite. One marshy area still exists at Ciénega Ranch, retained by an earthen dike along the edge of a drained meadow. Arroyo incision has been extreme, and vertical walls exceeding 8.0 m high are not uncommon through dense Mesquite bosques (*e.g.* Martin 1963a, plate 11).

Surface flow in the arroyo remains permanent along an approximately 12-km reach above a dike of Permian limestone, Cretaceous shale, sandstone, and conglomerate (Wilson *et al.*, 1960). Conditions have promoted streambed succession to a substantial ciénega along part of the arroyo floor (Figs. 14, 15, 16). Willows are established and the streambed is choked with Watercress (as well as *Ludwigia natans, Bidens* sp. and *Hydrocotyl verticillata*) growing in rich organic sediments. The channel is often ill-defined within constraints of arroyo walls, but occasional vertical-walled pools are present. Commercial developments on the Empire Ranch above the perennial reach have been planned by Gulf American Corporation Properties, who projected a maximum population of 42,000 persons within 70 years. A study of adequacy of groundwater supply (Arizona Water Commission, 1972) indicated that lowering of the water table as much as 100 m and depletion of base flows were likely, not only in Ciénega Creek, but also Sonoita Creek and Babocomari River.

One additional isolated ciénega exists in the upper Santa Cruz basin on Arivaca Creek (Fig. 21). According to Granger (1960), Kirk Bryan translated the Pima name Arivaca as "little reeds" or "little fence water." Riggs (1955), however, believed it to mean "where little people [small animals] dig holes." Whatever the origin of the name, Arivaca's water gave it an early historical importance. It was mentioned by Padre Kino as a *visita* of Guevavi, and was the site of the 1751 Pima revolt (Guiteras, 1894). Browne (1869) mentioned that it was:

> *...long celebrated for its rich mines and fine pastures... It contains a large amount of rich meadow land bordering on a never failing stream; it is well watered with oak, walnut, ash, cottonwood and mesquit [sic]*, and is capable of sustaining a population of 5 to 6,000 souls.

Hinton (1878) published a plate of the valley, which obviously depicted an expansive, unincised ciénega. Way's (1960) diary entry stated that the ranch in 1858 contained more than "...seventeen thousand acres of agricultural land, with permanent water, wood and grass." The ranch

Figure 17. Upper Santa Cruz drainage, San Rafael Valley, Arizona: Sheehy Spring, a mature ciénega community partially modified by introduction of non-native plants. Photograph 1982 by G. K. Meffe.

Figure 18. Upper Santa Cruz drainage, San Rafael Valley, Arizona: Sharp Spring Ciénega forming in arroyo near Sheehy Spring. Photograph 1981 by G. K. Meffe.

Figure 19. *Monkey Spring, Arizona: headspring. Photograph 1982.*

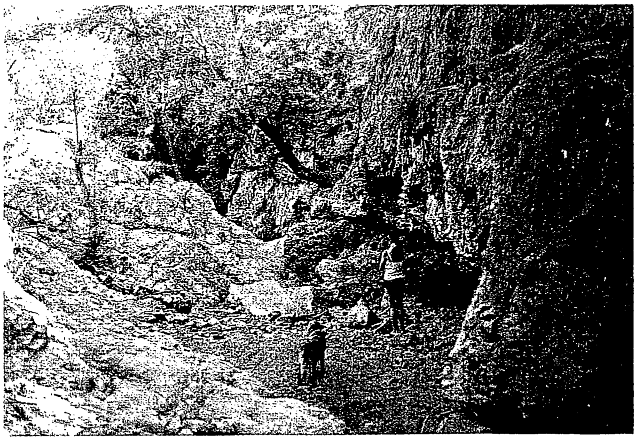


Figure 20. *Monkey Spring, Arizona: inactive travertine formed by outflow of spring prior to diversion in the late Nineteenth Century. Photograph 1982.*

to which he referred was the two *sitio* Land Grant issued to Tomás and Ignacio Ortiz in 1833 (Mattison, 1946). The area had long been known for its rich mines (Guiteras, 1894), and in 1856 the Sonoran Exploring and Mining Company obtained the land and established reduction works at Arivaca for the Heintzleman Mine on Cerro Colorado and other mines on the ranch (Mowry, 1864). The Mexican title was apparently lost and in 1902 the Court of Private Land Claims refused an appeal to confirm title to Arivaca Land and Cattle Company (Mattison, 1946).

A geological explanation for this ciénega is a dike of Cretaceous shales, sandstone, conglomerate, and limestone in the Las Guijas Mountains, which outcrops through Quaternary silts, sands, and gravels at Arivaca (Wilson *et al.*, 1960). These older rocks are obviously less permeable than alluvium, and force groundwaters to the surface. The short reach of perennial surface flow extends about 5.0 km through an incised channel below the road in Arivaca, and a short distance above, where ciénega habitat persists.

Just south of Arivaca is a large, mostly-dry meadow, a remnant of the formerly more extensive ciénega, edged by huge Cottonwood trees. Similar meadows extend upstream some distance, and younger Cottonwoods now line the stream course. Incision near the turn of the century extended above the present road to drain the ciénega, but construction of a concrete ford, which serves as a check dam, has resulted in aggradation and succession, now filling the arroyo. In light of its status as a significant remnant, preservation of this ciénega as a Natural Area was proposed by Smith and Bender (1973b).

Bryan (1952b) briefly recounted the little-known history of arroyo cutting in Arivaca Valley; in 1855 there were springs among the tules, a fine ciénega in 1863, and a *laguna* near the reduction works. The flood of 6 August, 1891 initiated entrenchment. As Cooke and Reeves (1976) pointed out, reasons for incision at Arivaca are unclear, although erosion lower in the drainage along Brawley Wash in Avra Valley was indisputably associated with artificial drainage concentration. Groundwater pumpage in the Avra valley is extensive and water tables have now undergone major declines (White *et al.*, 1966).

Gila River Mainstream. The vast importance of this major river to aboriginals, early explorers, travelers, and settlers is thoroughly documented (McClintock, 1921; Corle, 1951; Burkham, 1972; Dobyns, 1978, 1981; Rea, 1983) and cannot be over-emphasized. Aboriginal populations diverted its waters into elaborate and extensive irrigation systems and exploited its fishes (Kino, 1919; Bringas, 1977) as well as game in its riparian zones. Spanish explorers used it as a passage through inhospitable deserts, and in the 1820s the first American trappers found Beaver exceptionally abundant (Pattie, 1833). Reaches of its bed were heavily traveled by 49ers enroute to California. Within the next few decades agricultural communities developed on its banks.

We know from numerous journal descriptions in the mid-19th Century and before (Rea, 1983) that the Gila River also differed considerably from what we see today. Burkham's papers (1970, 1972, 1976a-b), most notably that of 1972, as well as Turner (1974), and others resulting from the U.S. Geological Survey's (USGS) Phreatophyte Project (Culler *et al.*, 1970), summarized and discussed changes which occured in the riverbed, and their hydrological implications. Summarizing results of Burkham's (1972) review of journals, surveyors' notebooks, and other sources, the Gila River in eastern Arizona:

> *...before 1875...probably was less than 150 feet [46 m] wide and 10 feet [3.05 m] deep at bankfull stage. The river meandered through a flood plain covered with willow, cottonwood and mesquite.*

The channel widened to 610 m between 1905 and 1917, and then narrowed again to 61 m by 1964. More recently the channel has again been widened by flooding, to 122 m in 1968 (Burkham, 1972), and to much more following high waters of 1978–79 (Minckley and Clark, 1984). Willow and Cottonwood are largely replaced by the exotic Saltcedar, *Tamarix chinensis* (Robinson, 1965; Culler *et al.*, 1970; Turner, 1974; Ohmart and Anderson, 1982). A similar pattern is documented in central Arizona (Eckman *et al.*, 1923), where Rea (1983) speculated that floods of 1905–17 washed out extensive marshlands that were never to return.

Apparent references to marshlands along and associated with the Gila River are found as far back as Coronado's 1540 explorations. His party is believed to have crossed the river near Geronimo (Fig. 9), where he described it as "...a deep and reedy stream" (Calvin, 1946). In 1864, Assistant Inspector-General of the U.S. Army, N. H. Davis, recommended to Captain Benjamin C. Cutler that Fort Goodwin be established on "La Ciénega Grande," in this same area (Davis, 1864). The fort was established, but had to be abandoned in 1870, largely due to malaria (Granger, 1960). This marsh has now disappeared. A high water table persists there, however, as the river is still perennial (Brown *et al.*, 1981), and an abundance of wells (24 in 7 adjacent sections on USGS [1960], Bylas 15′ topographic map) exploit it for agriculture. Downstream from old Fort Goodwin, along terraces on the north side of the Gila River, small ciénegas persist in springs and seeps near Bylas (Fig. 22). These springs flow from mounds or shallowly incised sources to spread and evaporate on the Saltcedar-dominated floodplain (Meffe, 1983; Meffe *et al.*, 1983). Marshes also persist at Indian Hot Springs near Eden (P. S. Martin, pers. comm., 1982).

Much further downstream, south of Phoenix, former wetlands mapped by Brown *et al.* (1981) are clustered up- and downstream from the mouth of the Santa Cruz River. Reaches of both the Gila and Santa Cruz rivers upstream from this area were typically dry during drought for the former and year-around for the latter. Sedelmayr (1955) described Indian settlements of the middle Gila River in 1744 as consisting of three rancherias, two near the Casa Grande (now Casa Grande National Monument), and "Still farther on the river runs entirely underground in hot weather, and where it emerges there is situated the great rancherias called Sudacsson [= Sudacson, *fide* Rea, 1983]." Russell (1908) noted that the dry reach of the Gila River was 120 km long, and perhaps resulted from upstream diversion of water for Indian irrigation. Emory (1848) noted diversions that dried segments of the river in this same reach, and Clarke (1852) commented that "Nearly the whole of the Gila is drawn off by zequias [*sic*] for irrigation..." Sweeny (1856) was told that the river was dry in this reach in summer 1851 due to its diversion by Pimas and Maricopas, and Bartlett (1854) observed this phenomenon the following summer, which again was attributed to "...water having been turned off by the Indians to irrigate their lands..."

Reasons for lack of surface water in the lower Santa Cruz, from a few kilometers north of Tucson to Sierra Estrella (Figs. 12, 13), also may include irrigation in its upper reaches. However, alluviation of the broad valley seems more of a factor. Modern topographic maps and aerial photographs clearly depict alluvial fans of the Gila forcing the Santa Cruz westward against bajadas of Sierra Estrella, producing a sediment "plug" behind (south of) which distributaries of the Santa Cruz and large, associated washes have deposited the "Santa Cruz Flats." The relatively narrow passage separating Sierra Estrella and South Mountain and inflow of Salt River just downstream from that defile also may be major factors perpetuating permanent stream flow in this region. First, bedrock must be shallower near these mountain blocks than in basins, thus forcing subsurface water to the surface. Second, proximity of mountainous terrain upstream on the erosive, high-volume Salt River should have resulted in large volumes of coarse alluvium that the lower-volume, less competent waters of the Gila could not remove, resulting in an alluvial plug and natural impoundment. Multiple channels, oxbows, "lagoons," "ciénegas," marshes, "many small creeks and seepage waters," and so on, recorded from the 17th through early 20th centuries in this area (Bartlett, 1854; Audubon, 1906; Kino, 1919; Sedelmayr, 1955; Bringas, 1977; Mathias, in Rea, 1983) all are descriptors of a complicated distributary system passing through an elevated, delta-like, alluviated area for both the lowermost Santa Cruz and middle Gila River.

Santa Teresa, later named Maricopa Wells, was an important watering place a few kilometers south of Río Gila along the Santa Cruz. Sedelmayr (1955) named the area, and described it as "...broad savannas of Reed Grass and clumps of Willow and a beautiful spring with good land for pasturage." Guiteras (1894) also noted "...a very copious spring." Bringas (1977) may have referred to the same place in the late 1700s as "...a ciénega which is to the west of the pueblos." In 1846, Turner (1966) described Maricopa Wells as "...a spot where the grass is excellent, wood sufficiently abundant, and water a short distance off." Bartlett's (1854) party camped there in 1852 and described it as follows:

> *...we reached some waterholes [Maricopa Wells]...It was indeed a pleasant sight to find ourselves once more surrounded by luxuriant grass. Although we had met with a little salt grass in one or two places on the march, which no animal would eat if he could get anything else, we had not seen a patch of good grass since leaving our camp at San Isabel* [sic], *fifty-six miles from San Diego [California]...we turned the mules out to luxuriate on the rich pasture before them, and creeping under some mezquit* [sic] *bushes, soon fell asleep...The water here is found in several holes from four to six feet below the surface, which were dug by Colonel Cooke on his march to California. In some of these holes the water is brackish, in others very pure. The Gila passes about two miles to the north; for one half of which distance the grass extends, the other half being loose sand.*

We expect this area represented the point where water rose from the Santa Cruz aquifer in response to impervious subsurface layers, perhaps those of the Sierra Estrella-South Mountain block(s), or as part of a burgeoning subsurface aquifer fed both by the Santa Cruz and Gila rivers. Ciénega conditions were almost certainly achieved, at least locally. Along the adjacent Gila River, however, riverine marshes appear to have prevailed.

Rea (1983) summarized most literature just cited, and more, to place the middle Gila River reach in the following ecological perspective:

> *Aboriginally the Gila at the Pima Villages was a stream of sufficient width to support tillable islands. Throughout most of the year the depth in most places was probably not usually greater than 3 feet (1 m) and the river was readily fordable on foot. At times the entire surface flow was diverted for irrigation or sank for part of its course into the sand. Such observations were probably coincident with seasonal periods of drought in the watersheds. The river gradient was shallow and the floodplain was so level that lagoons formed in places along the main channel. At least three such marshy areas existed along the Gila on what is now the [Gila River Indian] reservation: near Sacaton, at the confluence with the Santa Cruz River and at the mouth of the Salt River. The channel was well defined, and the banks were consolidated and well vegetated. Beaver abounded. Riparian timber consisting mostly of cottonwood, willow, and ash, was well developed. There was a dense understory of arrowweed, batamote, graythorn, and cane. The bottom lands were fertile, 6 to 8 miles (9.6 to 13 km) across and a strip several miles wide was cultivated by the Pima and Maricopa. Back from the fields and riparian growth were dense mesquite bosques.*
>
> *Though spotty, grasslands and pasturage were well developed on at least two areas on or near the reservation. About 8 miles (13 km) above Sacaton and below Casa Grande Ruins was a grassland many miles long....A second major grassland was west of Sacate and several miles south of the Gila, where a number of drainages (Vekol Wash, Greene's Wash, Santa Rosa Wash) running northwest converged with the Santa Cruz Wash, which once again became an above-surface stream approximately where it entered the reservation....Itinerants found abundant and luxuriant pasture for as many as a thousand pack animals and cattle. The water table was only 4 to 6 feet (1.2 to 1.8 m) below the surface. Peculiar edaphic conditions impregnated some of the lagoons and wells with so many soluble chemicals that their brackish water affected animals and man...*

Indications of riverine marshes rather than ciénega conditions include frequent mention of "reed grass," "carrizo," or "cane" (= *Phragmites communis*), "willows," "wild willows," or "alders" (= *Salix* spp.), and "batemote," "water willow," or "water-mote" (= *Baccharis salicifolia*) (Russell, 1908; Gilman, 1909; Eccleston, 1950; Evans, 1945; Sedelmayr, 1955; Garcés, 1968; Mathias, in Rea, 1983). In addition, notes by Emory (1848) on lines of trees marking abandoned river channels and on the presence of "quaking ground" indicated marshland conditions. Specific references to Cattail and large Sedges are surprisingly few in number, but reference to marshes or swamps where these plants dominate typically indicated avoidance of such places by horsemen. Mathias (in Rea, 1983) recalled *Scirpus* and *Typha* as common in

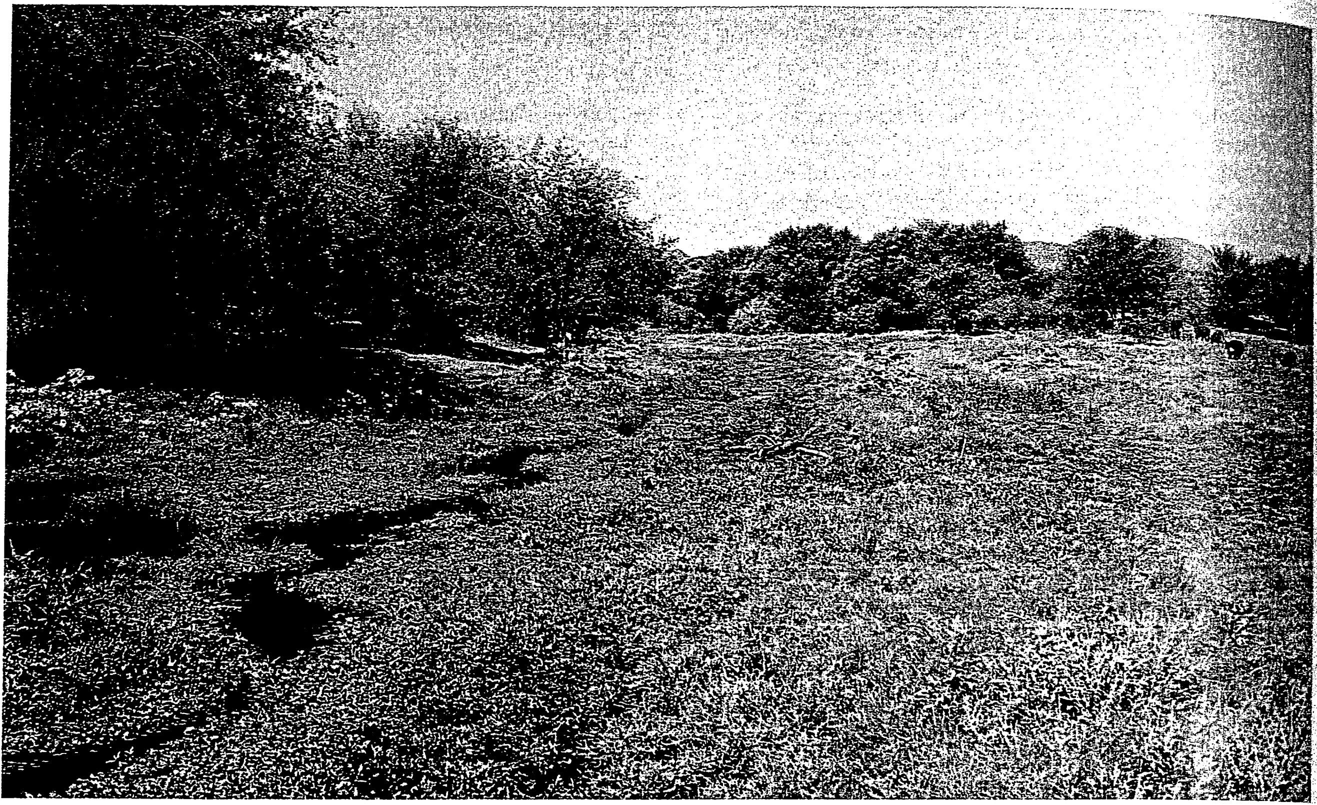


Figure 21. Arivaca Ciénega, Arizona. Photograph 1981 by Douglas G. Koppinger.

Figure 22. Bylas Springs, Arizona: Ciénega formation along one of several spring runs. Photograph 1982 by G. K. Meffe.

lagoon-like habitats of the region in the early 1900s, but Gilman (1909) mentioned a "tule marsh" only once in his description of the area. As noted before, Rea (1983) proposed that channel cutting by floods of 1905–17 (Burkham, 1972) destroyed these marshlands.

Discussion

Historical evidence demonstrates a wider distribution of ciénega and riverine marshland than is found today in Southeastern Arizona. That unincised, largely perennial streams of the 1850s became today's intermittent arroyos is well documented. The cycle of erosion and arroyo cutting that left only remnants of these habitats has been thoroughly discussed by various authors, without reaching concensus as to ultimate factors of causation.

Impacts of aboriginal man on regional ecology are variously interpreted. Hastings and Turner (1965) discussed the frequent assumption that Angloamerican culture arrived and altered a previously "natural" environment. They pointed out that a large Indian population undoubtedly was reflected in a degree of environmental change, yet did not feel that Indian activities had more than a minor influence on determination of vegetation patterns or erosion rates. They proposed that the greatest impact of Apaches on ecological history of the region may have been suppression of development of cattle and mining activities by other peoples, and thus delay of the impacts of heavy grazing.

Dobyns (1981), on the other hand, argued emphatically that influences of prehistoric man have been repeatedly under-estimated. He offered complex, multivariable hypothetical models of vegetation change and arroyo cutting based on historical and archaeological records of Indian activities. Dobyns' arguments focused on inferred broader Apache use of fire for hunting, greater impacts of aboriginal livestock herding, as well as greater affects of food and firewood gathering. He also suggested that erosion-control structures maintained by Puebloan peoples in headwaters, and flood-dispersing capabilities of diversion dams on lower mainstreams by Piman irrigation systems decreased erosion. Extreme human population crashes from epidemic disease and consequential neglect of these structures may have contributed to renewed cycles of erosion.

Impacts of 125 years of Spanish missionary, ranching, mining, and military activity, as well as a brief period of Mexican ranching, have not been widely implicated in discussions of causation of environmental change. Locally large livestock herds were maintained, although most ranching ventures were short-lived (Haskett, 1935, 1936; Wagoner, 1952, 1960).

Angloamerican impacts of grazing, vegetation change, wood cutting, mining, water diversions, groundwater exploitation, and artificial drainage concentration by roads, ditches, bridges, and railroads have been widely covered (Thornber, 1910; Duce, 1918; Bryan, 1922, 1925a–b, 1926, 1940; Thornthwaite *et al.*, 1942; Leopold, 1951b; Antevs, 1952; Humphrey and Mehrhoff, 1958; Hastings, 1959; Hastings and Turner, 1965; Denevan, 1967; Burkham, 1970, 1972, 1976a–b; Cooke and Reeves, 1976; Dobyns, 1978, 1981). In light of previous reviews, we feel no need to expand on these points. However, at least one important aspect associated with direct impact of grazing on bottomland vegetation has been overlooked.

Early data on numbers of cattle in Arizona counties were based on tax assessments, which likely underestimated actual numbers. Governor F. A. Tritle in 1885 claimed that at least 50% could safely be added to returns of the county assessors (Wagoner, 1952). Using such a correction we calculate an average of 377,474 cattle were grazing lands of Cochise, Santa Cruz, Pima, and Graham counties over the 5-year period preceeding the 1893 drought. Assuming greater accuracy of more recent reports, an average of only 180,200 cattle have grazed the same area over the period 1977 to 1981 (Arizona Crop and Livestock Reporting Service, 1981). We nevertheless see heavy impacts of grazing activities today, especially at watering sites.

Impacts of cattle on aquatic and riparian areas prior to the 1893 drought furthermore should have been even greater than double those of today. Cattle rarely travel greater than 5 km from water (Valentine, 1947; Herbel *et al.*, 1967), and only lightly utilize range greater than 3 km from water. Therefore, cattle in the 1880s must have been concentrated within a 5-km radius of natural streams. Since the innovation of stock tanks in the Arizona cattle industry did not occur until near the turn of the century, otherwise usable land would have been grazed at most seasonally. Vast areas of the region are greater than 5 km from natural surface waters (Brown *et al.*, 1981). Assuming a 5-km radius of grazing from water, we estimate that only 27 critically situated stock tanks would increase area available to cattle an amount equal to that provided by the Río San Pedro if it were perennial along its entire length. We thus hypothesize that stock tanks greatly reduce impacts on natural waters and riparian zones by providing more uniform livestock distribution. Effective cattle densities near natural waters must be greatly diminished from pre-turn-of-the-century levels. A more detailed analysis of this situation would be enlightening.

Long-term trends of climatic change were believed by Euler *et al.* (1979) to be ultimately responsible for arroyo incision, although they felt cultural activities may have advanced timing of initiation. They invoked multiple lines of evidence for prehistoric cycles of incision and climatic change. Bryan (1940) and Hall (1977) also recognized that overgrazing may have been only accessory to climate in incision causation. Considerable debate has centered over whether increased (Antevs, 1952; Martin, 1963a; Hall, 1977) or decreased (Bryan, 1940; Judson, 1952; Antevs, 1962; Euler *et al.*, 1979) rainfall, or perhaps changes in rainfall frequency and pattern (Leopold, 1951a; Hastings and Turner, 1965; Cooke and Reeves, 1976) caused initiation of incision cycles. Cooke and Reeves (1976) thoroughly discussed earlier examinations of regional climatic change as a factor in arroyo incision, as did Hastings and Turner (1965), but problems arose from lack of meteorological records prior to about 1895. They noted an apparent trend of decrease in mean annual precipitation since 1895, with greater decreases (5.0 cm) in winter rainfall than summer (3.0 cm). Temperatures increased slightly (0.56°C in winter, 1.11°C in summer). However, detailed analysis of daily rainfall data revealed no statistically significant changes in annual, annual summer, or annual non-summer precipitation totals during the century. They noted occasional droughts often followed by wet periods, and significant increases in frequency of light rains coupled with decreases in high-intensity rainfall over the same period.

Brown and Henry (1981) correlated the Palmer Drought Severity Index (PDSI), calculated from rainfall data for this century, with changes in southern Arizona deer populations. Increased incidence of drought in recent decades was evident in their analyses. This index may also serve as a useful indicator of critical moisture relationships for vegetation and its effect on stream flow regimes and erosion. Annual PDSI values might be calculated for earlier time periods using precipitation data inferred from tree rings. Dendrochronological data for the area has been widely accumulated and interpreted by workers at the Tree Ring Laboratory in Tucson (see numerous publications of Bannister, Blasing, Clark, Fritts, La Marche, Schulman, Smiley, Stockton, and their collaborators, included in the bibliography). Such valuable data have inferentially extended knowledge of past precipitation patterns and effects on hydrology and vegetation far into prehistoric times.

The argument that arroyo incision has been related to climatic shifts was countered by Patton and Schumm (1981), who presented field data indicating that geomorphological parameters are principal determinants of spatial and temporal patterns of arroyo cutting and filling, and that a close correlation between widespread climatic change and alluvial chronologies is not necessarily expected. Nevertheless, so long as massive degradation of the receiving system did not occur, headward erosion in tributaries could not physically occur. Conversely, substantial degradation of receiving streams should promote, accelerate, and perpetuate cutting in tributaries. Flooding in the 1880s was followed closely by similarly high runoff and further degradation of the Gila River in the period 1902–17 (Burkham, 1970), which may alone be adequate to explain incision throughout much of the drainage basin.

There seems little doubt that a combination of factors resulted in the geologic event of arroyo cutting. However, it also seems clear that events culminating in that catastrophe were influenced by man, and that livestock played a role in the scenario. Concentration of cattle along watercourses in southeastern Arizona in 1891–93 must have resulted in remarkable damage to riparian communities. Ciénegas, located at points of the most permanent water supplies and as a result supporting lush plant communities made up of species palatable to cattle, must have been destructively grazed and trampled. Fragmentation of the sponge-like surface deposits by cattle promotes drying of parts of present-day ciénegas, and we can visualize direct disruption of these marshlands in this way, even in the absence of arroyo formation. Ciénegas can be trampled to quagmires if organic sediments are deep, or to barren channels where substrates are relatively solid. The last condition is indicated in a photograph of Monkey Spring in 1889 (Hastings and Turner, 1965).

Southwestern Stream Hydrology. Ciénegas are plant communities which develop in southwestern streams where groundwaters perennially intersect the surface, and where stability is such that they can persist. Their development and persistence are influenced by meteorologic, biotic and hydrologic parameters, and ciénegas in turn affect stream hydrology (see Figs. 23 and 24).

The dynamic nature of stream systems has long been recognized, and the dynamic equilibrium concept of geomorphology is important to thorough understanding of ciénegas. Simply stated, the principle of this concept (Chorley, 1962) is:

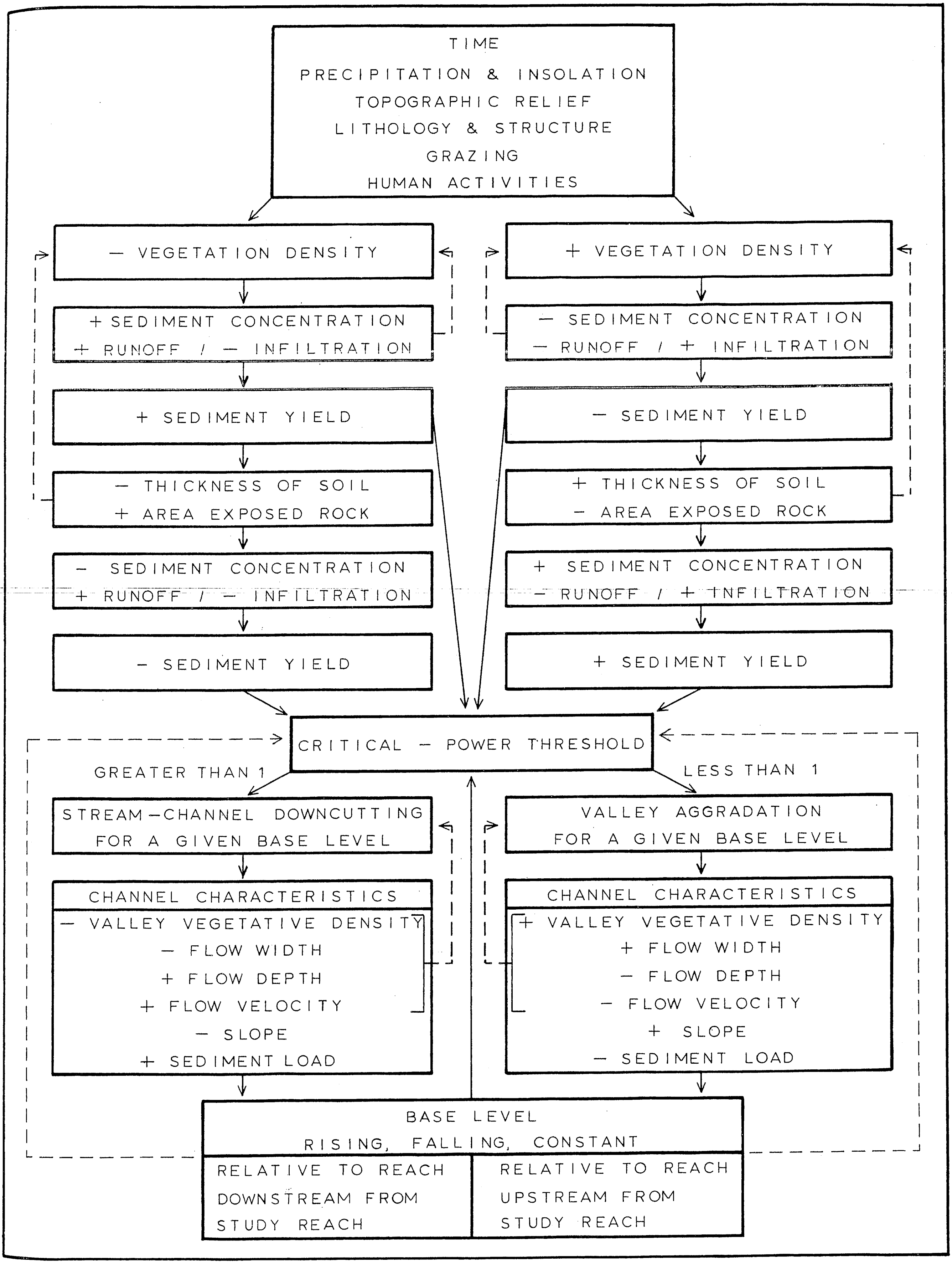
> *...that river systems proceed toward conditions of a steady-state balance, wherin the open systems balance a continuous (though not necessarily constant) supply and removal of water and sediment by adjustment of the geometry of the system itself. This steady-state open system is only rarely characterized by exact equilibrium, and generally the river and its landscape tend toward a mean form, definable only in terms of statistical means and extremes.*

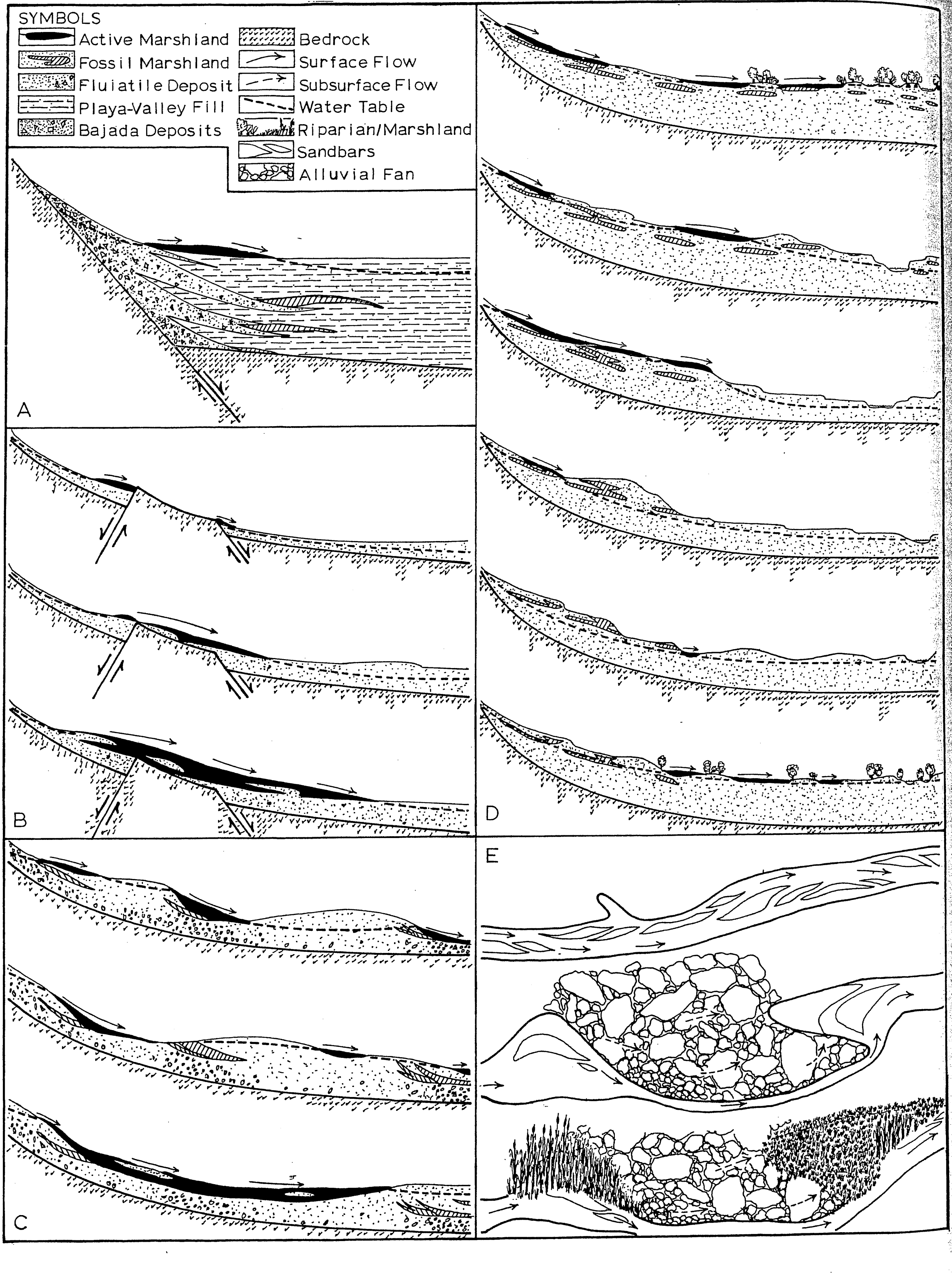
Unlike previous concepts, this "quasi-equilibrium" does not attempt to predict the ultimate form a river may take through a sum total of changes through time, but rather suggests a statistical range of immediate dynamic responses to any instantaneous change in the system. Rivers are recognized as not being static entities and not smoothly and continuously progressing toward an ultimate form. We now understand the river channel as a form representing the most efficient geometry, in terms of energy utilization, capable of accomodating the sum total of means and extremes of variability of flow that have occurred throughout its history (Curry, 1972). River channel and drainage hillslope variables thus interact, and the total system is in quasi-equilibrium, each variable reacting at different rates to compensate for changes in others (Schumm, 1977). Bull (1979, 1981) proposed use of his "critical power threshold" concept in analysis of the same basic hydrologic processes (see Fig. 23). Ciénegas are biological components of the physical stream systems. They are equally dynamic and reflect the history of watersheds in which they occur.

Our successional scheme proposed below is based on the presence of relatively stable discharge. Floods can rapidly remove accumulated organic deposits, and are of course a result of precipitation and runoff. Meteorologic and runoff conditions must therefore be examined relative to possibilities for stability sufficient to allow ciénegas to persist.

Martin (1963a) described summer anti-cyclonic monsoon rainfall patterns prevailing in the study area and their underlying meteorological bases (see also McDonald, 1956). Fogel (1981) provided statistical descriptions of spatial and temporal distributions and intensities of these precipitation events. High intensity, localized precipitation can produce destructive, sediment-scouring flash floods (*e.g.*, Ives, 1936; Jahns, 1949; Lewis, 1963; Melton, 1965; Fisher and Minckley, 1978; Collins *et al.*, 1981). Probability of a scouring flood at any headwater point is low, however, under a climatological regime with such temporal and spatial patchiness of precipitation. More geographically generalized and temporally protracted winter rainfall (distribution of which was also analyzed by Fogel, 1981) also contributes to increased

Figure 23. Simplified diagramatic interactions of hillslope and stream channel factors which influence hydrological and geomorphological phenomena. The Critical Power Threshold (C.P.T.) is defined by the formula $\frac{\textit{stream power}}{\textit{critical power}} = C.P.T.$*, where stream power is the ability of a stream to transport sediment, and as such is a function of discharge, velocity and sediment load as discussed in text. Critical Power (or Resisting Power) is the power required to transport the sediment load and thus varies with amount and size of sediment as well as channel roughness. Both stream power and critical power vary spatially and temporally. A stable system, or point in a system, occurs where* $C.P.T. = 1$*, with deposition found where* $C.P.T. < 1$ *and degradation where* $C.P.T. > 1$*. Dashed arrows depict self-enhancing feedback mechanisms. Given persistence of perennial surface flow and discharge stability for adequate time spans, ciénegas will develop wherever the system follows pathways to the right side of the figure. Changes in the system which result in situations depicted by the left-hand pathways produce incision. Responses will vary as a function of geological, meteorological and ecological factors including extent of alluvial fills as well as soil development and type. Form, rate and quantity of precipitation are important factors, as are extent and type of vegetation both on hillsides and in channels. Adapted from Bull (1981); copyright Institute of Ecology.*


TIME
PRECIPITATION & INSOLATION
TOPOGRAPHIC RELIEF
LITHOLOGY & STRUCTURE
GRAZING
HUMAN ACTIVITIES
− VEGETATION DENSITY
+ SEDIMENT CONCENTRATION
+ RUNOFF / − INFILTRATION
+ SEDIMENT YIELD
− THICKNESS OF SOIL
+ AREA EXPOSED ROCK
− SEDIMENT CONCENTRATION
+ RUNOFF / − INFILTRATION
− SEDIMENT YIELD
+ VEGETATION DENSITY
− SEDIMENT CONCENTRATION
− RUNOFF / + INFILTRATION
− SEDIMENT YIELD
+ THICKNESS OF SOIL
− AREA EXPOSED ROCK
+ SEDIMENT CONCENTRATION
− RUNOFF / + INFILTRATION
+ SEDIMENT YIELD
CRITICAL − POWER THRESHOLD
GREATER THAN 1
LESS THAN 1
STREAM−CHANNEL DOWNCUTTING FOR A GIVEN BASE LEVEL
CHANNEL CHARACTERISTICS
− VALLEY VEGETATIVE DENSITY
− FLOW WIDTH
+ FLOW DEPTH
+ FLOW VELOCITY
− SLOPE
+ SEDIMENT LOAD
VALLEY AGGRADATION FOR A GIVEN BASE LEVEL
CHANNEL CHARACTERISTICS
+ VALLEY VEGETATIVE DENSITY
+ FLOW WIDTH
− FLOW DEPTH
− FLOW VELOCITY
+ SLOPE
− SEDIMENT LOAD
BASE LEVEL
RISING, FALLING, CONSTANT
RELATIVE TO REACH DOWNSTREAM FROM STUDY REACH
RELATIVE TO REACH UPSTREAM FROM STUDY REACH


SYMBOLS
Active Marshland
Fossil Marshland
Fluiatile Deposit
Playa-Valley Fill
Bajada Deposits
Bedrock
Surface Flow
Subsurface Flow
Water Table
Riparian/Marshland
Sandbars
Alluvial Fan
A
B
C
D
E

probability of flood disturbance downstream as area increases. Drainage areas are again generally too small to supply adequate runoff from diffuse winter rains to produce scouring discharges near stream sources. Headwater streams are therefore the most likely places for stability to be achieved and maintained.

The capacity of soils to absorb rainfall determines amounts required to produce runoff. This is in turn a function of extent of soil development, geologic origin, structure and texture, vegetative cover, and previous moisture content. Equally intense thunderstorms on different basins may thus produce quite different types of floods. Shallow bedrock with little soil and vegetative cover will produce rapid runoff as sheet flow, and intense, short-lived ("flash") floods. Channel discharges of adequate stability to allow succession to ciénega are more likely to be found in areas of extensive soil development. Well developed, deep soils, with dense vegetation, allow greater infiltration and storage, and more precipitation is required to produce sheet flow and runoff. The net result is channel discharge dampening and attenuation by soil water storage. As a greater amount of work is done per volume of water by sheet flow than by channelized flow (Curry, 1972), more extensive sheet flow produced on barren soils carries more sediment to channels. Sediment load is, of course, also dependent on particle size, since smaller particles are more readily mobilized than larger ones. Furthermore, competence of flows to continue to mobilize sediments is inversely related to sediment load. For a given velocity of flow, less turbid waters are more competent than those already bearing heavy sediment loads. Gradient largely determines velocity, and thus also influences sediment transport, as does discharge volume that is correlated with drainage area. Channel roughness is another important factor influencing velocity. As channel roughness increases, velocity (and thus related factors) is diminished. The geographic location of ciénegas in Arizona in low-relief, rolling grasslands, or in alluvial plains bounded by relatively well-vegetated mountain fronts, is therefore not fortuitous. Slowing of runoff by dense vegetation, low gradients, and relatively deep soils undoubtedly contributes to their origins and perpetuation (Fig. 23).

Figure 24. Hypothetical diagrams depicting sequences of aggradation and degradation resulting in ciénega formation, maintenance, and destruction, with descriptions of physical biological events and features proposed to be involved in those scenarios. Scales are exaggerated. Refer to Figure 23 for definition of Critical Power Threshold (C.P.T.). (A) Ciénega development near lower edge of bajada where water table is impounded to intersect surface upon passage from coarse tributary alluvium to finer fill of receiving valley. C.P.T. < 1 in upstream portion of ciénega, producing aggradation of fine organic fills in active marshland. Downstream, as convexity increases due to upstream aggradation, increased slope and competence of flow produce C.P.T. > 1 and incision occurs. If flow stability is adequate, increased channel roughness created by vegetation can push the point where C.P.T. > 1 downstream, thus expanding ciénega. (B) Upfaulted bedrock across stream ponds alluvial groundwater producing succession to ciénega upstream. Downstream of upfaulted bedrock, increased slope and small alluvial aquifer on bedrock do not favor ciénega-forming conditions initially, but through mechanisms described for scenario A, ciénega may eventually extend downstream. (C) Fluvial deposition patterns of alternate convex and concave reaches produced by intermittent systems provide aquifers with surface seepage on steep downstream sides. If sufficiently constant, this seepage may allow ciénegas to form. Ciénegas may be removed by flooding which alters convex-concave pattern allowing succession to ciénega in new positions. (D) Ciénega evolution in tributary and receiving stream through varying cycles of change in base level of receiving stream at cross-section transect. Incision of receiving stream may lower water table causing extinction of ciénegas. Channel base level adjustments through time, along with stable water table, may eventually permit renewed localized succession to ciénega. Aggradation occurs in channels with eventual return to high water table and extensive ciénega conditions. (E) Impoundment of stream by course alluvium from landslide or deposited in receiving stream by flooding tributary. Stream power is far less than resistance of coarse bed load (i.e. C.P.T. < 1) and succession toward ciénega may ensue in new area of stability.

Ciénegas are channel phenomena, and thus are influenced by all hydrologic factors. They form at points where water permanently intersects the surface, and such points may be created in a myriad of physical ways. Coarse sediments carried by flash floods from tributaries can impound a receiving channel (*e.g.*, Cooley *et al.*, 1977) (similar to Fig. 24E), as can coarse materials dropped after flow dissipation through infiltration of high intensity, low volume floods as they pass downstream with progressive diminution of discharge (Schumm and Hadley, 1957; Patton and Schumm, 1981). Southwestern streams therefore develop an alternating convex-concave profile at a given point in time, even when passing over unconsolidated alluvium (Figs. 24C–D). Beaver dams, so common in the past (Dobyns, 1981; Davis, 1982), must also have resulted in such a profile. Steepened segments in channels with relatively high volumes of interstitial flow also may expose water, and thus stimulate ciénega formation.

Porosity of coarse bed loads results in significant underflow in southwestern streams. Relatively stable points of emergence of underflow into concavities of such channels may produce permanent reaches alternating with reaches of an ephemeral nature (Fig. 24C). Similarly coarse materials under- and overlain by lenses of impervious silts and clays may transport water across meanders. Upwelling then occurs to form a spring-like source of water. Coarse materials such as boulders can armor such outflows in an otherwise sandy floodplain, and the potential for marshland succession may be realized even in such an erosive system.

Springs rising along Basin and Range faults at valley edges may also release water and augment surface flows. Such springs have fixed-point origins. but the downstream extent of surface flow may vary with changes in artesian pressure of the aquifer and variations in available water. Constant water supplies of such systems also promote development of riparian marshlands that succeed to ciénegas.

Surface flows in streams of the region are most consistently produced above impervious dikes that intersect alluvial aquifers and force groundwaters to the surface (Figure 24b). The surfical extent of discharge will vary with seasonal and annual fluctuations of the water table, but convex-concave profiles also resulting from these structural features persist permanently in all but the geologic sense of time. Points of decreased competence of flow just upstream from dikes or other obstructions allow ciénegas to form.

Succession to Ciénega. Numerous causal mechanisms determining directions and patterns of successional sequences have been proposed, yet direct evidence in support of mechanistic models outlined by Connell and Slayter (1977) is meager and often limited in scope (Fisher, 1983). Evidence of mechanisms specifically determining progression of succession to ciénega communities is similarly lacking. In common with most studies of long-term succession, temporal limitations are such that experimental evidence has not been produced. However, the diversity of remnant ciénegas available for study, historical evidence, and observation of numerous successional sequences of varied ages developing between flood disturbances on Southwestern streams, has led us to conclude that orderly, predictable, community progression to ciénegas does occur, as does a predictable spatial distribution of communities. Inferential data supporting these conclusions are provided here. After briefly discussing the limited empirical data on stream succession in our study area, we outline temporal and spatial physical determinants of succession to ciénega climax, and propose some biotic mechanisms by which earlier communities may influence ascendency to ciénega. Experimental studies are encouraged to test our hypotheses and produce direct supporting or refuting evidence.

Development of biotic communities in southwestern streams has not been thoroughly studied. Campbell and Green (1968) and Fisher *et al.* (1982) respectively reviewed community succession on mid-elevation strands and in aquatic communities of a central Arizona stream after scouring floods. The former authors found strand vegetation consisting of *Baccharis glutinosa (= salicifolia), Salix exigua,* and *Pluchea (= Tessaria) sericea* on wetter sites, but did not address community changes through time. They felt, however, that vegetation was maintained in "perpetual succession" by periodic flood disturbance, and that abiotic factors and largely stochastic dispersal and establishment were more important in determining distribution patterns than were biotic interactions. Strand vegetation of the inland Southwest, consisting in addition to those species given by Campbell and Green (1968) of any number of characteristic annuals, biennials, or short-lived perennials (Minckley and Brown, 1982), scarcely contributes to succession toward ciénegas. Larger strand and riparian species may indeed act to increase scour by concentrating flow (Burkham, 1976b). Strands are furthermore above the level of permanently saturated soils.

Fisher *et al.* (1982) found algal succession following scour to progress through a diatom-dominated to a green-bluegreen-dominated algal community. An herbivorous invertebrate fauna rapidly invaded, followed by predators. They interpreted such algal sequences as "...often-interrupted, pioneer stages of a long-term successional sequence culminating in the desert ciénega." However, succession to ciénega in streams such as that studied by Fisher *et al.* (1982) would be improbable without increased flow stability. The longest interval between disturbance of such communities was on the order of only a few months. They only rarely recorded establishment of vascular hydrophytes, and thus did not report later community development. Algal successions described by Fisher *et al.* (1982) are characteristic of a physical environment fundamentally distinct from that necessary for succession to ciénega communities. It is likely that similar algal successions occur in more stable physical environments necessary for succession to ciénega, but a causal mechanism of succession relating the two communities is not obvious. We believe it likely that early stages of ciénega formation would establish regardless of previous presence or absence of an algal community and any modification of the environment it might have caused. These algal communities thus do not seem to represent early seral stages in the progression to ciénega, but rather an independent successional sequence (Blum, 1956; Minckley, 1963).

Fisher (1983), in a review of theory and empirical evidence of succession in streams, offered a definition of the term which we adopt here. He defined succession as a sequence of communities, resolvable in both time and space, in which "...the ascendency of each is influenced by its predecessors." We also include in our definition the requirement of Connell and Slayter (1977) that this progression of communities occur in the absence of significant trends in physical regime. Streams are thus ecoclines in both time and space, and ciénegas temporal and spatial phenomena, dependent in both dimensions on a relatively constant physical environment.

Figure 23 and the series of diagrams in Figure 24 illustrate and summarize varying scenarios of topography, geology, hydrology, and climatology in which different geomorphic events and processes relate to ciénegas. If the requirement of aggradation exceeding degradation is met and stable surface flow persists we propose that succession toward ciénega will occur. We agree with Fisher that ciénegas represent a climax community of headwater stream succession at points where perennial surface water persists, but refer to it as an aquatic community, rather than terrestrial, in light of the requirement for saturated soils. Ciénegas display apparent attributes of climax communities characterized by Odum (1969), while streams lacking ciénegas display attributes typical of younger communities. Martin's (1963a) palynological evidence of long-term persistence (>4,000 years), with rare cycles of incision and re-building, as well as Sayle's and Antev's (1941) and Antev's (1962) geological data, indicate that they are a persistent, long-lived community (see also Mehringer and Haynes, 1965; Mehringer *et al.*, 1967; and others). Deep accumulations of organic sediments deposited in ciénegas and exposed in contemporary arroyo walls provide further testimony. The community is regionally and altitudinally definable, and appears to result from intermediate stages that prepare the locale for subsequent stages through physical and chemical alterations of habitat. Ciénega systems are obviously more detritus based than are young, autotrophic stream communities as described by Fisher *et al.* (1982). Organic accumulations are large, and organisms appear to be narrow niche specialists. Furthermore, ciénegas effectively resist perturbations. We have observed flooding of a magnitude sufficient to scour systems discussed by Fisher *et al.* (1982) pass over well-developed ciénegas with little damage (in part, Collins *et al.*, 1981).

We have also observed rapid invasion of saturated streambeds in arroyos by vascular hydrophytes, and consequential initiation of organic deposition during periods of flow stability. These accumulations are sometimes removed by scouring floods, but continue to build under more stable flow regimes. Plants such as *Bidens* spp., *Typha domingensis,* and *Scirpus* spp. are early colonists on barren, flooded soils in the region. As flooded soils increase in organic content as a result of accumulation of vegetation from upstream, plus *in situ* growth, death, and decay of vascular hydrophytes, soil aeration decreases and redox (Eh) potentials drop (Teal and Kanwisher, 1961; Armstrong, 1975). Early, deeper- or larger-rooted colonists are ultimately excluded by such changes, and replaced by more tolerant, shallower-rooted species that live on the surface and have a small proportion of their biomass as roots (Barber, 1982). Anaerobic respiration by soil organisms results in reduced products, many of known phytotoxicity. Bolen (1964) and Howes *et al.* (1981) presented evidence that distributions of marshland plant species and growth forms are correlated with soil Eh. Known adaptations of emergent plants to such environments include an ability to aerate root zones (Armstrong, 1964, 1975; Teal and Kanwisher, 1966), utilize anaerobic respiratory pathways (Chirkova, 1971; Armstrong, 1975), and oxidize reduced phytotoxins (Armstrong, 1975). Armstrong (1964, 1975, 1978), Armstrong and Boatman (1967), Hook *et al.* (1972), Teskey and Hinckley (1977), and Levitt (1980) provided some reviews of waterlogged soils and plant adaptations to them.

We predict that such factors act to produce a temporal succession through marshland seral stages including *Typha* spp., tall Bulrushes such as *Scirpus acutus* and *S. californicus,* and *Salix gooddingii* or *S. lasiolepis,* to a low-sedge (*e.g., Eleocharis* spp.) dominated ciénega. As organic materials accumulate, water-levels rise accordingly through flow impedence, capillarity, and other water-holding attributes of the spongy detritus itself. Bank storage increases as water levels in the channel are further stabilized. Spates may move inorganic materials onto the marsh and interbedding of stream- and side-slope-derived sand and gravel will accrue among lenses of organic debris. Lenses of clays or other impermeable materials deposited by sheet flow over ciénegas may produce locally perched water tables.

Ciénegas become increasingly heterogeneous as a result of local equilibrium adjustments. Constraint of the channel by input of inorganic debris from side slopes (Melton, 1965) may produce locally increased gradient and flow concentration promoting surface incision. Lowered water tables accompanying incision allow germination and regrowth of less hygric species such as Goodding Willow and Fremont Cottonwood. Addition of trees presents greater heterogeneity, with roots concentrating sheet flow and inducing undercutting, and fallen logs performing similar functions. Local incisions persist as deep, slit-like pools until filled by succession back to the closed ciénega condition.

Cooke and Reeves (1976) documented increased gradient of valley floors downstream from former and extant ciénegas. As deposition occurs in ciénegas, stream gradient below, and consequently velocity of flow, increases. Competence gained in this manner is augmented by decreased suspended load as sediments are trapped by vegetation. We believe this may be another mode of formation and perpetuation of vertical-walled pools characterizing many ciénega habitats (Fig. 18). Nick points formed by local disturbances are rapidly eroded headward by highly competent water until an equilibrium is reached.

Points at which aggradation exceeds degradation are mobile in response to principles of dynamic equilibrium (Curry, 1972; Bull, 1979, 1981), so that the ciénega somewhat violates climax concepts by migrating locally as physical aggradation divorces the aquatic/semiaquatic system from its water supply. Salinized, oxidized, and drier soils that result from ciénega migration may be colonized by Saltgrass, then by Sacatón. These habitats may return to ciénega if water tables again become available, or succeed to Mesquite bosque communities if further drying occurs. Mesquite invasions occur only after water tables are lowered by local (or regional) incision that allows leaching of salts and drying of soils to a point which allows germination and growth of seedlings (Bryan, 1928). Geologically determined patterns of spatial distribution thus combine with climatologically and topographically determined temporal patterns of disturbance frequency, as well as biotic interactions, to define local community structure. The ultimate community occupying such a place is dictated by terrestrial climate if permanent water drops below root zone. Persistence of stable surface discharge, however, allows maintenance of the ciénega climax.

Ciénegas act as self-protecting, water-storage reservoirs, and as such influence stream hydrographs, and consequently spatial and temporal distribution of different seral stages in succession. Flows downstream from ciénegas are less variable and of greater permanence than flows in streams without them. The large amount of storage capacity and slow release of water, dampen and attenuate flood peaks. As such, ciénegas create downstream conditions more conducive to establishment of ciénega vegetation than were previously found, and expansion downstream might be expected. Upstream expansion of ciénega also occurs as increased channel roughness due to vegetation produces decreased competence and deposition of clays and silts, which form impervious layers (Melton, 1965; Howes *et al.*, 1981). Groundwater is further impounded, and the point of

Table 2. Attributes of various wetland habitats of the American Southwest discussed in text.

Attributes	**Alpine Meadowlands**	**Ciénegas**	**Riverine Marshes**
Altitude (m)	>2,000	1,000–2,000	<1,000
Drainage position	headwaters	headwaters and low-order streams	high order streams
Climatic factors	complete winter snow cover	brief hillslope snow cover only	no snow
	alternate freezing/thawing	occasional insignificant freezing (brief edge ice only)	no freezing
Basin physiography	low-relief, broad depressions	relatively narrow valley floor bounded by Basin and Range-type mountains	Broad alluvial valleys distantly bounded by mountains.
Flow classification	lotic or lentic (depression)	lotic	lotic
Discharge characteristics	no scouring floods	low probability of scouring floods	higher probability of scouring floods
Channel structural control	little	relatively tight by bounding ranges	little, bounding ranges distant
Position in channel	bank to bank	along edge, leaving narrow channel or may cover channel	edge, backwaters, oxbows; substantial open water
Surface water ephemerality	perennial to briefly ephemeral	perennial	perennial
Adjoining hillslopes characteristics	extensive soil development	extensive soil development	alluvial, desert soils
	conifer forest	semi-desert or Plains/Great Basin grasslands or Madrean Evergreen woodland	Lower Colorado or Arizona Upland subdivision of Sonoran Desertscrub
	little exposed bedrock	little exposed bedrock	large amount exposed bedrock
Edaphic factors	soils saturated, may dry seasonally	soils permanently saturated	soils permanently saturated
	soils seasonally anoxic-reducing	soils perennially anoxic-reducing	lower levels soil anoxia-oxidizing
	high organic content in soils	high organic content in soils	lower organic content in soils
	low percolation rates	generally low percolation rates, but may be inter-bedding of coarser lenses	higher percolation rates
Vegetation	low, emergent sedges; grasses; riparian shrubs *(Salix, Alnus)*	low, emergent sedges; riparian trees (Salicaceae)	tall, emergent vegetation *(Typha, Phragmites)*
Grazing	naturally and by livestock	naturally and by livestock	largely ungrazed
Relative longevity	long	intermediate	short

surface-groundwater intersection moves upstream (Fig. 24C). Aggradation in ciénegas produces increased gradients downstream which stimulate incision, so that alternating ciénega and arroyo, as described by early travelers, would be predicted.

Historical information further indicates an tendency toward occurrence of low-statured, sedge-dominated, ciénegas in headwaters, and tall-sedge dominated riverine marshes along lower elevation, higher order channels with permanent flow. To some extent the pattern persists today. We propose that these two communities intergraded, interdigitated, and blended in a spatially and temporally dynamic manner along the drainage gradients in response to numerous variables.

At a yet undefined and dynamic point where stability sufficient for ciénega maintenance is lost due to increased watershed size, ciénegas give way to riverine marshes, assuming presence of perennial water. Release of channels from tight structural control of valley-bounding ranges also appears to be a factor in this transition. Riverine marshes were common in oxbows and backwaters of large rivers such as the Gila where it was perennial in the broad alluvial Phoenix and Safford valleys. Similarly, such marshes occurred along the lower Río San Pedro and were associated with the Río Santa Cruz and Ciénega Creek on the broad, alluvial Tucson formation. The distribution of ciénegas in these same systems is correlated with narrower valleys and tighter structural control found further upstream.

We propose that riverine marshes are and were maintained as transitory communities predictably removed by catastrophic flooding resulting largely from winter rainfall and runoff, or dried by channel migration across valley floors. Being short-lived, such marshes do not accumulate large amounts of organic material, and soils are less anaerobic than older organic soils. Greater discharges of higher order channels under natural conditions also tend to maintain less anaerobic soils through greater percolation rates. Hypothesized ecological and hydrological attributes of these related communities are summarized in Table 2. On larger, impounded rivers where water deliveries are constant, dams replace ciénegas as water storage reservoirs and regulators of discharge. Extensive riverine marshes persist today below such ameliorating structures (Minckley and Brown, 1982; Ohmart *et al.*, 1975; Ohmart and Anderson, 1982).

Biological Significance of Ciénegas. Within an evolutionary or geological time frame, ciénegas are transitory, and as such biotas obviously endemic to them have not evolved. However, their frequent association with springs, which commonly have associated endemics as a result of greater permanence, and their role as refugia for Tertiary and Recent species incapable of survival in the recently evolved, ephemeral arid-land systems, endow them with a level of reliction not found in other local aquatic systems. In this way ciénegas are similar to springs of Death Valley, Great Basin, Chihuahuan Desert, and elsewhere, where relicts of Pluvial lakes and streams find refuge. This is especially evident in hydrobiid molluscs. These are minute, operculate, apulmonate snails of the genera *Tryonia* and *Fontelicella*, which have living representatives in most spring-fed ciénegas discussed here (J. J. Landye, Flagstaff, AZ, pers. comm., 1982). Certain fishes also are characteristic of ciénega formations. Thick-bodied chubs of the genus *Gila* are more abundant in ciénegas than elsewhere. In our study area these include *Gila intermedia*, whose distribution in Gila River basin (Minckley, 1973; Rinne, 1976) corresponds almost exactly to that of ciénega habitat in the San Simon, San Pedro, and Santa Cruz basins. *Gila purpurea* may be the corresponding species in the Ríos Yaqui, Matape, and Sonora systems (Hendrickson *et al.*, 1980). The endangered Sonoran topminnows *(Poeciliopsis o. occidentalis, P. o. sonoriensis)* are now essentially restricted to ciénegas and springs in the United States (Meffe *et al.*, 1982, 1983). Large river fishes such as Colorado Squawfish, Razorback Sucker *(Xyrauchen texanus)*, Roundtail Chub *(Gila robusta)*, and others, were associated with riverine marshes in the San Pedro and Gila rivers when greater and more stable discharges were maintained. Aggradation in downstream parts of the San Simon and Santa Cruz rivers presumably excluded these last species.

Southwestern streams, in both past and present conditions, are unique in many ways. They differ from European and Eastern U.S. systems where most theory of stream ecology has been developed, and aspects in which they differ are critical in determining spatial and temporal attributes of succession. Surface flows in more mesic regions are continuous and increase in volume and stability downstream. In the study region, surface flows maintained by bedrock in headwaters sink into alluvial fills or disappear from evapotranspiration downstream. Perennial surface discharges on lower valley floors may be present only where impervious dikes intersect alluvial aquifers. These streams are heterogeneous systems that display temporal and spatial discontinuities of disjunct surface discharges and intervening dry reaches.

Contrary to the situation in more mesic areas, unpredictability of flow continuity precludes development of biotic communities dependent on and stabilized by import from upstream communities. Application of the River Continuum Concept outlined by Vannote *et al.* (1981) is thus largely inappropriate. Formerly, under less variable, continuous flow regimes associated with widespread ciénega-marshland communities, its principles may have been more applicable. Yet, the downstream progression from ciénega to riverine marsh communities remains based on a gradient of increasing instability, still in violation of River Continuum principles. Subterranean processes carried out largely by bacteria in streambed alluvia are certainly important in these systems and we expect will prove to be principal factors determining what products are exported downstream. Export by surface discharges may be only temporally important.

Perpetuation of ciénega habitat will require maintenance of permanent groundwater and a balance between aggradation and degradation. Permanence achieved by pumpage, with attendent fluctuations and other disruptions, will scarcely achieve the ciénega climax. Nor will check dams and other erosion control devices unless they intersect barriers to groundwater flow. Ideal structures will seal alluvial cross-sections of drainageways near headwaters, inducing bank and channel storage and causing intersection of flowing groundwaters and surface. Anaerobiosis of sediments will then occur, and the ciénega habitat should build to mound over the perennial reach. Ultimately, sediments may build to allow local "climatic" change in access by aquatic/semiaquatic species to perennial water, and Sacatón/Mesquite communities will appear. Maintenance of open waters for vertebrates such as fishes, and to provide diversity equivalent to that in historic ciénegas, may require artificial deepening or control of some vegetative components by unnatural means such as local dredging or limited livestock grazing.

The present scattered distribution of ciénegas makes them aquatic islands of unique habitat in an arid-land matrix. Among rapidly disappearing aquatic habitats of the Southwest, ciénegas have a definite potential for perpetuation, and should be given high priority as a unique remnant of our natural heritage.

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