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Riparian vegetation dynamics and evapotranspiration in the riparian corridor in the delta of the Colorado River, Mexico

Pamela L. Nagler[a,*], Edward P. Glenn[b], Osvel Hinojosa-Huerta[c], Francisco Zamora[d], Keith Howard[e]

[a]US Geological Survey, Southwest Biological Science Center, Sonoran Desert Research Station, BioSciences East Building, Room 125, University of Arizona, Tucson, AZ 85721, USA
[b]University of Arizona, Soil, Water and Environmental Science Department, Environmental Research Laboratory, Tucson, AZ 85706, USA
[c]University of Arizona, School of Natural Resources, Tucson, AZ 85721, USA
[d]Sonoran Institute, Tucson, AZ 85711, USA
[e]US Geological Survey, MS 973, Menlo Park, CA 94025, USA

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Abstract

Like other great desert rivers, the Colorado River in the United States and Mexico is highly regulated to provide water for human use. No water is officially allotted to support the natural ecosystems in the delta of the river in Mexico. However, precipitation is inherently variable in this watershed, and from 1981–2004, 15% of the mean annual flow of the Lower Colorado River has entered the riparian corridor below the last diversion point for water in Mexico. These flows include flood releases from US dams and much smaller administrative spills released back to the river from irrigators in the US and Mexico. These flows have germinated new cohorts of native cottonwood and willow trees and have established an active aquatic ecosystem in the riparian corridor in Mexico. We used ground and remote-sensing methods to determine the composition and fractional cover of the vegetation in the riparian corridor, its annual water consumption, and the sources of water that support the ecosystem. The study covered the period 2000–2004, a flood year followed by 4 dry years. The riparian corridor occupies 30,000 ha between flood control levees in Mexico. Annual evapotranspiration (ET), estimated by Moderate Resolution Imaging Spectrometer (MODIS) satellite imagery calibrated against moisture flux tower data, was about $1.1\,m\,yr^{-1}$ and was fairly constant throughout the study period despite a paucity of surface flows 2001–2004. Total ET averaged $3.4\times10^8\,m^3\,yr^{-1}$, about 15% of Colorado River water entering Mexico from the US Surface flows could have played only a small part in supporting these high ET losses. We conclude that the riparian ET is supported mainly by the shallow regional aquifer, derived from agricultural return flows, that approaches the surface in the riparian zone. Nevertheless, surface flows are important in germinating cohorts of native trees, in washing salts from the soil and aquifer, and in providing aquatic habitat, thereby enriching the habitat value of the riparian corridor for birds and other wildlife. Conservation and water management strategies to enhance the delta habitats are discussed in light of the findings.

Keywords: Desert river; Cottonwood; Willow; Saltcedar; Estuary; Remote sensing

1. Introduction

The world's major arid zone rivers have been harnessed for human use, and in many cases their deltas have been dewatered, with little if any water reaching the sea (Drinkwater and Frank, 1994; Poff et al., 1997; Graf, 1999; Baron et al., 2002; Nilsson and Svedmark, 2002; Shafroth et al., 2002, 2005; Gleick, 2003). This was the case for the Colorado River delta in Mexico from 1964, when Glen Canyon Dam was completed, to 1981, when Lake Powell behind Glen Canyon Dam reached capacity for the first time (Fig. 1) (Zamora-Arroyo et al., 2001; Nagler et al., 2005b). Up to then, excess precipitation in the watershed was simply stored in the still-filling reservoir. After 1981, major releases of water ($100–800\,m^3\,s^{-1}$) to the

*Corresponding author. Tel.: +1 520 626 2113; fax: +1 520 670 5001.
E-mail address: pnagler@ag.arizona.edu (P.L. Nagler).

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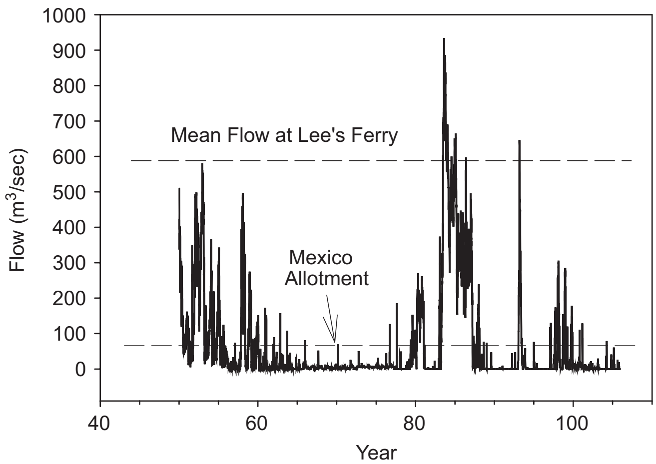

Fig. 1. Flows in the Lower Colorado River at the Southerly International Boundary from 1950 to 2005. Dashed lines show the mean flow below Grand Canyon and the Mexico allotment withdrawn at Morelos Dam.

delta and Gulf of California have occurred during El Nino cycles in 1983–1988, 1993, and 1997–2000, and smaller ‘‘administrative spills’’ (2–5 $m^3 s^{-1}$) (water ordered by irrigators but not used) have flowed from the US to Mexico in other years (Fig. 1). On average, about 15% (82 $m^3 s^{-1}$) of the annual flow of the Lower Colorado River at Lee's Ferry below the Grand Canyon has reached the riparian corridor in the delta since 1980, but the flows are extremely variable (standard deviation = 170 $m^3 s^{-1}$) and are not guaranteed to continue into the future (Nagler et al., 2005b). Other cross-border flows into the delta include agricultural drain flows and canal seepage from the US to Mexico that supports off-channel wetlands (Zamora-Arroyo et al., 2005).

The large and small river flows have markedly improved the habitat value of the riparian corridor in the delta (Hinojosa-Huerta, 2006; Hinojosa-Huerta et al., 2006). Although an introduced shrub, saltcedar (*Tamarix ramosissima*), is the dominant plant species in the delta, the flood flows have established cohorts of native cottonwood (*Populus fremontii*) and willow (*Salix gooddingii*) trees on the sand bars and terraces, and marsh habitat in the oxbows and backwaters of the river channel (Nagler et al., 2005b). The improved habitat supports large numbers and a high diversity of resident and migratory birds, such that the riparian zone of the Lower Colorado River in Mexico has been recognized as an important regional ecosystem (Hinojosa-Huerta, 2006; Hinojosa-Huerta et al., 2006; Zamora-Arroyo et al., 2005).

The revived habitats have sparked a debate about how to manage water flows to the delta. Environmental advocacy groups have urged that an ‘‘environmental allotment’’ of water be dedicated to the delta ecosystems. One suggestion is that 1% ($1.85 \times 10^8 m^3 yr^{-1}$) of the annual flow of the Lower Colorado River should be sent to the delta ecosystems (e.g., Cockburn and St. Clair, 2001). Other groups are attempting to purchase enough water to provide a ‘‘maintenance flow’’ of 2 $m^3 s^{-1}$ ($6.3 \times 10^7 m^3 yr^{-1}$) to be used for restoration projects in the riparian zone (Cornelius et al., 2003). On the other side of the debate, agricultural and municipal water users object to environmental set-asides in this rapidly growing but water-short region (e.g., Kuhn, 2005).

Developing a rational conservation program for this ecosystem will require knowing the water requirements (both volume and quality) and the potential sources of water that are available to support the riparian ecosystem, and in particular the native trees and marshes that are such important ecosystem components. The main riparian species in this region are phreatophytes, deriving most of their water from the shallow aquifer under the river channel and terraces (Naumburg et al., 2005; Pataki et al., 2005; Cleverly et al., 2006); they depend on a pulse flood regime to establish new cohorts (Poff et al., 1997; Nagler et al., 2005b) then on subsurface water sources for subsequent growth (Naumburg et al., 2005; Stromberg et al., 2006). Riparian species in the delta differ markedly in the depth of ground water they can access and the salinity they can tolerate in the aquifer (reviewed in Glenn and Nagler, 2005). The ecohydrology of riparian ecosystems can therefore be quite complex, prohibiting simple management solutions to achieve restoration goals (Wilcox et al., 2006). Simply providing a small, steady source of surface water might not be sufficient to restore and maintain native trees. A better understanding of the ecohydrology of the riparian zone was listed as a priority conservation need in a recent environmental assessment of the Colorado River delta (Zamora-Arroyo et al., 2005).

In natural arid-zone stream systems, recharge of the alluvial aquifer under a river may occur mainly by surface river flows, and riparian vegetation can be limited by the volume of annual recharge of the aquifer, related to precipitation in the watershed and in some cases to pumping of ground water for human uses (e.g. Stromberg et al., 2006; Cleverly et al., 2006). In river deltas developed for irrigated agriculture, by contrast, recharge of the alluvial aquifer may be mainly by regional recharge from surrounding agricultural districts, and vegetation is not necessarily limited by water availability. Rather, water quality can be a limiting factor for agricultural and riparian species, due to the accumulation of salts in agricultural drain water. This is the case in the Nile Delta in Egypt, where withdrawal of water from the aquifer by pumping does not keep pace with recharge through infiltration, resulting in a perched, saline water table that damages crops (Dawoud et al., 2005). The riparian zone in the Colorado River delta is surrounded by over 200,000 ha of irrigated fields in the Mexicali and San Luis valleys, and infiltration of irrigation water and canal seepage support a permanently high water table throughout the valley, with subsurface flows moving in the direction of the river channel, which acts as a conduit to the Gulf of California (Portugal et al., 2005). The salinity of the Colorado River at the international border with Mexico is nearly 1000 ppt,