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Ecosystem services and the value of water in the Colorado River Delta and Estuary, USA and Mexico: Guidelines for mitigation and restoration

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Introduction

The Colorado River once delivered 16 x 10^9 m^3 per year to the river's delta and estuary in the northern Gulf of California (Figure 1). Since the completion of upstream dams, irrigation projects and aqueducts, the river's flow is now completely diverted for human uses and no surface water reaches the Gulf of California in normal years (Figure 2). The economic benefits to society have great, but the environmental costs to natural systems have been severe. The Colorado River is the largest single source of freshwater for cities and agriculture in the arid southwestern United States and northwestern Mexico. The river's water comes from snowmelt in the Rocky Mountains.

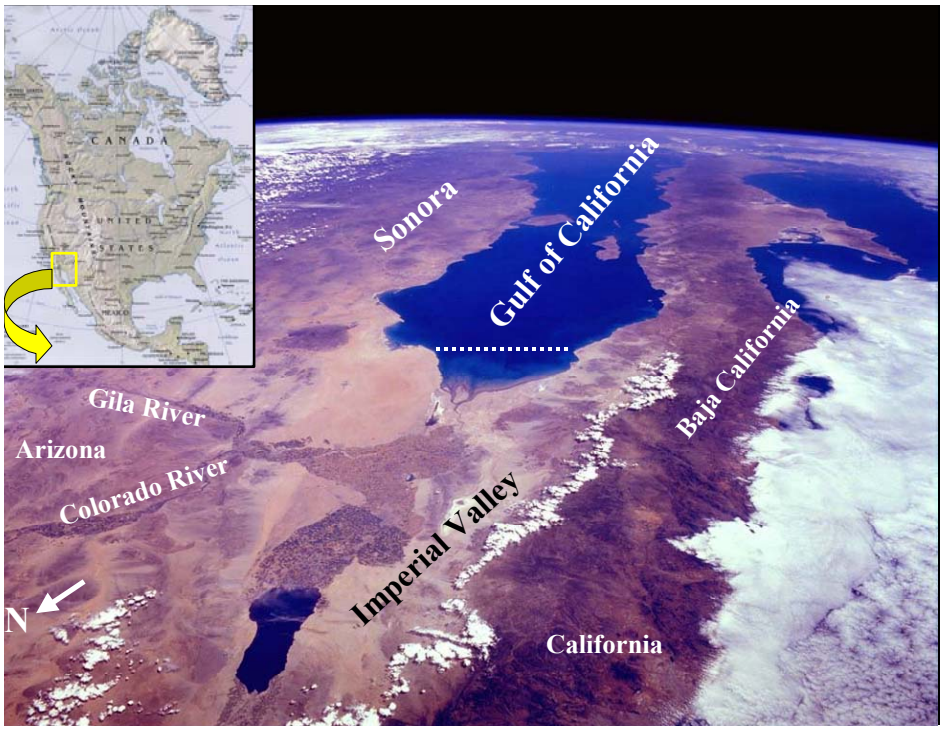

Figure 1. Location of study area and Colorado River delta and Gulf of California, looking south. Dark areas in the Imperial Valley in the USA and Mexico are irrigated agriculture. Lake at bottom of image is the Salton Sea, a saline lake created accidentally in 1905 and now maintained

by agricultural return flow. Dashed line in Gulf of California marks the approximate limit of the former estuary and is 100 km long.

Allocations of water among the US states and between the US and Mexico were determined in a series of inter-state agreements, international treaties and court decisions between 1922 and 1963. Upper Colorado Basin US states (Colorado, New Mexico, Utah and Wyoming) are entitled to 9.2 x 10^9 m^3 per year, Lower Basin US states are entitled to 9.2 x 10^9 m^3 per year and Mexico receives 1.8 x 10^9 m^3 per year. The total legal entitlements to water (20.2 x 10^9 m^3 per year) exceed tree-ring based estimates of average flow (16 x 10^9 m^3 per year) during the past 500 years. There are more legal rights to water than available water in this rapidly growing region. No water is allocated for natural systems. Conflicts over water use are common and are likely to increase. The importance of water in the western United States was summed up by the American humorist Mark Twain, who said "Whiskey is for drinking, water is for fighting".

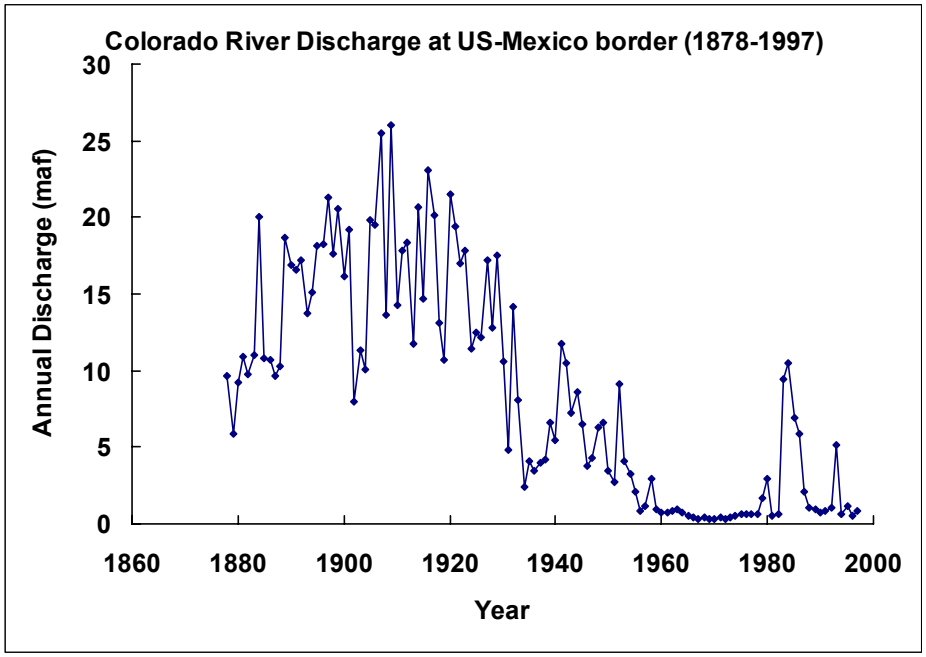

Figure 2. Draining the river. Colorado River discharge at US-Mexico border from 1878 to 1997. Discharge (flow) units are in millions of acre-feet (maf) (1 acre-foot = 1,233 m^3). With the exception of El Niño years in the 1980's and early 1990's, the US delivered only its treaty obligation of 1.5 maf (1.8 x 10^9 m^3) to Mexico. All of Mexico's share is used in agriculture and cities. River water no longer reaches the Gulf of California.

In Arizona and California, approximately 80% of the water is diverted for agriculture and 20% for cities. Increasing urban growth in southern Nevada, southern California and Arizona is likely to increase urban use at the expense of agricultural use. In southern California, a recent agreement permits the sale of agricultural water to urban users, with part of the water's price determined by the need for environmental mitigation. This agreement may be a model for future transfers of water from agriculture to cities.

Ecosystem goods and services

Ecosystem goods and services are the benefits that human populations derive, directly or indirectly, from ecosystem functions. Table 1 lists some of the services and goods provided to human society by natural ecological systems.

Ecosystem goods and services	
Gas regulation	Waste treatment
Climate regulation	Pollination
Disturbance regulation	Biological control
Water regulation	Refugia
Water supply	Food production
Erosion control	Raw materials
Soil formation	Genetic resources
Nutrient cycling	Recreation and culture

Table 1. Ecosystem goods and services (after Costanza et al., 1997)

In a landmark but controversial paper, Costanza et al. (1997) provide rough estimates of the dollar value of ecosystem services in each of 11 biomes, including river floodplains, grasslands, croplands, estuaries, and marine shelves. Biomes vary in both the type and total value of ecosystem services provided. Costanza et al. (1997) estimated the monetary value of ecosystem goods and services by synthesizing existing estimates of "willingness to pay", the cost of substitute methods for providing the same services and goods, and other approaches.

Note that these are estimates of the monetary value of natural systems to human society; they do not estimate the total value of the natural world because they do not "monetize" any spiritual, ethical, moral or intrinsic values.

The diversion of Colorado River water for agriculture and municipal use has changed the type and value of ecosystem goods and services provided by the 12,000 km^2 delta and estuary.

Converting the landscapes of the Colorado Delta and estuary

In the Colorado Delta and Imperial Valley, irrigation projects transformed floodplain, wetland, and desert biomes into cropland, while in the northern Gulf of California, upstream diversions of all types converted estuarine habitats into biomes more similar to marine shelf habitats.

The environmental effects of water diversion and the conversion to agriculture have been severe. In terrestrial and riparian habitats, natural vegetation is now restricted to a narrow zone along the former course of the river and to wetlands created by agricultural return flow. Endangered species include desert pupfish and several species of birds (Glenn et al., 2001, Hinojosa-Huerta et al., 2002). In the former estuary, population densities of a brackish-water mollusk have been greatly reduced (Kowalewski et al., 2000; Rodriguez et al., 2001) and a sciaenid fish and an endemic porpoise may be affected by the change in habitat. In addition, shrimp harvests are reduced when river water does not reach the Gulf of California (Galindo-Bect et al., 2000).

I used conservative estimates from Costanza et al. (1997) to estimate the total dollar value of ecosystem services in the original and the converted biomes of the delta and estuary (Figure 3). The conversion of desert to cropland doubled the value of services provided per

hectare. In contrast, the conversion of floodplain and wetland biomes to cropland decreased the value of ecosystem services by two orders of magnitude per hectare. In the marine environment, the transformation from an estuarine to a marine shelf biome decreased the value of ecosystem services by an order of magnitude per hectare (Figure 3).

Prior to the diversion of water and the conversion of natural biomes to cropland, the value of delta and estuary ecosystems services totaled ~ $2.7 billion per year. Since diversion and conversion, the annual value has decreased by an order of magnitude to ~$260 million. The net loss of value of ecosystem services caused by the diversion of Colorado River water is ~ $2.4 billion per year.

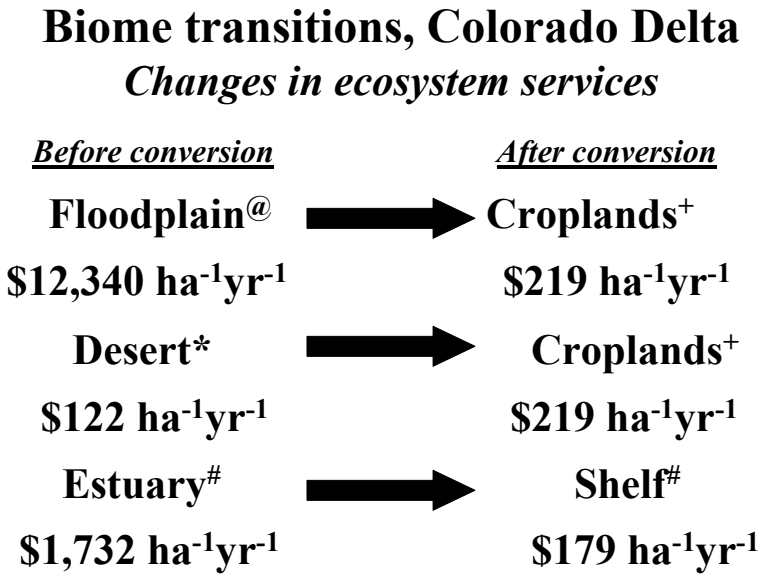

Figure 3. Biome transitions and per hectare changes in the value of ecosystem services in the Colorado Delta and estuary before (left column) and after (right column) conversion of the landscape for agriculture. Symbols as follows: ha = hectares; @ not including disturbance regulation; *desert values assumed to be half of rangeland values; + rangeland values used where cropland values are not known; # value of nutrient cycling not included.

The ecosystem value of water

Because the value of ecosystem services in the region depend on the availability of water, these valuations can be used to estimate a value for Colorado River water. Assuming that the Colorado River supplies 13 million acre-feet (16 billion cubic meters) of water per year, the ecosystem service value of water is $208 per acre-foot ($0.17 per m^3). Current U.S. agricultural water prices for Colorado River water range from $16 to $32 per acre-foot ($0.001 to $0.002 per m^3 and municipal prices range from $300 to more than $880 per acre-foot ($0.24 to $0.71 per m^3). Existing prices are based on the cost of conveyance and market forces, not on the value of the lost ecosystem services. The ecosystem cost of $208 per acre-foot ($0.17 per m^3) is a hidden subsidy currently paid through the loss of nature's services to society.

Although these estimates are only rough approximations, they provide a starting point for negotiations over the appropriate environmental mitigation costs that should be included in the price of water in this arid region. In addition, ideal restoration efforts should restore the types and values of the original ecosystem services provided by the natural system. In the case of the Colorado River delta and estuary, the current ecosystem services deficit could be largely "paid off" by restoring floodplain habitat through fallowing ~170,000 hectares of cropland. The water saved would flow to the Gulf of California and then restore ~57,000 hectares of estuary.

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