THE UPPER/NORTHERN GULF OF CALIFORNIA HAS NEVER BEEN BRACKISH OR ESTUARINE

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BACKGROUND

The idea that, in the past, the Colorado River ever delivered enough fresh water to the Upper Gulf to create brackish or estuarine conditions is a myth.

There have never been empirical records of how much Colorado River water reached the Upper Gulf. Publications on the subject have usually used flow meter data from Lees Ferry (on the Arizona-Utah border), occasionally from a Yuma flow meter, or rarely from the Morelos Diversion Dam built in 1950 (providing the first data on how much river water flowed across the border into Mexico). Note that Morelos Dam is not a true dam; it is simply a switching station for water crossing into Mexico, diverting it to various agricultural areas and city water supplies in the Mexicali Basin. Lees Ferry marks the legal transition from the Upper Colorado River Basin to the Lower River Basin. From Lees Ferry the river flows more than 1000 km south, through the hottest landscapes in the U.S., before crossing the border into Mexico.

A long chronicle of tree-ring research has shown a historic mean Colorado River flow past Lees Ferry of ~13.5 X 10^9 m^3 (~11 million acre-feet) annually. The amount reaching Mexico (1000 km to the south) would have been far less than that, perhaps ~6.5 X 10^9 m^3 (~5.5 maf) annually. The Mississippi River discharges 554 X 10^9 m^3 annually to the Gulf of Mexico, and the Columbia and Fraser Rivers discharge 236 X 10^9 m^3 and 110 X 10^9 m^3 annually to the Pacific, respectively. Even Niagara River discharges 183 X 10^9 m^3 annually to Lake Ontario. By comparison, the Colorado's flow to the Mexican border is trivial. The concept of a "Mighty Colorado" is a myth.

But it seems that even this small flow crossing the border into Mexico rarely reached the Upper Gulf. Instead, it was trapped on the huge delta (8,612 km^2/3,225 mi^2), which is mostly below sea level and where many low basins have always held the river's water and prevented it from reaching the sea (e.g., Salton Basin, Laguna Salada Basin, Volcano Lake, Pescadero Basin, Santa Clara Basin, etc.). When filled, Laguna Salada alone covers ~1000 km^2.

The reason most of the Colorado River Delta is below sea level is because the San Andreas Rift System is spreading at a rate of 4-5 cm/yr (1.5-2 in/yr), creating tectonic pull-apart basins (grabens) and causing the rift valley to continually subside (at a rate of 1-3 mm/yr). The mean rate of subsidence has simply been greater than the mean rate of river sediment infill. The Salton Trough is 73 m (240 ft) below sea level and Laguna Salada is 11 m (36 ft) below sea level. Both are filled with primarily Colorado River sediment 6,000 m (19,685 ft) thick, testimony to their ~5 million history of capturing the Colorado River's water.

Since the 1970s, it has likely been only during "flood years" that any river water could have reached the Gulf (1978, 1982-1988, 1993, 1997-1999). 1983 to 1989 were unusually wet years in the Southwest. Extreme flood flows occurred 1984-1988 when great amounts of river water reached the Delta. However, most of this discharge ended up in Laguna Salada where it was lost to evaporation. During flood years the lower delta is covered by 2,500 km^2 of trapped, standing, fresh water (see photo below).

There has never been a single oceanographic measurement of brackish water (i.e., <30 ppt) in the Upper Gulf. The actual estuary is basically just the delta, and it stops at Montague Island (only north of the island could brackish water ever have occurred).

THE FACTS

(1) **THERE IS NO RECORD OF PRE-DAM BRACKISH WATER IN THE UPPER GULF.** Nineteenth-century (pre-dam) oceanographic data show the Upper Gulf to be fully marine, never brackish, (e.g., Roden 1958).

(2) **EVEN FLOOD YEARS DO NOT CREATE BRACKISH CONDITIONS.** Lavín and Sánchez (1999) took advantage of a natural experiment to assess pre-dam Colorado River influence on salinity in the Upper Gulf by measuring the effects of the enormous 1993 flood release on the river. An estimated maximum 550 m^3 per second of river water crossed the border into Mexico at Morelos Dam during a March–April pulse release, for a total 2-month discharge of about 2.9 X 10^9 m^3, or an average daily flow of 47.5 X ~$10^6 m^3$, and during this period salinities off San Felipe remained oceanic, averaging 35.4 ppt.

(3) **PRE-DAM CLAM SHELLS SHOW NO RECORD OF LOW-SALINITY WATER IN THE UPPER GULF.** Based on oxygen isotopes in shell layers, estimates of pre-1935 natal salinities of "delta clam" shells (*Mulinia modesta*) show no evidence of pre-dam brackish water environment south of Isla Montague (Cintra-Buenrostro et al. 2012).

(4) **LONG -TERM SATELLITE DATA SHOW NO RECORD OF LOW-SALINITY WATER IN UPPER GULF.** John All (2006, 2007) used remote-sensing imagery to show that no water flowed beyond Morelos Dam (into Mexico) from 1958 to 1983, as Lakes Mead and Powell filled. During this time, all downstream riparian areas on the Delta disappeared and Lake Maquata (Laguna Salada, today) dried up. Laguna Salada/Lake Maquata was historically a large lake fished by locals (especially the Cucupá People). John All used the same techniques to show that no water reached the Sea of Cortez from 1989 to 2000, even during flood years (when much of the fresh water was diverted into Laguna Salada).

(5) **AVERAGE ANNUAL SALINITY OF THE UPPER GULF DOES NOT CHANGE SIGNIFICANTLY BETWEEN WET AND DRY PERIODS.** Rodríguez-Pérez et al. (2024) found Upper Gulf salinity to range around 34.5 ppt throughout the 1980s and 1990s, based on satellite data (i.e., no signs of hyposalinity or brackish water even during flood years).

(6) **THE HISTORY OF UPPER GULF OCEANOGRAPHY PROVIDES NO RECORDS OF BRACKISH CONDITIONS AND INDICATES RIVER WATER IS MOSTLY IMPOUNDED ON THE DELTA.** Brusca et al. (2017) reviewed the history of oceanographic research in the Northern Gulf (~350 papers), concluding that: (1) the Upper Gulf has never been brackish; (2) the amount of river water reaching the Upper Gulf has rarely been large, usually absent altogether (the river instead

emptying into the Salton Basin, Laguna Salada, and other basins on the delta), and never enough to create brackish or estuarine conditions below Isla Montague.

(7) **MEAN DAILY TIDAL FLUSHING OF THE UPPER GULF EXCHANGES MORE WATER THAN AN ENTIRE YEAR OF RIVER FLOW.** Rojas-Bracho et al. (2019) calculated the amount of oceanic water exchanged in the Upper Gulf due to the area's extreme tides. They found that the amount of river water reaching the Upper Gulf has historically been far too small to have any significant impact on the salinity of the region, and the size of the daily tidal exchange makes it physically impossible for the Upper Gulf to become brackish. Given the average 3.87-meter tidal range in the Upper Gulf, and the semidiurnal nature of its tides, a mean of over 25.5 X 10^9 m^3 of oceanic tidal water flushes into and out of the region daily, which is more than the highest estimates of Colorado River water reaching the Upper Gulf in an *entire year*. Thus, the influence of the river's discharge on salinity in the Upper Gulf has always been trivial, pre-dam and post-dam.

ENDNOTE

The southernmost Gulf first opened ~8 Ma as an embayment in what is now the mouth of the Gulf of California. Colorado River first reached the Gulf of California ~5.4 Ma (Dorsey et al. 2018). The Upper Gulf has some of the most extreme tides in the world, up to 30 feet at the river's mouth. During spring tides, the tidal flow used to reach over 65 km up-river from Montague Island. Today it only reaches ~25 km upriver, where it is stopped by a sand bar that has bult up since the nearly complete loss of river water in the 1970s. At mean sea level, the Upper Gulf has a surface area of 3.3 X 10^9 m^2 and a volume of 48.5 X 10^9 m^3. The average depth is 14.7 m, the average tidal range, on flow or ebb phases, is 3.87 m. About half (52%) the volume of water in the upper Gulf is flushed in-and-out with each tidal cycle, and there are 2 tides daily. Given the average 3.87 m tidal range in the upper Gulf (San Felipe and El Golfo de Santa Clara), and the semidiurnal nature of the tides, around 25 X 10^9 m^3 of tidal water flushes into and out of the region daily. That is far more than the highest estimates of Colorado River water reaching the upper Gulf in an entire year! Thus, the potential influence of the river's discharge on salinity in the upper Gulf is nil.

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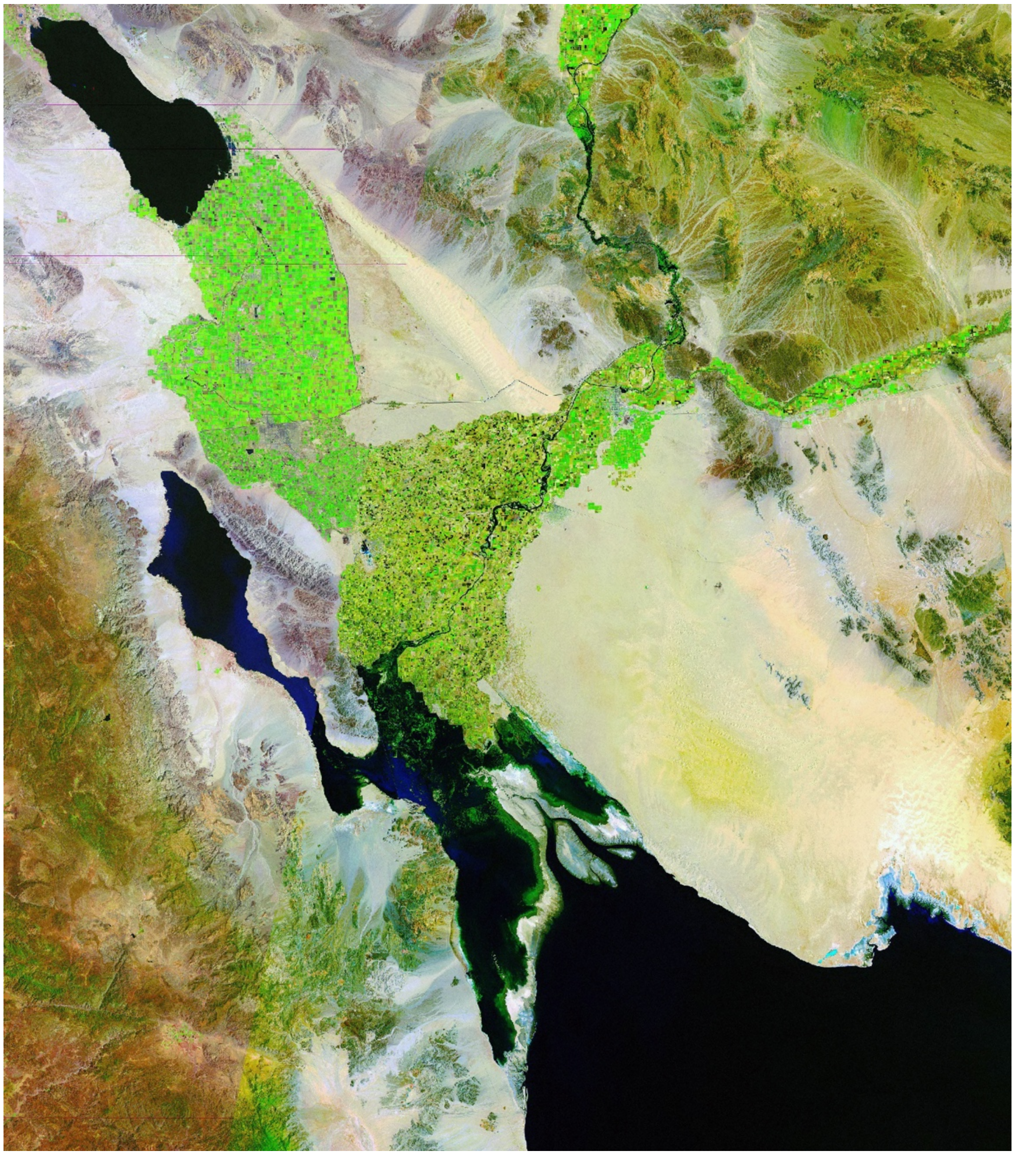

“The river was nowhere and everywhere.” Aldo Leopold, *A Sand County Almanac*.

The 1983-84 El Niño event led to “flood year” excess water releases into the Colorado River channel, filling Laguna Salada Basin and connecting it to Ciénega de Santa Clara as the delta flooded from April to June. Laguna Salada covers ~1,000 km^2 and the total flooded area of the delta is ~2,500 km^2. In this image, you can see that essentially all of the river’s water is trapped on the lower delta behind berm-barriers to the Upper Gulf. The water eventually evaporates or infiltrates into the delta’s sediments. LANDSAT images courtesy of Alejandro-Hinojosa-Corona (CICESE, Ensenada).