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Shaping the 2014 Colorado River Delta pulse flow: Rapid environmental flow design for ecological outcomes and scientific learning

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ABSTRACT

In 2014, the United States and Mexico jointly delivered an environmental flow to the Colorado River Delta, as authorized in a 2012 binational water management agreement known as Minute 319. The agreement specified a volume of water, the source of the water, that the water should be delivered as a pulse flow, and that the objectives of the pulse flow were to pilot environmental restoration and learn about the hydrologic and ecological responses to water delivery into the Colorado River Delta. The Minute did not specify the characteristics of the pulse flow, but rather specified a process, calling on a group of stakeholders, including federal, state, and local water managers as well as non-governmental conservation organizations from both countries, to develop a flow delivery plan.

The flow delivery plan was developed, approved, and executed in an exceptionally short period of time, with limited scientific data, under numerous operational constraints. The unique feature that made the hydrograph development a success is the exceptionally close interaction between policy makers, water managers, and scientists, driven by clear objectives for ecological outcomes and scientific learning. In describing this case study, we also document the inevitable tradeoffs that led to a flow design that best met the needs of all parties while fully meeting the needs of none. In so doing, we rationalize the characteristics of the flow delivery hydrograph.

1. Introduction

Rivers are lifelines for human and natural communities. Economies throughout the world rely upon the clean water, food, fiber, energy, and recreation that healthy rivers provide. However, riverine ecosystems are seriously impaired and continue to degrade. Freshwater-dependent species are imperiled worldwide, declining at rates much faster than terrestrial and marine species (WWF, 2014).

Flow alteration and over-allocation are major causes of river degradation globally (Dudgeon et al., 2006). Diversions, levees, and dams alter natural streamflow in rivers, while excessive withdrawals chronically deplete flow volumes. Riverine species evolved with, and depend upon, seasonal fluctuations in streamflow, which prepare seedbeds and nourish native plants, cue spawning and migration, flush salts and sediment, and create the natural cycles of disturbance and replenishment that sustain diverse, resilient river systems.

Environmental flows describe the timing and amount of water that lakes, rivers, streams and estuaries need to sustain natural functions, processes and resilience in harmony with thriving agriculture, cities, and industries. Because freshwater systems vary geographically, myriad scientific approaches have emerged to determine environmental flow needs (Annear et al., 2004; Tharme, 2003). The vast majority of these methods first build hydrographs (expressed as daily or seasonal volumetric flow rates [e.g., cubic feet per second or cubic meters per day] or water levels [e.g., feet or meters above a datum]); then determine the volume of water (e.g., acre-feet or cubic meters) needed to create such hydrographs; and finally seek ways to obtain those volumes through dam operation, water re-allocation, or other means (Dyson et al., 2003; Richter et al., 2006).

Decision makers expect the science supporting such water management changes to have low levels of uncertainty. To reduce uncertainty in environmental flow determinations, scientists use data and tools that are well-calibrated to local conditions. These

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tools, such as hydraulic models and ecological response relationships, can require several years to develop and fine-tune.

Paradoxically, opportunities to deliver environmental flows often arise unexpectedly. For example, exceptional flooding or infrastructure failure may prompt the unanticipated release of high flows from a reservoir. These opportunistic events afford little time to formulate long-term management objectives and to plan, fund, and execute careful experiments to support them. Lacking clear expectations or scientific hypotheses, these events become lost opportunities to affect water management (Olden et al., 2014).

Here we describe a situation in which a set volume of water was suddenly made available to meet environmental objectives, with a short timeframe for science in a data-poor context. In 2014, the United States and Mexico jointly delivered an environmental flow to the Colorado River Delta. The environmental flow, termed a "pulse flow," was authorized in a 2012 binational water management agreement known as Minute 319. The agreement specified a volume of water, the source of the water, that the water should be delivered as a pulse flow (high magnitude, short duration event, as might naturally result from a spring snowmelt—albeit at a much smaller scale), and that the objectives of the pulse flow were to pilot environmental restoration and learn about the hydrologic and ecological responses to water delivery into the Colorado River Delta. The Minute did not specify the characteristics of the pulse flow, but rather specified a process, specifically calling on a group of stakeholders, including federal, state, and local water managers as well as non-governmental conservation organizations from both countries, to develop a flow delivery plan. This paper summarizes the deliberations that went into planning the Minute 319 pulse flow and, in so doing, rationalizes the characteristics of the flow delivery hydrograph.

Within five months, a team of scientists reverse-engineered a flow hydrograph under dynamic physical and policy constraints, and designed and initiated a comprehensive monitoring plan. The unique feature that made the hydrograph development a success is the exceptionally close interaction between policy makers, water managers and scientists, driven by clear objectives for ecological outcomes and scientific learning. In describing this case study, we also document the inevitable tradeoffs that led to a flow design that best met the needs of all parties while fully meeting the needs of none.

2. Background

2.1. Description of the Colorado River Delta

The Colorado River's delta is comprised of sediments deposited over some 800,000 ha (2 million acres) extending from Yuma, Arizona, south into Mexico, where the river flows to the Upper Gulf of California (Fig. 1). The Colorado River historically flowed unobstructed into its delta, with an average annual volume of 18,400 million cubic meters (Mm^3), but ranging widely from 6200 Mm^3 to 30,800 Mm^3 (U.S. Bureau of Reclamation (USBR), 2012). Resulting primarily from snowmelt, the majority of historic flows arrived in the late spring and early summer (Luecke et al., 1999; Mueller et al., 2017). These flows spread expansively through the Colorado's delta, and several accounts from the early 20th century describe the immense extent of its wetlands and riparian *bosques*, as well as vast areas of open water (Sykes, 1937; Leopold, 1948).

During the 20th century, federal policy in the United States and Mexico encouraged development of the Colorado's water via infrastructure, both large and small. The vast majority of these dams and diversions were constructed prior to enactment of environmental laws in the United States and Mexico, and a 1944 Treaty between the two countries that addresses the Colorado and other border rivers did not provide for flows to sustain the environment. Flows reaching the river channel in the delta diminished significantly and large flows have occurred only occasionally since 1960 (Table 1). From 1965–2001, the flow averaged 2100 Mm^3. In recent years, flows to the river channel in the delta were further diminished by extended drought in the Colorado River Basin as well as by increased management effort to reduce excess deliveries to Mexico (USBR, 2015). Between 1990 and 2010, the average flow was 24 Mm^3 (20,000 acre-feet (AF)) per year (Cohen, 2013). By the late twentieth century, about 90% of the delta's native ecosystems had been largely replaced by a highly productive agricultural landscape (Glenn et al., 1996).

Table 1
Annual flow volumes (millions of cubic meters) reaching the Colorado River channel in the delta. Average flow for 1300–1900 is calculated using tree-ring analysis, and does not take evaporation and evapotranspiration losses into account. Average volumes for 1965–2001 and 2002–2010 are calculated as the difference between gaged volumes at the Northerly International Boundary and at Mexico's diversion at Morelos Dam into the Alamo Canal. (Cohen, 2013, 2016).

Timeframe	Average annual volume (Mm^3)
1300–1900	18,400
1965–2001	2100
2002–2010	24
2014 pulse flow	130

The remnant Colorado River that today exists in its delta extends from Morelos Dam downstream to the mouth, where the river meets the Upper Gulf of California (Fig. 1). The first 37 km (23 miles) downstream from Morelos Dam are known as the "Limitrophe", where the west bank is Baja California in Mexico, and the east bank is Arizona in the United States. From there downstream and to the south, the river continues in Mexico until it reaches the Gulf.

For about 21 km (13 miles) downstream from Morelos Dam, the river channel contains water (Shafroth et al., 2017), forming a sluggish stream fed by shallow groundwater and leakage from the dam. The perennially wet channel directly below Morelos Dam supports some of the highest quality habitat remaining in the Colorado River Delta outside of managed restoration sites.

Downstream, near the Southerly International Boundary (SIB), groundwater levels dropped more than 9 m (30 feet) between 1983 and 2010 (Cohen, 2013), resulting in the loss of perennial base flows. In recent years, the Colorado River channel has been dry in its delta for about 40 km, with groundwater depths now exceeding 15 m (50 feet) (Cohen, 2013). The dry channel passes through San Luis Rio Colorado, a city of 160,000 people.

Eighty km (50 miles) downstream from Morelos Dam, the river re-emerges as a series of sluggish pools where it is once again fed by shallow groundwater and agricultural drainage. It is here, where groundwater remains close to the land surface and water is found in the channel, that conservation organizations have established the largest habitat restoration sites, collectively known as the Laguna Grande complex, of more than 1000 ha (2500 acres) currently planted with native riparian vegetation or planned for restoration.

Continuing downstream (114 km (70 miles) below Morelos), the river grows to a wide, slow-moving stream where the tributary Rio Hardy contributes up to 4.5 cubic meters per second (m^3/s) (160 cubic feet per second [f^3/s]) of agricultural drainage and treated municipal wastewater. Below the Hardy, saline groundwater (due to tidal influence and evapoconcentration) supports a vast riparian area dominated by non-native saltcedar (*Tamarix* sp.). Further towards its terminus, the remaining vegetation ultimately gives way to vast expanses of mud and salt flats—the hypersaline remains of the once-prolific estuary.

Habitat degradation has been considerable during the Colorado River Basin drought that started in 2000 and has not yet abated,