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Editorial

It takes more than water: Restoring the Colorado River Delta

1. Introduction

Environmental flows have become important tools for restoring rivers and associated riparian ecosystems (Arthington, 2012; Glenn et al., 2017). In March 2014, the United States and Mexico initiated a bold effort in restoration, delivering from Morelos Dam a "pulse flow" of water into the Colorado River in its delta for the purpose of learning about its environmental effects (Flessa et al., 2013; Bark et al., 2016). Specifically, scientists evaluated whether the pulse flow, albeit miniscule compared to historical floods, could provide the ecological functions needed to establish native, flood-dependent vegetation to restore natural habitat along the riparian corridor.

Prior to the flow release, the Colorado flowed to its delta only when the water was not stored or delivered for human use (Mueller et al., 2017). For eons, that occurred regularly as snow melted in the Rocky Mountains and water flowed along the river into the Upper Gulf of California (Glenn et al., 2013). But extensive development of the Colorado's water in both countries through the 20th century reduced the volume in the river, and starting in the early 1960′s, the river stopped regularly flowing below Morelos Dam (the furthest downstream dam on the Colorado River); by 2014, the river had not reached the sea in 16 years. Remnant riparian habitat in the Colorado River Delta was both diminished and degraded (Hinojosa-Huerta et al., 2013). Sightings of wildlife dependent on that remnant habitat, including approximately 380 species of birds, were decreasing in the region (Hinojosa-Huerta et al., 2013). Much of the potentially restorable habitat, where the groundwater table is shallow, lies more than 60 km (40 mi) downstream from Morelos Dam. Between Morelos and several targeted downstream restoration sites lies a 40 km (24 mi) perennially dry reach overlying a depressed groundwater table, where native mesic riparian plants cannot survive. In this context, expected ecological impacts of the 2014 delivery of water for the environment were uncertain. How would the water move through the altered river corridor to the targeted restoration sites? Could the existing irrigation infrastructure be used to by-pass water around the dry section? How would riparian vegetation respond? Would wildlife respond?

This special issue of Ecological Engineering, "Delta Environmental Flows", documents much of what has been learned as a result of this environmental flow release. Additionally, two official monitoring reports have been published jointly by the United States and Mexican sections of the IBWC, and a third and final report is forthcoming in 2018 (IBWC, 2014; IBWC 2016).

The papers in the special issue illustrate the ways in which the scientific contributions intersect with and support the vision and goals of the conservation non-governmental organizations (NGOs) implementing restoration in the Colorado River Delta. The scientific articles also stand on their own in addressing more general issues in restoration science.

2. Our unique collaboration

The Colorado River Delta is almost entirely located in Northwestern Mexico, downstream of its large watershed covering approximately 632,000 km^2 (244,000 mi^2) in the United States. NGOs identified that ecological restoration of the Colorado River Delta is dependent on binational collaboration, particularly coordinated efforts to designate and deliver environmental flows to the region (Pitt et al., 2000), and defined conservation priorities (Zamora-Arroyo et al., 2005).

The riparian restoration effort in the Colorado River Delta, and the 2014 pulse flow in particular, are the products of a remarkable collaboration (Kendy et al., 2017). The United States and Mexico, two countries that had mostly considered the Colorado River a subject for dispute, began to work side by side on restoration in the delta, collaborating to deliver the political will, water, funding, field instrumentation, field labor, as well as many hours of data processing and analysis. Moreover, the two federal governments did not deliver these commitments alone, but collaborated with a host of nontraditional partners including state governments, universities, non-governmental conservation organizations (NGOs), and philanthropies to plan and implement water delivery and monitoring plans (Pitt and Kendy, 2017).

Collaboration between the United States and Mexico was formalized in the adoption of Minute 319, an agreement that gives further definition to the 1944 treaty upon which the two countries rely to define how the Colorado River is shared (Kendy et al., 2017). In Minute 319, amidst a host of new approaches to Colorado River management at the border, the two federal governments committed to: deliver environmental flows to the Colorado River in Mexico as a pilot project; study their hydrologic and ecological effects; and provide funds for restoration activities such as reforestation with native trees and shrubs in designated restoration areas. Minute 319 committed the United States and Mexico to provide a one-time "pulse flow" water delivery, and additionally, a group of NGOs was to provide "base flow" deliveries—low magnitude water deliver-

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ies for habitat maintenance spanning the full 5-year term of the Minute.

Minute 319 was signed in late 2012, and by mid-2013 the two countries, acting through the United States and Mexican sections of the International Boundary and Water Commission (IBWC), the Mexican National Water Commission (CONAGUA) and the U.S. Bureau of Reclamation, had convened an array of non-federal actors from both countries, including stakeholders, water users, scientists, and experts to help implement the environmental flows (Kendy et al., 2017; Pitt and Kendy, 2017). The federal agencies tasked a pair of conservation NGO representatives, one each from the United States and Mexico, with leadership of this collaboration to plan the pulse flow release and design and implement a monitoring program to assess its impact. The individuals that collaborated to deliver and study the pulse flow include university experts, some with long careers working in the Colorado River Delta and some with expertise gained elsewhere, federal and state agency scientists and policy experts, federal river operators, as well as scientists, attorneys, and other experts from the NGOs who have a long history of work related to habitat restoration in the Colorado River Delta.

In addition to making water available for the pulse flow, the two federal governments collaborated to provide financial support for science and resource management, funding both on-the-ground restoration activities implemented by NGOs, and funding scientific monitoring. Federal agencies also implemented key components of the scientific monitoring. Private, philanthropic organizations also funded restoration and science activities.

3. A landscape-scale pilot project in riparian restoration

The architects of Minute 319 wisely established the pulse flow and the subsequent base flows within a framework designed to assess impacts and inform any future water deliveries for environmental restoration. A primary goal outlined in the Minute 319 agreement was to "Evaluate the ecosystem response, most importantly the hydrological response and, secondarily, the biological response to the flows" (IBWC, 2012; p. 13; see also Flessa et al., 2013). There were no pre-determined measures of success; the Minute 319 Science Team was formed and deployed to track the lateral and downstream extent of the pulse flow surface water (Ramirez-Hernandez et al., 2017), groundwater table dynamics in the vicinity of the riparian corridor (Kennedy et al., 2017; Rodriquez et al., 2017), bird abundance and diversity (Darrah et al., 2017; Osvel Hinojosa-Huerta et al., 2017 in preparation), local and regional vegetation response using remote sensing (Jarchow et al., 2017a,b) and ground surveys within actively-managed restoration sites (Schlatter et al., 2017) and in other reaches of the river (Shafroth et al., 2017). In some sites, land managers removed exotic vegetation and used machinery to grade and reconnect backwater areas with the main channel prior to the flow release to determine if active restoration techniques combined with environmental flows would improve restoration success (Schlatter et al., 2017). In addition, surveys of the living and "pre-dam" molluscan fauna at the mouth of the river (Dietl et al., 2017) provided a valuable baseline for future efforts to restore a portion of the river's former estuary.

4. What did we learn?

Although rivers have refilled nearly dry channels before, rarely has there been an opportunity to prepare in advance with enough time to monitor the effects. The high quality and substantial amount of scientific knowledge obtained as a result of the Minute 319 flows is demonstrated by the papers in this special issue—and in related papers that have been published or are forthcoming. The knowledge gained is being actively applied to existing restoration activities and will be applied to future releases. We also expect that the knowledge gained from the environmental flows to the delta will be of use to restoration in other arid regions across the world.

Highlights from monitoring efforts include (Kendy et al., 2017):

- The pulse flow inundated approximately 1600 ha (4000 acres) of the floodplain and the river reached the Gulf of California for the first time since 1998 (Nelson et al., 2017).
- Surface water flow rates and volumes decreased downstream as a result of high rates of infiltration (Rodriquez et al., 2017). Ninety-four percent of the 130 Mm^3 release recharged soil water and groundwater.
- The groundwater table rose as much as 9 m locally, with effects deceasing away from the channel. Water-table elevations returned to pre-pulse-flow levels within 6 months (Ramirez-Hernandez et al., 2017).
- Pulse flow discharge was not sufficient to widen the channel or to scour or bury significant amounts of existing vegetation (Mueller et al., 2017; Shafroth et al., 2017). Minor bank erosion and channel bed scour and fill on the order of 1 m or less was limited to the first 50 km downstream of Morelos Dam, which released the pulse flow into the delta.
- The regional system of irrigation canals successfully delivered a portion of the pulse flow water to downstream restoration sites, avoiding dry river reaches with high infiltration rates (Schlatter et al., 2017).
- Establishment of native riparian trees was most successful in actively managed restoration sites, where managers graded and connected abandoned meanders to the main river channel; mechanically cleared nonnative vegetation; and provided supplemental baseflow deliveries after the pulse flow; recruitment of new trees was less successful in other river reaches (Shafroth et al., 2017).
- The pulse flow caused a 16% increase, as measured with remote sensing, in vegetation greenness along the channel and floodplain compared to pre-pulse-flow greenness (Jarchow et al., 2017a,b)
- The abundance and diversity of birds in the riparian zone increased in the two years after the pulse flow (Darrah et al., 2017). Diversity and abundance are greater in the managed restoration sites than in the rest of the riparian zone.
- The small amount of the pulse flow water that reached the Gulf of California had limited detectable effects on the hydrology and biology of the estuary (Daessle et al., 2017), but research of previous, larger floods showed a positive correlation between river flows and fisheries catch (Duval and Colby, 2017) and a shift in the composition of the bivalve community (Dietl et al., 2017).
- Surveys, interviews and media coverage document that the social response to the pulse flow was exceptionally positive (Kendy et al., 2017).

5. What do we still need to learn?

Have we learned everything that we need to know? Of course not. Many questions remain regarding water management and deliveries, regional groundwater dynamics, future restoration priorities, and social and economic benefits of flow deliveries and restoration in dryland river systems. The situation is similar to that in the Grand Canyon following several years of managed floods; none of the floods produced unambiguous results in terms of management prescriptions, but they presented surprise resource responses relative to ecosystem models, and the opportunity to develop more focused river management options (Melis et al., 2015, 2016).

In terms of remaining questions on water management and deliveries in the delta, a missing piece of the puzzle is the impact of deliveries on groundwater and restoration success. Additionally, questions remain regarding the capacity of irrigation canals and the Hardy River (a tributary to the Colorado River in the delta) to effectively deliver water to restoration sites at critical periods for vegetation and wildlife.

Regional groundwater dynamics exert important yet poorly understood influence on restoration longevity. As is the case for many riparian systems in arid regions, much of the vegetation within the delta is dependent on relatively shallow groundwater tables for survival. However, intensive groundwater pumping in the border region and lack of surface flows have altered regional groundwater pathways and surface-groundwater relationships, degrading groundwater-dependent ecosystems along the delta's riparian corridor, including restoration sites. Reversing this trend requires understanding the shifting regional water balance, which in turn requires quantifying the timing and volume of groundwater inflows along the border region and outflows to the Gulf of California. Additionally, relatively little research has been conducted to assess how groundwater dynamics (and vegetation health) are impacted by agricultural return flows near the riparian corridor, both in terms of water availability and salinity. Understanding this dynamic hydrological system is crucial for both riparian corridor restoration and improved management of groundwater resources. Doing so will be enhanced by cooperation between Mexican and United States agencies responsible for groundwater monitoring and scientists and restoration specialists.

There is still much to be learned about how to achieve successful restoration through the delivery of environmental flows. Because water for the environment is in such short supply, learning how to use it efficiently is a central goal. The results of the pulse flow described in this special issue don't provide all the guidance needed for future restoration efforts. Furthermore, restoration takes time. Patches of new vegetation take many years to grow large enough to attract and sustain wildlife. A single pulse flow and four years of base flows are insufficient for long-term restoration. To understand the long-term effects of restoration efforts can require monitoring water deliveries, groundwater, water quality, vegetation and wildlife for decades. Continuous adaptive management and scientific monitoring are essential.

The Minute 319 flow deliveries largely focused on providing benefits to the riparian corridor in the Delta. However, downstream of the riparian zone lies the estuary, where the river meets the sea, stimulating marine productivity and providing nursery grounds for shrimp and fish. What would it take to bring a small portion of the estuary back to life? Can the river's water be directed to the estuary in an efficient manner? How can the success of estuarine restoration be measured?

Finally, social and economic benefits of flow deliveries and restoration require further investigation and attention. How are people using the restoration sites? Are they a source of pride? How many jobs are created by restoration activities? What is the economic benefit of riparian restoration? Understanding the answers to these questions would further demonstrate benefits of flows and restoration and could inform future United States-Mexico collaboration.

6. What happens next?

Minute 319, the existing binational framework for restoration in the Colorado River Delta, sunsets at the end of 2017. At the time of this writing, it is unknown whether the United States and Mexico will adopt an extension to the Minute. The states in the U.S. that share the Colorado River have articulated their support for such an extension (Buschatzke et al., 2017), and the benefits of the existing binational framework have been lauded by many (Castle et al., 2016). In addition to the demonstration of ecological restoration discussed in this volume, benefits of Minute 319 include a flexible approach to sharing water in times of limited supply and times of abundant supply, incentives for Mexico to store water in severely depleted United States reservoirs, and binational investments in water conservation. With Colorado River reservoirs filled only to 50% of capacity, and the prospects of extended and historically unprecedented droughts in a climate warmed world (Udall and Overpeck, 2017), a new Minute may be more important than ever.

The contribution of the federal governments, in terms of water, science, and resources to support the non-federal restoration and scientific activities has been monumentally important. Moreover, the formal, federal partnership, both between the two countries, and between the federal agencies and the non-federal partners, created an atmosphere of mutual support in which many institutions and individuals stretched to provide as much as they could to ensure the success of the restoration efforts. If the federal partnership ends, it is hard to forecast what the future delta restoration efforts will look like. However, it is also evident that restoration in the delta is possible without the federal governments, albeit at a much reduced scale. The NGO collaborative working in the delta formed Raise the River (http://raisetheriver.org), a campaign to bring private dollars to support restoration in the Colorado River Delta.

Finally, as this special journal issue documents, the restoration partnership invested in an effort to understand how water deliveries into the Colorado River Delta influence its hydrology and ecology. Future deliveries of water for the environment into the Colorado River Delta, whether with or without federal partnership, will look different because of what we have learned. It will remain important to invest in science to monitor those future water deliveries and their effects. Anticipating improved, but increasingly complex operations to deliver water for the environment to the Colorado River Delta, we look forward to closer collaboration among water managers, scientists and restoration specialists, and among restoration specialists working in different sites.

Without water, restoration efforts in the Colorado River Delta will not succeed, but as the articles in this volume demonstrate, water alone will not suffice. Water, collaboration, active management, and science are all necessary. Water in the Colorado River Basin is scarce, and will likely become scarcer with time (Udall and Overpeck, 2017). Scientific monitoring of future environmental flows and associated restoration activities in the Colorado River Delta will give us the information we need to optimize the ecological and social benefits we can create with water, a most precious resource.

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