An aerial photograph of the Colorado River Delta, showing a winding river through a vast, arid landscape. The river is a deep blue, contrasting with the light brown and tan colors of the dry earth. In the foreground, a large, dark brown, stylized tree trunk and its branches are superimposed over the image, extending from the bottom left towards the center. The background shows distant mountains under a clear blue sky.

# **Minute 319 Colorado River Delta Environmental Flows Monitoring**

**Initial Progress Report**

**December 4, 2014**

## Authority

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This report and study was carried out by the United States and Mexico in accordance with Section III.6-Water for the Environment and ICMA/ICS Exchange Pilot Program under Minute 319 of the International Boundary and Water Commission, United States and Mexico entitled “Interim International Cooperative Measures in the Colorado River basin through 2017 and Extension of Minute 318 Cooperative Measures to address the continued effects of the April 2010 earthquake in the Mexicali Valley, Baja California”, dated November 20, 2012. This interim report was prepared as a step in furtherance of Minute No. 319 Art. III.6.f, and includes information on the environmental results achieved by the delivery of water pursuant to the pilot program.

### Participating Agencies

International Boundary and Water Commission  
United States and Mexico

#### For the United States:

Environmental Defense Fund  
Sonoran Institute  
The Colorado River Basin States  
The Nature Conservancy  
University of Arizona  
U.S. Department of the Interior, Bureau of Reclamation  
U.S. Geological Survey

#### For Mexico:

El Colegio de la Frontera Norte  
Comisión Nacional de Áreas Naturales Protegidas  
Comisión Nacional del Agua  
Pronatura Noroeste  
Universidad Autónoma de Baja California

## Acknowledgements

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This report was prepared for the International Boundary and Water Commission by Dr. Karl Flessa (University of Arizona), Dr. Eloise Kendy (The Nature Conservancy) and Karen Schlatter (Sonoran Institute) on behalf of all the people and organizations engaged in monitoring in the Colorado River Delta under Minute 319.

These efforts represent a collaborative effort of many entities who directly and indirectly participated in all phases of this study promoting a binational partnership among federal agencies, universities, and non-governmental organizations.

\*Cover photo credit, Colorado River connecting to the delta- Francisco Zamora with support from LightHawk

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# 1.0 INTRODUCTION AND EXECUTIVE SUMMARY

## 1.1 INTRODUCTION

Minute No. 319 (Minute 319), Interim International Cooperative Measures in the Colorado River Basin Through 2017 and Extension of Minute 318 Cooperative Measures to Address the Continued Effects of the April 2010 Earthquake in the Mexicali Valley, Baja California, was signed by the two Sections of the International Boundary and Water Commission (IBWC) on November 20, 2012. A component of Minute 319 is Section III.6, Water for the Environment and ICMA/ICS Exchange Pilot Program (ICMA – Intentionally Created Mexican Allocation; ICS – Intentionally Created Surplus), which outlines that the “pilot program will arrange for the means to create 158,088 acre-feet (195 mcm) of water for base flow and pulse flow for the Colorado River Limitrophe and its delta by means of the participation of the United States, Mexico, and non-governmental organizations.” “Implementation of this Minute will provide a mechanism to deliver both base flow and pulse flow” ... “tentatively during 2014 but no later than 2016.” “[T]he information developed through implementation of this Minute will be used to inform future decisions regarding binational cooperative efforts to address proactive actions in the Colorado River Delta.” “To provide for the delivery of the base flow and pulse flow for environmental purposes under this Minute, the Commissioners [of both Sections of the IBWC] will direct the Consultative Council and the Environmental Work Group to prepare a Delivery Plan, which will include a schedule of monthly flows, delivery points and volumes in an amount of approximately 105,392 acre-feet (130 mcm) for pulse flow and 52,696 acre-feet (65 mcm) for base flow.” A portion of the funds provided in Section III.6.d by the United States will provide funding for projects in Mexico which will generate 50% of this pulse flow. The sources of water to implement this flow shall be from ICMA created or water deferred by Mexico under Section III.1. The Consultative Council and Environmental Work Group formed and tasked a binational Environmental Flows Team (Table 1) to develop the Delivery Plan (membership included representatives of U.S. and Mexican Federal and State agencies and non-governmental organizations).

As part of the pilot program, Minute 319 required that “resources for a joint investigation of the different aspects of the pilot program should be obtained. The resources for this investigation should be provided by the United States and Mexico.” Environmental flows were one of the items to be investigated through an evaluation of the “the ecosystem response, most importantly the hydrological response, and secondarily, the biological response.” To achieve this goal, the binational Environmental Flows Team worked with scientists and experts to develop plans for ecosystem response monitoring. Ecosystem monitoring was conducted before, during, and after the March 23 to May 18, 2014 pulse flow. Monitoring activities were conducted in the riparian corridor of the Colorado River Delta (Fig. 1) by binational teams (Table 2) and these activities will continue through 2017. This Initial Progress Report summarizes activities and preliminary results through July 24, 2014. Additional reporting will follow with the preparation of an Interim Report by December 2016 and a Final Report by June 2018.

## 1.2 EXECUTIVE SUMMARY

As provided in Minute 319 of the U.S.-Mexico Water Treaty of 1944, a pulse flow of approximately 130 million cubic meters (105,392 acre-feet) was released to the riparian corridor of the Colorado River Delta from Morelos Dam at the U.S.-Mexico border. The water was delivered over an eight-week period

that began on March 23, 2014 and ended on May 18, 2014. Peak flows were released early in this period to simulate a spring flood. Some pulse flow water was released to the riparian corridor via Mexicali Valley irrigation canals.

Base flow volumes totaling 65 mcm (52,696 acre-feet) are also being delivered to new and pre-existing restoration areas during the term of Minute 319 through December 31, 2017. One hundred and twenty-nine hectares (320 acres) of non-native vegetation in the Laguna Grande area were cleared and graded to promote regeneration of native vegetation. Portions of the site were hydro-seeded with native vegetation and 38 hectares (94 acres) of the site were planted with native trees. In the Miguel Aleman restoration site, 35 hectares (86 acres) were cleared and graded and of these, 10 hectares (25 acres) were planted with native trees.

The monitoring program established by Minute 319 assembled baseline information on the hydrology and biology of the riparian corridor and deployed binational, multi-agency teams of scientists during and after the pulse flow. Results of these efforts through July 24, 2014 are reported in this interim report.

Ground-based and remotely-sensed data were collected to evaluate the ecosystem response to the pulse flow.

Surface water from the pulse flow rapidly infiltrated into the sandy subsurface in the first 60 km (37 miles) downstream of Morelos Dam. Scour and deposition modified the channel bed topography, but bank erosion of the existing channel was minor. Smaller volumes inundated the river channel farther downstream, including areas that had been prepared for restoration of native vegetation. Pulse flow surface water reached the Gulf of California on May 15, 2014.

The water table rose in response to the pulse flow. Groundwater effects dampened with increasing distance from the active channel. The initial slow groundwater-level rise in dry sediment was followed by more rapid changes in groundwater levels as the sediment saturated. The water table then declined at varying rates after its peak.

Seeds of both native and non-native vegetation dispersed during the pulse flow release and recession. Both native and non-native vegetation germinated in response to the pulse flow. Seedlings of native species were present primarily in Reaches 1 and 4 (Figure 1). Preliminary remote-sensing data and aerial observations suggest that greenness has increased, compared to prior years, since the pulse flow.

As expected, surveys of resident birds, in the short time since the pulse flow, showed little change over previous years. Populations of migratory birds are affected by many factors in addition to changes in the delta's riparian habitats.

Future work includes additional analyses of hydrologic and biological data collected during and immediately after the pulse flow, periodic ground-based and remotely-sensed monitoring of new and pre-existing vegetation, monitoring of ground water behavior in restoration sites, comparison of pre- and post-pulse flow Lidar data on topography and vegetation cover, and monitoring of bird life. Future reports are scheduled for December 2016 and June 2018.

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**Table 1.** Representatives of the binational Minute 319 Environmental Flows Team

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Karen Schlatter, Sonoran Institute  
Pat Shafroth, U. S. Geological Survey  
Eduardo Soto, Comisión Nacional de Áreas Naturales Protegidas

River Corridor Team for the Lower Delta

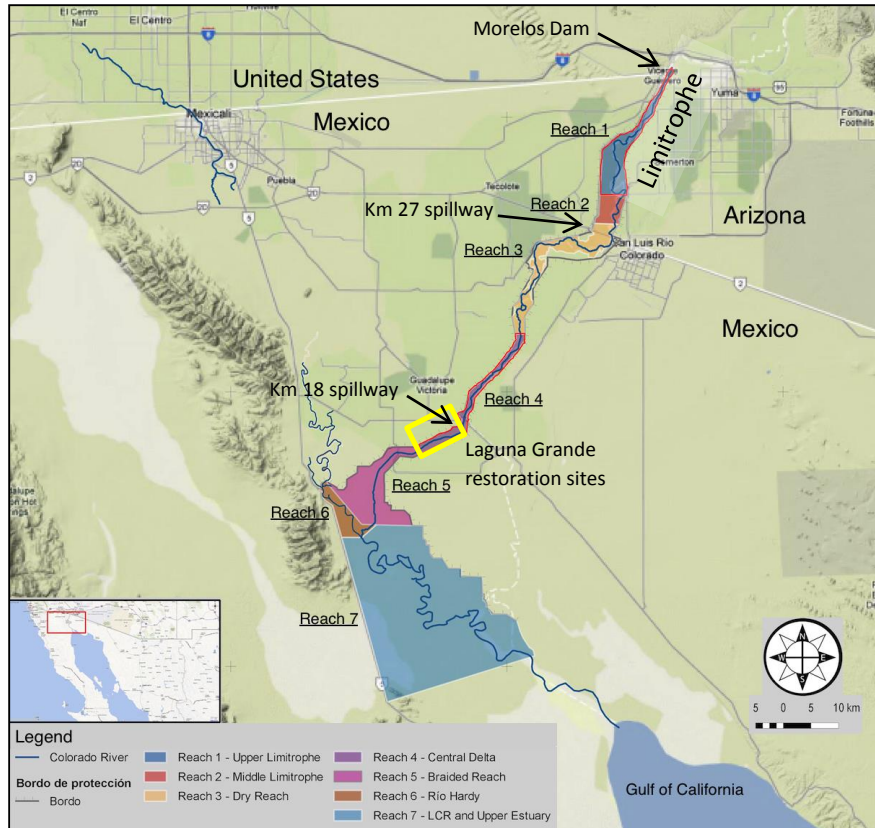
Karen Schlatter, Sonoran Institute  
Francisco Zamora-Arroyo, Sonoran Institute

Remote-Sensing Team

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Pamela Nagler, U.S. Geological Survey  
Steve Nelson, Independent scientist  
Jeff Milliken, Bureau of Reclamation  
Francisco Zamora-Arroyo, Sonoran Institute

**Table 2.** Representatives of binational teams responsible for monitoring the ecosystem response of the pulse flow and base flow.





**Figure 1.** Colorado River Delta study reaches for Minute 319 monitoring activities.

## 2.0 SUMMARY OF MONITORING METHODOLOGY

The following list describes the general monitoring activities that have been conducted before, during, and after the pulse flow.

- Baseline (pre-pulse flow) conditions from published reports and from field observations were summarized.
- Surface-water discharge, groundwater behavior, and water salinity were measured during the pulse flow. Geophysical techniques were used in the Limitrophe section of the study area (i.e., Reach 1 and 2) to further understand the immediate groundwater response to the pulse flow.
- Post-pulse flow groundwater monitoring is on-going.
- Pulse flow arrival times were tracked on the ground using direct observations and temperature sensors.
- Scour chains, topographic surveys, grain-size analyses, and suspended sediment samples were used to estimate erosion and deposition.
- The areal extent of inundation was documented as the flow progressed, using direct observations and aerial and satellite (Landsat, WorldView) images.
- Light Detection and Ranging data were acquired before and after the pulse flow to document topographic changes resulting from the pulse flow and to help map the distribution, composition, and structure of vegetation.

- Topography was surveyed along 21 transects perpendicular to the channel in order to relate the germination, growth, and survival of new vegetation to changes in channel and floodplain topography.
- Germination of native and non-native vegetation was surveyed along 21 transects co-located with topographic survey transects and groundwater monitoring sites. The influx of seeds, changes in soil salinity and texture, and vegetation cover along the 21 transects were monitored before and during the pulse flow.
- One hundred and twenty-nine hectares (320 acres) of non-native vegetation in the Laguna Grande area were cleared and graded to promote regeneration of native vegetation. Portions of the site were hydro-seeded with native vegetation and 38 hectares (94 acres) of the site were planted with native trees. Detailed surveys of new vegetation, groundwater conditions, soil conditions, and bird populations were conducted.
- In the Miguel Aleman restoration site, 35 hectares (86 acres) were cleared and graded and of these, 10 hectares (25 acres) site were planted with native trees.
- Vegetation health (“greenness”) assessments that began in 2000 using satellite-based remote-sensing data are on-going.
- Photographic images at fixed locations within the riparian corridor shortly before and during the pulse flow were assembled. Repeat photography continues to be collected.
- Baseline vegetation and riparian bird surveys (begun in 2002) and marsh bird surveys (begun in 2004) were expanded to include additional areas in the Limitrophe, restoration sites and elsewhere.
- Zooplankton and water quality continue to be monitored between the Gulf of California and the lowermost river reaches.

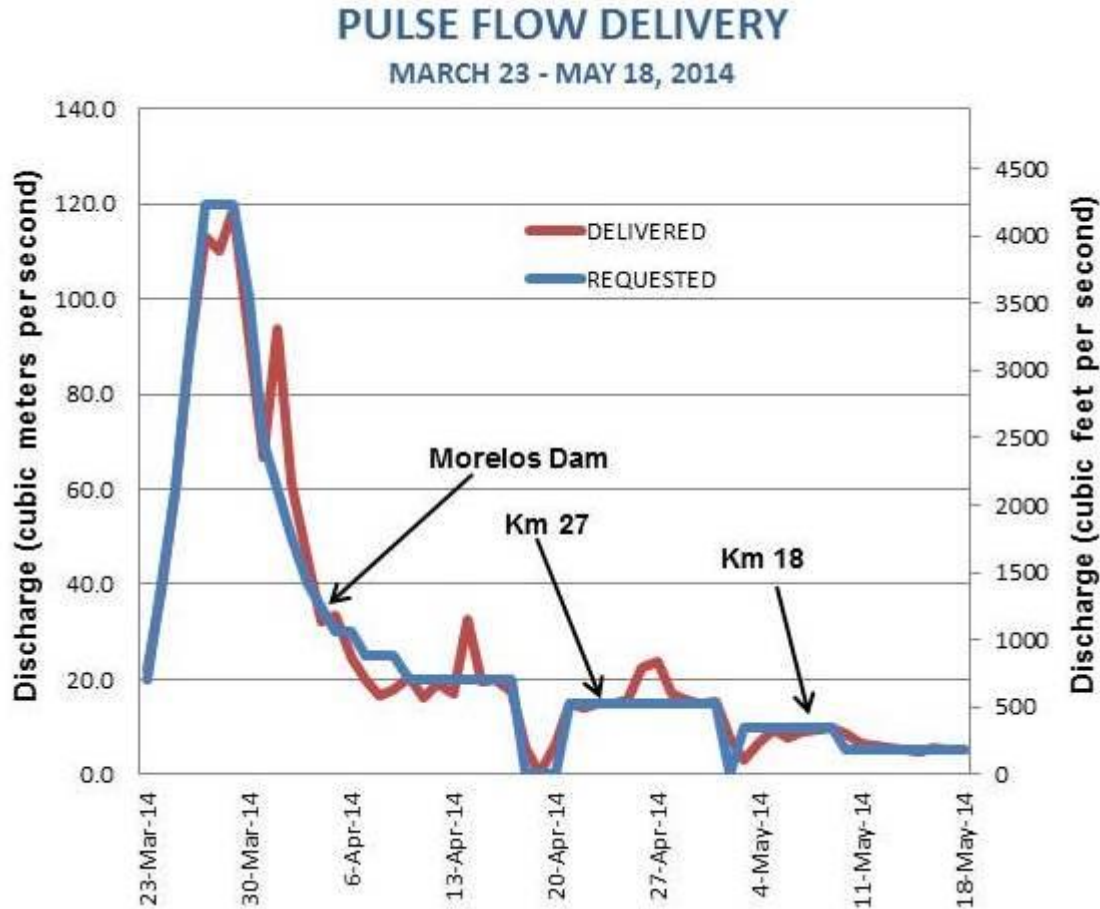
## 3.0 INITIAL RESULTS

### 3.1 PULSE FLOW AND BASE FLOW WATER DELIVERIES

The pulse flow delivered a total of 132<sup>1</sup> million cubic meters (mcm) (107,000 acre-feet [af]) to the riparian corridor of the Colorado River Delta, starting March 23 and ending on May 18, 2014. Water was delivered from Morelos Dam, and from the Km 27 spillway of Canal Reforma (river km 37; river mile 23) and the Km 18 spillway of Canal Barrote (river km 79; river mile 49) (Fig. 1 and Fig. 2).

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<sup>11</sup> 130 mcm were delivered as the pulse flow delivery, and an additional 2 mcm were delivered as operational surplus.



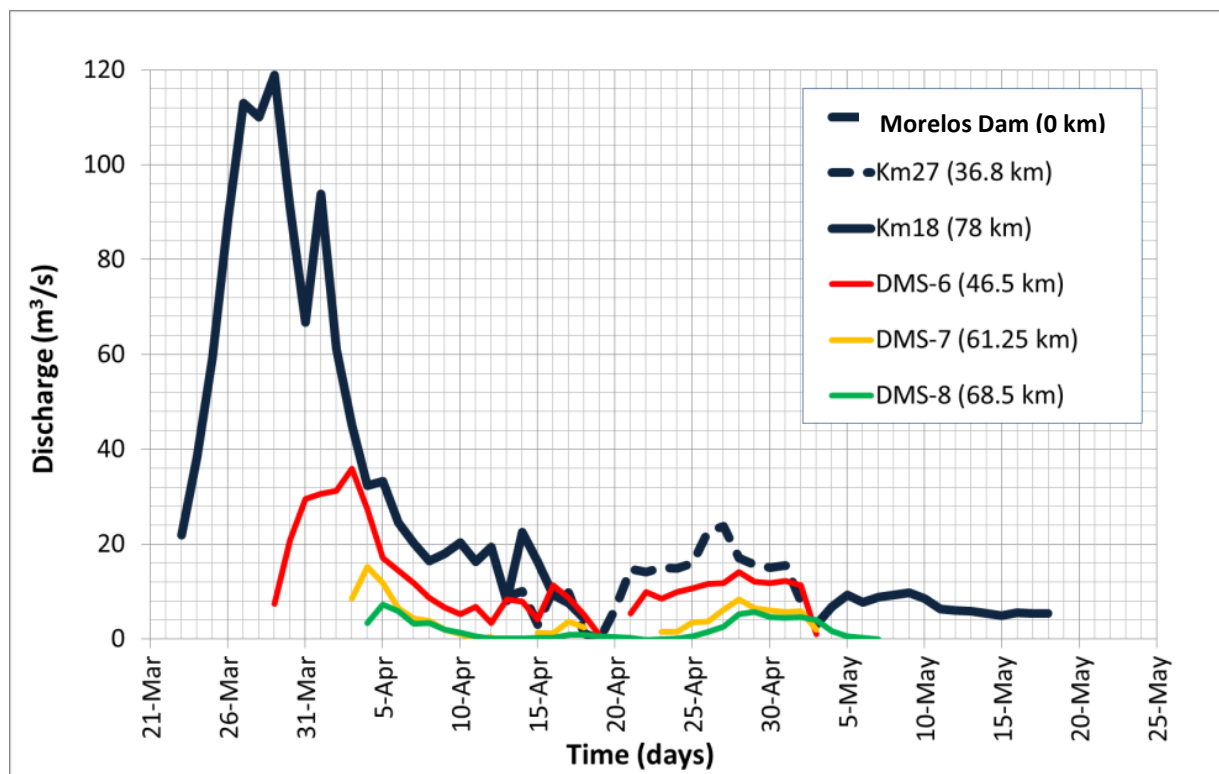
**Figure 2.** Delivered and requested pulse flow water deliveries to the study area. Scheduled Morelos Dam deliveries began on March 23 and ended on April 17; deliveries from the Km 27 spillway of Canal Reforma (at river km 37; river mile 23) began on April 13 and ended on May 1; deliveries from the Km 18 spillway of Canal Barrote (at river km 79; river mile 49) began on May 3 and ended on May 18, 2014. Source: Mexican Section of IBWC.

Since November 20, 2012, the Colorado River Delta Water Trust has delivered base flows to the Laguna Grande and Miguel Aleman restoration sites. Base flows to support habitat restoration are scheduled to continue through 2017 and official accounts of past base flow deliveries are not available at this time.

### 3.2 SURFACE WATER

Published records, satellite images and direct observations indicate that surface water from the Colorado River had not reached the sea since at least 2000.

Streamflow decreased rapidly with increasing distance downstream (Fig. 3). The pulse flow's surface water front advanced at highly variable rates (Fig. 4; from about 1 to 20 km per day or 0.5 to 13 miles per day), advancing faster when the channel surface was wet than when it was dry. The pulse flow reached the Laguna Grande restoration sites in Reach 4 on April 5-6. Pulse flow releases from the Km 18 spillway, which began on May 3, enabled the water front to resume its downstream flow; pulse flow water connected with tidal water from the Gulf of California in the afternoon of May 15, 2014 (Fig. 5).



**Figure 3.** Variation in discharge through time at three discharge measuring stations (DMS 6, 7 and 8 – colored lines) in Reach 3 and discharges at Morelos Dam (Presa Morelos) and at the Km 27 and Km 18 spillways (black lines). Note the delay in the time of peak flows, and the reduced discharges at the measuring stations relative to the Morelos Dam and Km 27 spillway. Km 18 releases occurred downstream of DMS 8 and had no effect on the discharges measured upstream. Scale conversion: 100 m<sup>3</sup>/s (cubic meters per second) is approximately 3,500 ft<sup>3</sup>/sec (cfs). Distance information (in parenthesis) indicates distance of measuring stations from Morelos Dam, in kilometers.

Surface flows were slowed or impeded by vegetation in the channels, diverted into former meanders, or ponded behind road crossings or informal, locally constructed dams. Less than one percent of the total pulse flow release mixed with tidal waters from the Gulf of California for this operational release strategy (Fig. 6). Surface flow from the pulse stopped about May 24, 2014. Surface flows inundated approximately 1,830 hectares (ha) (4,522 acres) of channel and floodplain. Approximately 50 ha (120 acres) of the 109 ha (270 acres) of the prepared areas in the Laguna Grande restoration area were flooded.

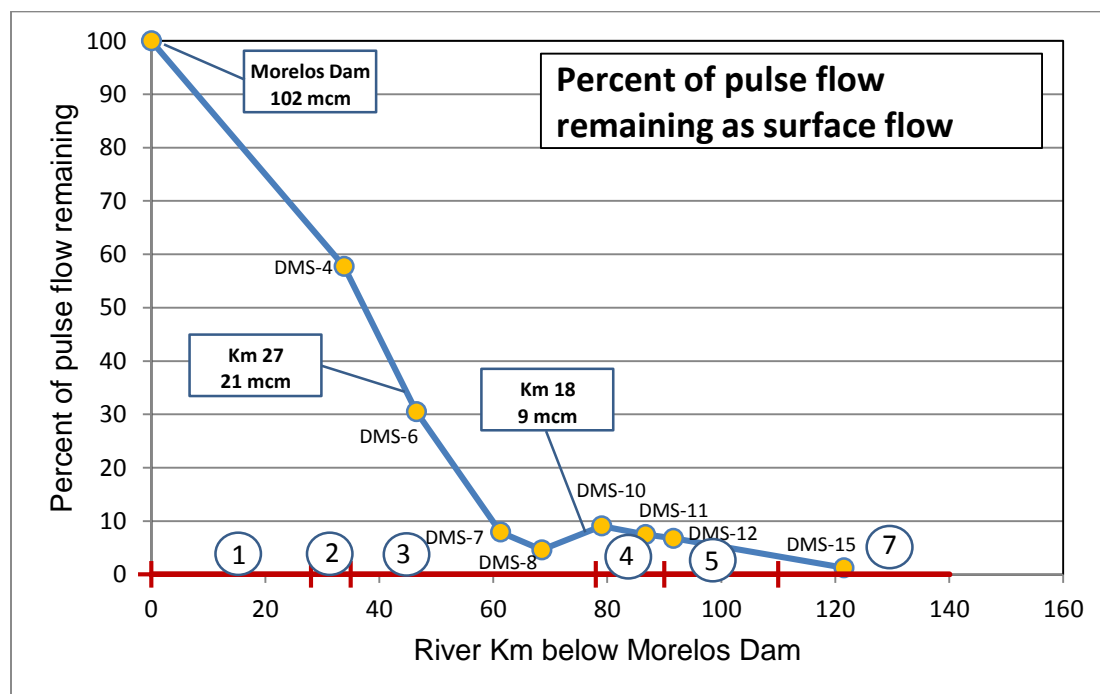




**Figure 4.** Progress of surface pulse flow water. Source: U.S. Department of the Interior, Bureau of Reclamation.



**Figure 5.** View looking north, from tidal waters of the Gulf of California (lower) to approaching Colorado River pulse flow (upper). **A.** Tidal channel (lower) and Colorado River (upper) May 13, 2014. **B.** Flooded area at high tide (lower, muddy water) connected with pulse flow of Colorado River (upper, blue water). May 15, 2014. Both images by Francisco Zamora, Sonoran Institute, with aerial support from LightHawk.



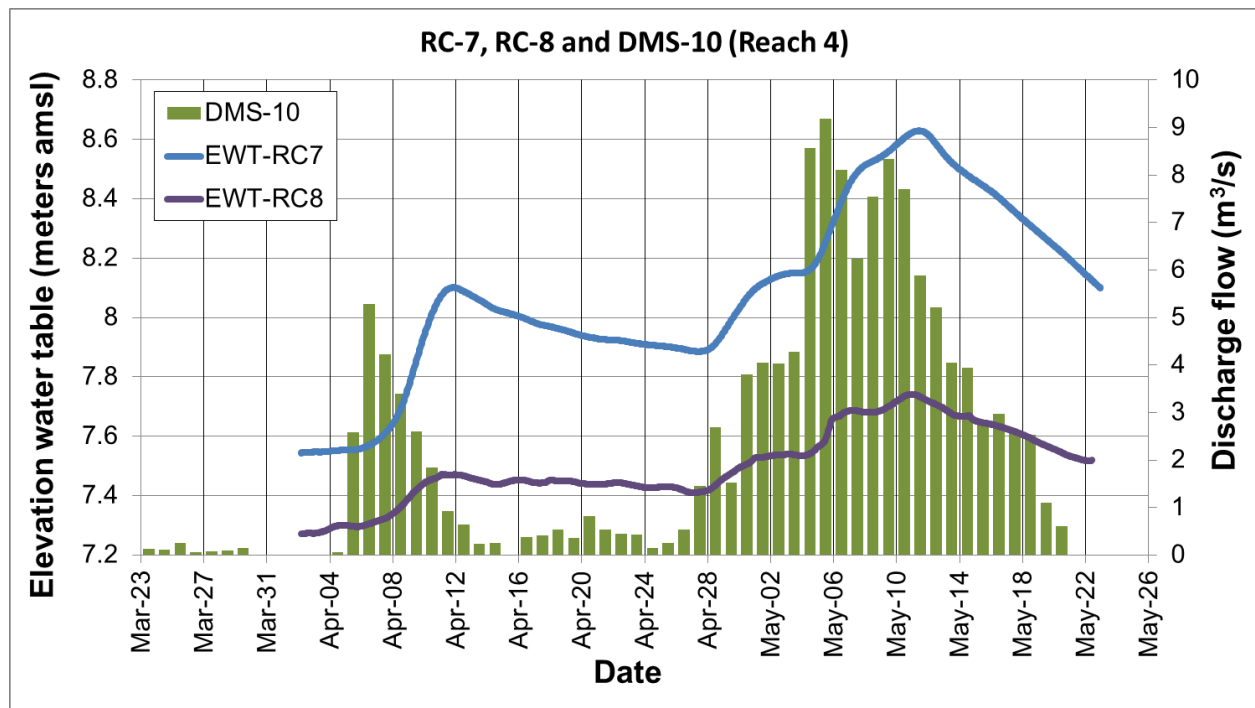
**Figure 6.** Percentage of total pulse flow remaining as surface flow with increasing distance (as river km) downstream from Morelos Dam. Morelos Dam released 102 million cubic meters (mcm) = 83,000 acre-feet (af); Km 27 spillway released 21 mcm = 17,000 af; Km 18 spillway released 9 mcm = 7,000 af. DMS numbers refer to discharge measuring stations. Circled numbers between red tick marks indicate river reaches. Distance scale: 60 river km = 37 miles; 100 km = 62 miles.

### 3.3 GROUNDWATER

Information on baseline groundwater conditions from published studies showed that the pre-pulse water table was at or near the surface in Reach 1, decreased sharply in Reaches 2 and 3, was close to the surface in Reach 4, and decreased again until the confluence with the Hardy River.

Most of the pulse flow's water infiltrated to groundwater, transpired from plants, evaporated from soil and water surfaces, or was retained in soil and topographic depressions. A significant portion of the pulse flow water infiltrated into the aquifer beneath Reaches 1, 2 and 3. More than 90 percent of the water released from Morelos Dam and Km 27 spillway did not flow farther than river km 60 (river mile 37), 26 km (16 mi) downstream of the Southerly International Boundary (Fig. 6).

The water table in all reaches rose in response to the pulse flow. Aquifer response to the pulse flow varied along the river, across transects, and with time. Generally, groundwater behavior mimicked surface-water fluctuations. Groundwater effects dampened with increasing distance from the active channel. The initial slow groundwater-level rise in dry sediment was followed by more rapid changes in groundwater levels as the sediment saturated. The water table then declined at varying rates after its peak (Fig 7). Quantitative models are being developed to describe and predict infiltration behavior of surface water under various conditions.



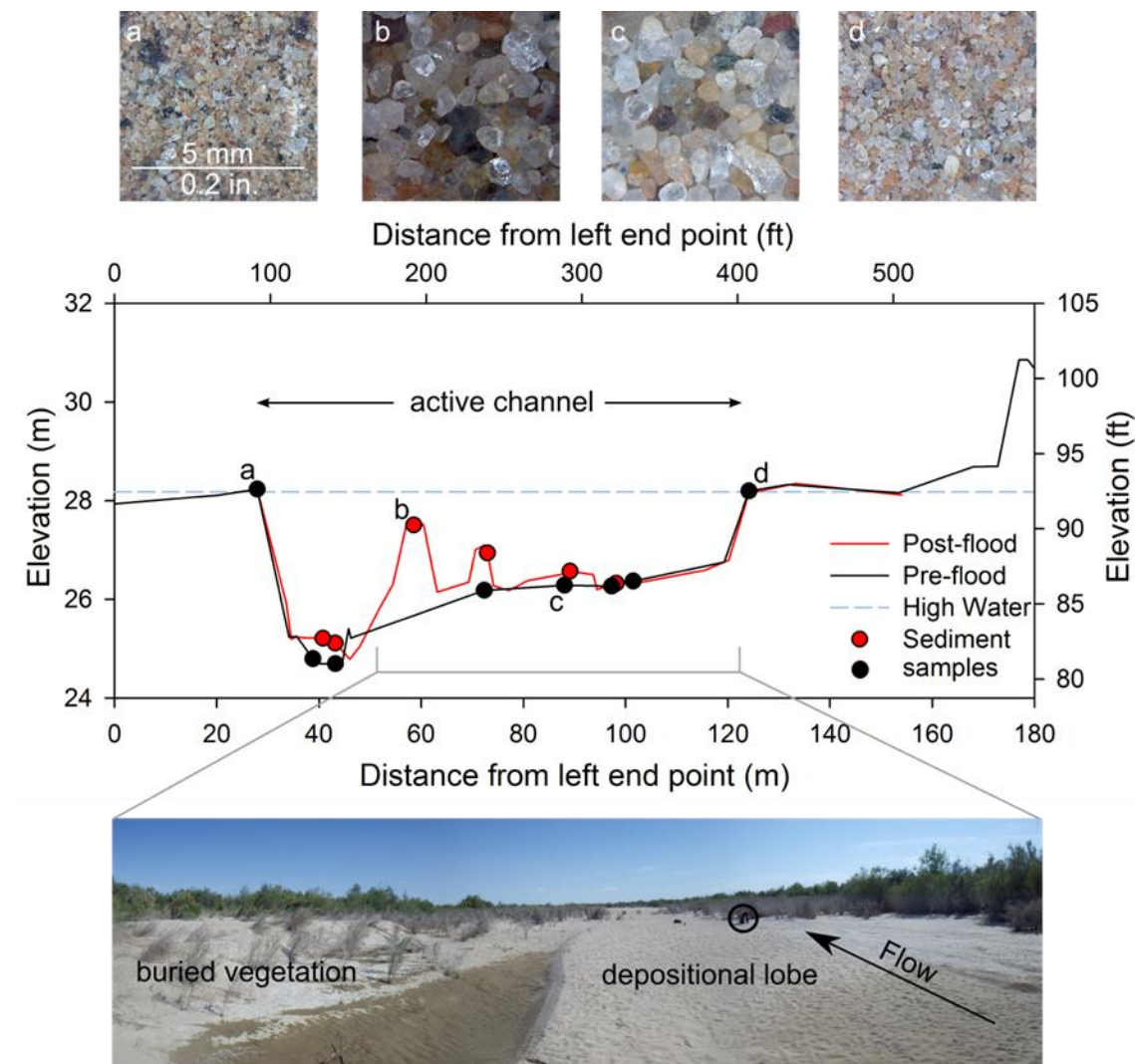
**Figure 7.** Example of groundwater response to pulse flow in Reach 4. Green bars show surface discharge at DMS 10 through time. Solid lines show elevation of water table (EWT) above mean sea level at two locations downstream (RC-7, RC-8) of DMS 10. English equivalents: 8.8 m = 29 ft; 10 cms = 353 cfs.



### 3.4 GEOMORPHOLOGY

Baseline assessments of riparian geomorphology are based on high-resolution pre-pulse topographic surveys along 36 cross-channel transects, and pre-pulse airborne Lidar surveys.

Channel and floodplain sediments are predominantly sand. In places, the pulse flow scoured sediment to depths of approximately one meter (3.3 ft), and deposited about two meters (6.6 ft) of sediment farther downstream. Scour and deposition modified the channel bed topography (Fig. 8), but bank erosion of the existing channel was minor. Models are being developed of sediment movement under different flow regimes in order to understand and predict geomorphic changes resulting from river flows.



**Figure 8.** Example of channel change at USGS cross section 12 in the Limitrophe reach (32° 34' 20" N; 114° 48' 36" W [NAD83]). (Top) Microscope camera ("sandcam") images of sediment at different locations across the channel as indicated in the middle panel. (Middle) Pre- and post-flood surveys showing net aggradation at this cross-section. Black and red dots show the location of pre- and post-flow sediment samples, respectively. Vertical axes show elevation above mean sea-level (NAVD88). (Bottom) Image looking downstream at the cross-section; a person is circled for scale at the location of the cross-section.



### 3.5 VEGETATION

Baseline information on the distribution of vegetation and presence of seedlings is based on the published literature, ongoing surveys by Pronatura Noroeste, and 21 pre-pulse seedling surveys.

Seeds of both native and non-native vegetation dispersed during the pulse flow release and recession. Both native and non-native vegetation germinated in response to the pulse flow (Fig 9). Seedlings of native species were present primarily in Reaches 1 and 4.

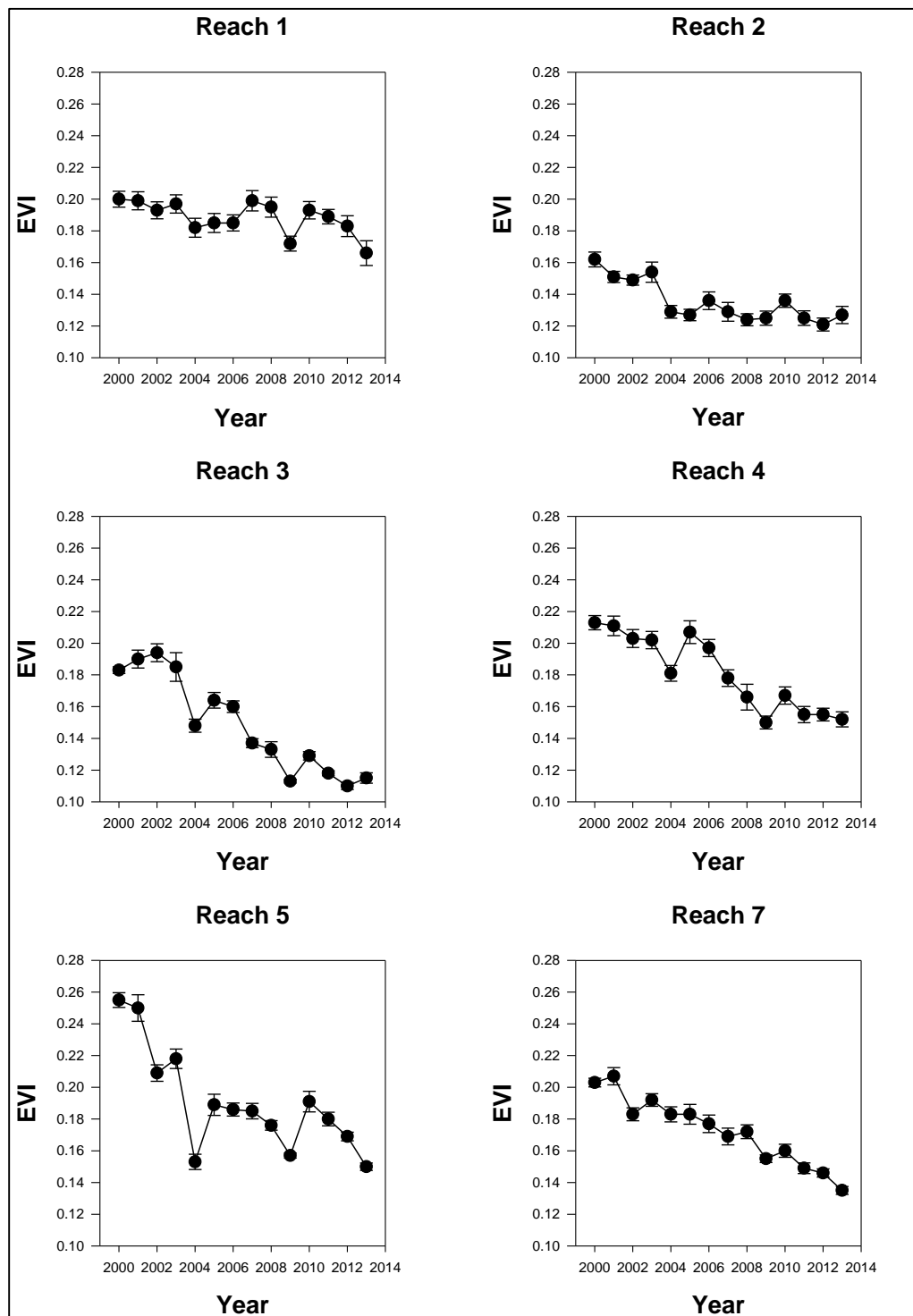


**Figure 9.** Cottonwood (left) and willow (right) seedlings in the Laguna Grande restoration site on May 17, 2014, approximately 1.5 months following the arrival of the pulse flow to the site. Seedlings are approximately 4-5cm (1.8 inches) in height.

Seedlings of non-natives, principally *Tamarix* spp. (saltcedar), were common in all reaches. The survival of native and non-native seedlings through the first summer after the pulse flow was assessed in October 2014.

Growth and survival of native and non-native seedlings will mostly depend on soil moisture derived from groundwater. Green vegetation, as measured by the MODIS satellite sensor, decreased steadily in all river reaches from 2000 through April 9, 2014 (Fig. 10), indicating increased plant water stress. Preliminary remote-sensing data (June 2014) and aerial observations suggest that greenness has increased since the pulse flow. Landsat 8 imagery over all river reaches showed a 36% increase in NDVI (Normalized Difference Vegetation Index - a measure of greenness) in June, 2014 compared to June, 2013. NDVI increased in all reaches except Reach 4, where vegetation had been cleared prior to the flow

event to promote flooding and germination, and Reach 6, which drains the Rio Hardy and is above the confluence with the Colorado River. A marked greening occurred in Reach 7 at the end of the pilot canal where water from the pulse spilled onto the floodplain.



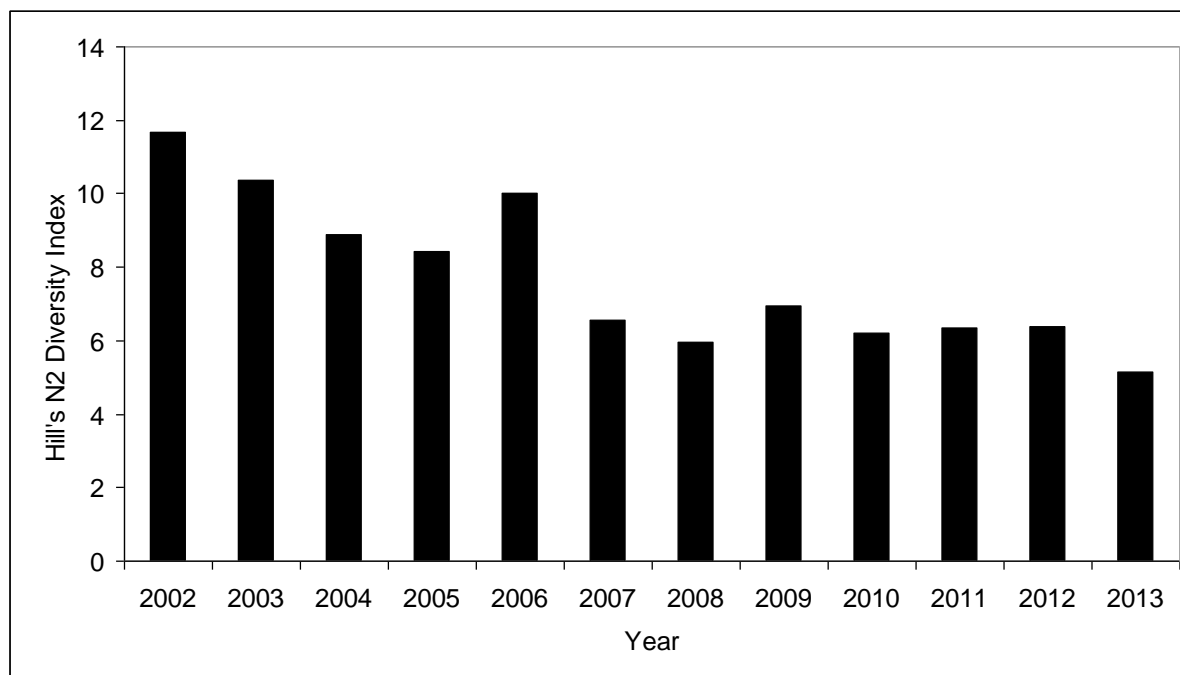
**Figure 10.** Decrease in the Enhanced Vegetation Index (EVI) from MODIS imagery in Colorado River Delta river reaches, 2000- April 9, 2014. Annual means are based on 23 16-day composite collections at 5 sites per reach.

Error bars are standard errors of means. Across reaches, EVI decreased by 31%, which corresponds to a 59% decrease in green foliage density after subtracting out the value for bare soil (about 0.1).

### 3.6 BIRDS

Baseline (pre-pulse) information about birds has been assembled from the published literature and ongoing surveys of birds conducted by Pronatura Noroeste since 2002.

Average abundance of birds in the riparian corridor has increased from 2002 to 2013, but species diversity has decreased (Fig. 11) and composition has changed. The abundance of riparian-dependent land birds and breeding water birds has declined, while the abundance of birds related to agricultural and urban development, exotic birds, and raptors has increased. Spring 2014 surveys were conducted during the pulse flow; winter 2014 surveys were conducted in January 2014 before the pulse; summer 2014 surveys were conducted after the pulse. No changes were observed in the spring 2014 surveys in the riparian zone relative to the previous spring. Preliminary analyses suggest an increased presence of migratory birds along open water areas but the abundance of migratory birds is controlled by many factors in addition to changes in this local habitat. Bird abundance and species richness were higher in the active restoration sites than throughout the rest of the floodplain. Bird populations are expected to change if existing and new vegetation responds to the pulse flow. Such changes should be evident from longer-term monitoring activities.



**Figure 11.** Average avian diversity (Hill's N2 Diversity Index) per point from 2002 to 2013 at 136 survey sites along the floodplain of the Colorado River in Mexico, between the Southerly International Boundary and the confluence of the Colorado with the Hardy River.

## 4.0 CONTINUING ACTIVITIES

The immediate, direct hydrological effects of the pulse flow will become evident as additional data are gathered and analyzed. The biological response to the pulse flow will take more time to develop, and will require additional monitoring, analysis, and synthesis. Existing vegetation response to the pulse flow and groundwater levels will be tracked, as will the survival and growth of new vegetation, the success of active restoration efforts, changes in bird populations, and changes in zooplankton.

Hydrology and biology are closely linked in this arid environment. A wealth of high-quality data continues to be collected to assess the ecosystem response of the pulse flow. Understanding hydrology and biology response in the riparian zone of the Colorado River Delta is essential to understanding the effects of the pulse flow of 2014.