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Groundwater response to the 2014 pulse flow in the Colorado River Delta

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ABSTRACT

During the March-May 2014 Colorado River Delta pulse flow, approximately 102 × 10^6 m^3 (82,000 acre-feet) of water was released into the channel at Morelos Dam, with additional releases further downstream. The majority of pulse flow water infiltrated and recharged the regional aquifer. Using groundwater-level and microgravity data we mapped the spatial and temporal distribution of changes in aquifer storage associated with pulse flow. Surface-water losses to infiltration were greatest around the Southerly International Boundary, where a lowered groundwater level owing to nearby pumping created increased storage potential as compared to other areas with shallower groundwater. Groundwater levels were elevated for several months after the pulse flow but had largely returned to pre-pulse levels by fall 2014. Elevated groundwater levels in the limitrophe (border) reach extended about 2 km to the east around the midway point between the Northerly and Southerly International Boundaries, and about 4 km to the east at the southern end. In the southern part of the delta, although total streamflow in the channel was less due to upstream infiltration, augmented deliveries through irrigation canals and possible irrigation return flows created sustained increases in groundwater levels during summer 2014. Results show that elevated groundwater levels and increases in groundwater storage were relatively short lived (confined to calendar year 2014), and that depressed water levels associated with groundwater pumping around San Luis, Arizona and San Luis Rio Colorado, Sonora cause large, unavoidable infiltration losses of in-channel water to groundwater in the vicinity.

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1. Introduction

Surface water and shallow groundwater are critical for irrigation and municipal and industrial supply in the Mexicali Valley in northwestern Mexico and Yuma Valley in the southwestern United States. Both surface water and groundwater depend on the Colorado River, which is delivered directly and also provides the major source of groundwater recharge in the region. Below Morelos Dam (Fig. 1), in the absence of storm flows, all of the water in the river (from leakage around Morelos Dam and irrigation return flow) infiltrates. The channel becomes dry about 14 km downstream from Morelos Dam, and remains dry until about km 70. Away from the river, infiltration and groundwater recharge occurs in the many unlined irrigation canals and drains, and beneath irrigated agricultural fields. In many places groundwater is pumped and delivered to irrigation canals for conveyance to agricultural fields. Surface water and groundwater in the delta are tightly coupled and additions or subtractions to one are rapidly observed in the other.

In March-April 2014 a “pulse flow” of water, as agreed upon in Minute 319 between the US and Mexico, released about 102 × 10^6 m^3 (82,000 acre-feet) of water into the normally-dry channel of the Colorado River below Morelos Dam, on the US–Mexico border (Fig. 1). The river follows the US-Mexico border for about 33 km below Morelos Dam, then flows an additional 100 km in Mexico to the Gulf of California. Additional surface water was delivered via irrigation canals, both during the pulse flow and over the remainder of 2014 and 2015. The majority of the pulse-flow water infiltrated, leading to groundwater-level rises throughout the river corridor. This paper reports on a collaborative effort between the U.S. Geological Survey and Universidad Autonoma de Baja California to monitor the effects of the pulse flow on groundwater in the Colorado River Delta. Groundwater levels were monitored across a network of shallow piezometers in the riparian corridor and in wells in the Yuma Valley. In addition, microgravity data were collected across a network of stations in the limitrophe reach of the Colorado River between the Northerly

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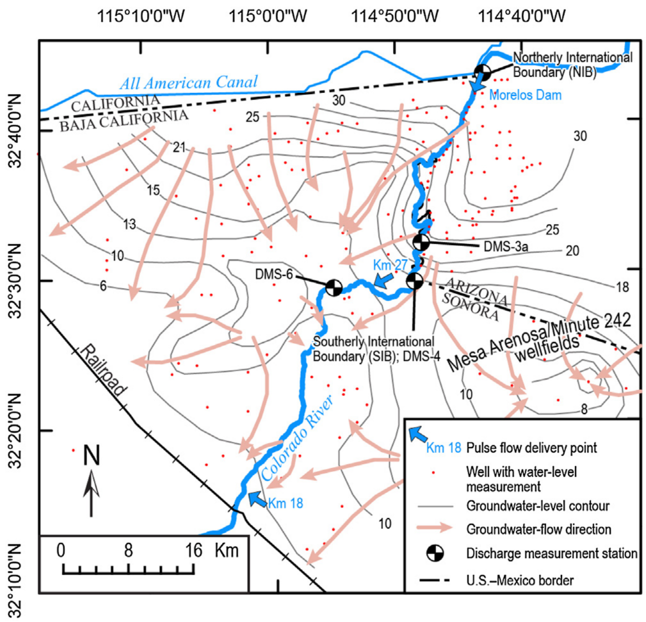

Fig. 1. Regional groundwater flow in the Mexicali and Yuma Valleys in 2006, the most recent year for which data are available in the Mexicali Valley. Data from Lesser (2006) and U.S. Bureau of Reclamation (2015).

and Southerly International Boundaries (NIB and SIB, respectively) to provide a direct measurement of aquifer-storage change.

The purpose of evaluating groundwater levels is two-fold. First, by adding water to the groundwater-flow system, the pulse flow affected discharge from the system, by elevating water levels in pumping wells, or by increasing or prolonging discharge to the river channel. The effect of any particular recharge event (such as the 2014 pulse flow) on aquifer discharge depends on the aquifer diffusivity between the locations of recharge and discharge, and the distance between where recharge and discharge occur (Leake, 2011). Therefore, the effect of the pulse flow on aquifer discharge is independent of the rate and direction of regional-groundwater flow (that is, groundwater gradients), and infiltration and recharge in downstream reaches can have hydrologic effects even on up-gradient discharge. The second purpose for evaluating the effect of the pulse flow on groundwater is to track the eventual fate of recharged water. The pulse flow comprised relatively low-salinity water with around 700 mg/L of total dissolved solids (measured at the Northerly International Boundary, USGS streamgaging station 09522000). Essentially all of the groundwater in the Yuma and Mexicali Valleys has higher salinity than the pulse flow water, with some areas above 2000 mg/L (Dickinson et al., 2006; Herrera Barrientos et al., 2006). Infiltrated pulse-flow water followed regional groundwater gradients, which are evaluated at a number of piezometer transects throughout the study area. Areas downgradient from the river channel, whether riparian or agricultural, will receive the benefit of the low-salinity pulse-flow water.

2. Hydrogeologic setting

The Mexicali Valley and Yuma Valley aquifers are formed within the Salton Trough, an active rift zone opened along a complex network of faults and spreading centers (Parsons and McCarthy, 1996). Although major faults are present in the region, including the Algodones fault and Sand Hills fault, they are assumed to be at sufficient distance and/or depth from the river channel in the study area as to have little influence on shallow groundwater flow (Coes et al., 2015). Sediment-filling in the Salton Trough occurred from transgressions of the Gulf of California from the south, from fluvial deposits of the Colorado River, and to a lesser extent, from alluvial deposits that form the basin margins (Olmsted et al., 1973). Total sediment thickness in the basin center is upward of 3000 m, and sediment thins to zero at the basin margins. The uppermost deposits that comprise the portion of the aquifer that interacts with surface water, and are therefore the focus of this paper, are predominantly discontinuous sand, silt, and clay deposits dating to the Pleistocene and Holocene (Olmsted et al., 1973; Dickinson et al., 2006).

The regional groundwater potentiometric surface is affected primarily by groundwater pumping, irrigation seepage and return flows, and recharge from episodic flows in the Colorado River. Groundwater is generally shallow throughout the study area; unsaturated zone thickness ranges from 0 to about 15 m beneath the river channel. The highest groundwater levels and steepest gradients are in the northeast part of the study area, in the Yuma Valley in the U.S. and in Mexico, south of the All American Canal (Fig. 1). These gradients indicate southerly and southwesterly groundwater subflow, and are influenced by irrigation, seepage from the All American Canal, and infiltration in the river channel. Fig. 1 shows conditions in 2006 (the most recent available data for the Mexicali Valley) in the study area and does not reflect the decrease in seepage caused by lining portions of the All American Canal (Coes et al., 2015). In the central part of the study area, the potentiometric surface is much flatter than in the northwest. Groundwater flow is generally towards well fields in the Mexicali Valley, and to the East towards the Mesa Arenosa/San Luis Mesa and Minute 242 well fields (Ramírez-Hernández et al., 2013). In the southwest part of the study area, little data are available to constrain the potentiometric surface, but groundwater flows both southward toward the Gulf of California, and, in the more northern part of the delta, northward to the city of Mexicali and the Imperial Valley.

3. Methods

3.1. Groundwater and stage data

Groundwater data were collected at 85 piezometers and monitoring wells established by UABC and USGS specifically for the pulse flow and other Colorado River studies (Fig. 2). These are primarily small diameter (2.54 cm–5.08 cm) and shallow (about 5–15 m), with 1.52 m screened intervals at the bottom of each. Piezometers were installed by hydraulic auger, hand auger, and direct push. In addition, groundwater-level data at 154 US Bureau of Reclamation wells along the levee east of the river in the limitrophe reach and to the east in the Yuma Valley area were used in the analysis. Groundwater levels were measured using electric sounding tapes approximately weekly during the pulse flow and quarterly thereafter. Pressure transducers were installed in 51 wells to measure groundwater levels continuously. Piezometer data used in the analysis are available at http://go.usa.gov/xZPUV. In addition to piezometer data, river-stage data from pressure transducers were used to show water-surface elevation on piezometer cross-sections. Groundwater data were contoured using inverse distance weighting.

3.2. Gravity data

Microgravity describes precise measurements of changes in Earth's gravitational field. If other influences on gravity, such as Earth tides, atmospheric pressure, and elevation change are accounted for, microgravity provides a direct measurement of mass (storage) change in the aquifer and unsaturated zone (Pool, 2008). If the water table is approximately flat and moves vertically up and down (i.e., there isn't significant mounding and/or depressions at