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Understanding Flows Through the Remnant Colorado River Delta

Recommendations for Streamgage Sites and Data Collection

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EXECUTIVE OVERVIEW

The Southerly International Boundary (SIB), where the Colorado River separates Baja California, Mexico, from Arizona, U.S.A., is the site of the last gaging station on the river. The river runs another ~75 miles (120 km) from SIB to its mouth at the Gulf of California. However, no data on the river's flows below SIB has been collected for more than twenty years. Several related factors drive the need to install new streamgages and improve hydrologic data collection and reporting in the remnant Colorado River delta:

- efforts to verify the delivery of flows leased or otherwise dedicated for instream uses require a credible mechanism for recording such deliveries;
- efforts to restore emergent wetland and riparian habitats in the remnant Colorado River delta require data on surface and sub-surface flows;
- understanding the interaction of surface and groundwater requires data on actual surface water flows;
- investment in on-farm irrigation efficiency would benefit from place-based information on the volume of irrigation return flows; and
- understanding inputs into the Upper Gulf of California and the response of marine species requires data on surface water flows.

The two immediate objectives of this paper are: (1) the installation of new streamgages in the remnant Colorado River delta, and (2) improved collection and reporting of data on the daily volume of water pumped from drainage pumps in operation in the Mexicali Valley, at locations that would generate data of value to restoration practitioners, hydrologists, and binational institutions.

The Institute recommends installing gaging stations at the following locations:

1. **At or near the site of the former M.C. Rodriguez gaging station**
2. **At the KM 38 wasteway**
3. **At the Riíto Drain**
4. **At the intersection of the Laguna Salada Canal and the San Felipe Highway.**

The Institute also recommends that the responsible agencies collect and publish, or otherwise make available, hydrologic data from the following sources:

1. **KM 27 wasteway**
2. **Rio Hardy pump station**
3. **Principal del Sur drain, at the river levee pump station**
4. **Carranza drain, at the river levee pump station.**

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INTRODUCTION

The Southerly International Boundary (SIB), where the Colorado River separates Baja California, Mexico, from Arizona, U.S.A., is the site of the last gaging station on the river. The river runs another ~75 miles (120 km) from SIB to its mouth at the Gulf of California. However, no data on the river's flows below SIB have been collected for more than twenty years. This absence of data hampers efforts to correlate river stage and discharge, information that is critical to on-going habitat preservation and restoration activities in the remnant Colorado River delta. The anecdotal data on discharge from agricultural drains in the lower delta also limits understanding of surface-groundwater interactions in the lower Mexicali Valley, information that will become increasingly important as the probability of a return of the periodic flooding and recharge of the late 20th century becomes increasingly remote. Information on actual river flows through the remnant delta would: increase understanding of the river's hydrology as a whole, including groundwater-surface water interaction; facilitate efforts to restore riparian and emergent wetland habitats; and improve understanding of irrigation efficiency and return flows in the Mexicali and San Luis valleys.

CURRENT CONDITIONS

Accounts of river flow below SIB range from zero[1] to a volume undiminished from that at SIB,[2] though a recent water balance suggests that losses to evapotranspiration and infiltration slightly exceed gains from returns from agricultural drainage below SIB in this reach.[3] Recorded flows at SIB vary dramatically on a seasonal and annual basis, underscoring the importance of monitoring and recording flows downstream. No measurable flow has been recorded at SIB for extended periods in many years; in 1996, no flow was recorded at SIB on any day that year. Peak daily discharge at SIB reached 33,000 cfs (934 m^3/sec) in 1983, the highest value recorded at the site. Although the average annual flow recorded at SIB from 1975-2004 was 1,928 thousand acre-feet (KAF) (2,378 million cubic meters (MCM)), the average flow during the 18 non-surplus years[4] during this period was only 86.5 KAF (106.7 MCM).

In non-surplus years, irrigation returns likely constitute the majority of the flow in the river below SIB. Tributaries to the Colorado River below SIB include the Rio Hardy and several agricultural drains (all of which convey irrigation return flows from fields in the Mexicali Valley), two wasteways returning water diverted at Morelos Dam, and effluent from the City of San Luís Río Colorado. In the next several years, a new facility treating wastewater from the City of Mexicali will begin discharging treated effluent into the Rio Hardy drainage, increasing flow by an estimated 20 KAF (25 MCM) annually.

The river loses water below Morelos Dam to infiltration, especially in its upper reaches, though the volume of infiltration has not been determined. Additional losses include evapotranspiration, especially by emergent vegetation and, during high flows, discharge into the Laguna Salada via a channel maintained by the Comisión Nacional de Agua (CNA).

Purpose & Need

Several related factors drive the need to install new streamgages and improve hydrologic data collection and reporting in the remnant Colorado River delta:

- efforts to verify the delivery of flows leased or otherwise dedicated for instream uses require a credible mechanism for recording such deliveries;
- efforts to restore emergent wetland and riparian habitats[5] in the remnant Colorado River delta require data on surface and sub-surface flows;
- understanding the interaction of surface and groundwater requires data on actual surface water flows;
- investment in on-farm irrigation efficiency would benefit from place-based information on the volume of irrigation return flows; and
- understanding inputs into the Upper Gulf of California and the response of marine species requires data on surface water flows.

Objectives

The two immediate objectives are (1) the installation of new streamgages in the remnant Colorado River delta, and (2) improved collection and reporting of data on the daily volume of water pumped from drainage pumps in operation in the Mexicali Valley, at locations that would generate data of value to restoration practitioners, hydrologists, and binational institutions. This information will greatly increase understanding of the quantity of water flowing through the delta region, and will also improve understanding of the interaction of groundwater and surface water in the region.

Background

The Colorado is a profoundly degraded river. Perhaps the area most affected by the development of Colorado River water is the river's delta-estuary ecosystem. Historically, the Colorado River delta and the Upper Gulf of California sustained tremendous levels of biological productivity and diversity. As late as 1922, even after much of the delta had been cleared for agriculture and irrigators had begun to divert the river, Aldo Leopold described the region as a "milk and honey wilderness."

Human demands have dramatically reduced the amount of water reaching the delta. Except for unusually high flood years, virtually the entire flow of the Colorado is now captured and used before reaching the river's mouth. However, even without the historic flows, the remaining delta and upper gulf ecoregions still comprise one of the largest and most critical desert wetlands in North America, as well as one of the world's most diverse and productive marine ecosystems. In the late 1990s, flood releases from upstream dams prompted the re-emergence of ecologically valuable riparian habitat,[6] and were strongly correlated with a rise in the shrimp catch in the Upper Gulf, an indication of the estuary's renewed viability.[7] The challenge is to ensure that the delta's various habitat types receive sufficient flows of water, at the frequency, magnitude, and quality needed to ensure their long-term survival.

The current drought in the Colorado River basin has increased this challenge. In September, 2005, the U.S. Bureau of Reclamation published a notice to solicit comments and hold public meetings on the development of shortage guidelines for the Lower Basin of the Colorado River.[8] These shortage guidelines will likely define the conditions under which deliveries of Colorado River water to Mexico will be reduced, per the 1944 Treaty with Mexico. This represents an additional threat to water availability in Mexico, and could further reduce the availability of water for ecological purposes. Mexico currently pumps groundwater to supplement its insufficient allocation of Colorado River water; further reductions in surface water availability will place greater stress on limited groundwater supplies. It is unclear how Mexico will meet its human and ecological needs in the delta, when the availability of surface water is diminished.

Achieving restoration and sustainable management of the delta and estuarine ecosystems that are dependent upon Colorado River flows requires a better understanding of the conditions that currently exist. Streamflow data in the delta region is very limited, and those records that do exist are not especially accurate. The last active gaging station on the mainstem of the Colorado River is at the Southerly International Boundary, approximately 75 river miles (120 km) above the river's mouth. The USGS rates the accuracy of this gage as 'poor', with an error of >15%.[9] The actual amount of water that reaches the river's mouth is not known; it is often estimated to be similar to that recorded at SIB, though this is likely inaccurate.[10]

Historically, two gages existed downstream of SIB: El Marítimo and M.C. Rodriguez. El Marítimo, the last gaging station on the Colorado River, was located on the right bank, 47 miles (76.6 km) below SIB, 18 miles (30.0 km) below the railroad bridge, 3.6 miles (6.0 km) east of the KM 70 signpost on the San Felipe highway, and two miles below the confluence of the Colorado River and Río Hardy. The gage consisted of a water-stage recorder and cableway. Records were based on both double and single current measurements and from a continuous record of gage heights. Discharge data from this station are only available from January, 1960 through July, 1968, when it was determined that tidal influences, combined with a naturally-formed sand berm at the river's mouth, distorted the data. Station records subsequent to 1968 are limited to mean daily gage height, which reflects tidal influence as well as mainstem discharge and agricultural drainage.[11]

The M.C. Rodriguez gaging station, formerly located on the left bank of the Colorado River about 24.5 miles (39.4 km) downstream from SIB and 4.5 miles (7.2 km) upstream from the railroad bridge, was dismantled on August 31, 1983, due to high water and eroding banks. The gage consisted of a water-stage recorder and cableway. Records were based on both double and single current measurements and from a continuous record of gage heights. Normal flows were measured by wading at a section 2,000 feet (600 m) below the gage. The discharge-relationship curve was extended for higher flows based on discharge measurements made at the gage.[12]

Currently, no streamgages exist downstream from SIB. In non-surplus conditions, some 40 KAF (50 MCM) enter the mainstem between SIB and the railroad bridge, with an estimated 75 KAF (90 MCM) entering below the railroad bridge and via the Rio Hardy. In surplus years, these volumes increase to 190 KAF (235 MCM) and an estimated 80 KAF (100 MCM), respectively. But accurate, daily discharge records do not exist.

STREAMGAGE SITES

Gaging stations record the stage and discharge (elevation and flow) of a stream at a particular site, where the channel's dimensions are known. The selection of a gaging station site is extremely important: poor site selection can impair data quality. Several factors challenge site selection in deltaic areas such as the Colorado River delta:

- the unstable nature of deltaic stream channels generally;
- the potential for tides to distort measurements;
- the tendency for flow to be irregular;
- the potential for vandalism in remote areas; and
- the difficulty in defining a stage-discharge relationship.[13]

RECOMMENDED GAGE LOCATIONS

The Institute recommends installing gaging stations at the following locations (see Figure 1, below):

1. **At or near the site of the former M.C. Rodriguez gaging station**, on the left bank of the Colorado River about 39.4 km downstream from SIB and 7.2 km upstream from the railroad bridge. Replacing the Rodriguez gage would offer the following benefits:

    - measurement of daily discharge close to sites targeted for restoration;
    - comparison of current data to historical data from the former Rodriguez gage (records from the former gage exist for the period June 1951 – July 31, 1983);
    - expansion of the Colorado River streamflow network, increasing understanding of the river's basin-wide hydrology; and
    - in conjunction with the installation of piezometers and the development of a groundwater model, greatly improved understanding of surface/groundwater interactions downstream of SIB.

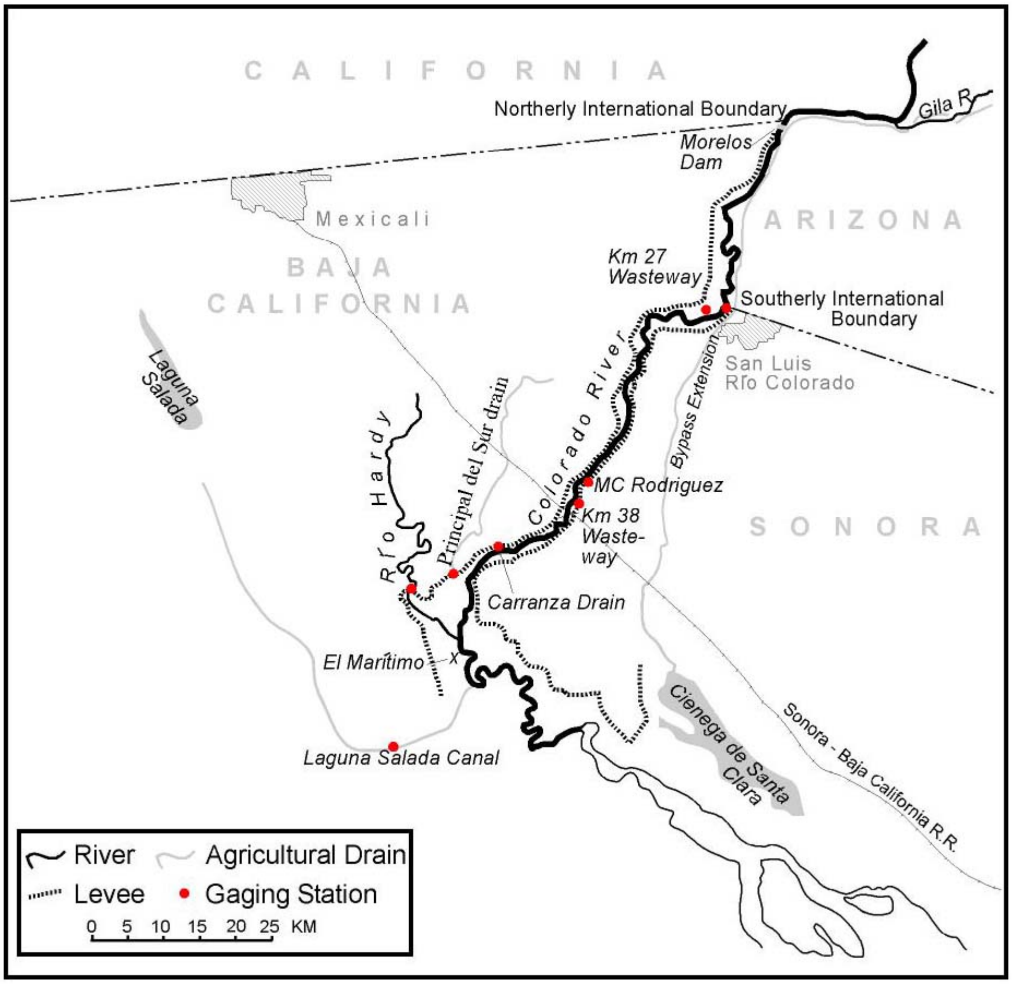

Fig. 1. Potential streamgage locations in the remnant Colorado River delta.

2. **At the KM 38 wasteway**, located in the Colonia Bojorquez, on the left bank of the river, 1.3 km upstream of the railroad bridge and 5.9 km downstream from the former site of the Rodriguez gage. This wasteway could be used to deliver water to restoration sites that lie downstream; continuous, accurate measurement will be important to verify delivery and correlate discharge with ecological response (as appropriate). Currently, monthly records of discharge through the wasteway are computed based upon gate openings, rather than continuous automated measurements. The wasteway has direct road access, and discharges into a maintained dirt canal 200 meters long with a total capacity of 13.0 m^3/sec, permitting ready development of stage/discharge curves.

3. **At or near the mouth of the Riíto Drain**. The Riíto discharges a reported one cubic meter per second of agricultural drainage from the San Luís Valley into the Cienega de Santa Clara, near the mouth of the Main Outlet Drain Bypass Extension.[14] A continuous record of actual daily discharge from the Riíto drain will assist efforts to monitor the response of the Cienega to varying inflows, complementing the daily discharge records of the Bypass Extension at the border. There is limited access to suitable sites along the drain, though the drain could lend itself to straightforward stage-discharge curves. Some residents of the nearby Ejido Johnson conduct a limited ecotourism operation at the Cienega; potentially, one or more could be employed to monitor the gaging station.

4. **On the Laguna Salada canal where it passes beneath the San Felipe Highway**. During high flows, this canal diverts water into the Laguna Salada basin from the mainstem, approximately 16 km downstream from the former site of the El Marítimo gage. The canal passes under a bridge on the San Felipe highway, which provides a reasonable site for a gaging station. Records from this site will need to be adjusted for tidal influence. Information on the volume of water diverted to the Laguna Salada will improve understanding of the total volume of water flowing to the river's mouth, permitting a better understanding of the biological response in the Upper Gulf of California to freshwater inputs.

RECOMMENDATIONS FOR ADDITIONAL DATA COLLECTION & REPORTING

The Institute recommends that the responsible agencies collect and publish, or otherwise make available, hydrologic data from the following sources:

1. **KM 27 wasteway**. The wasteway discharges to the river shortly below SIB; the gaging station there reportedly includes a water-stage recorder and cableway,[15] suggesting that daily discharge data is, or could be, collected and published. The KM 27 wasteway generates a very significant contribution to the river's flow, especially in critical low-flow periods: based on monthly discharge records, the wasteway increased Colorado River flows below SIB by slightly more than 50% in the most recent 10 years of record; in non-surplus years, the contribution was roughly equal to the river's flow at SIB. The lack of daily discharge records from this site hampers efforts to determine the actual volume of water flowing through the remnant delta, whether the wasteway generates a baseline flow, and the relationship between stage and discharge. Such records would greatly improve understanding of the Colorado River

in the remnant delta. The Institute recommends that such records be published in the IBWC's annual *Western Water Bulletin* and posted on the IBWC website,[16] alongside the daily discharge records already posted there.

2. **Rio Hardy pump station**. The pump station is located in a small forebay on the left bank of the Rio Hardy where the river is impounded by the levee, at Campo Mosqueda. It is at this point that the Rio Hardy, draining much of the western Mexicali Valley, crosses the levee defining the extent of the western floodplain of the Colorado River. Information on daily electrical use by the pumps could be used to determine the volume of Rio Hardy water discharged across the levee. This data should be supplemented with periodic measurements of the volume of water passing through a nearby gate on the levee, immediately adjacent to Campo Mosqueda. Anecdotal reports indicate that this gate releases 0.2 m^3/sec on a constant basis. The Rio Hardy provides a substantial – though currently undocumented – proportion of the flow of the Colorado River near its mouth; these records will improve understanding of the volume of this flow. This flow data would also be valuable for property owners and restoration practitioners downstream of the levee crossing.

3. **Principal del Sur drain**, where it crosses the river's right levee approximately 10 km northeast along the levee from Campo Mosqueda. This drain annually conveys an estimated 25 KAF (30 MCM), but it is not clear how much of this water reaches the mainstem. An existing array of pumps at the levee may be used to extract water from the drain and move it over the levee, although information on how frequently these pumps operate has not been obtained. A small gate also exists in the levee. The Institute recommends that data on pumping rates be recorded and distributed, and that discharge through the gate be monitored. Additional surveys should be done downstream from this discharge point, to determine the fate of these waters.   In low-flow years, this drain potentially could contribute a significant portion of the total flow in the reach between the railroad bridge and the confluence with the Rio Hardy. Additionally, areas downstream of the levee crossing have been identified as potential restoration sites; information on the timing and magnitude of drainage flows to the area will be important for designing appropriate restoration plans.

4. **Carranza drain** crosses the river's right levee approximately half-way between the railroad bridge and the mouth of the Rio Hardy. Although total annual flow has been estimated at about 5 KAF (6 MCM), the drain discharges adjacent to a site that has been identified for potential restoration; daily discharge records for the Carranza drain will aid efforts to determine water availability for the site. Similar to the Principal del Sur drain,

water from the Carranza drain is pumped across the levee. The Institute recommends that data on pumping rates at this site be recorded and distributed.

REMOTE DATA COLLECTION

The proliferation of remote sensing and satellite imagery has created new methods for estimating stage and discharge. Several studies have been conducted using satellite imagery, microwaves, and/or single aperture radar with varying satellite platforms in the last couple of decades. Although remote sensing is currently not a feasible sole source of data, due to limitations in resolution, frequency of data collection, and availability and cost of satellite data, periodic review of such data can identify potential sources of error with traditional streamgage measurement (such as changes in extent in backwaters adjacent to gages, and development of new stream channels) and supplement such measurements.[17]

Researchers at the University of Arizona frequently employ remote sensing data to evaluate conditions in the remnant delta. Potentially, such data could be correlated with streamflow stage and discharge measurements made at restoration sites and future records from the stations identified above, to interpolate general streamflow information in other reaches of the river. Periodic review of remote sensing data can also provide additional insight into flood stage discharge and extent, as well identifying changes in the extent of backwaters that could affect gage measurements.

OBTAINING & INSTALLING STREAM GAGES

Several mechanisms exist for obtaining and installing stream gages at the sites identified above. Of these, recent cooperative agreements between U.S. and Mexican agencies may offer the easiest means of transferring equipment and resources to Mexico's Comisión Nacional de Areas Naturales Protegidas (CONAP) and/or CNA. Such efforts would expedite the development of sound data for the remnant delta, and would promote binational comity.

The *Joint Declaration between the [U.S.] Department of the Interior and the [Mexican] Secretariat of Environment, Natural Resources, and Fisheries [now SEMARNAP]to enhance cooperation in the Colorado River Delta*,[18] signed May 18, 2000, states the departments' intent to "Support the IBWC's Colorado River Delta Task Force in its effort to identify physical and hydrological conditions of the Delta." The U.S. Geological Survey (USGS), part of the Department of the Interior, is a recognized expert in developing streamgage networks and installing gages, and could provide assistance to CONAP and/or CNA in site selection and gage installation under the auspices of the Joint Declaration. USGS may also be able to donate one or more of the decommissioned stream gages in the U.S. to the Colorado River delta gaging effort.

IBWC Minute No. 306,[19] signed December 12, 2000, notes that the IBWC, "through the binational technical task force, shall examine the effects of flows on the existing riparian and estuarine ecology of the Colorado River from its limitrophe section to its delta …." The IBWC facilitates binational cooperation and compiles and disseminates hydrologic data;

increasing the delta streamgage network would meet the intent of Minute 306 and fall well within IBWC's existing functions. IBWC should work proactively with its partner organizations in the U.S. and in Mexico to install gages in the locations recommended above, and to improve data collection and distribution. Such efforts will forward IBWC's mission, particularly the objectives identified in Minute No. 306.

On March 21, 2001, SEMARNAP, the California Environmental Protection Agency, and the California Resources Agency signed a Joint Declaration, "In Order to Carry Out Joint Activities for the Conservation and Sustainable Development of the Sea of Cortez Region."[20] The three agencies declared their intent to, among other objectives, coordinate "research about the physical, hydrological, and biological conditions of the region." Research on inflows to the Sea of Cortez falls squarely within these stated objectives, affording a potential mechanism for the State of California to participate in cooperative efforts to expand the delta streamgage network. Additionally, the governors of Baja California and California recently reiterated their commitment to binational cooperation, suggesting that this Joint Declaration continues to offer a viable mechanism for channeling State of California resources in support of installing and maintaining streamgages in the Colorado River delta. In addition to the promoting comity, such resource transfers could generate mitigation credits for California parties, if structured appropriately.

CONCLUSION

The installation of streamgages at the locations noted above, in conjunction with improved data collection and dissemination, will dramatically improve understanding of the hydrology of the lower Colorado River, assisting efforts to restore emergent wetland and riparian habitats in the remnant delta. Several existing diplomatic mechanisms could facilitate the placement of such gages, expediting their installation. Such binational efforts offer a ready means of demonstrating cross-border cooperation, and will facilitate future efforts to respond to variable flows along the Colorado River.

ENDNOTES

[1] Fradkin, P.L. 1981. *A River No More: The Colorado River and the West.* Tucson: University of Arizona Press.

[2] Galindo-Bect, M.S., E.P. Glenn, H.M. Page, K. Fitzsimmons, L.A. Galindo-Bect, J.M. Hernandez-Ayon, R.L. Petty, J. García-Hernandez, and D. Moore. 2000. Penaeid shrimp landings in the upper Gulf of California in relation to Colorado River freshwater discharge. *Fishery Bulletin* 98: 222-225.

[3] Cohen, MJ & C. Henges-Jeck. 2001. *Missing Water*: *The Uses and Flows of Water in the Colorado River Delta Region*. Oakland, CA: Pacific Institute.

[4] 'Non-surplus' here refers to years in which the U.S. delivered less than 1,700 kaf (2100 MCM) of Colorado River water to Mexico.

[5] See Zamora-Arroyo, F., J. Pitt, S. Cornelius, E.P. Glenn, O. Hinojosa-Huerta, M. Moreno, J. García-Hernandez, P. Nagler, M. de la Garza, and I. Parra. 2005. *Conservation Priorities in the Colorado River Delta, Mexico and the United States.* Prepared by the Sonoran Institute, Environmental Defense, University of Arizona, Pronatura Noroeste Dirección de Conservación Sonora, Centro de Investigación en Alimentación y Desarrollo, and World Wildlife Fund-Gulf of California Program. 103 pp.

[6] Luecke, D.F., J. Pitt, C. Congdon, , E. Glenn, C. Valdés-Casillas, and M. Briggs. 1999. *A Delta Once More*: *Restoring Riparian and Wetland Habitat in the Colorado River Delta*. D.C.: Environmental Defense Publications.

[7] Galindo-Bect, et al. 2000.

[8] 70 Fed.Reg. 57322.

[9] Hill, B.M. 1993. *Hydrogeology, Numerical Model and Scenario Simulations of the Yuma Area Groundwater Flow Model*: *Arizona, California, and Mexico*. Modeling Report No. 7. Phoenix: Arizona Dept. of Water Resources. October.

[10] Cohen, M.J., C. Henges-Jeck, and G. Castillo-Moreno. 2001. A preliminary water balance for the Colorado River delta, 1992-1998. *Journal of Arid Environments* 49: 35-48.

[11] Comision Internacional de Limites y Aguas (CILA). Dated 1983. *Boletín Hidrométrico, No. 24*, p. 41.

[12] International Boundary and Water Commission (IBWC). Dated 1983. *Western Water Bulletin*: *Flow of the Colorado and other Western Boundary Streams and Related Data*. Department of State, United States of America, p. 38.

[13] Chen, Y.C. and C.L. Chiu. 2002. An efficient method of discharge measurement in tidal streams. *Journal of Hydrology* **265:** 212-224.

[14] Burnett, E., I. Kandl, and F. Croxen. 1993. Cienega de Santa Clara: Geologic and Hydrologic Comments. U.S. Bureau of Reclamation, Yuma Projects Office, Yuma, Arizona.

[15] IBWC's annual *Western Water Bulletin* (annual, p. 35) incorrectly implies that the KM 27 wasteway discharges to the river 8 km *upstream* of SIB.

[16] See http://www.ibwc.state.gov/wad/histflo2.htm

[17] See Koblinsky, C.J.; R.T. Clarke; A.C. Brenner; and H. Frey. 1993. Measurement of river level variations with satellite altimetry. *Water Resources Research* **29:** 1839-1848 and Xu, K.; J. Zhang; M. Watanabe; C. Sun. 2004. Estimating river discharge from very high-resolution satellite data: a case study in the Yangtze River, China. *Hydrological Processes* **18**: 1927-1939.

[18] On file with the author.

[19] See http://www.ibwc.state.gov/files/minutes/min306.pdf

[20] On file with the author.