

**IRRIGATION ENGINEERING IN SEISMIC ZONES – MEXICALI VALLEY, MEXICO**

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**ABSTRACT**

On April 4, 2010 an earthquake of Richter magnitude 7.2 occurred with an epicenter south of Mexicali within the irrigated zone of Mexicali Valley. Extensive damage occurred to main and lateral canal structures, plus to field irrigation systems and the main drainage network. This paper describes the engineering for a new major irrigation water conveyance system to service the most heavily impacted zone of 80,000 acres. Considerations included identification of the causes of the damage, selection of canal versus pipeline, relocation costs of people along new routes, and improved flexibility of water delivery. Major investigations regarding soils, topography, etc. were conducted in a compressed timeline of only 4 months. Construction is anticipated to begin in December 2011.

**INTRODUCTION**

The Mexicali Valley in Baja California (and some area in the state of Sonora) has approximately 500,000 acres of irrigable land. The water is owned by the national government and administered by CONAGUA, the Mexican equivalent of the USBR. An area CONAGUA office is responsible for the network of major canals (District 014) that distribute water to both agricultural districts and municipalities (primarily Tijuana and Mexicali cities). The major canals are maintained and operated by the “Colorado River Irrigation District, S. de R.L. I.P. de C.V.”, which is an umbrella water-user organization such as the Friant Water Users Association. The Mexicali Valley is administratively and hydraulically divided into 22 “modulos” or smaller irrigation districts (water user associations), each responsible for operation and maintenance of smaller canals and direct deliveries to field turnouts (Figure 1). The “modulos” provide the board members for the S. de R.L.

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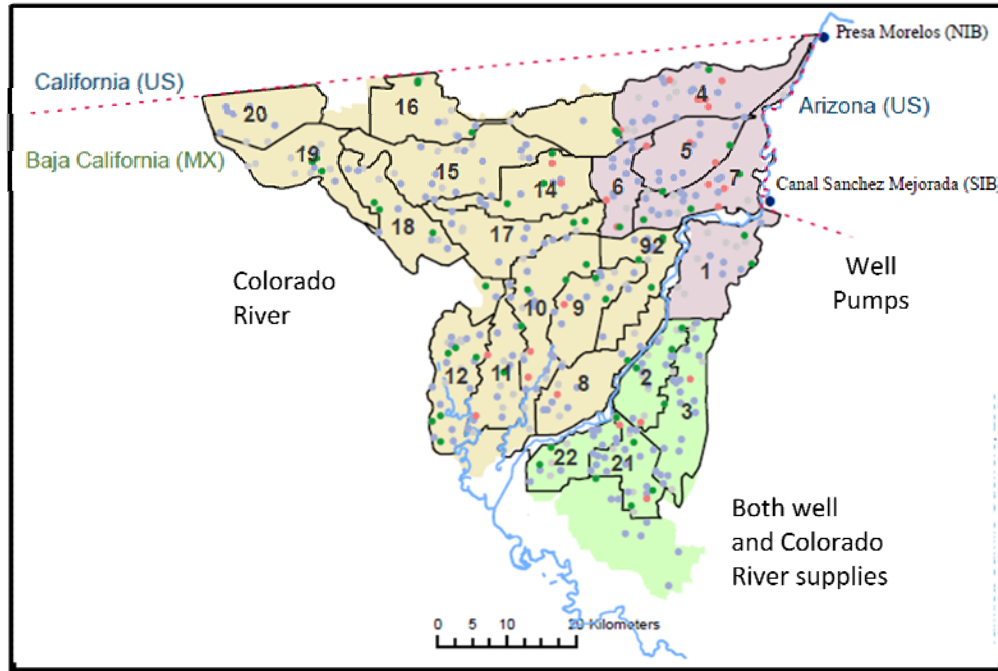


Figure 1. District 014 (Mexicali Valley) showing Modulos (by number) and sources of water (by color).

On April 4, 2010 an earthquake of Richter magnitude 7.2 occurred with an epicenter south of Mexicali within the irrigated zone of Mexicali Valley. The modulos that suffered the most damage from the earthquake were Modulos 10, 11, and 12, with about 80,000 irrigated acres. The irrigation water to those modulos was supplied by the concrete-lined Nuevo Delta Canal (about 15 miles long), which is in turn supplied by the Reforma Canal, which receives its water from the Colorado River at Morelos Dam (Presa Morelos on Figure 1). This paper focuses on the plans to rebuild/replace the Nuevo Delta Canal, which was heavily damaged.

The areas of the Valley that experienced the most earthquake damage had also recently experienced serious subsidence problems, which are attributed by some to the adjacent geothermal energy fields that may have insufficient groundwater recharge. Figure 2 shows anticipated subsidence over the next 30 years, although in some areas the 2010 earthquake caused more than twice the 30-year predicted subsidence.



Figure 2. Lines of equal subsidence predicted by CICESE to occur within 30 years. Units are cm. The geothermal production zone is on the center left-hand side of the figure. The blue lines show the Reforma Canal (top, flowing right to left), and the old, damaged Nuevo Delta Canal (center, flowing from top to down).

Besides subsidence, the design also had to consider locations of fault lines and zones of liquifaction. Figures 3 and 4 indicate the locations of these potential problem zones.

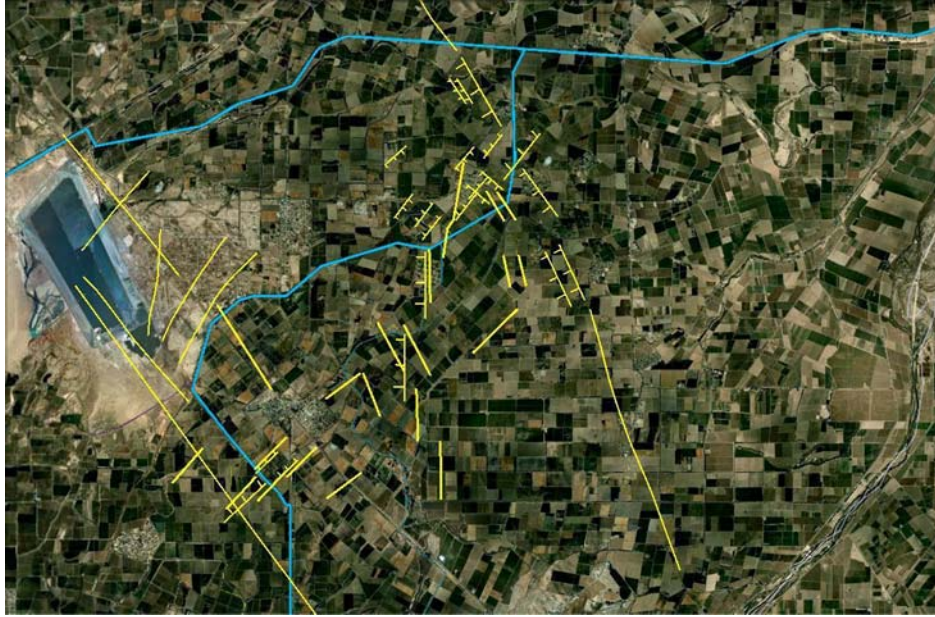


Figure 3. Fault lines in relation to the Reforma Canal and Nuevo Delta Canal.



Figure 4. Zones of liquefaction in relation to the Reforma Canal and Nuevo Delta Canal.

The agricultural fields suffered substantial damage due to a combination of subsidence and liquefaction in the subsurface. Small “volcanoes” appeared in fields across a huge area – where water flowed up from the saturated subsurface and discharged large amounts of sand plus salty water across the soil surface. Figure 5 illustrates this phenomenon.



Figure 5. Sand volcanos that arose from subsurface liquefaction.

The canals and drains suffered considerable damage. Drain embankments sloughed in, as did canal embankments.



Figure 6. Remnants of a large drain channel that completely filled in during the earthquake.

The canal damage caused by factors other than overall subsidence varied depending upon the location. The figures below give examples.



Figure 7. Slumping of embankment into the canal. Photo courtesy of CONAGUA.



Figure 8. Movement of the entire canal embankment away from the canal. Photo courtesy of CONAGUA.



Figure 9. Fissures in the embankment road. Photo courtesy of CONAGUA.

### Selecting a New Route

The damaged Nuevo Delta Canal traversed multiple fault lines and liquefaction zones. Plus, it fell within zones of anticipated subsidence.

Over thirty different replacement routes were analyzed and compared in terms of economics, right-of-way acquisitions, residential relocation costs, road crossings, topography, costs, available pressure, command area, and ability to enhance existing water delivery service. These considerations were overlaid on the maps of subsidence, liquefaction, and faults. The final route is shown in Figure 10.



Figure 10. Proposed route of new canal, showing faults, subsidence, and liquefaction zones.

## **Designing to Minimize Future Damage**

One design/construction option was to use pipelines instead of canals. Multiple large diameter (96”), steel ribbed reinforced HDPE pipes were considered as the best pipeline option, but the price was more than double that of a new canal. Furthermore, there were concerns about the ability to quickly repair such pipes, and to maintain them free of sediment.

Therefore, the focus was on how to properly construct the new canals to minimize the type of embankment failures that occurred during the April 4, 2010 failure.

If one looks at the failures that occurred in the Mexicali canal embankments during the April 4, 2010 earthquake, common circumstances in failure zones appear to be:

1. The canal banks were constructed of native materials, with a high silt percentage, that were not well compacted.
2. There was high seepage loss from the canals prior to the earthquake – indicating that the canal embankments under the cracked concrete lining, at least in many areas, were saturated.
3. A high water table existed, indicating that the soil immediately under the base of the canal and its embankment were saturated.

With the exception of localized shear caused by displacement of soil along/crossing a fault line, the damage exhibited classic symptoms of slope instability. This type of embankment failure is sometimes associated with a different manifestation of liquefaction than was mentioned earlier (sand volcanoes in fields due to subsurface liquefaction). For canal bank failure, the embankment becomes more “slippery” due to the rapid buildup of high pore pressures during cyclic shear of saturated soils. If the pore pressure builds up on uncompacted soil, the potential for slippage (shear failure) increases as compared to on compacted soils.

The new canal will incorporate the following features to minimize problems that existed on the old canal:

1. The soil will be over-excavated, filled with compacted soil, and then the cross section for the new canal will be cut from the compacted soil.
2. The canal embankments and the “footing” of the canal itself will be kept dry by preventing moisture from entering from above and below. The two solutions will be:
  - a. The canal will be lined with a geomembrane to prevent seepage from “above”. That geomembrane is equipped with a fuzzy material on its surface so that concrete will adhere to it. Concrete will be applied with a 3” thickness over the geomembrane. The concrete will provide mechanical protection from cleaning operations and other physical damage that might occur.
  - b. A tile drain will be installed approximately 6’ below the bottom of the canal, and to the side, to help lower the water table immediately under the canal. This will help minimize moisture from entering the embankment from below, and will possibly provide a more stable footing for the whole structure.

## **Operation Enhancement Features**



The old Nuevo Delta Canal had almost no ability to provide flexible service to the water user associations (modulos). The old cross regulators (check structures) were manual sluice gates, and the flow measurement devices at all bifurcations and turnouts were uncalibrated.

The replacement canal, called the “4 de Abril” canal, will incorporate the following key control features:

1. A Replogle flume (broad-crested weir) at the head.
2. Long-crested weirs for check structures.
3. New standardized submerged orifice flow meters for turnouts.
4. Two regulating reservoirs, with pumps in and out to automatically maintain the adjacent canal pool water level.
5. Improved flow control and measurement at the heads of major bifurcations.

Because of the significant vandalism problems and historical challenges with SCADA and automation in the Mexicali Valley, there will be no automation except for on the pumps that put water into and out of the reservoir. The PLC controller has been specially designed by ITRC to use two simple water level probes (rather than pressure transducers) and fixed speed pumps (as opposed to using VFDs).

## CONCLUSION

The 4 de Abril replacement canal for the Nuevo Delta Canal in Mexicali Valley avoids major areas of subsidence, faults, and liquefaction. The canal will be constructed with lining, drainage, and compaction to minimize embankment failure. The new canal has features that will enhance the water delivery service to the water users by providing more flexible, equitable, and dependable deliveries. Construction is scheduled to begin in December of 2011.