

# Earthquakes and Irrigation in the Mexicali Valley

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**Abstract.** *On April 4, 2010, a 7.2 magnitude earthquake occurred within the Mexicali Valley approximately 30 miles south of the U.S. Border. Fields and canals within approximately 64,000 acres were severely damaged, with about 141,000 total acres damaged. This paper reports on the types of irrigation and drainage damage that occurred, the response by the governments and farmers, and the corrective efforts that have been and will be made on-farm and to the irrigation water distribution system that supplies the canals.*

**Keywords.** Irrigation, drainage, earthquake, Mexicali, Baja California.

## **The Mexicali Valley**

The Mexicali Valley in the Mexican state of Baja California (plus some area in the state of Sonora) has approximately 500,000 acres of irrigable land. It is comparable to its northern neighbor, California's Imperial Valley, which also has 500,000 acres of irrigated land and which has the same water supply – the Colorado River. Crops are similar, but Mexicali Valley has less water allocation per acre, so in Mexico there are higher acreages of grains and cotton. The Mexicali Valley also lacks the good regional drainage system that the Imperial Irrigation District operates and maintains in the Imperial Valley.

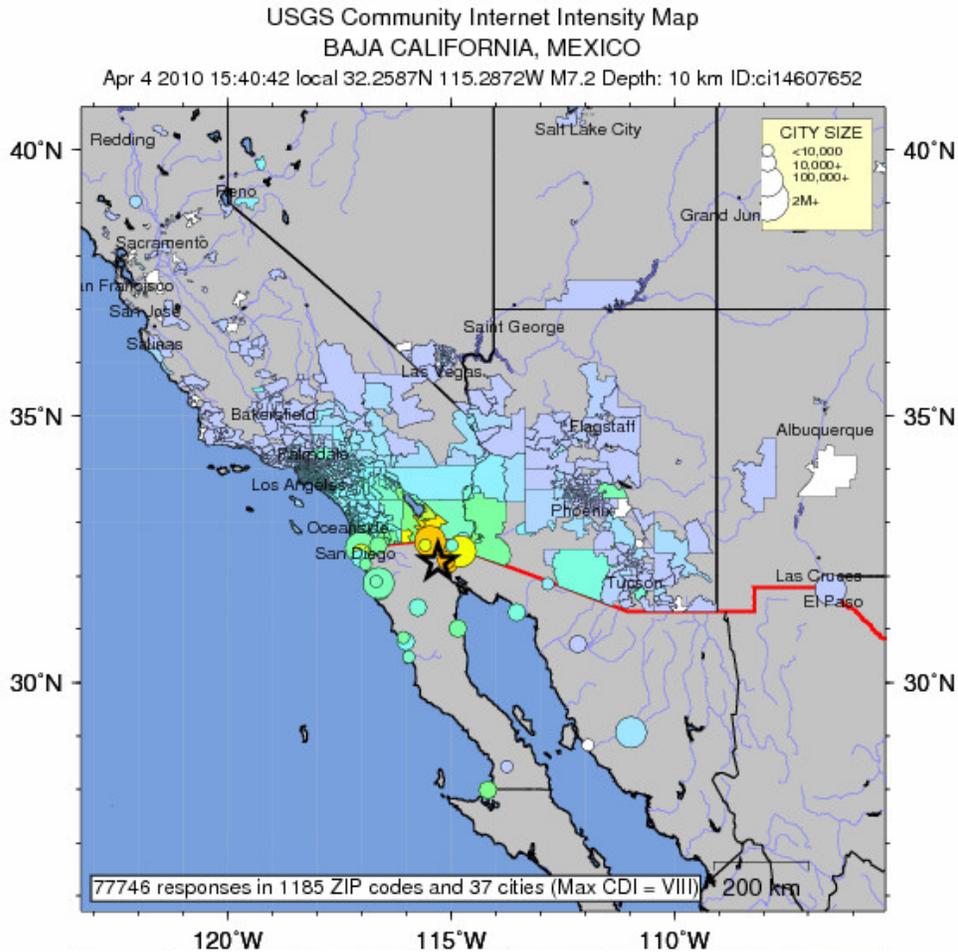


Figure 1. USGS map showing location (black star) of the epicenter of the April 4, 2010 earthquake in Mexicali Valley, approximately 35 miles south of the US border.  
<http://earthquake.usgs.gov/earthquakes/dyfi/events/ci/14607652/us/index.html>

In Mexico, the water is owned by the national government and administered by CONAGUA, the Mexican equivalent of the USBR. The Baja California 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 in California.

The Mexicali Valley District 014 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. These “modulos” provide the board members for the S. de R.L. Just as in the USA where there can be arguments between the USBR and individual irrigation districts, there can be friction between CONAGUA and the modulos and S. de R.L.

## The Earthquake of April 4, 2011

The Imperial Valley and Mexicali Valley have both experienced frequent earthquakes over the decades. The magnitude 7.2 (Richter scale) was the largest recent quake, and could have been much more devastating (i) if the epicenter had been in the city of Mexicali, and (ii) if it had occurred on a workday rather than on a Sunday afternoon. Figure 2 shows the location of the epicenter, which is in a largely rural area. The primary brunt of the devastation was felt on irrigated agriculture, with some local communities being flooded by water from collapsed canals.

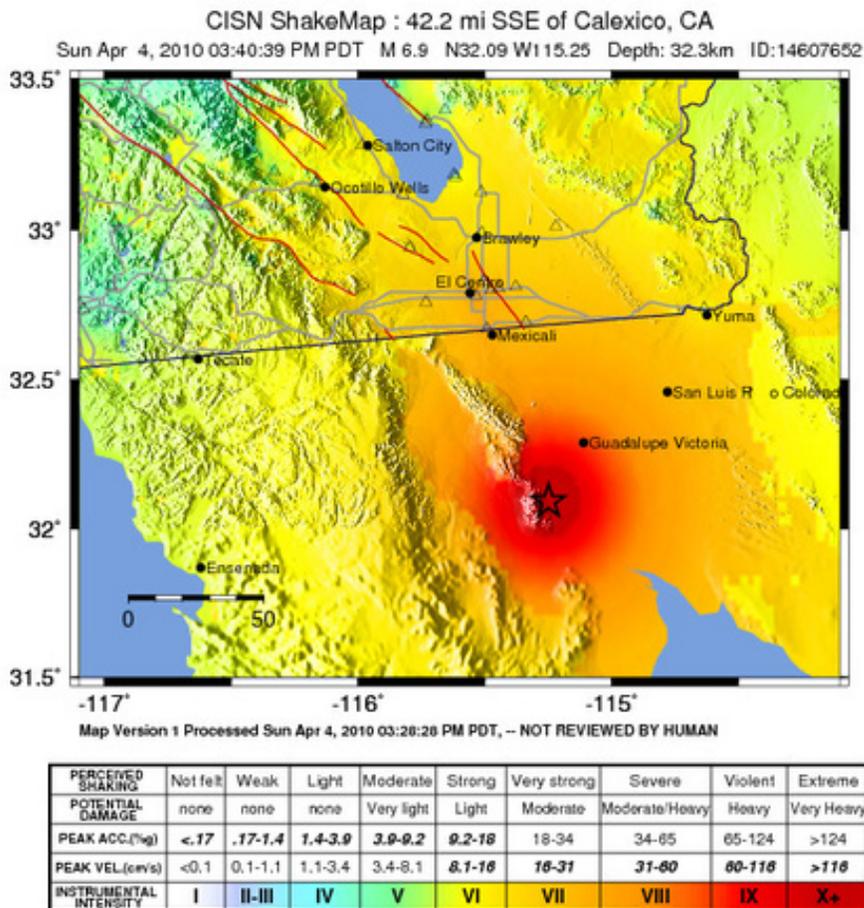


Figure 2. Shake map for the April 4, 2010 earthquake.  
<http://www.myfoxla.com/dpp/news/local/major-earthquake-hits-baja-california-20100404>

Figure 3 shows the clearly visible scarp of the fault in the aftermath of the earthquake.



Figure 3. The quake pushed this mountain six feet into the air and 10 feet to the side in some places. The dark ribbon that runs through the mountain shows freshly exposed dirt. Photo by John Fletcher, Ensenada Center for Scientific Research and Higher Education (CISESE).

The earthquake was devastating to approximately 80,000 acres of irrigated land, with further damage on additional acreage (summarized later in this paper). The leveling of fields was completely destroyed; level fields became undulating and in many cases the slopes were reversed. The major drainage ditches for the lower part of the valley simply collapsed and filled in. Large canals cracked and heaved, and smaller lateral canals were often completely filled in with soil. Perhaps one of the most damaging and visually interesting aspects was the appearance of "volcanoes" of salty water that covered vast acreages of land, covering fields with sand and salty water. These were caused by liquefaction of the saturated subsoil.



Figure 4. "Volcanoes" of sand brought up by salty water onto fields.



Figure 5. Typical covering of fields with liquefied subsurface soil that upwelled during the earthquake.



Figure 6. Damage to canal lining.



Figure 7. Field that was flooded by water from a damaged canal.



Figure 8. Damaged secondary canal.



Figure 9. Drainage ditch that had collapsed and was partially excavated to provide limited remedial removal of salty water.



Figure 10. Fissures in the embankment road. Photo courtesy of CONAGUA.

The modulos that suffered the most damage were Modulos 10, 11, and 12 (see Figure 11). The irrigation water to these modulos was supplied by the concrete-lined Nuevo Delta Canal (about 15 miles long), which was in turn supplied by the Reforma Canal, which receives its water from the Colorado River at Morelos Dam (Presa Morelos on Figure 11). The Nuevo Delta Canal was almost completely destroyed.

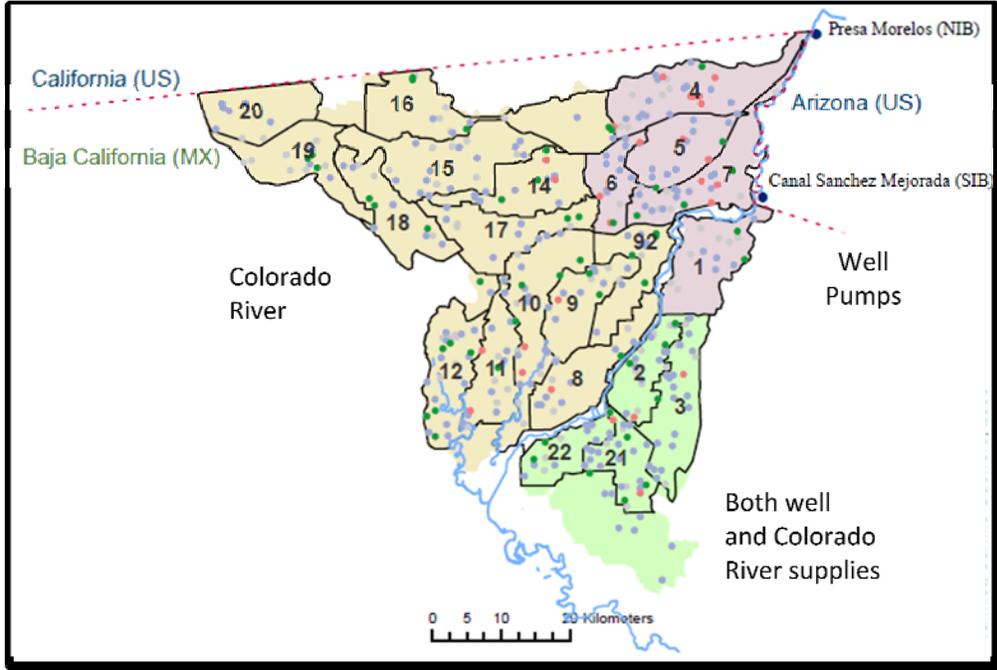


Figure 11. District 014 (Mexicali Valley) showing Modulos (by number) and sources of water (by color).

Table 1. Types of Damage to Farm Land (Orozco-Riezgo, 2011). Area in hectares (1 ha = 2.47 acres). In many cases, multiple problems occurred on the same fields. Therefore the final row "total area" does not equal the sum of the previous rows.

Type of damage	High	Medium	Low	Impacted surface (Ha)
Lack of irrigation water	24,083	16,705	3,285	44,073
Unevenness of land	18,666	12,667	1,719	33,052
Water table flooding	9,679	9,122	3,205	22,007
Land cracking	8,712	7,600	1,713	18,024
Flooding by ruptured irrigation canals	810	305	58	1,173
<b>Total area with one or more problem</b>	<b>26,106</b>	<b>18,390</b>	<b>12,539</b>	<b>57,035</b> (140,877 ac)

Main damages to the hydraulic system and drains (Orozco-Riezgo, 2011) were:

- 57 km of main irrigation canals; Reforma, Nuevo Delta and Revolución canals.
- 350 km of secondary canals.
- 380 km of the drainage system.
- The total affected farming land area was 57,035 ha. (140,877 acres).

### Reaction to the Damages

The *modulos* and S. de R.L. were very quick to respond in various ways. The S. de R.L. quickly diverted water into drains if canals had been destroyed – as a simple means of just getting water out into the agricultural area so farmers could pump from the drains. The S. de R.L. also began almost immediate emergency repair of canals. But substantial, deliberate reconstruction required the involvement of the federal government's CONAGUA – both because CONAGUA held the money, and also because permanent improvements required a more detailed design approach than the *modulos* and S. de R.L. were accustomed to using. Therefore, the majority of the impacted area has not had crops for two seasons.

While the irrigation district and S. de R.L. were rapidly re-establishing water delivery service wherever possible, the state and federal governments began to assess the damage and to develop a specific plan. During the first 60 days, intensive surveys were conducted to identify the areas and types of damage.

A very interesting aspect of the Mexicali situation was that the Federal government held an insurance policy that covered damage to the primary and secondary canals in the event of a natural disaster. The exact dollar figure is not known, as the final designs for the reconstruction of those canals is nearing completion at this time. It is anticipated

that re-construction of the large canals will begin in early 2012. Therefore, except for the design portion of this work, the insurance has not yet had an impact.

Meanwhile, there was no crop insurance policy in place that covered damage due to earthquakes. Therefore, the government has spent about \$32 million (US) to help farmers recover crop losses and to re-level their fields. Approximately \$101 million (US) has been spent on temporary rebuilding/patching of main and secondary canals.

### Replacing the Nuevo Delta Canal

The damaged Nuevo Delta Canal traversed multiple fault lines and liquefaction zones. Plus, it fell within zones of anticipated subsidence due to groundwater extractions (without recharge) from an adjacent geothermal field.

A design feasibility contract was provided by CONAGUA to Ingeniería Dennis of Mexicali, with the Cal Poly ITRC as a sub-contractor. Over thirty different replacement routes were analyzed and compared in terms of economics, right-of-way acquisitions, 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 of the replacement canal, called "April 4", is shown in Figure 12.



Figure 12. Route of new April 4 canal, showing faults, subsidence, and liquefaction zones.

While large diameter (3 - 96" diameter) ribbed polyethylene pipelines were considered at first, that idea was discarded due to their expense and unknowns. 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.

There was very little to go on. Certainly, there has been a long history of soil mechanics work on embankment failure. There are also many earth-filled dams. But there was almost no guidance for the construction of new agricultural irrigation canals in seismic prone areas. And the new feasibility design of the replacement for the Nuevo Delta Canal needed to be completed within a few months, eliminating the possibility of doing research on new techniques. Therefore, Ing. Dennis and ITRC visually examined the types of failures that had occurred in the Mexicali canal embankments during the April 4, 2010 earthquake, and combined those observations with basic knowledge of soil mechanics to generate a solution. It was noted that canal bank failure appeared most commonly in the following situations:

1. The canal banks were constructed of native materials, with a high silt percentage, that were not well compacted. From basic soil mechanics applied to slope stability problems, we know that this is undesirable.
2. There were high seepage losses from the canals prior to the earthquake due to cracked concrete lining. We concluded that in many areas, the soil under the concrete was saturated.
3. A high water table existed, indicating that the soil immediately under the base of the canal and its embankment were saturated.

Ing. Dennis recommended that the following features be incorporated into the final design 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.

Furthermore, the new canal will be designed to provide much better water delivery service to the modulos. The old Nuevo Delta Canal cross regulators (check structures)

were manual sluice gates, and the flow measurement devices at all bifurcations and turnouts were uncalibrated.

The replacement (April 4) canal will incorporate the following key control features:

1. A broad-crested weir at the head to measure flow rate.
2. Long-crested weirs for check structures within the canal to stabilize water levels.
3. New standardized submerged orifice flow meters for turnouts.
4. Two large 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.

There will be no automation except for on the pumps that put water into and out of the reservoir. The programmable logic controller (PLC) will use an ITRC design of two simple water level probes (rather than pressure transducers) and fixed speed pumps (as opposed to using VFDs). Canal pool capacities have been defined to avoid excessive cycling of the pumps.

## **Conclusion**

A devastating 7.2 Richter scale earthquake struck the Mexicali Valley irrigated area on April 4, 2010. It caused damages to about 141,000 acres of fields and the supply canals. Fields were primarily damaged from flooding, upwelling of sand and saline water, and destruction of the land leveling. The Mexican federal and state governments implemented programs to help farmers, and an insurance-funded program will pay for new canals and reconstruction of damaged canals. A new canal design was developed to avoid future failures in this seismic-intensive zone.

## **References**

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