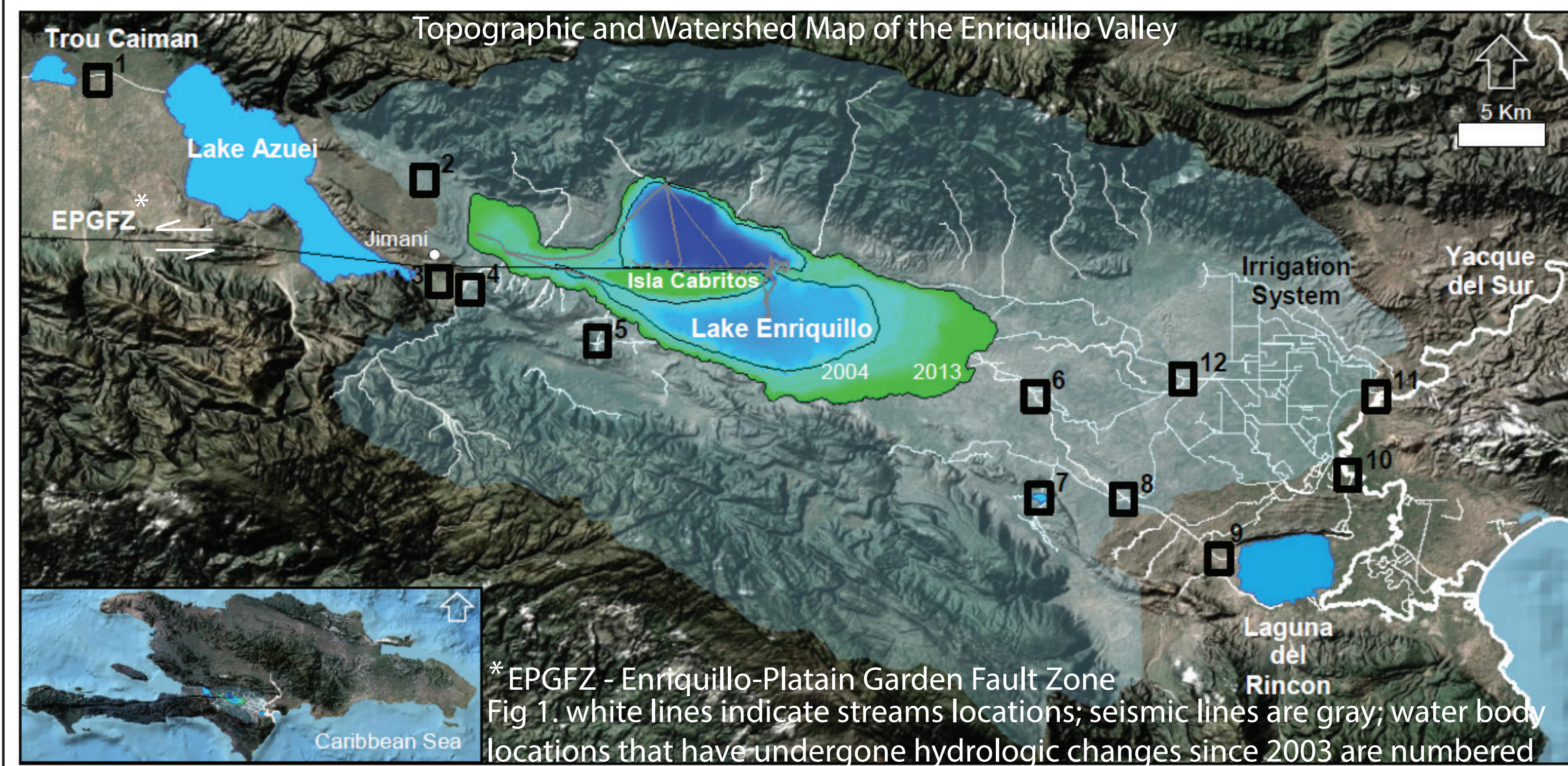


ABSTRACT

Lakes Enriquillo and Azuei, the two largest lakes in Hispaniola and in the Caribbean, have risen 10 and 5 m respectively within the last 8 years. Higher lake levels have submerged towns, road systems, fertile agricultural areas and utilities, and have threatened to submerge the major overland highway and customs crossing that connects the Dominican Republic and Haiti. In this study, we use active source seismic data, satellite imagery, and regional meteorological data to quantify and assess controls on the recent lake level rises. Although data are limited, the analyses indicate that the lakes' water level changes may be attributed to increased rainfall and perhaps changes in hydraulic connectivity across the drainage basin. We show that a weak correlation exists between changes in Lake Enriquillo's and Azuei's water levels and precipitation rates (0.2 and 0.08 respectively, 1984-2012) and that both lakes experience periods of anti-correlation where, for example, water level drops at Lake Azuei (~20 masl) coincides with water level rises at Lake Enriquillo (41 mbsl). From these observations, we propose that the lakes experience intermittent periods of hydraulic connectivity along reactivated or newly developed stratigraphic-controlled sub-surface transport pathways. We also note that moderately small (<Mw 5) earthquakes along the large active fault system that extends through both lakes may promote or limit hydraulic conductivity on decadal or shorter time scales. The extents to which recent earthquakes have triggered changes in groundwater flow at this site remain unclear but represent an important topic of future research.

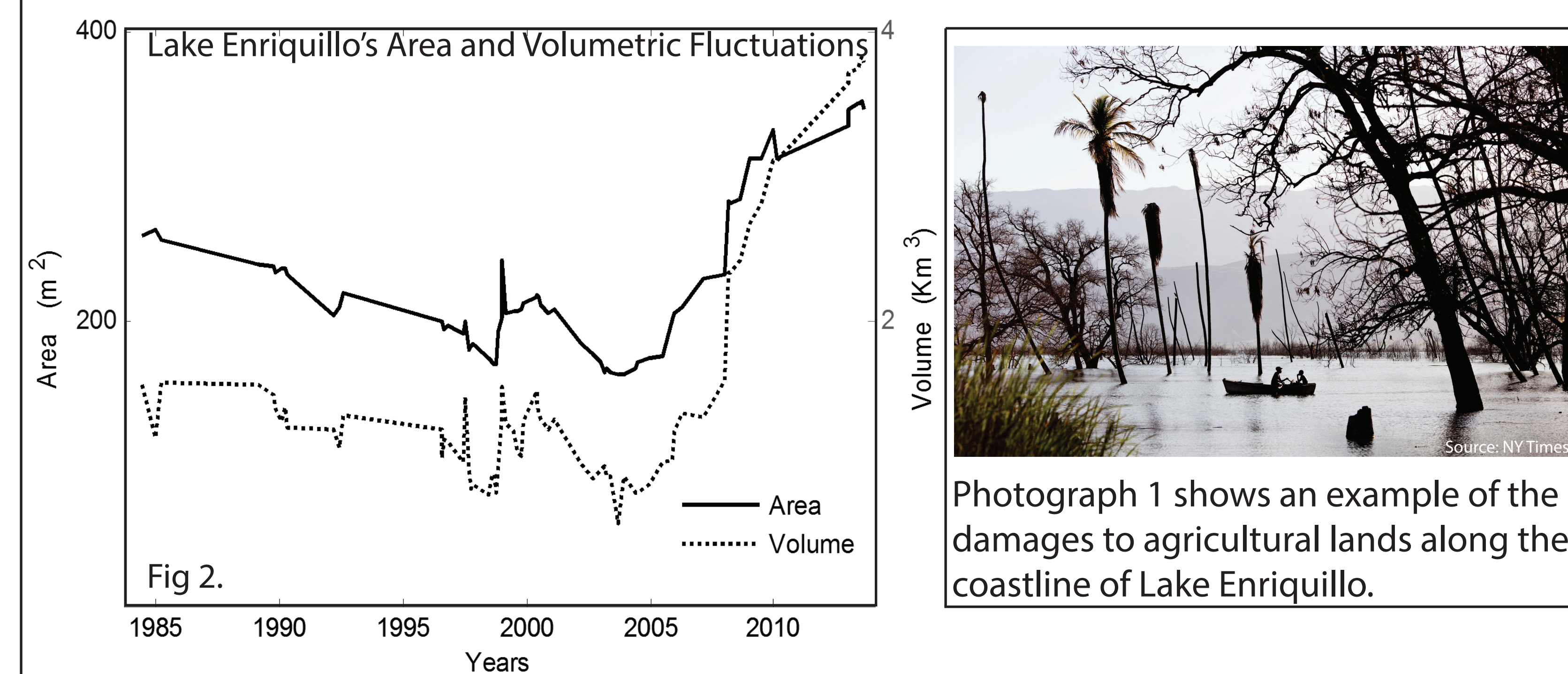
GEOLOGIC SETTING

Lakes Enriquillo and Azuei are located ~ 5 km away from each other in Dominican Republic and Haiti respectively (Fig. 1). The hypersaline Lake Enriquillo forms both the largest lake (352 km²) and the lowest point (41 mbsl) in the entire Caribbean region. Lake Azuei is a smaller (137 km²) fresh-water lake that lies ~ 20 m above sea level.



RECENT FLOODING IN THE REGION AS A RESULT OF LAKE LEVEL RISES

Lake Enriquillo and Azuei has more than doubled their surface areas between 2005 - 2013 (Fig 2). Within the past three years, rising waters from the lakes have displaced 10,000 families living in 16 rural communities and submerged 46,500 acres of agricultural lands assessed at ~ \$2.5 million USD. ² Understanding the cause of lake level rises is crucial for hazards management efforts in the region.

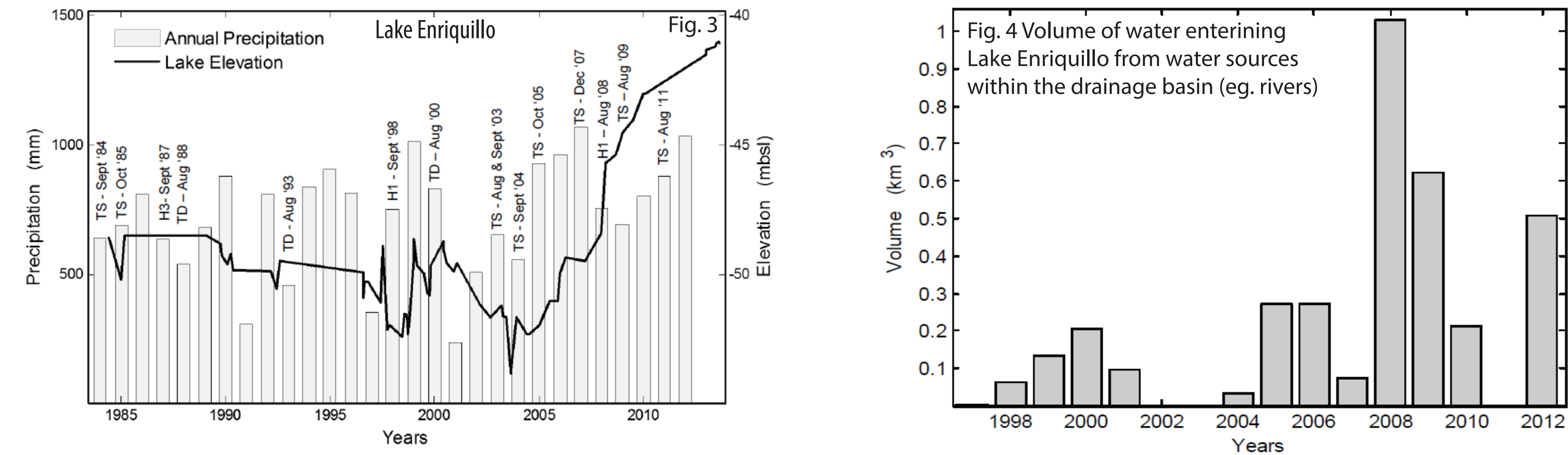


HYPOTHESES TESTED

1. The lakes are responding to weather and climate pattern change in the region.
 2. Changes in hydraulic connectivity between water bodies in the valley play a role in lake flooding.
- N.B. It has been shown that land use change is not significant enough to cause the observed lake rises.⁴

ARE THE LAKES RISING AS A RESULT OF WEATHER PATTERN CHANGES IN THE REGION?

Lakes Enriquillo and Azuei have risen following a 211 mm/yr increase in precipitation (2005-2013) and following at least 7 storms (Fig. 3). However, weak correlations (0.2 and 0.08 respectively) between lake levels and precipitation rates, along with high volumes of water required from the drainage basin to fill Lake Enriquillo between 2008-2012 (Fig. 3, 4), imply that weather patterns are unlikely to be the sole cause of the recent lake level rises.



Hydraulic Connectivity Hypothesis: Lake Enriquillo's volume changes between 2008-2012 can be attributed to greater hydraulic connectivity between Lake Enriquillo and Lake Azuei, the Rio Yacque del Sur or the Caribbean Sea.

ARE LAKES ENRIQUILLO AND AZUEI HYDROLOGICALLY CONNECTED TO EACH OTHER?

From 1984 until 1997, Lake Azuei experienced sustained periods of lake level rises followed by short periods of lake level drops (Fig. 6). During these same short periods, Lake Enriquillo experienced very abrupt lake level rises. Between 1997 and 2013, Lake Enriquillo experiences three of its most dramatic growths directly following significant lake level drops at Lake Azuei (Fig. 6). Here, Lake Azuei appears to act as an upstream dam that opens (loses large volumes of water to Lake Enriquillo) and closes (retains its water) at different times as lake levels change (Fig. 5, 6).

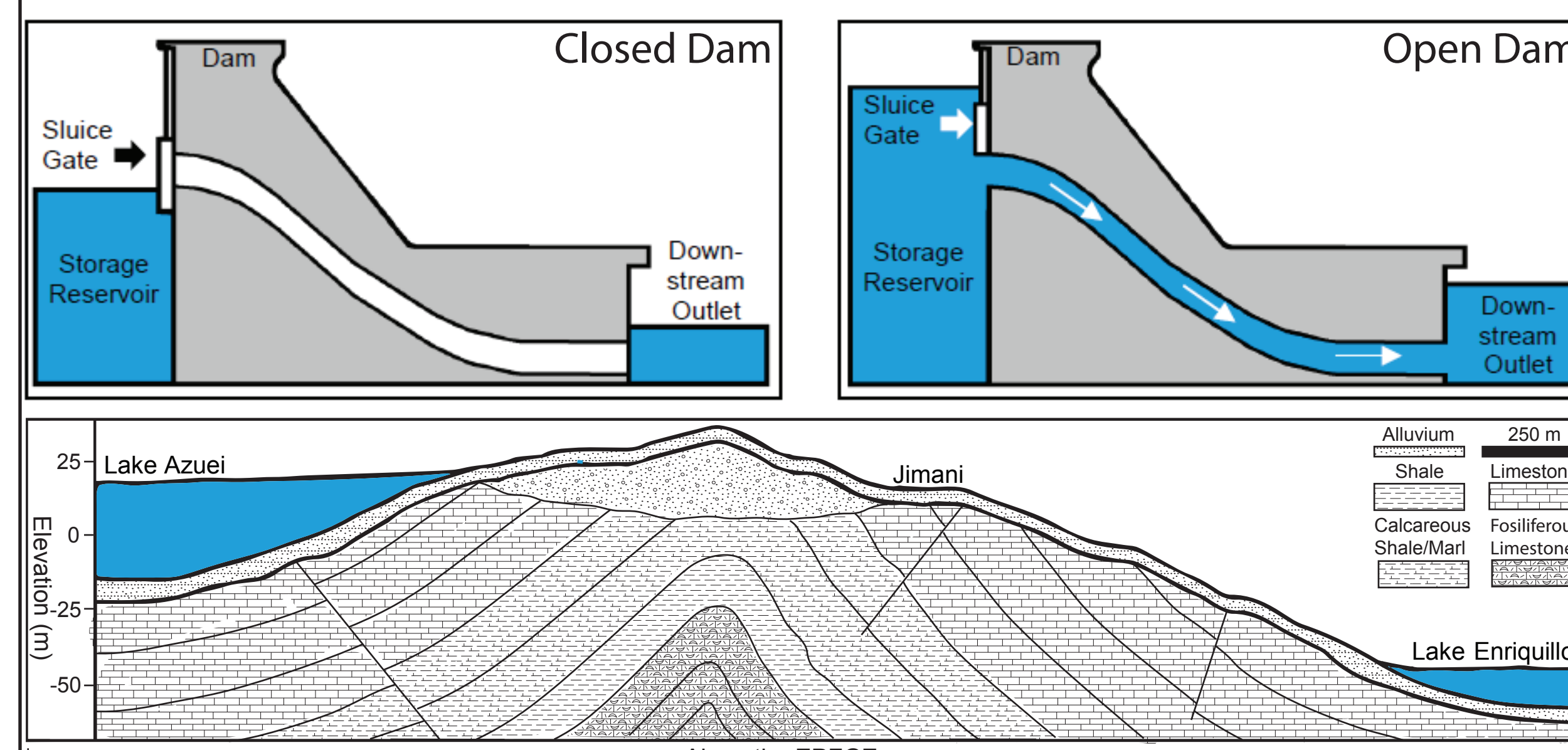
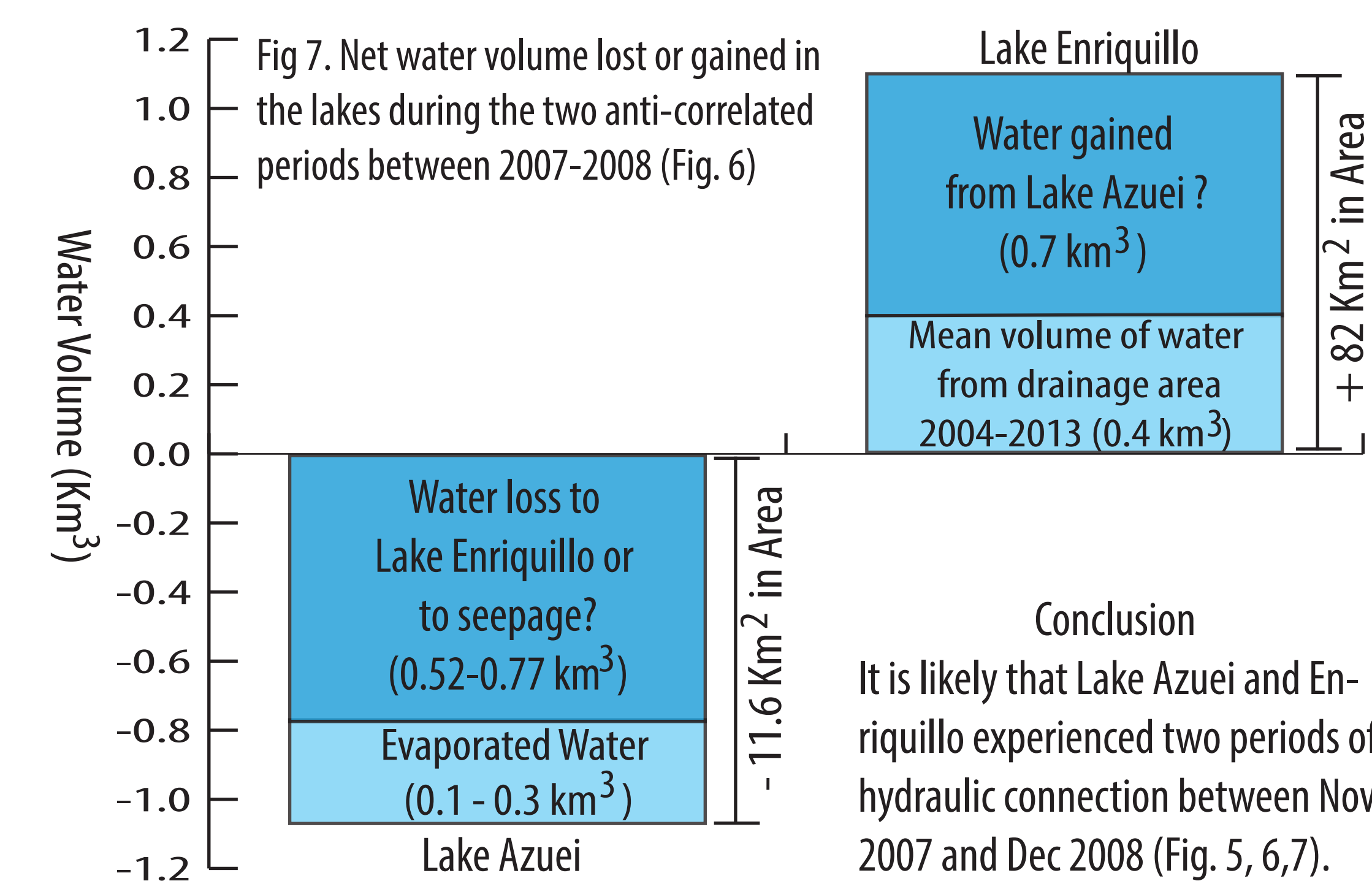


Fig. 5 Artist rendered scaled sketch of the geology between Lakes Enriquillo and Azuei based on regional geological maps. Vertical exaggeration is ~ 50 x.

Geology that supports an inter-lake connection between 2007-2008

- ** A new sinkhole between the two lakes (2007) (Fig. 1, box 3)
- ** Mid-highly permeable carbonate rocks in the subsurface (Fig. 5)
- ** A potential water flow boundary parallel to the EPGFZ (Fig. 1, 5)
- ** A 60 m hydraulic head between the lakes (Fig. 5)
- ** Numerous wells and aquifers between the lakes (in Jimani)



DOES THE CARIBBEAN SEA PLAY A ROLE ?

Higher salinity values generally correspond to lower lake level elevations and vice versa (Fig 8).^{1,3,5} Therefore, the fall in salinity from 90 to 22 ppt between 2005 and 2013 indicates that mostly fresh water has been introduced to the lake since 2005. This indicates that the Caribbean Sea is unlikely to be contributing large volumes of water to Lake Enriquillo.

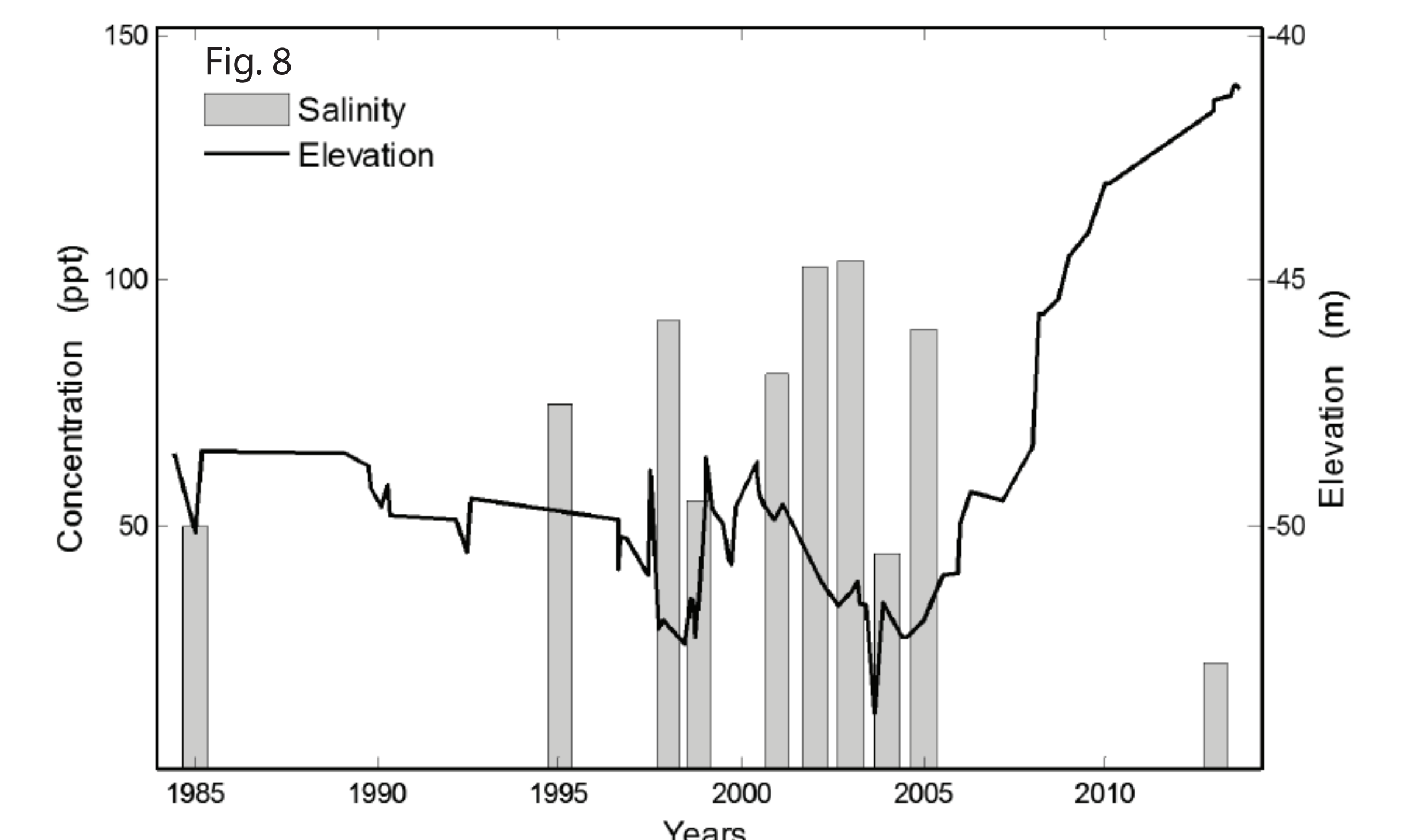
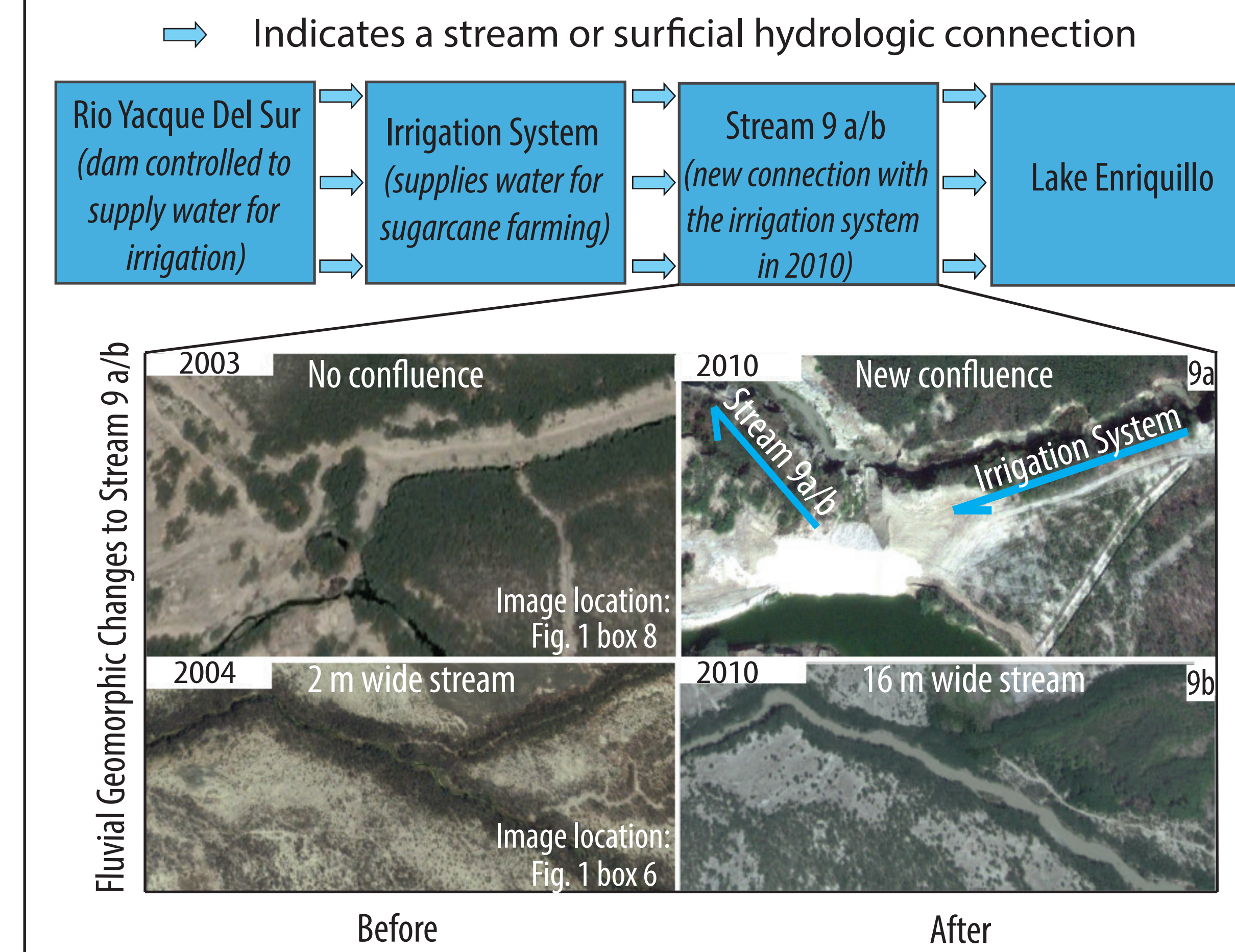


Fig. 8 Relationship Between Lake Enriquillo's Salt Concentrations and It's Water Levels

IS LAKE ENRIQUILLO RECEIVING WATER FROM THE YACQUE DEL SUR OR ANY NEW STREAMS IN THE VALLEY?

Lake Enriquillo's hydrologic connection to the Yacque del sur (Fig. 1, 9)

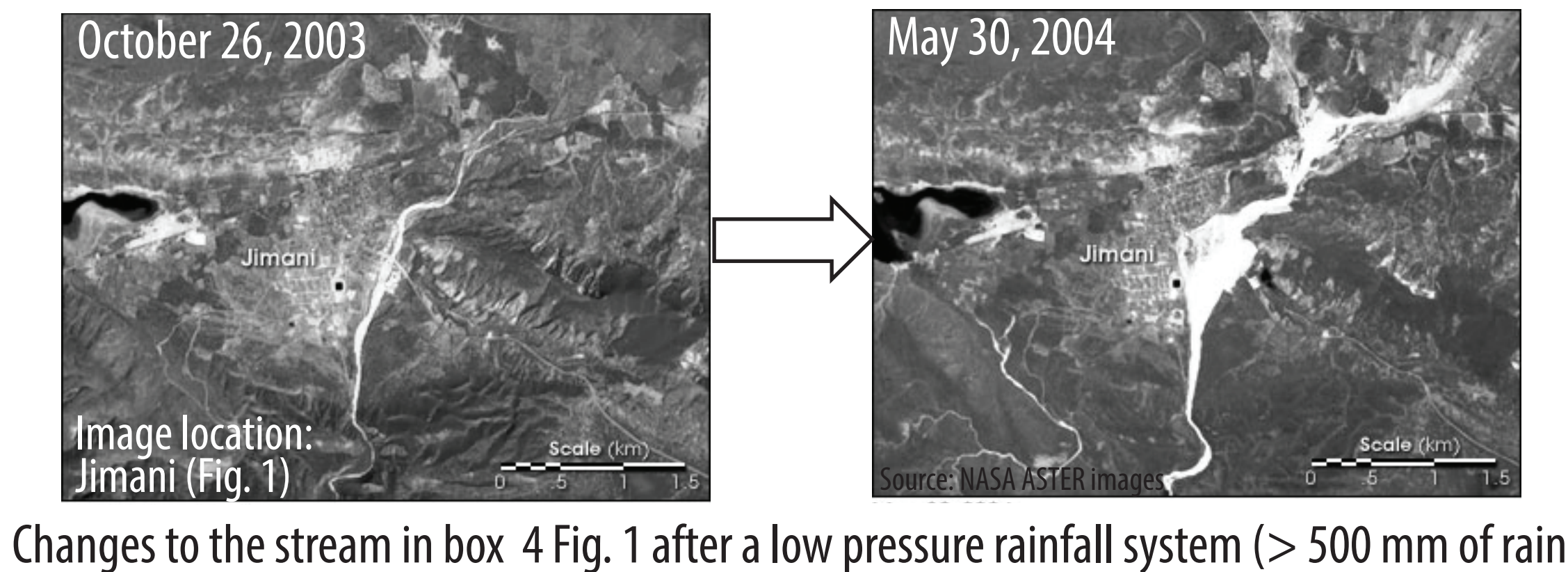


Hypothesis: Since stream 9 a/b has been deepened and widened, Lake Enriquillo should, to a certain stream width to depth ratio threshold, see significant increases in the volume flux rate of water from the stream.

Lake Enriquillo is now (since 2010) connected to a new or reactivated stream (Fig. 10) that formed along the location identified by box 2, Fig. 1.

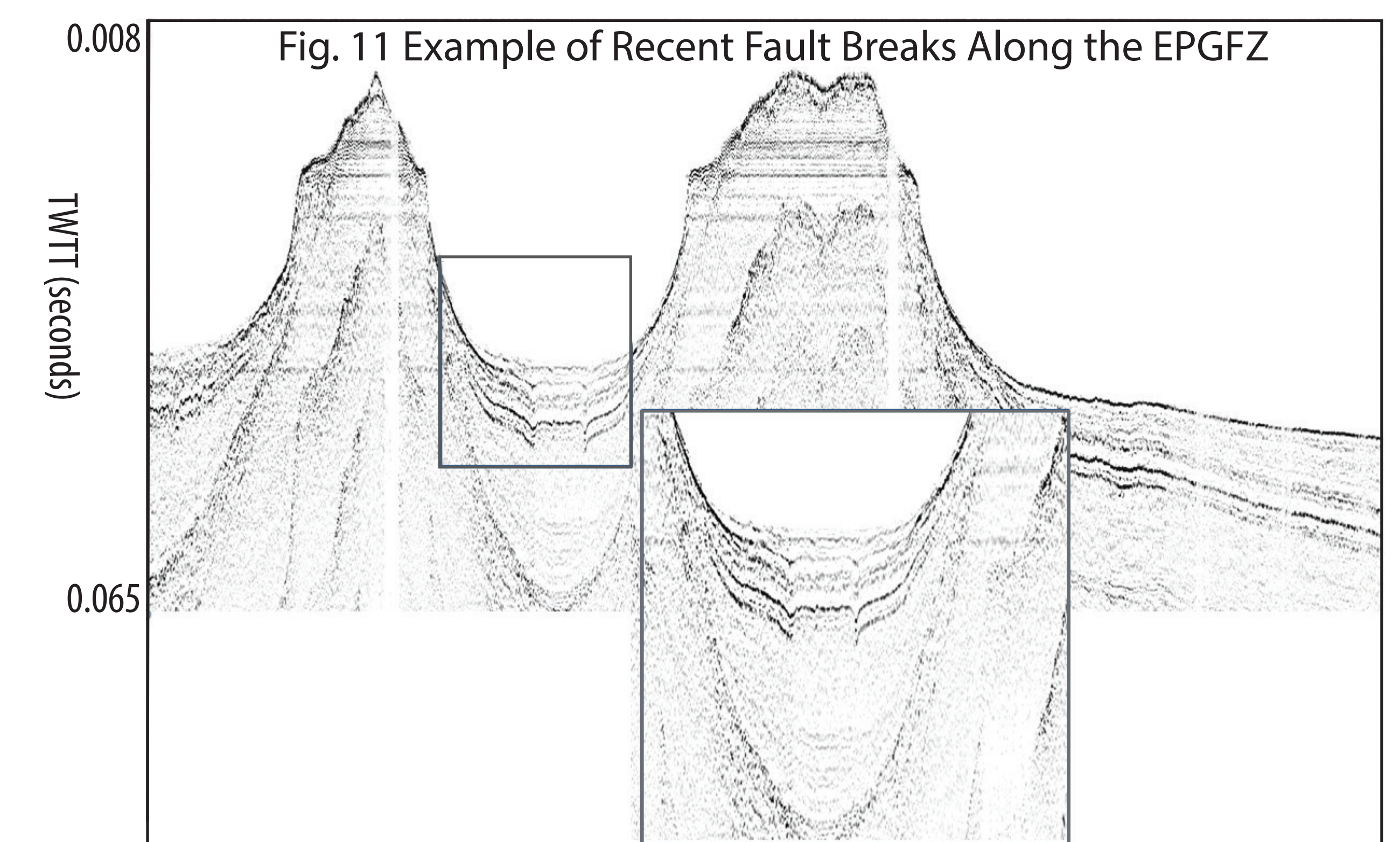
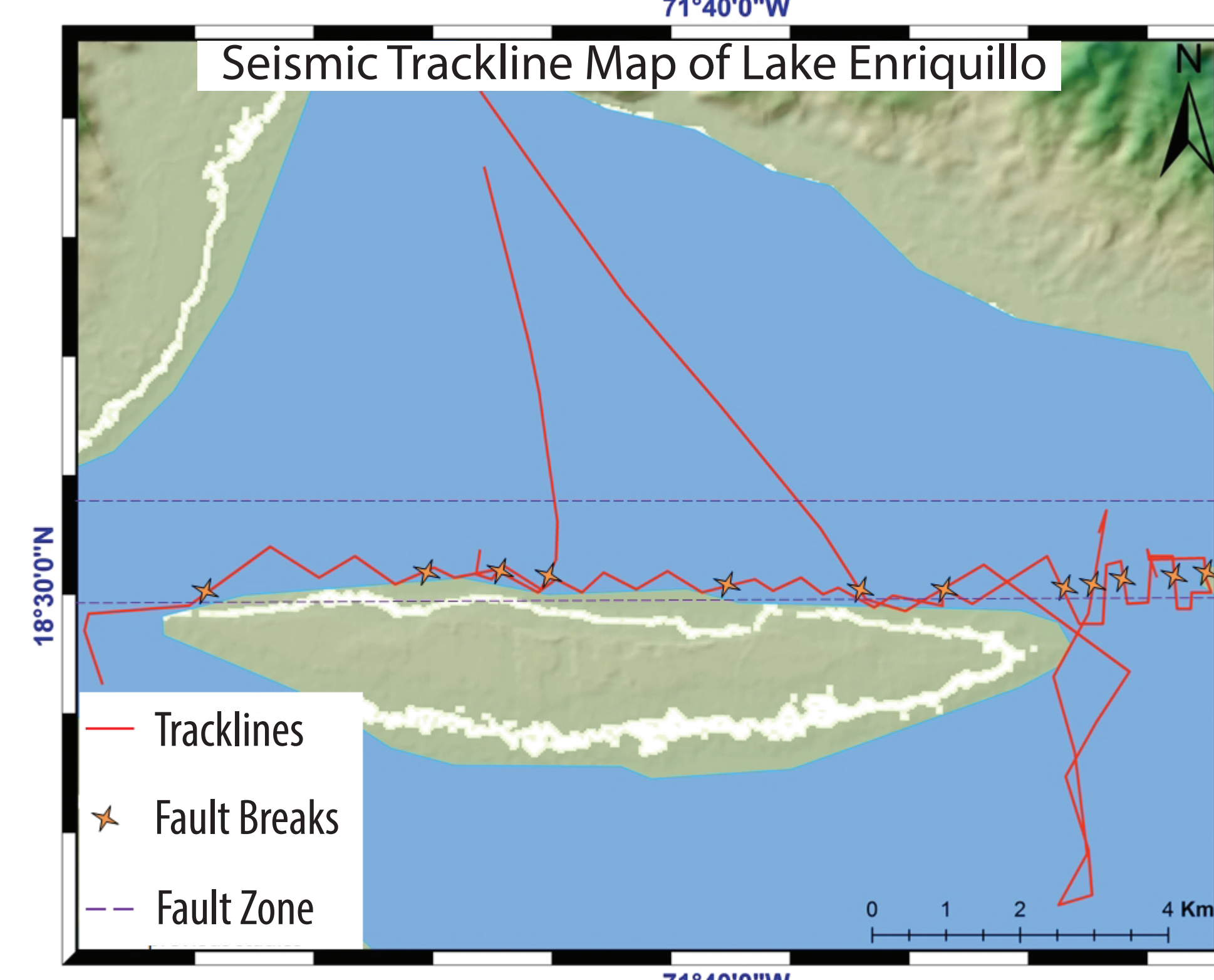


Fluvial geomorphic changes correlate closely with large rainfall events.



DISCUSSION - TECTONIC ACTIVITY ALONG THE EPGFZ

Seismic images reveal recent breaks along the EPGFZ (Fig. 11). Long term activity along this fault system may affect the bathymetry and water level of Lake Enriquillo. Periods of anti-correlation between Lakes Enriquillo and Azuei may also be related to earthquake activity in the region (Fig. 6).



CONCLUSIONS

1. Not Weather Patterns Alone
 Changes to a wetter climate are unlikely to be the only cause of the recent 10 and 5 m rise in Lake Enriquillo's and Azuei's water levels respectively.
2. Fluvial changes affect the lakes
 Lake Enriquillo receives water from the largest river in the country (Rio Yacque Del Sur). Bed widening and increases in flux from this river play a role in lake level rises.
3. Sub-surface changes affect the lakes
 Lake Enriquillo may have intermittent hydrologic connections to Lake Azuei in Haiti, as shown by significant drops in Lake Azuei correlating closely with rapid rises in Lake Enriquillo.
4. Future Work: Constrain water budget
 Studies should better constrain the lakes' water budgets by further quantifying the potential volume flux rates of the identified water inflows and outflows into and away from the lakes.

ACKNOWLEDGEMENTS AND REFERENCES

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