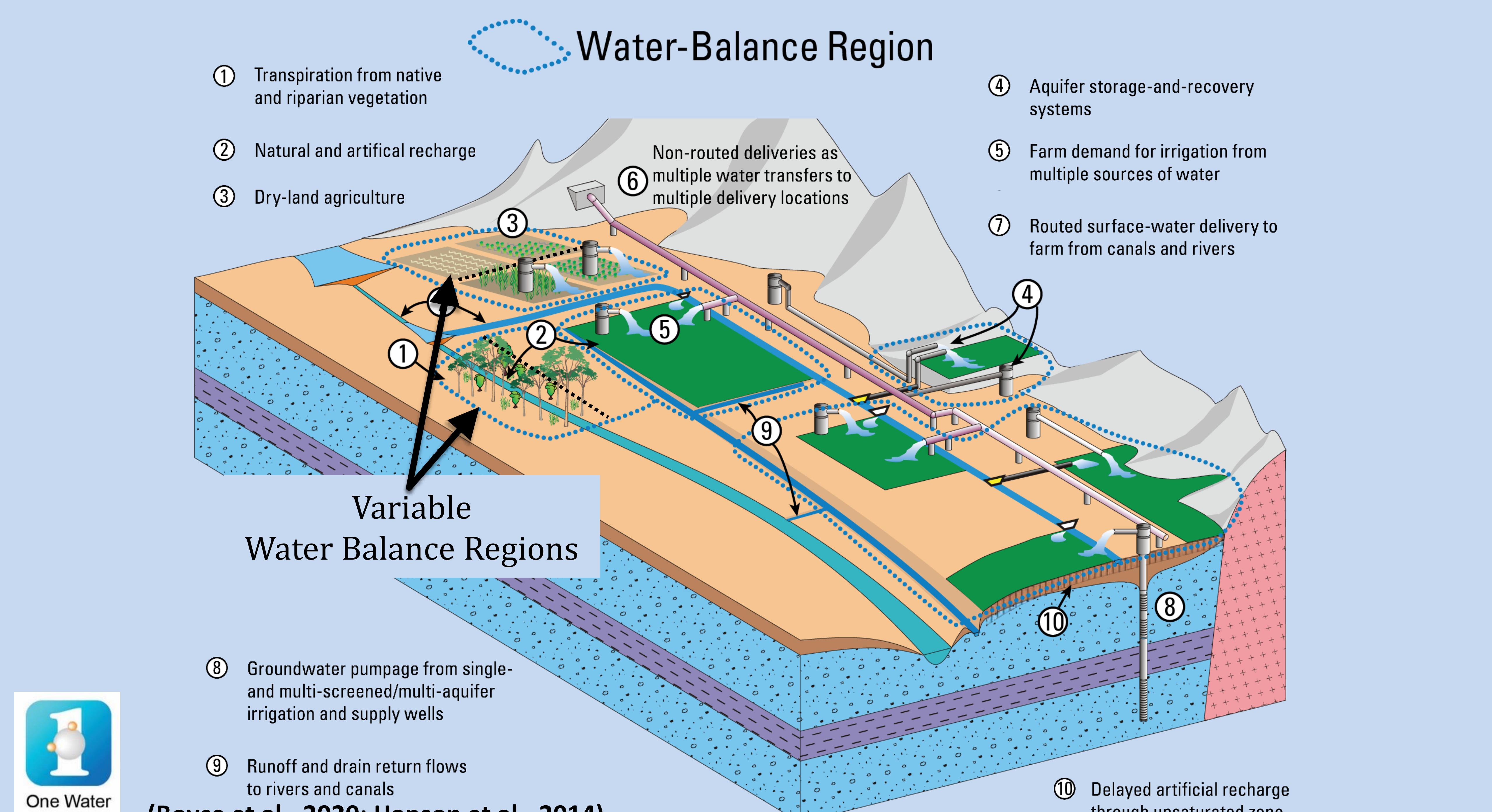
(1) Hydrogeological numerical models are built using geological, physical or chemical boundaries; can they integrate jurisdictional boundaries too? If yes, how? If not, why not?

One Water

- **Yes** ➔ Model codes such as **One-Water** can perform multiple levels of boundaries for hydrologic budgets that include jurisdictional boundaries. Plus multiple Budgets: “Water-Balance Subregions (WBS)” , GW, SW, Land, Climate, & Subbudgets (Wells Crops, etc). Layered approach in One-Water allows multiple levels of analysis. With Surface-water Operations (SWO) (Tightly-coupled Reservoir Operations) in One-Water the supply-and-demand framework also can include external supplies and demands.

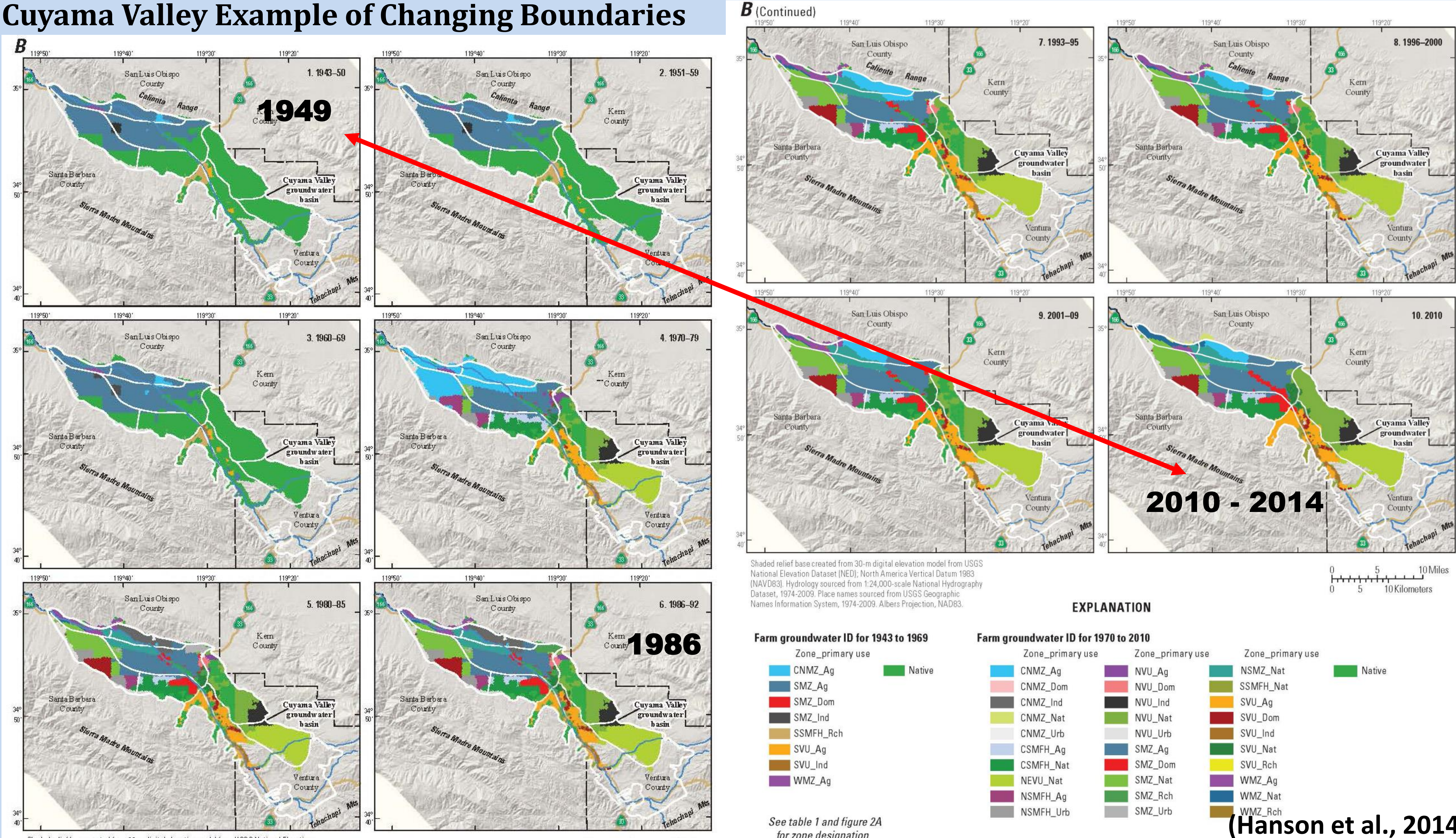
- Boundaries are dynamic and can change through time as land ownership, Supply/demand relations change, or jurisdiction boundaries change ➔ In Cuyama Valley example land ownership governed water use(Supply/Demand relations) that evolved (1950 – 2014) over ten different changes of WBS. Originally Valley was a Spanish Land Grant to the Ruiz family (still live in Santa Barbara Canyon) & was mostly sold to white ranchers with other parts homesteaded, & then progressively dissected into multiple farms & ranches changing the supply-and-demand relations through time.

- Rio Bravo Transboundary model example (RGTIHM) ➔Southern part of the Rincon Valley-Mesilla Basin-Conejos Medanos (53 of the 71 WBS) includes the Bateria (Wellfield), plus native & urban subregions in Mexico. WBS honored Groundwater/Watersheds plus International, State, and irrigation district and subregions within the irrigation districts that receive different sources of water.

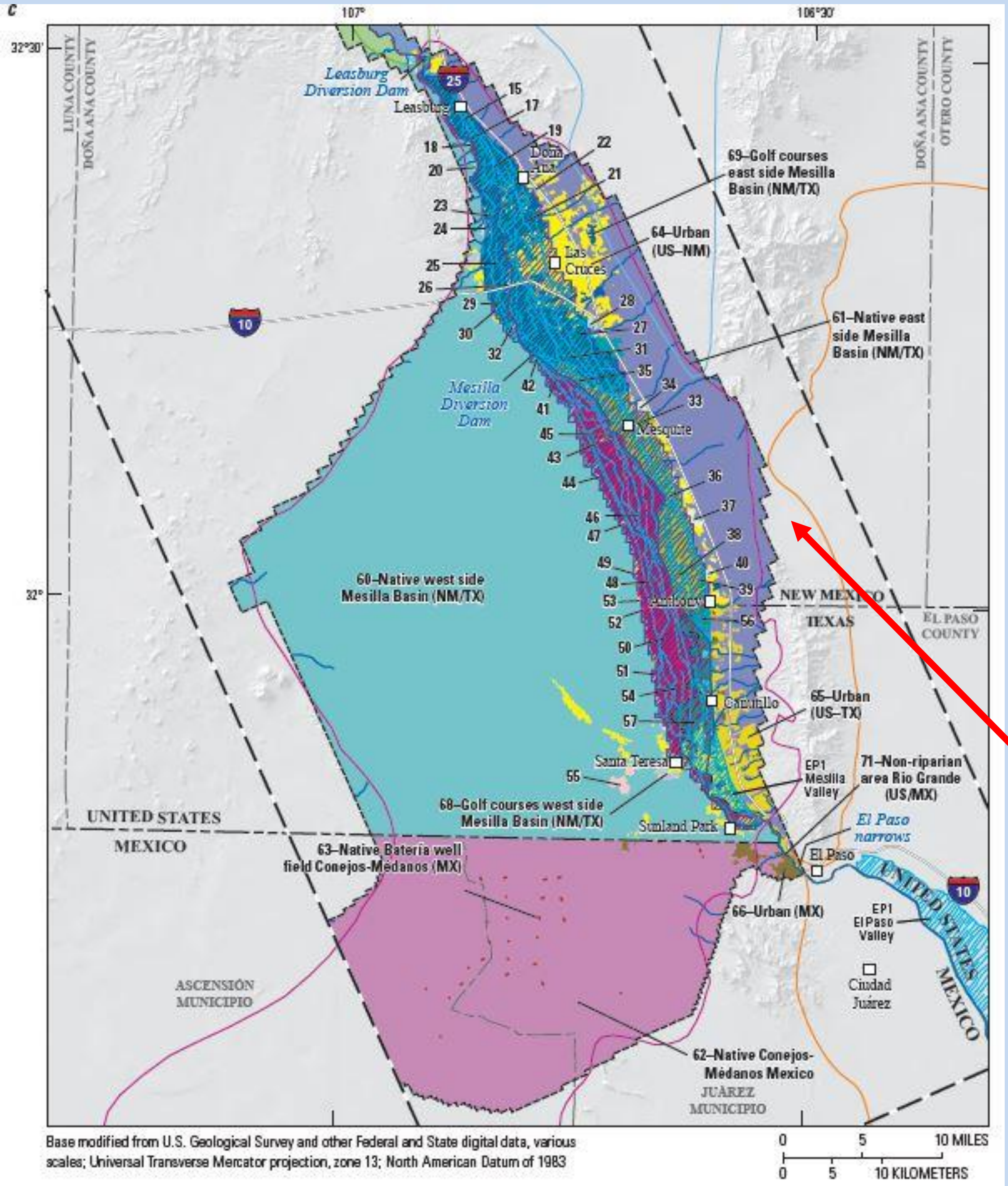


(Boyce et al., 2020; Hanson et al., 2014)

Cuyama Valley Example of Changing Boundaries



(Hanson et al., 2014



RGTIHM Transboundary Model

71 Water-Balance Subregions (WBS) needed for Supply-and-Demand Simulation Based on the lands with common supply sources

Rincon Valley, New Mexico, USA

18 WBS

Mesilla Basin, USA (New Mexico & Texas) & northern Conejos-Medanos Basin, Chihuahua, MX

53 WBS

(Hanson et al., 2020)

One Water

(2) Name the top three challenges encountered in building a numerical model of an aquifer shared by two or more countries. Explain your choices.

One Water

- **Data Sharing ➔** Digital, Georeferenced, **accessible data for "Self-Updating Models**." Includes Data-sharing Protocols (different agencies are data collectors/compilers)➔ Linkages ➔ locations, methods, & frequency of data transfers, data QA/QC, automated links to land-based data networks (plus filtering) & remotely sensed data products/analysis.

- **Input/Observation Data ➔** Climate, Reservoir Operations, Well Pumpage/Well Info (Muni/Industrial, Domestic, Agricultural), Groundwater use, Streamflow/Diversions, Land Ownership, & LAND USE (monthly-annual), Water use/sources, & Crop Production

- **Geochemical Data - Conceptual Framework/Transport ➔** Geochemical (Majors, Minors, Halogens (Salinity typing), Stable & Unstable Isotopes, Emerging contaminants (pharmaceuticals, pesticides/herbicides), Natural contaminants (ex As, Cr, nitrate), Field Temperature, EC, TDC, & DO. End-member samples also needed for mixing & transport analysis, as well as source age and movement analysis too.

Layered Hierarchy & Workflow for "Self-Updating Models"

Smart Farms, Houses, & Factories → ***Smart Agriculture, Cities, Industry, & Reservoirs***

(Land/Satellite/Drone Data Systems) ← **Smart Watersheds** ← **Smart Valleys**

Data Network Example: Distrito De Riego Del Rio Yaqui, Sonora, Mexico ➔ 530 Pozos, Presas, Suelo, Climatico, etc.

- Climate/Boundary Conditions
- Water Infrastructure/ Governance
- Land Use & Natural/Human Water Demands

→ One-Water Model

Self-Updating

Inputs/Observations

One Water

(3) What physical-chemical processes should be modeled that are specific to transboundary aquifers and useful for shared management?

One Water

- **Water Sources** ➔ Precipitation, Surface Water (Regulated/Unregulated), Groundwater, Recycled Water, Imported Water, Land Subsidence, Salinity Management, Desal
- **Coupled Flows** ➔ Groundwater-Surface-Water Interactions ➔ Surface-water capture & Delivery interference ➔ **Conjunctive Use**
- **Land Use** ➔ Land ownership, Land Use, Shared Supply (Water, Diversions, Ponds, etc), Formal infrastructure (canals, drains, diversions, wasteways), & Informal Supplies ➔ **Water Use & Land Use are Biggest Data GAPs Worldwide!!**
- **Climate Change/Variability** ➔ Effects on Land Use (Agriculture), Surface-Water, Reservoir Operations, & Groundwater **Sustainability**
- **Reservoir Operations** ➔ Linkage To Reservoir(s) with tight coupling between supply-and-demand between reservoir releases & keep track of deliveries/carry-over to multiple users and for multiple uses within a Watershed based on multiple operating rules for Agricultural, Municipal, Ecological flows + Flood Protection, Recreation & Off-grid demands. **Reservoir connections in IHM models needed for Lower Rio Grande, Colorado (Mexicali/Yuma/Gila/Imperial), Tijuana, & Rio Conchos)**
- **Salinity (Leaching)** ➔ **Loss of arable land, reduced productivity, salt accumulation**: Model Irrigation as mixture of irrigation waters plus additional water for leaching the soil/root zone for salinity subject to salt tolerance of the crops, salinity of applied waters, salinity of groundwater, & level of leaching efficiency (***10 - >50% more water needed for leaching!!***)

Salt Load: **Applying 1 ac-ft of water** with a total dissolved **salt concentration of 735 ppm** would potentially add **1 ton of salt to an acre of crops** (Cahn and Bali, 2015)

Lost Productivity: Estimates of **reduced productivity ranged from 6 to 17 percent** with about 42 percent of 122,000 measured locations over a 9-year period exceeding the salinity threshold for the **agricultural lands of the Lower Arkansas River Valley**; Colorado intensively farmed for over 120 years (Morway and Gates, 2012).

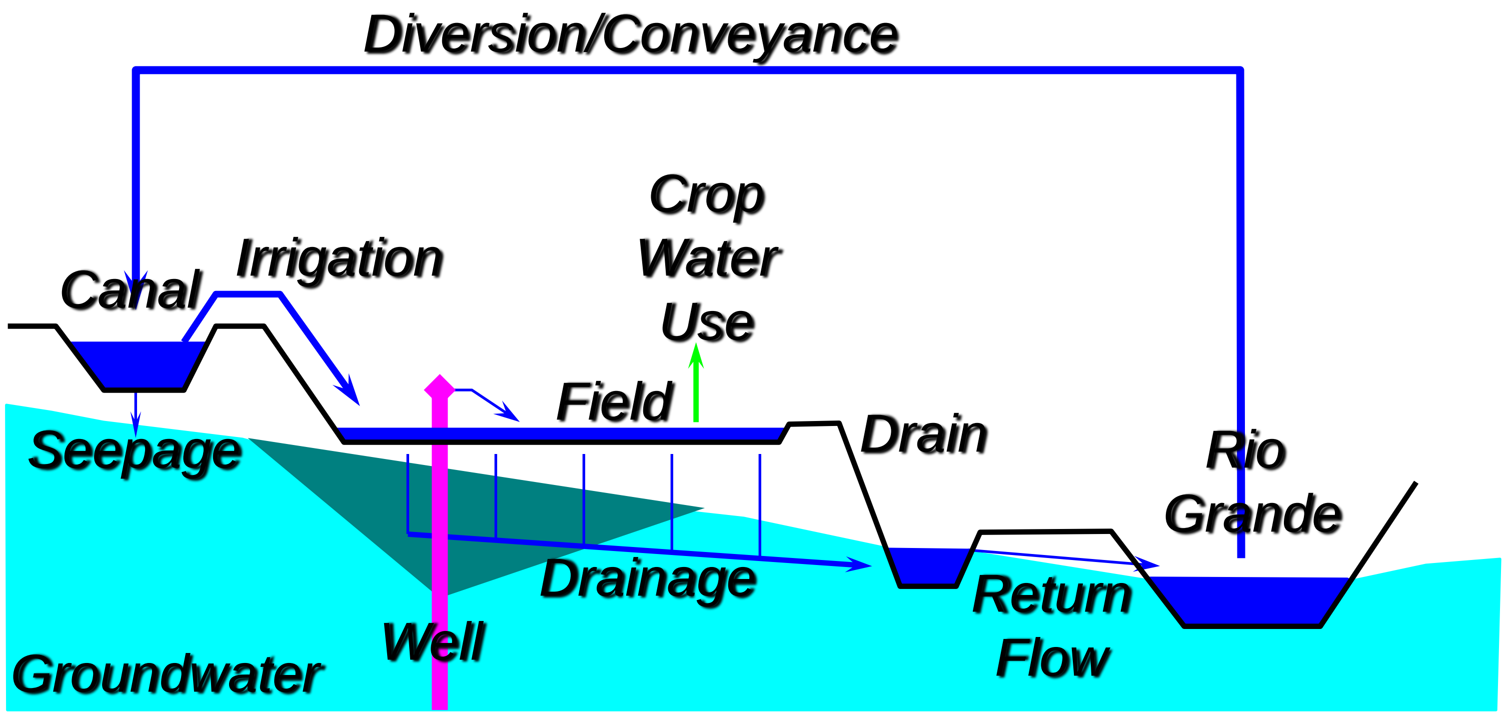
Secondary Effects: Perched aquifer water of the Oxnard Plain saltier than seawater from accumulation of Irrigation percolation **(Failed wells & Aquifer cross contamination)**

Salinity in US-Mexico Transboundary ➔ Lower Rio Grande, Hueco Bolson, Mimbres Basin, Colorado River & TJ

Groundwater-Surface-Water Interactions

Lower Rio Grande Problem: Release to diversion hydrology altered by groundwater pumping in New Mexico

One Water

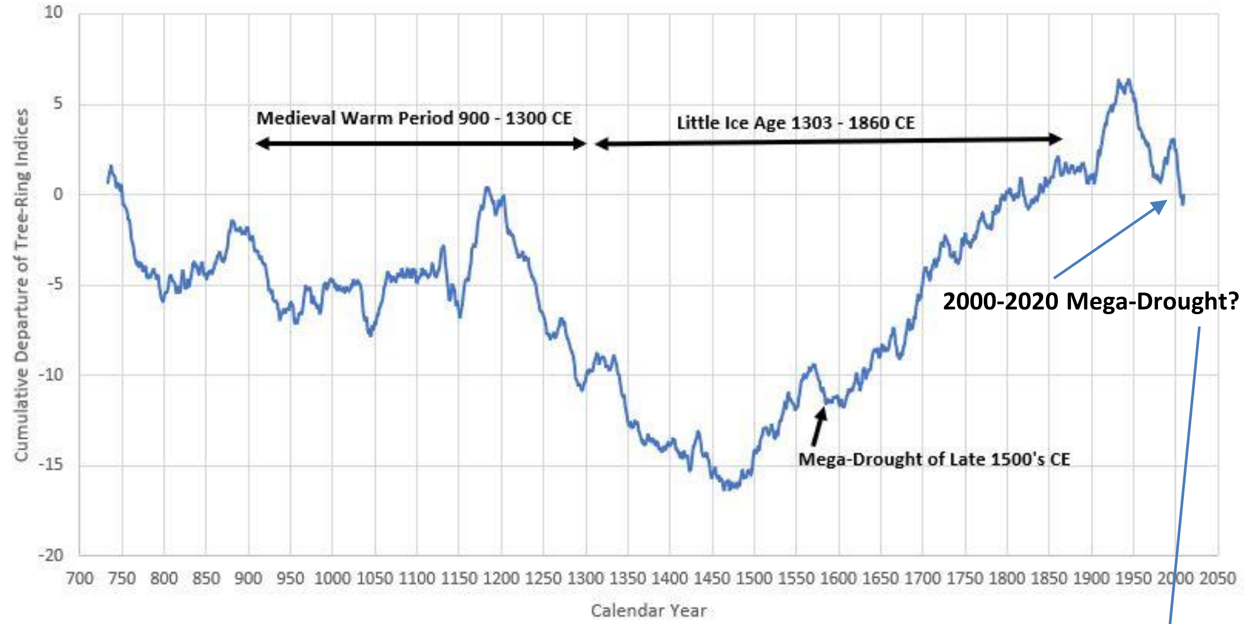


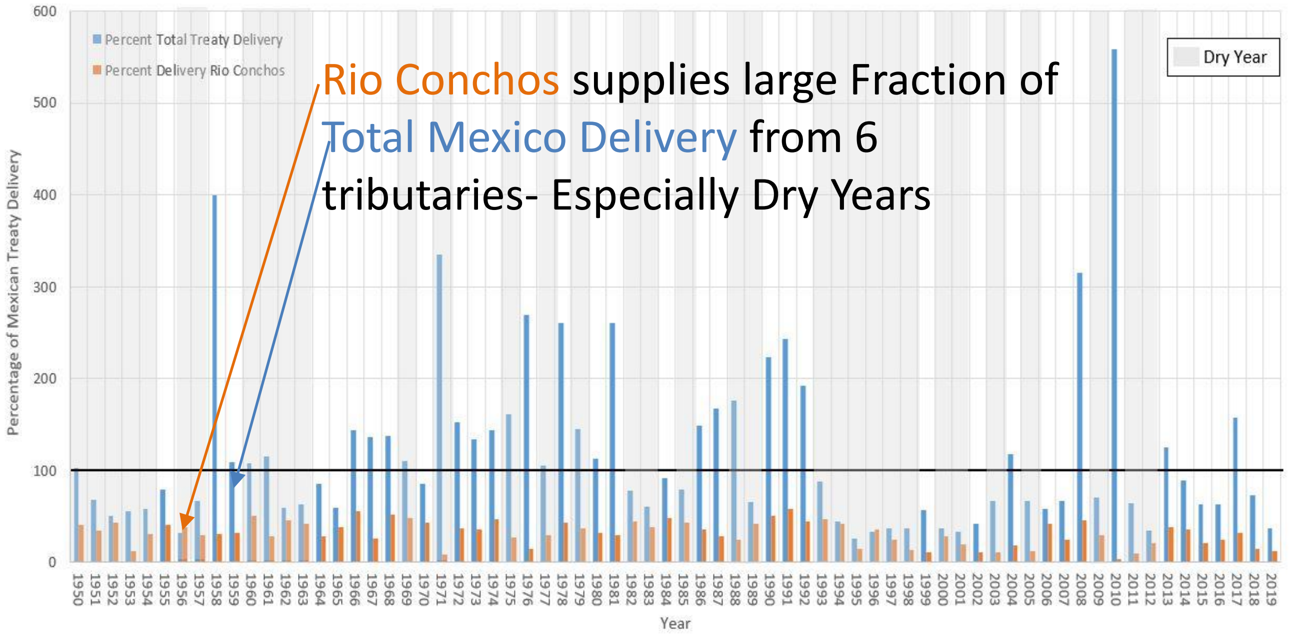
Climate Change/Variability – Rio Conchos

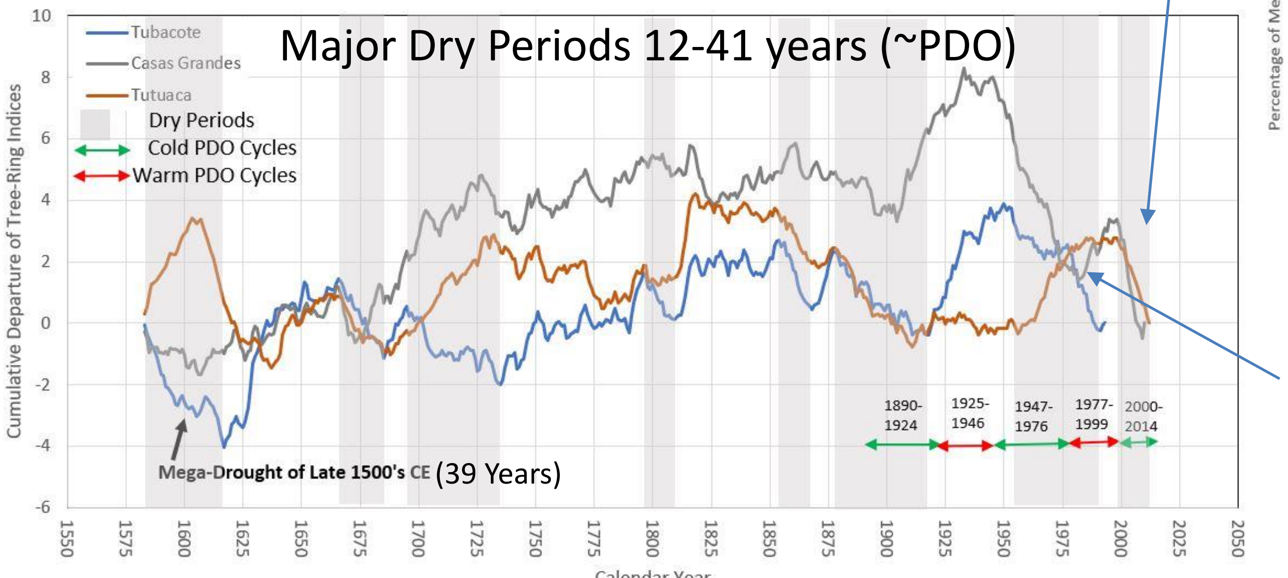
One Water

Climate variability and evaluation of transboundary reservoir supply for water sustainability in Chihuahua, Mexico

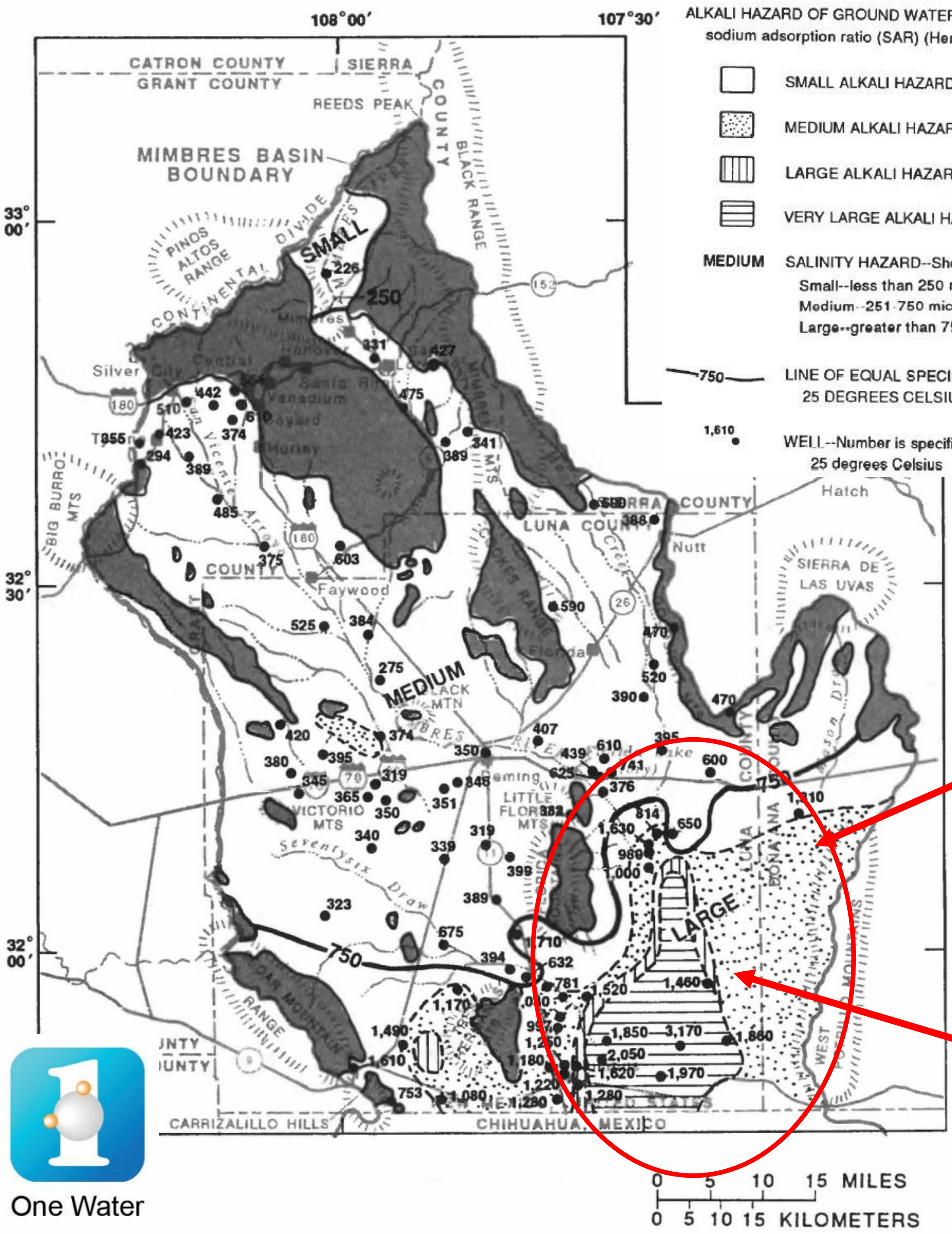
By Dra. Marusia Renteria Villalobos & R.T. Hanson (2020, In Review, Journal of Hydrology)

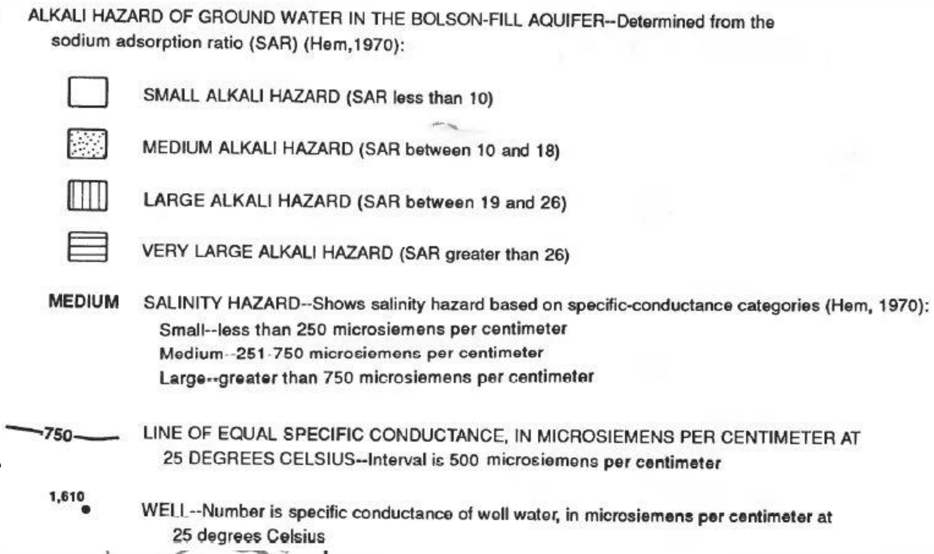


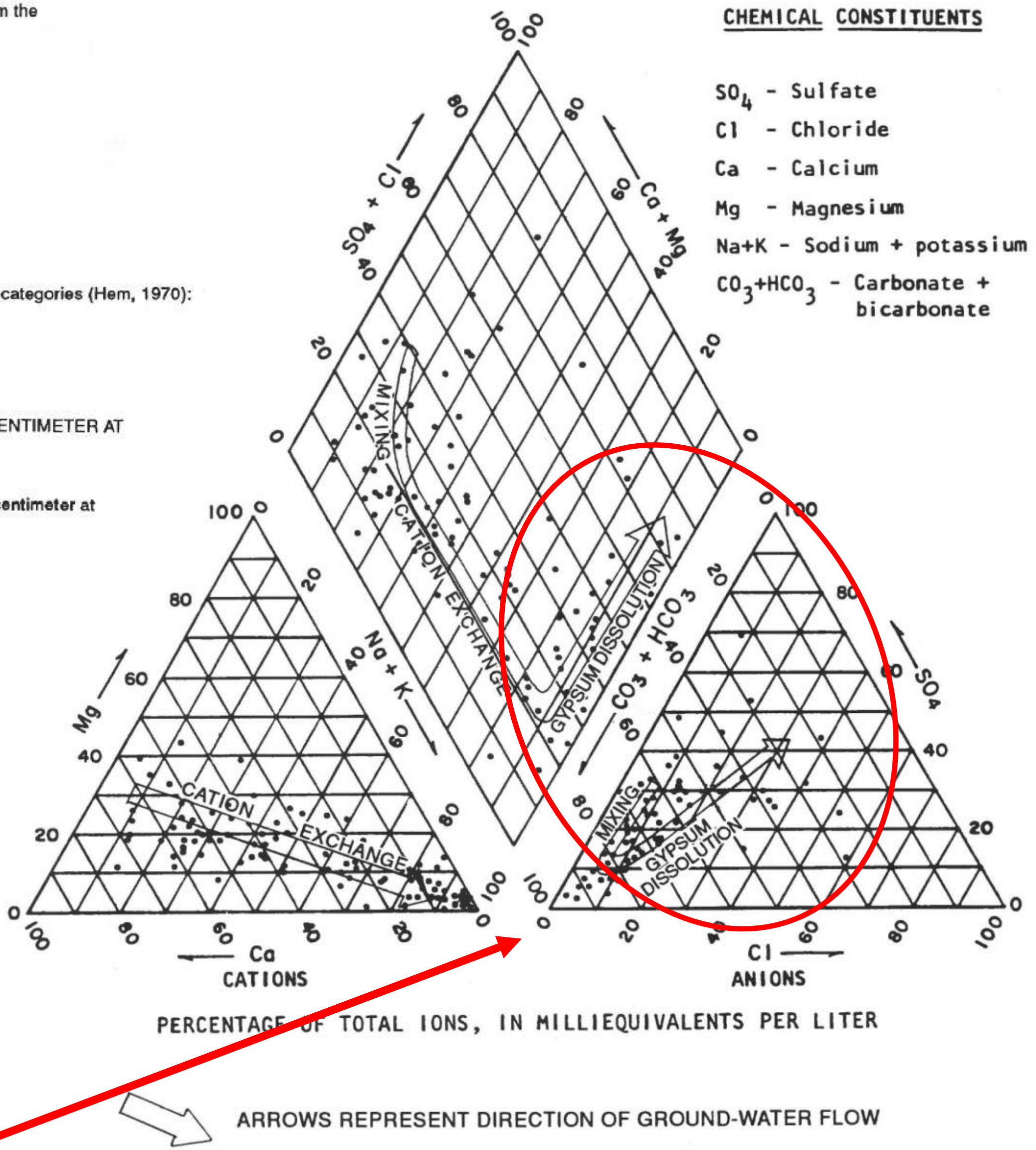




Climate affects Treaty Deliveries and Supplementary Groundwater Use ➔280 wells installed during 1994-95 when La Boquilla and FIM reservoirs were closed to irrigation-water deliveries on Rio Conchos





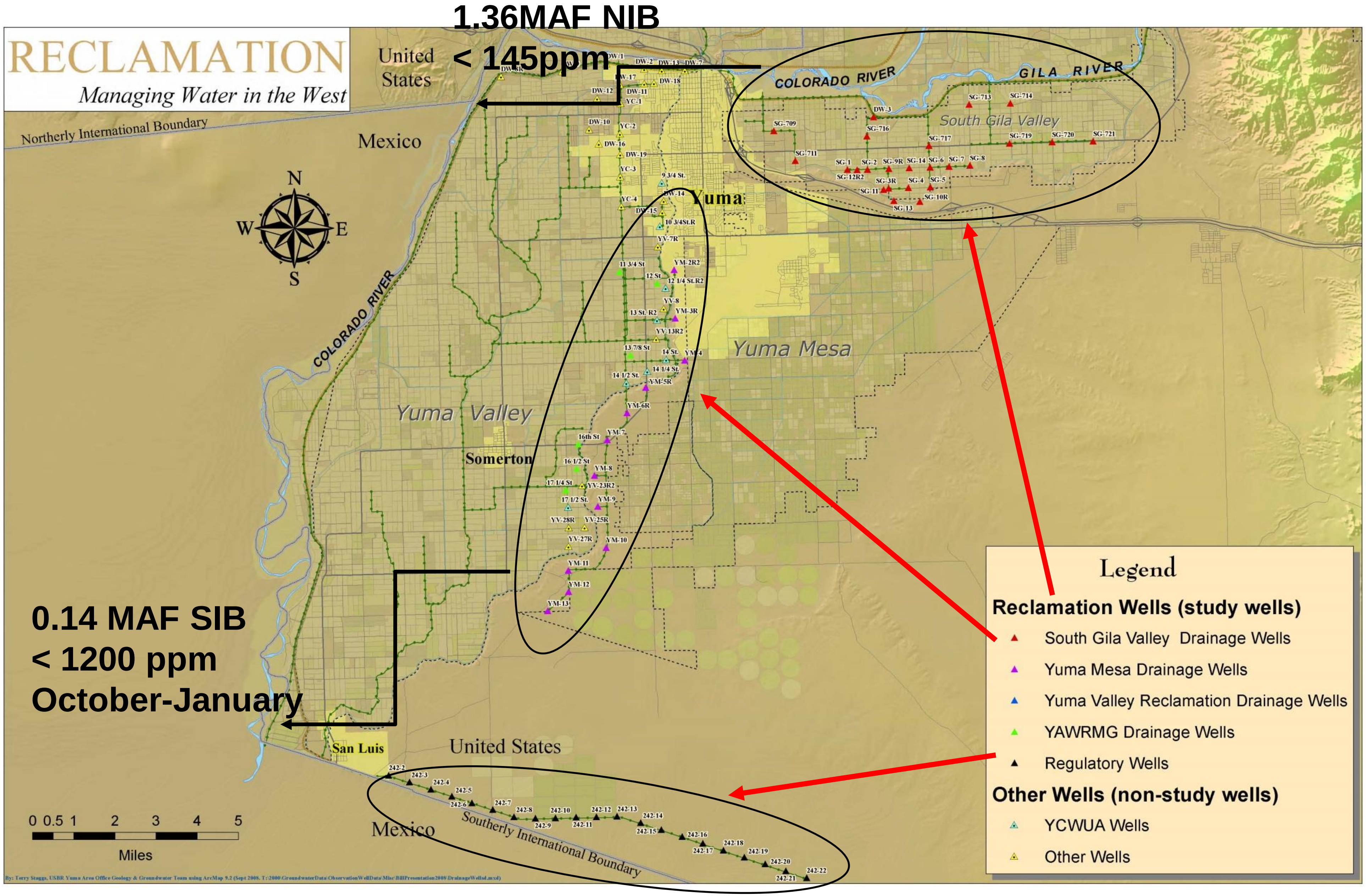


High Sodium Adbsorption Ratio (SAR >26) Salinity Hazard (>750 uS/cm)

Abandoned Agriculture: Transboundary Mimbres Basin from Saline Groundwater ➔ Closed Basin since 1976 in NM (NM-SEO) (Hanson et al., 1994)

One Water

YUMA US-Mexico Colorado River Optimization – Saline GW Replacement



USBR ➔ Replacing Colorado River Water Deliveries with Saline Groundwater from Yuma and Gila River Valleys

(4) Provide a real example of a transboundary aquifer model anywhere in the world that has been successful as a management tool, an information tool, or a data-integration and harmonization tool. Or all of the above.

One Water

RGTIHM: Rio Grande (Rio Bravo) Transboundary IHM (Hanson et al., 2020) & previous LRGFMP2011 model (Hanson et al., 2013)

(1) USBR Environmental Impact Statement (EIS) of Lower Rio Grande Operations & related operating Transboundary agreement (USBR, EBID, & EP1) (USBR, 2016; Ferguson et al. 2015),

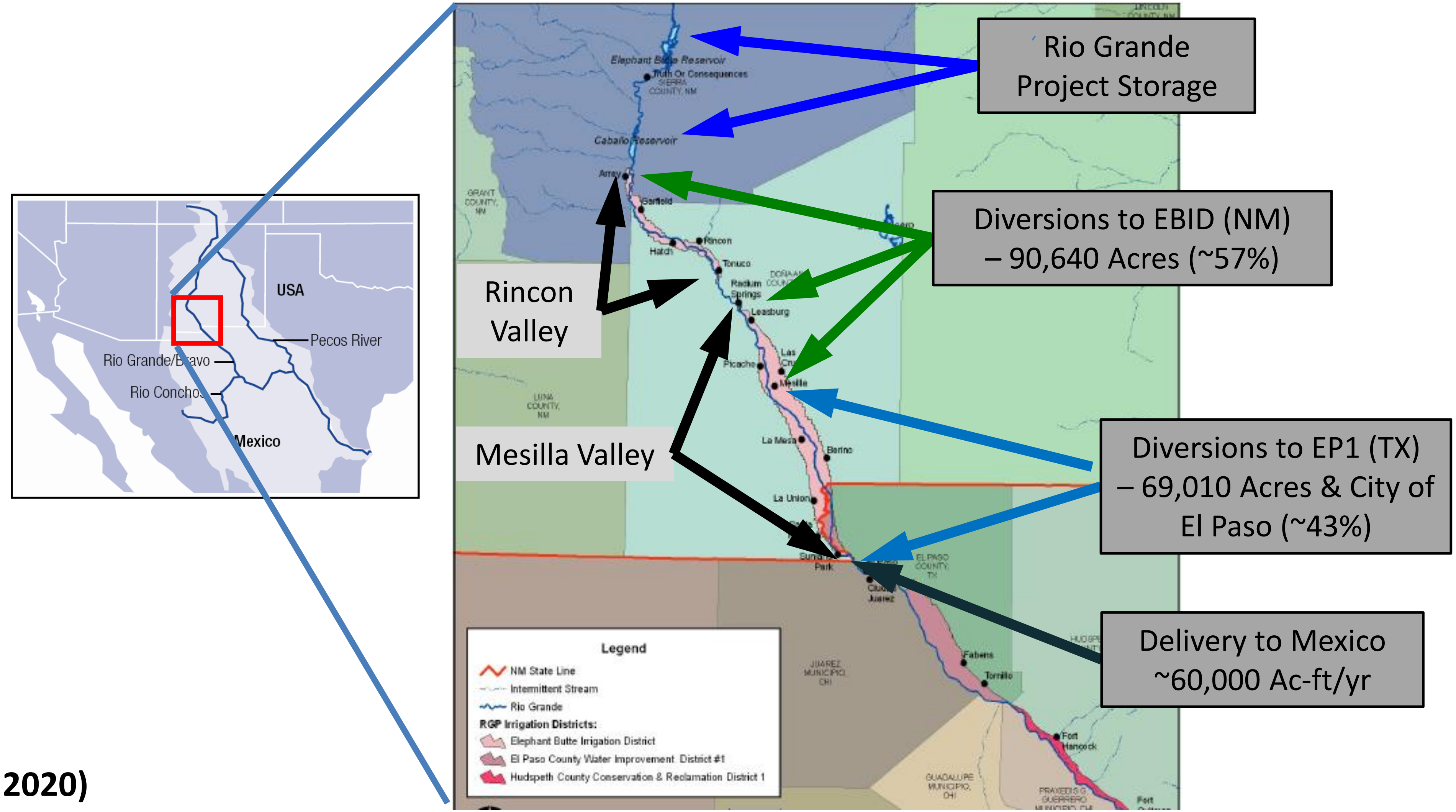
(2) Developed by TAAP to demonstrate transboundary application (Hanson et al., 2013)

(3) Developed for future USBR Operations and litigation support for two U.S. Supreme Court Cases (NM vs USBR & TX vs NM) and mitigation analysis/future operations

(4) No data cooperation from JCAS, JMAS, CILA, or CONAGUA even with TAAP (IBWC/CILA) data-share agreement.

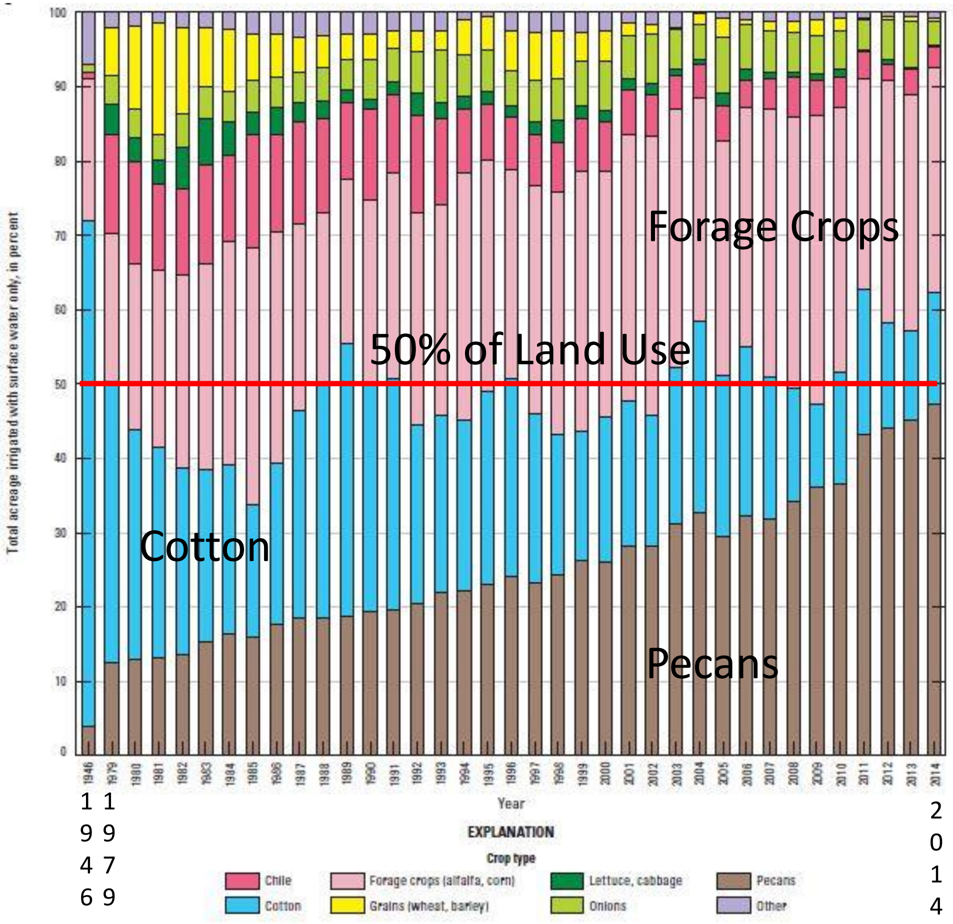
(5) USDA Water-Use Project could use this modern model…stay tuned?

U.S. Bureau of Reclamation - Rio Grande Project

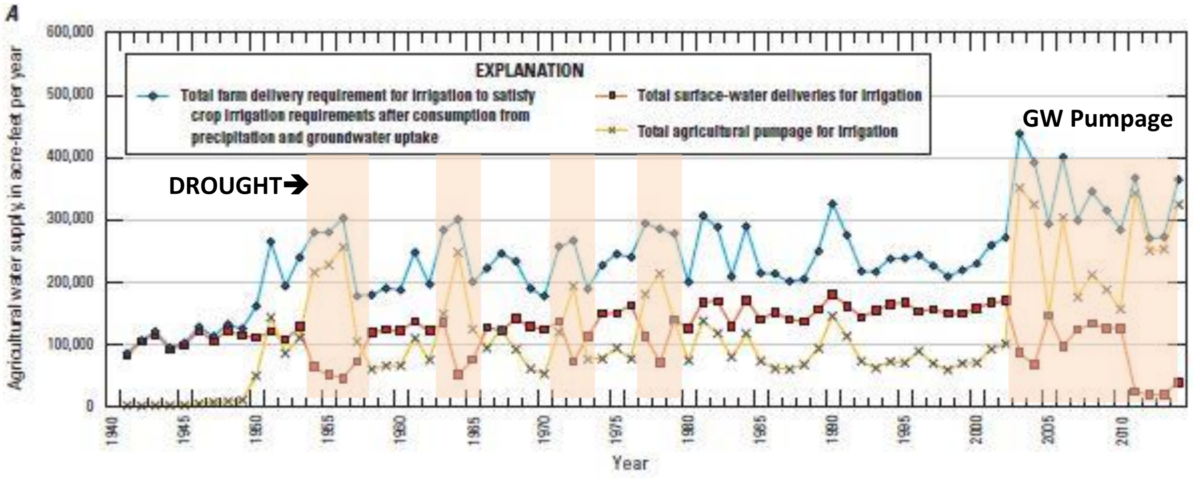


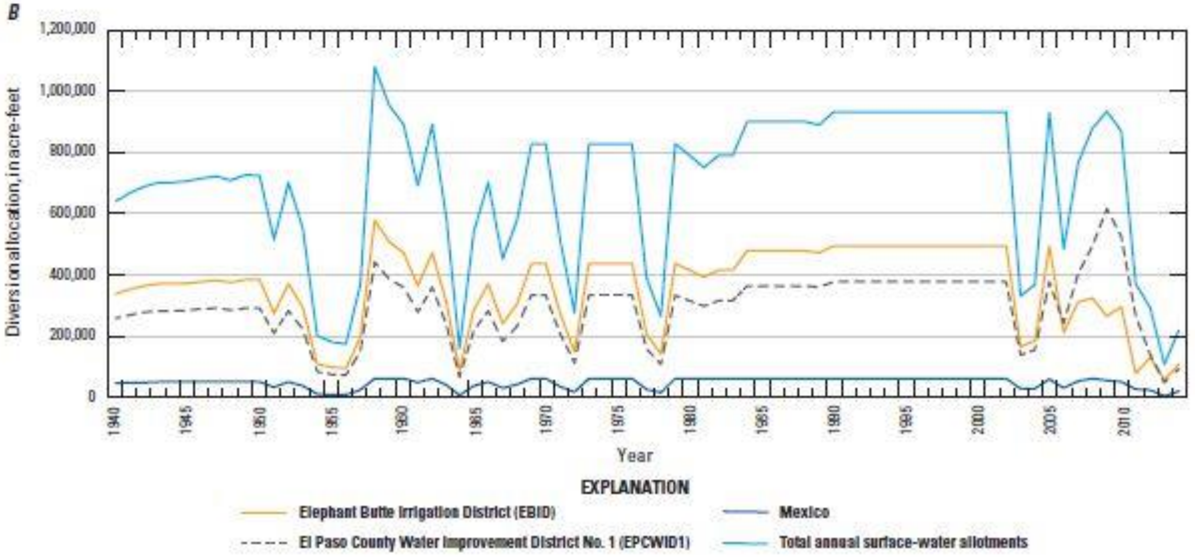
(Hanson et al., 2020)

One Water



Increased Water Demand & "Hardening of Demand" with shift to more Pecan Orchards

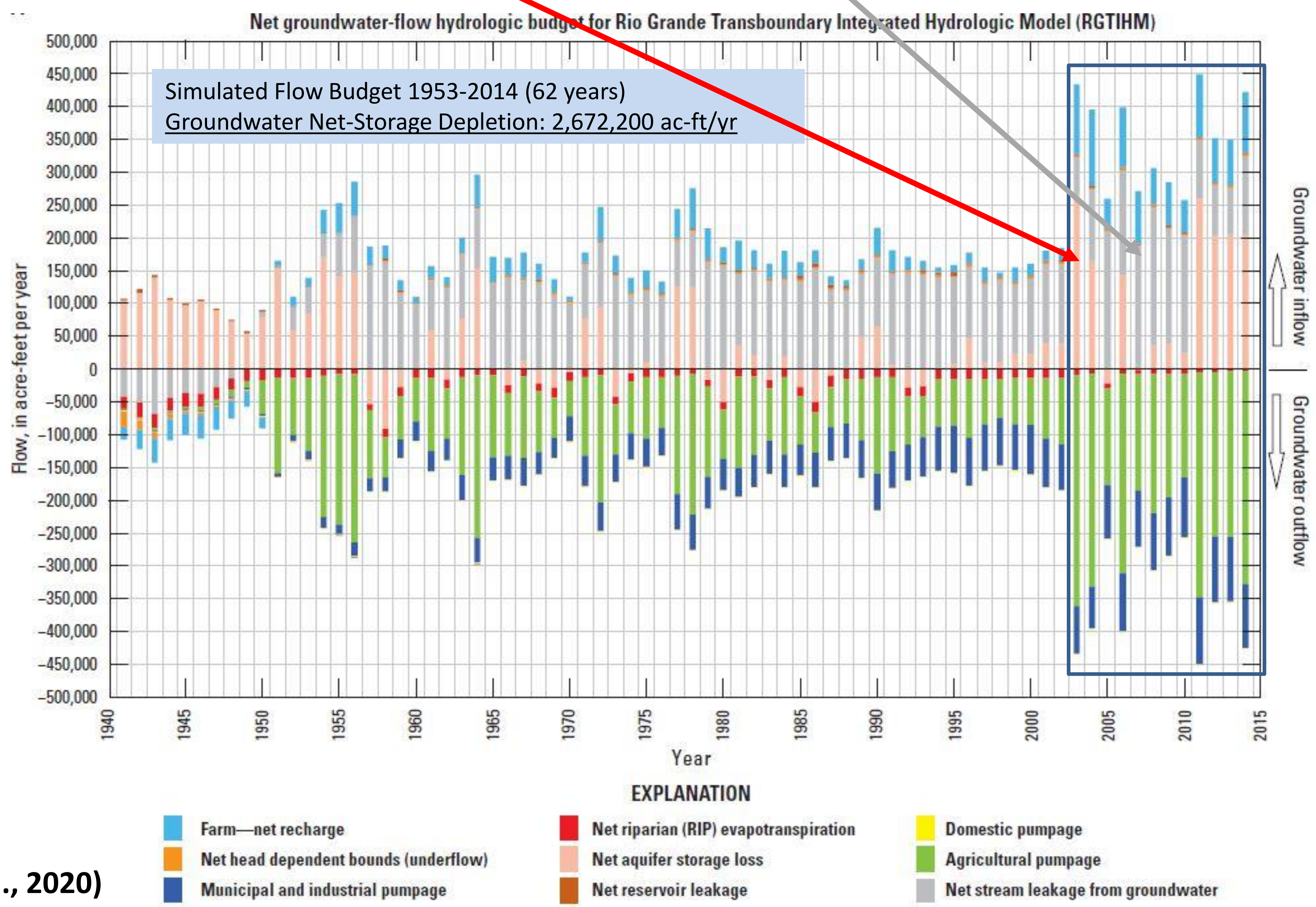




Increased Total Farm Delivery Requirement (TFDR) & Groundwater use in dry years with less surface-water allocations from Reservoir

(Hanson et al., 2020)

GROUNDWATER BUDGET: Storage Depletion & Streamflow Capture: cyclic and sustained 2003-2014



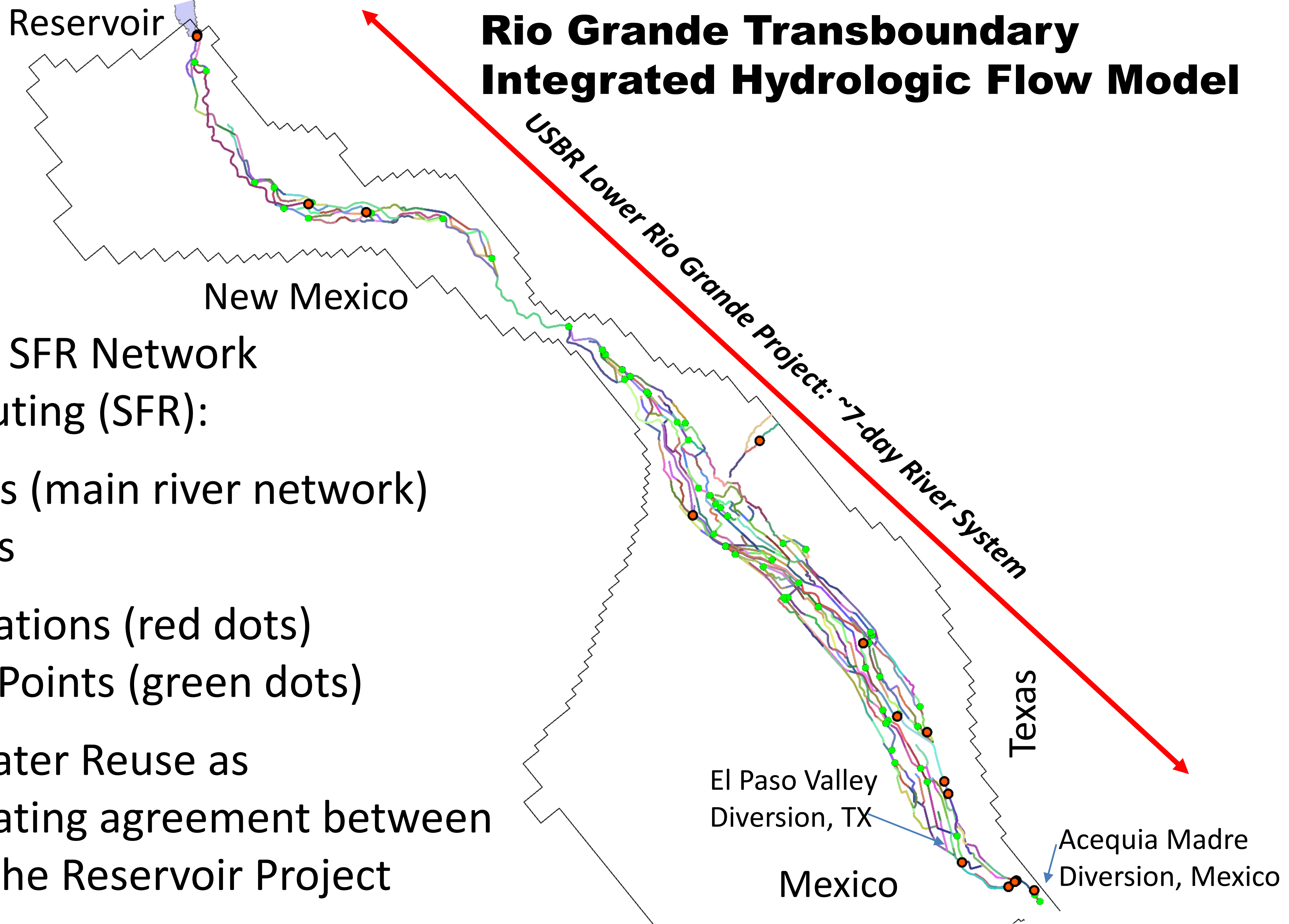
(Hanson et al., 2020)

One Water

Rio Grande Transboundary Integrated Hydrologic Flow Model

One Water

(Hanson et al., 2020)

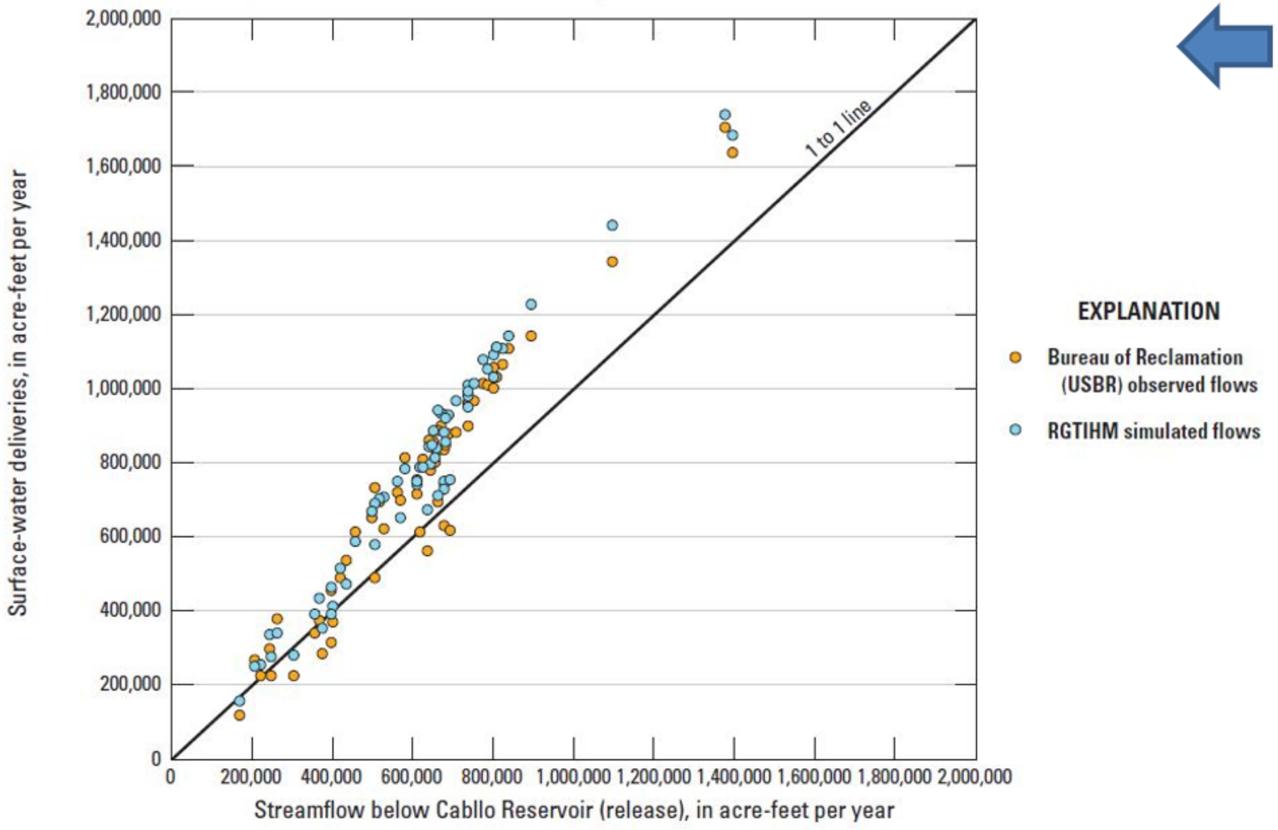


RGTIHM's Valley SFR Network
Stream Flow Routing (SFR):

- 478 Segments (main river network)
- 6,344 reaches
- 16 Inflow locations (red dots)
- 71 Diversion Points (green dots)
- 20 to 30% Water Reuse as part of the operating agreement between Districts within the Reservoir Project

One Water

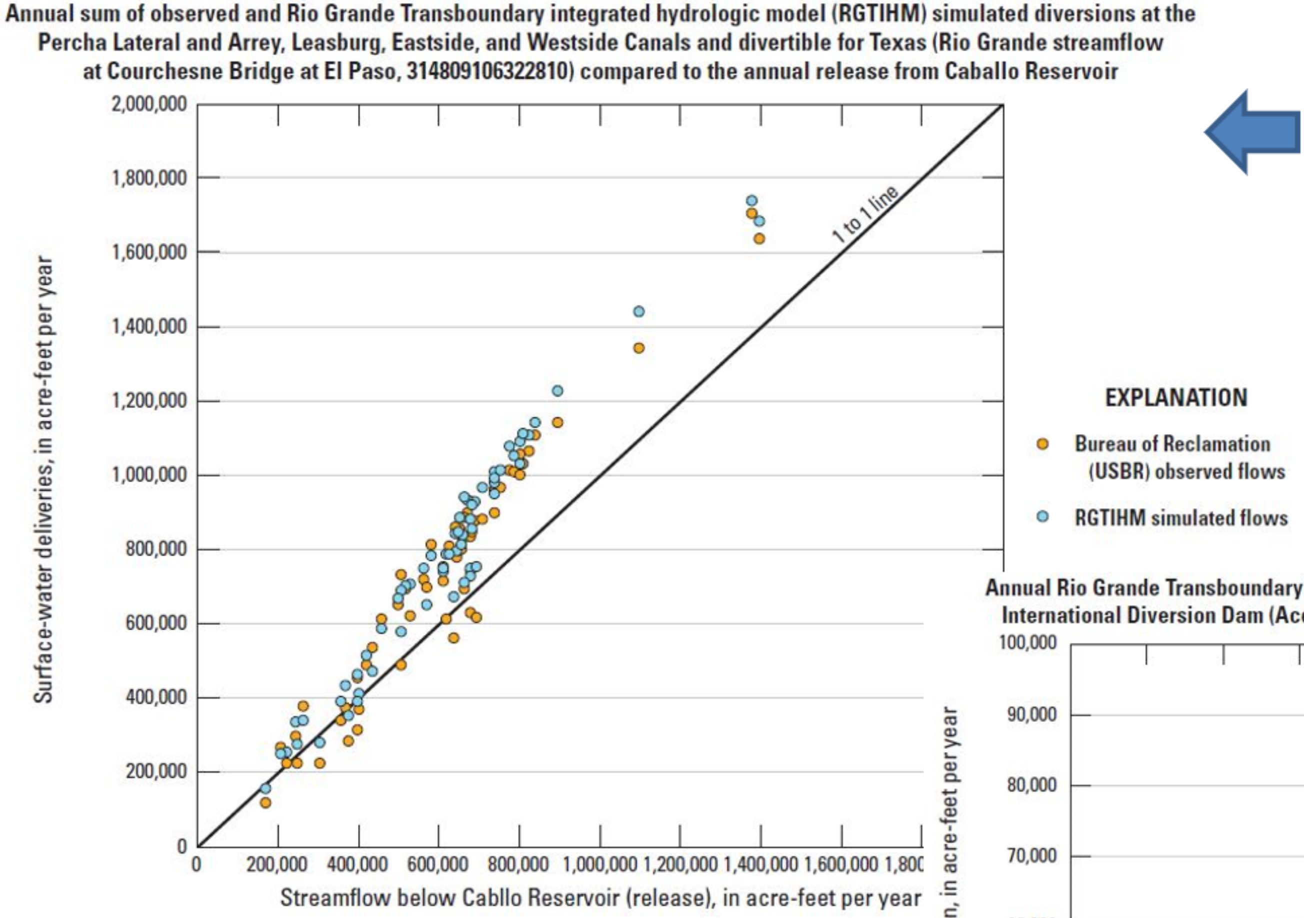
Annual sum of observed and Rio Grande Transboundary integrated hydrologic model (RGTIHM) simulated diversions at the Percha Lateral and Arrey, Leasburg, Eastside, and Westside Canals and divertible for Texas (Rio Grande streamflow at Courchesne Bridge at El Paso, 314809106322810) compared to the annual release from Caballo Reservoir



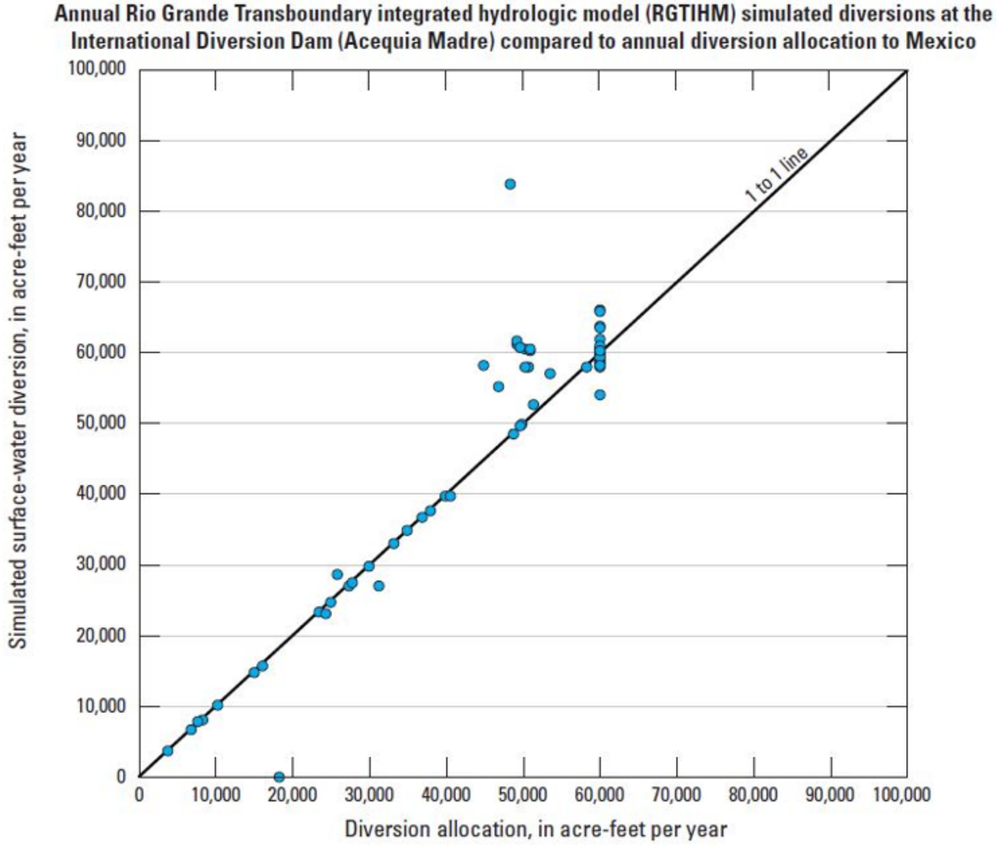
Operational Flows vs Divertible Water: Approximates reported relation➔ Deliveries>Releases (Reuse of Surface Water)

One Water

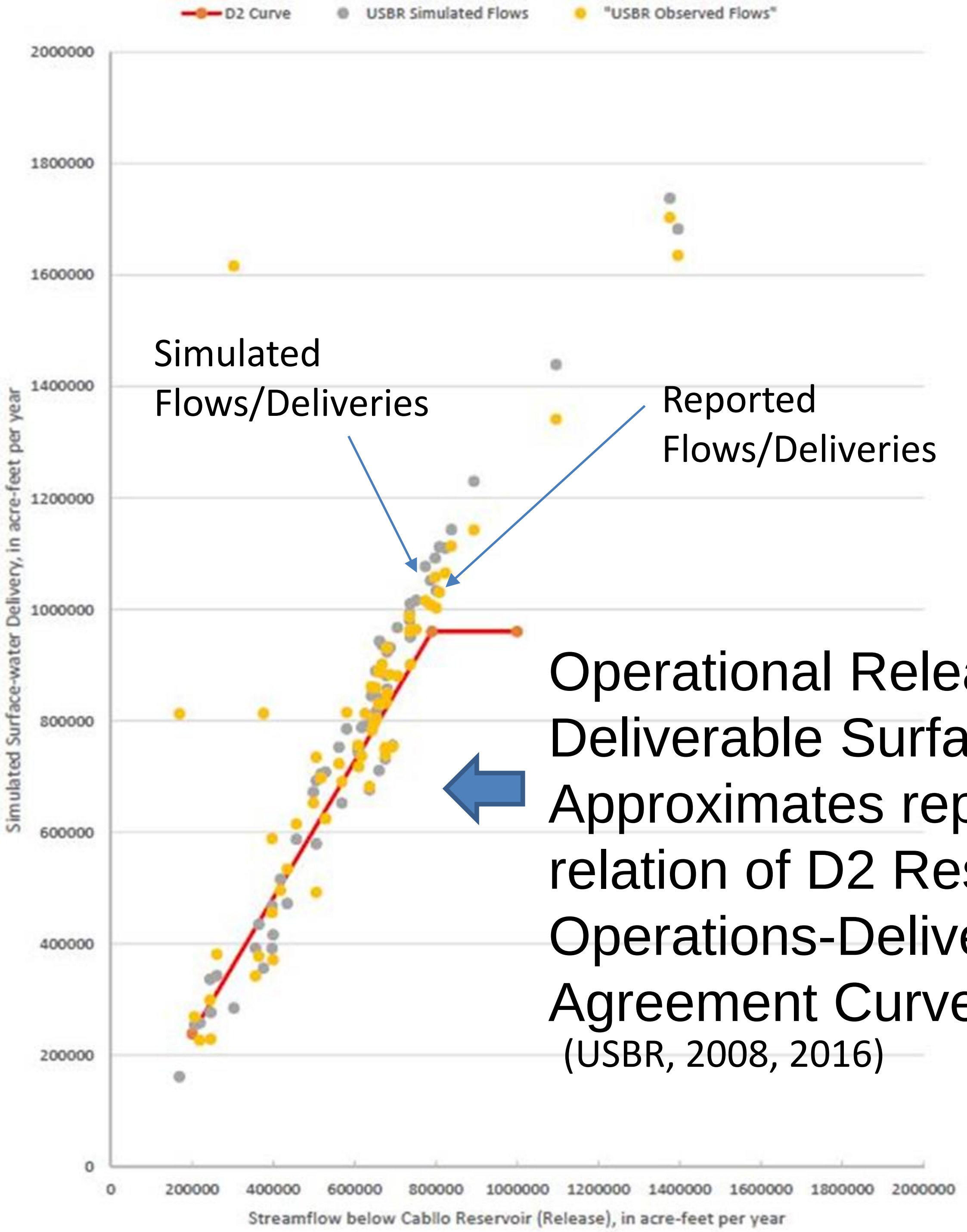
Operational Flows vs Divertible Water: Approximates reported relation➔ Deliveries>Releases (Reuse of Surface Water)



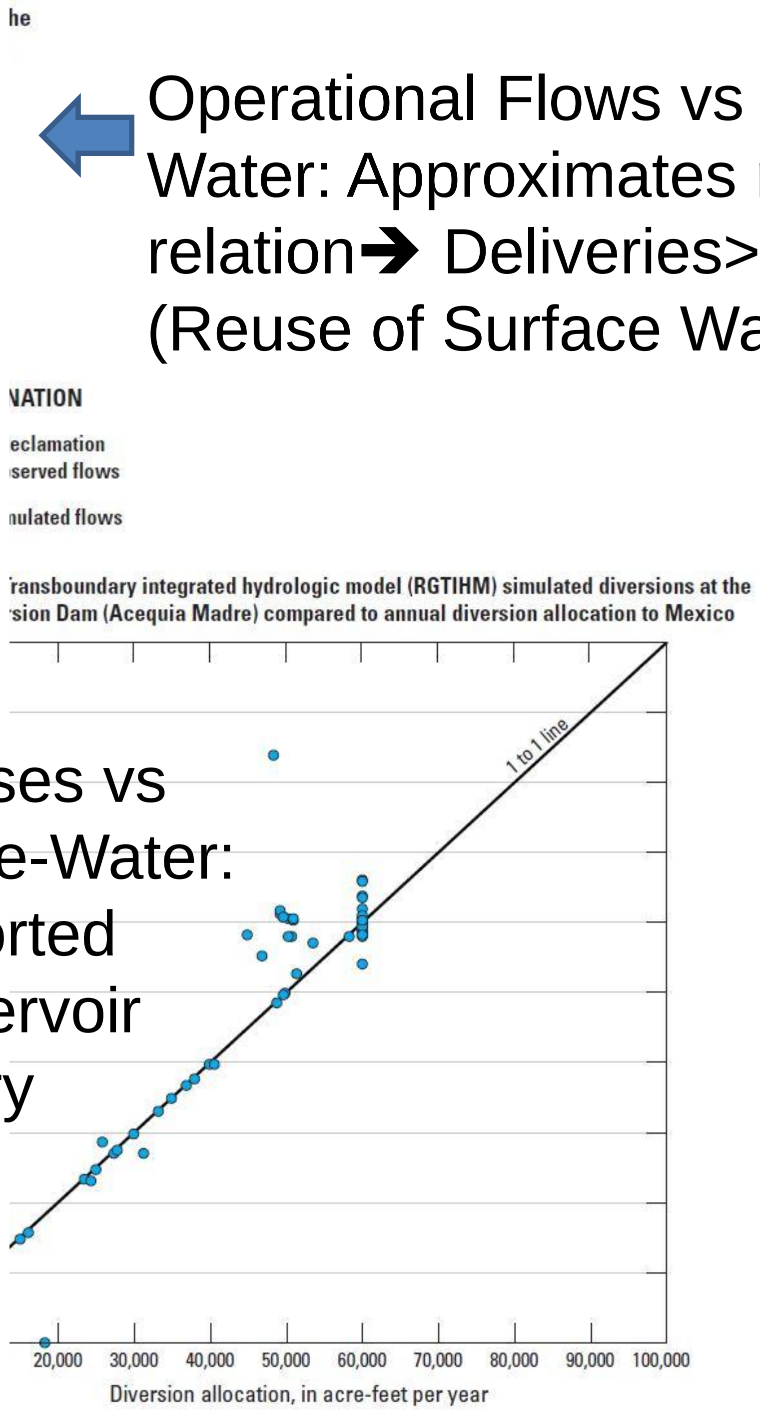
Treaty Deliveries to Mexico: Generally honors or exceeds all deliveries



One Water



Operational Flows vs Divertible Water: Approximates reported relation ➔ Deliveries>Releases (Reuse of Surface Water)



Operational Releases vs Deliverable Surface-Water: Approximates reported relation of D2 Reservoir Operations-Delivery Agreement Curve (USBR, 2008, 2016)