Impacts of Variable Climate and Effluent Flows on the United States-Mexico Transboundary Santa Cruz Aquifer

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Introduction

The Transboundary Santa Cruz Aquifer (TSCA) is located in Northwestern Mexico and Southwestern United States (U.S.). Groundwater from the transboundary aquifer is shared by the states of Arizona, U.S. and Sonora, Mexico, particularly by the cities of Nogales, Arizona, and Nogales, Sonora. The Arizona-Sonora border region is subject to climate uncertainties, limited water availability, and water quality issues. The objective of this study is to assess the impacts of changes in groundwater demand, effluent discharges, and climate uncertainties within the TSCA. Groundwater recharge in the TSCA is highly sensitive to climate uncertainties and physical water and wastewater transfers from both the U.S. and Mexico. Perennial flows in the area depend on the effluent discharges from Nogales, Sonora in Mexico and Nogales, Arizona in the U.S. Wastewater from these cities has been treated at the Nogales International Wastewater Treatment Plant (NIWTP) in Arizona for decades and is discharged into the Santa Cruz River. In 2012, Los Alisos Wastewater Treatment Plant (LAWTP) was built in Mexico to treat a proportion these wastewater. Population growth and residential construction have increased groundwater demand in the area, in addition to wastewater treatment and sanitation demands. These human activities, coupled with climate uncertainties and possible reductions to effluent discharges in the U.S. portion of the TSCA influence the hydrology of the area. We use a conceptual water budget model to analyze the long-term impact of the different components of potential recharge and water losses within the aquifer and downstream of the NIWTP, including changes in projected climate for the 2020-2059 period that are based on three downscaled CMIP5 RCP8.5 Global Climate Models. This study is part of the U.S. Transboundary Aquifer Assessment Program (TAAP) effort.

Study Area

Figure 1. The U.S.-Mexico Transboundary Santa Cruz Aquifer.

Figure 2. Photographs of the Santa Cruz River downstream of the Nogales International Wastewater Treatment Plant (NIWTP).

Wastewater Treatment in the TSCA

Nogales International Wastewater Treatment Plant (NIWTP), Arizona, USA.

- Operated and maintained by the International Boundary and Water Commission (IBWC)
- Capacity: 645 lps (28,259 MGD)
  MX: 434 lps (19,015 MGD)
  AZ: 211 lps (9,244 MGD)

Figure 3. The NIWTP in Arizona, U.S.

Los Alisos Wastewater Treatment Plant (LAWTP), Sonora, Mexico.

Capacity: 220 lps (9,639 MGD)
Future enlargement: 330 lps (14,458 MGD)

Figure 4. LAWTP in Sonora, Mexico.

Methodology

We use a conceptual water budget model approach that incorporates different scenarios of effluent discharge, groundwater demand, and natural river flow.

The model considers five sources of aquifer recharge (Nelson, 2007): Santa Cruz River natural surface streamflow (SCR_{in}), mountain-front recharge (MFR), effluent discharge from the NIWTP (Eff), incidental agricultural return flow (Ag), groundwater inflow from the tributaries (GW_{trib}), and subsurface inflow from aquifers at the southern boundary of the study area (GW_{in}). Water losses are attributed to evapotranspiration (ET), withdrawal from wells (P_w), Santa Cruz River streamflow (SCR_{out}), and groundwater exiting the study area (GW_{out}).

The water budget equation for the present study conceptual model can be expressed as follows:

$$SCR_{in}+MFR+Eff+GW_{in}+Ag+GW_{trib}=ET+P_w+SCR_{out}+GW_{out}+\Delta S$$

where ΔS represents the positive or negative change in the aquifer and vadose zone storage.

Projected Future Climate

Projected future climate (2020-2059) utilized is based on precipitation projections from three CMIP5 RCP8.5 Global Climate Models (GCMs):

1. HadGEM2-ES (Global Environmental Model, Version 2) from the United Kingdom Meteorological Office the Hadley Centre.
2. MPI-ESM-LR from the Max Planck Institute for Meteorology.
3. GFDL-ESM2M (Earth System Model) from the NOAA Geophysical Fluid Dynamic Laboratory.

Two types of downscaling procedures were used: Dynamical and statistical.

Water Budget Model Input

The water budget model was developed using seven climate scenarios: Six projected future downscaled climate models (2020-2059) and one historic ensemble.

The main model flux that was different in each of these seven scenarios is SCR_{in}. The development of the SCR_{in} climate scenarios is based on Shamir and Halper (2019) and described in Tapia et al. (2020).

We used the weather generator to produce 100 realizations of hourly precipitation for 40-years. The seven ensembles were used as input to a hydrologic modeling framework that simulates streamflow in the Santa Cruz River near the NIWTP.

Data

The policy-driven scenarios include groundwater withdrawal management and various effluent discharge scenarios (Table 1 and 2).

Table 1. System Inflows (Tapia et al., 2020).

System Inflows	Mm^3/yr (avg.)	Source	Notes
Mountain Front Recharge (MFR)	6.17	Osterkamp, 1973; Nelson, 2007; ADWR, 2012b.	The contribution to the aquifer from recharge along the mountain front. Assumed to recharge the aquifer at a nearly uniform rate.
Tributary recharge (GW_{trib})	9.22	Aldridge and Brown, 1971; Halpenny and Halpenny, 1985; Nelson, 2007.	Recharge distributed over 14 tributaries within the study area: 8.14-10.30 Mm^3/yr. In this study, we used an average of 9.22 Mm^3/yr.
Santa Cruz River natural flow (SCR_{in})	33.57 Range (0-100)	Based on Shamir et al., 2017 and Shamir and Halper, 2019.	Estimated Santa Cruz River inflow for 1945-2017 using flow at NIWTP[1] for the winter (October-April) and the flow at the Nogales gauge for the summer (May-September).
Effluent Discharge (Eff)	17.44	Based on IBWC historic registries and interviews with key informants.	1. Avg. effluent discharge pre-LAWTP[2]
	24.6		2. Max. effluent discharge pre-LAWTP
	12.58		3. Min. effluent discharge pre-LAWTP
	16.02		4. Avg. effluent discharge post-LAWTP[3]
	22.08		5. Max. effluent discharge post-LAWTP
	14.6		6. Min. effluent discharge post-LAWTP
	20.34		7. U.S.-Mexico agreed-upon contributions
	5.42		8. Arizona's avg. contributions for 1996-2018
Incidental Agricultural Return (Ag)	3.65	ADWR, 2012a.	25% of irrigated agriculture.
Groundwater in (GW_{in})	9.25	Keith Nelson and Olga Hart, ADWR Personal Communication June 2018).	Nelson (2007) estimated consistent subsurface influx to the study region from the Potrero area, Nogales wash, microbasins, and Sonoita Creek.

[1]NIWTP: Nogales International Wastewater Treatment Plant, Arizona, Mexico.
[2]pre-LAWTP: Pre-development of Los Alisos Wastewater Treatment Plant, Sonora, Mexico (2000-2012).
[3]post-LAWTP: Post-development of Los Alisos Wastewater Treatment Plant, Sonora, Mexico (2013-2017).

Table 2. System Outflows (Tapia et al., 2020).

System Outflows	Mm^3/yr (average)	Source	Observations
Evapotranspiration (ET)	16.04 18.5 20.97	Gatewood et al., 1950; Masek, 1996; Nelson, 2007.	Dry Season Medium Season Wet Season
Withdrawal from wells (P_w)	19.49 29.97-28.37	Nelson, 2007; ADWR, 2012b.	1997-2002 average 2006-2025 projections
Subsurface outflow (GW_{out})	27.14	Olga Hart and Keith Nelson, ADWR Personal communication, June 2018.	Estimated to range between 20.97-33.30 Mm^3/yr
Surface outflow (SCR_{out})	10.98	Annual flow at the Amado streamflow gauge (USGS09481770).	Measured at the Amado streamflow gauge during 2004-2009. Record adjusted to remove baseflow that was not apparent after the upgrade to the NIWTP.

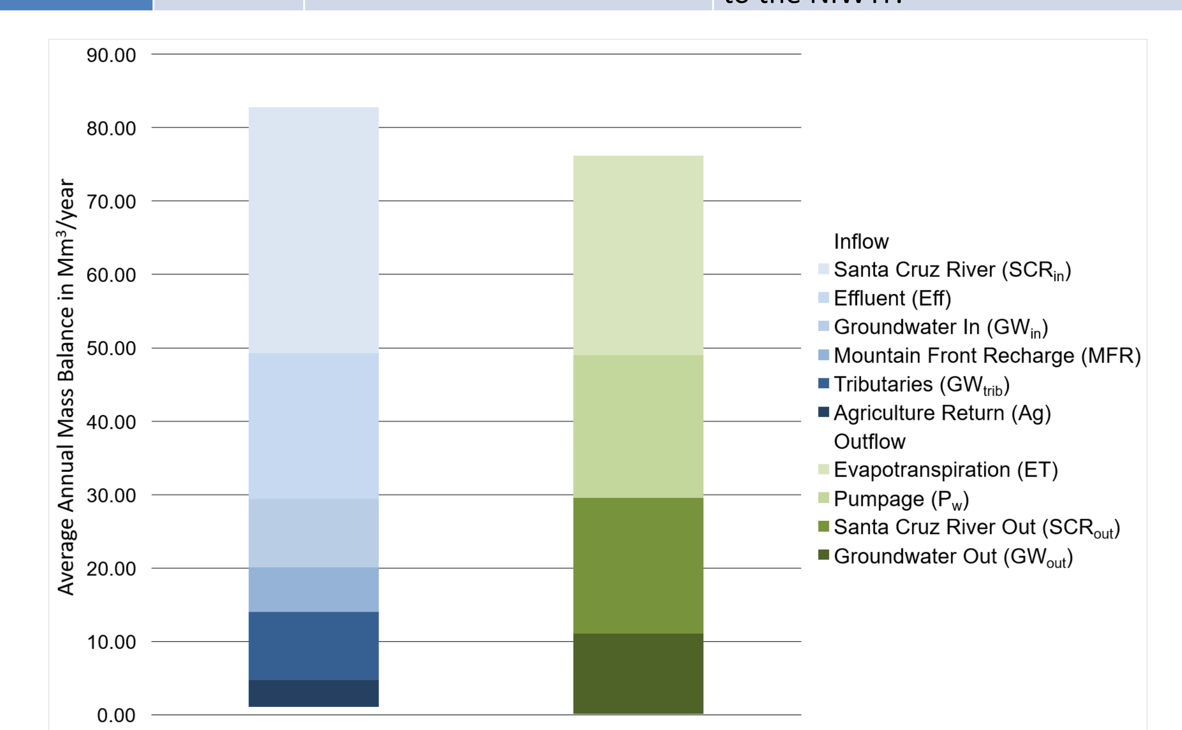

Figure 5. Average annual mass balance simulation using the water budget model (1945-2017). In this simulation: SCRin is the daily estimated Santa Cruz River inflow, Eff is the mean annual effluent for 2000-2017 (Tapia et al., 2020).

Results

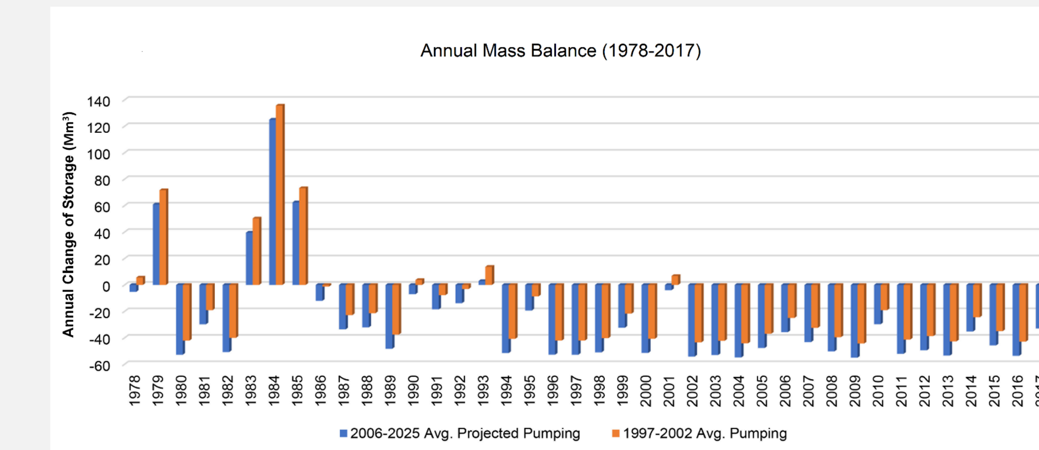

Figure 6. Annual water balance (1978-2017) forced with 1997-2002 and 2006-2025 groundwater pumping average scenarios. Eff is with LAWTP scenarios (Tapia et al., 2020).

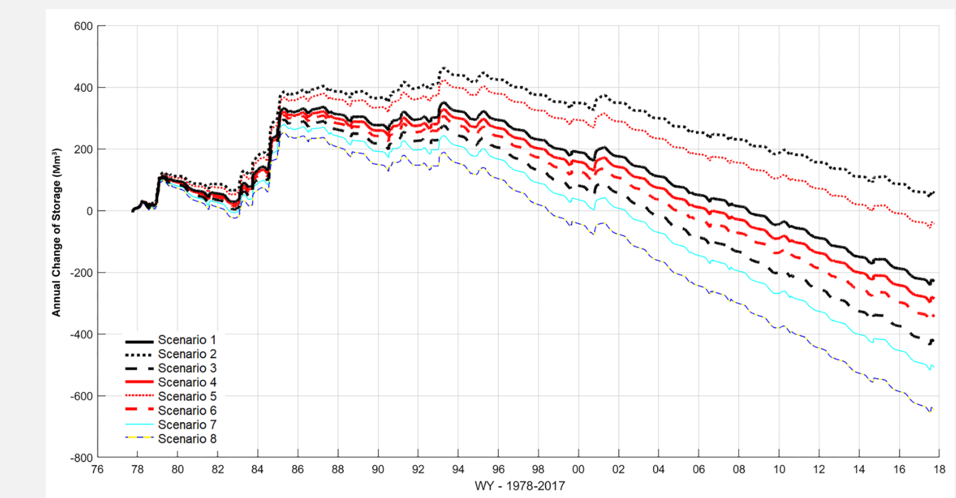

Figure 7. Cumulative water budget for 1978-2017 with different treated effluent discharge scenarios and 1997-2002 average pumping. (Tapia et al., 2020).

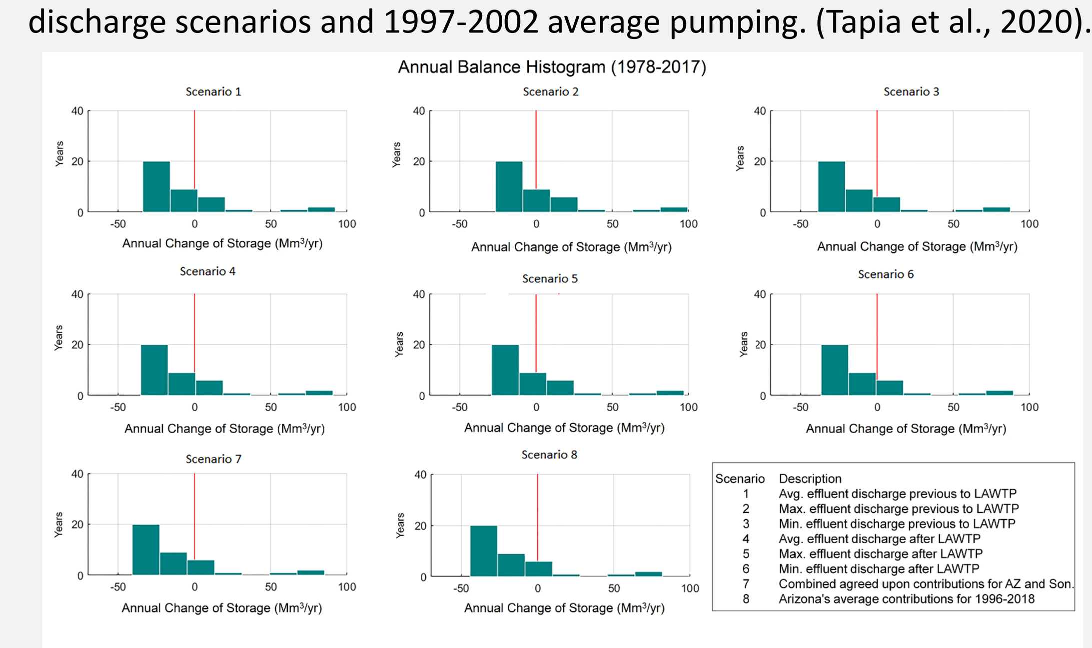

Figure 8. Histogram of the annual water balance (1978-2017) considering 1997-2002 average pumping (Tapia et al., 2020).

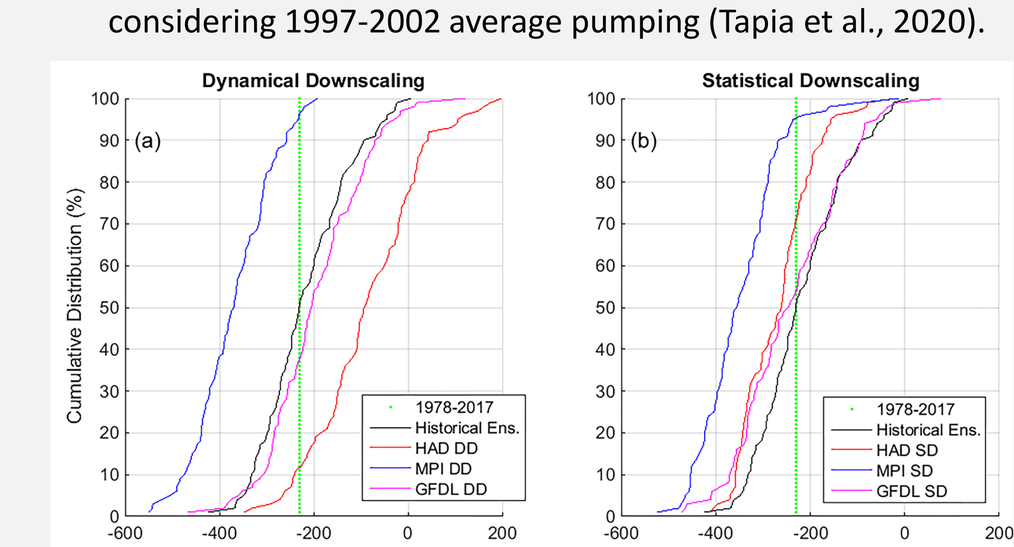

Figure 9. Cumulative distributions of projected 2020-2059 40-year cumulative water balance by the three GCMs dynamically (a) and statistically and (b) downscaled simulations. The green line indicates as a reference the nominal case study using estimated SCR inflow for 1978-2017. The black line represents the cumulative distribution of the ensemble that represents the historic period (Tapia et al., 2020).

Conclusion

Water budget model simulations for the TSCA for most effluent discharge scenarios and groundwater pumping projections reflected groundwater deficit. Additionally, climate projections showed variations that range from severe long-term drying to positive wetting. This research improves the understanding of the impact of natural and anthropogenic variables on water sustainability, with an accessible methodology that can be globally applied.

For more information about this study please refer to Tapia et al. (2020)
For more information about the TAAP please go to https://wrrc.arizona.edu/TAAP

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