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 of these wastewater flows. 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. Changes in projected climate for the 2020-2059 period 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

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 (10,015 MGD)
- AZ: 211 lps (9,244 MGD)

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

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

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), mountain-front recharge (MFR), effluent discharge from the NIWTP (Eff), incidental agricultural return flow (Ag), and groundwater inflow from the tributaries (GW infl), and subsurface inflow aquifers in the southern boundary of the study area (GW out). Water losses are attributed to evapotranspiration (ET), withdrawal from wells (Pp), Santa Cruz River streamflow (SCR), and groundwater exiting the study area (GW out.).

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

\[ SCR_{net} = MFR + Eff + GW_{in} + P_{p} + SCR_{out} - GW_{out} - ET \]

where DS represents the positive or negative change in storage.

Projected Future Climate

Projected future climate (2020-2059) utilized 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 downsampling 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. The development of the SCR 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).

<table>
<thead>
<tr>
<th>System Inflows</th>
<th>MfR/yr (MgD)</th>
<th>Source</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountain-front Recharge (MFR)</td>
<td>18.8</td>
<td>ADWR, 2012c.</td>
<td>The contribution to the aquifer from recharge along the mountainous regions. Assumed to recharge the aquifer at a nearly uniform rate. Recirculation distributed over 14 tributaries within the study area. 8.14-10.32 MMDyr. In this study, we used an average of 9.22 MMDyr.</td>
</tr>
<tr>
<td>Santa Cruz River natural flow (SCR)</td>
<td>32.2</td>
<td>ADWR, 2012c.</td>
<td>Estimated Santa Cruz River inflow for 1945-2012 using flow at NIWTP for the winter (October-April) and the flows at the Nogales gauge for the summer (May-September). (LAWTP) Increase in flow due to development of Los Alisos Wastewater Treatment Plant, Sonora, Mexico (2002-2012).</td>
</tr>
<tr>
<td>Incidental agricultural return (Ag)</td>
<td>3.0</td>
<td>ADWR, 2012c.</td>
<td>7. U.S.-Mexico agreement on contributions.</td>
</tr>
<tr>
<td>Total inflow</td>
<td>68.0</td>
<td>ADWR, 2012c.</td>
<td>8. Arizona eng contributions for 1990-2018. 25% of irrigated agriculture.</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>System Outflows</th>
<th>MfR/yr (MgD)</th>
<th>Source</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsurface outflow (GW out)</td>
<td>37.0</td>
<td>ADWR, 2012c.</td>
<td>Estimated range between 15-40 MMDyr.</td>
</tr>
</tbody>
</table>

Wet season (6 months): 5 months April to September. Drought season (6 months): 5 months October to March.

Conclusion

Water budget model simulations for the TSCA for most effluent discharge scenarios and groundwater pumping scenarios projected 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.