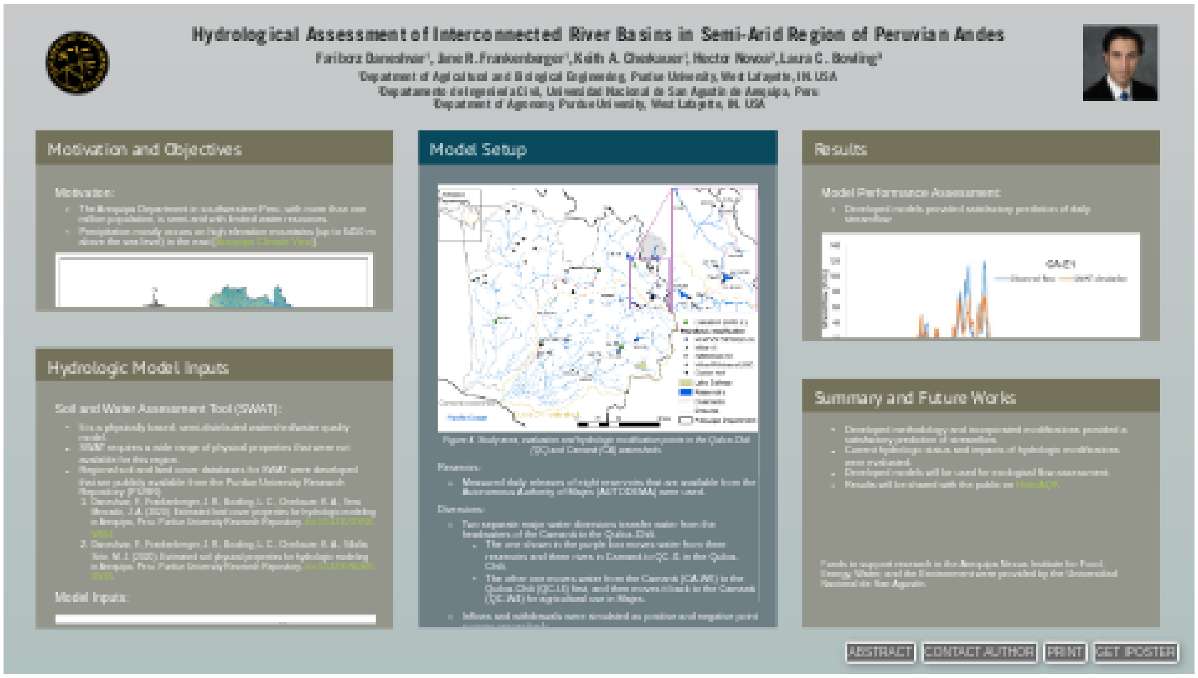
Hydrological Assessment of Interconnected River Basins in Semi-Arid Region of Peruvian Andes



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MOTIVATION AND OBJECTIVES

Motivation:

- The Arequipa Department in southwestern Peru, with more than one million population, is semi-arid with limited water resources.
- Precipitation mostly occurs on high elevation mountains (up to 6450 m above the sea level) in the east [Arequipa Climate View (https://mygeohub.org/groups/nexus_swm/arequipa_climate)].

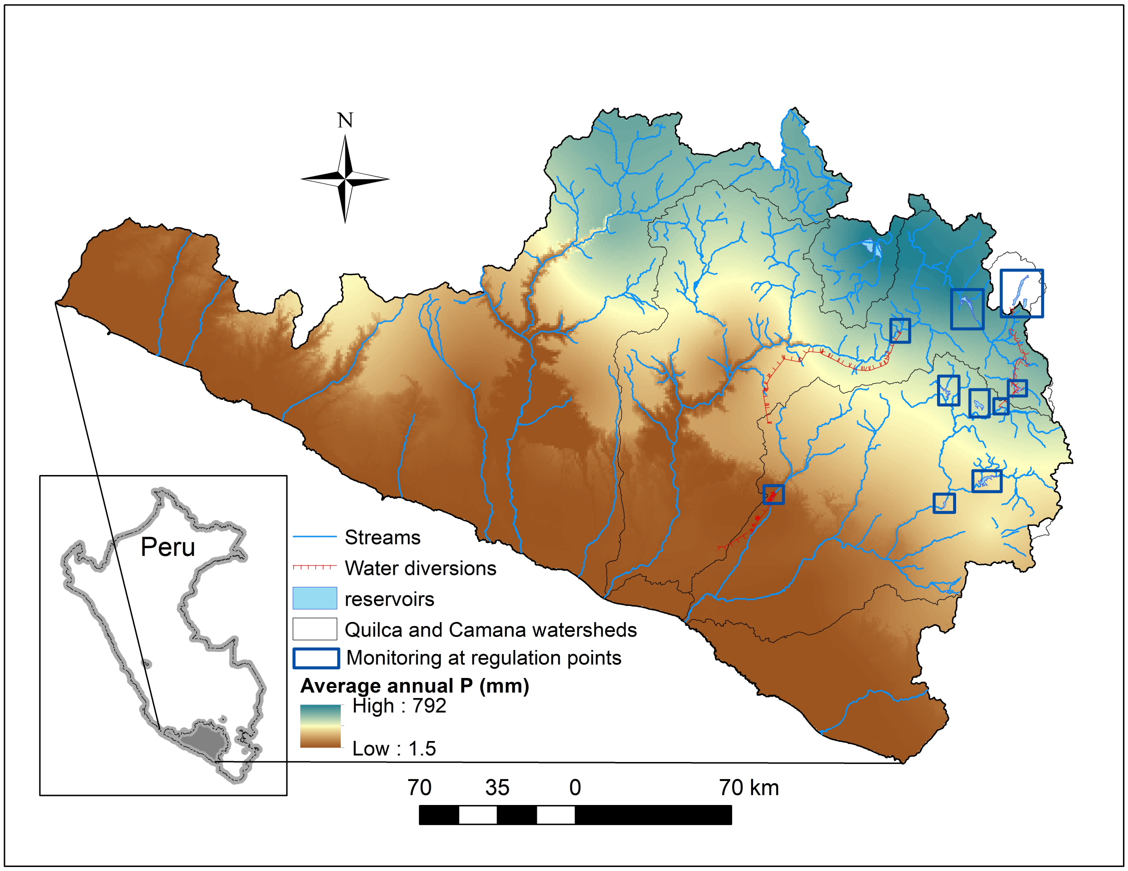

Figure 1. Average annual precipitation map of Arequipa. Boxes show monitoring of flow at regulation points.

- Water management infrastructure, including eight reservoirs and ~200 km of canals, are constructed to supply water for hydropower, urban, and agricultural demand.
- Hydrologic data are needed for the management of water resources.
- The current hydrologic monitoring system is designed for regulation points.
- The natural hydrology of the region is not well studied.
- Hydrologic modeling will help to know how much, when, and where water is available for better allocation of water use.

Objectives:

- Develop hydrologic models with the incorporation of water infrastructure to simulate the hydrological cycle of two interconnected river basins of Quilca-Chili (QC) and Camaná (CA) in Arequipa.

- Evaluate the impact of water infrastructure on natural hydrology

HYDROLOGIC MODEL INPUTS

Soil and Water Assessment Tool (SWAT):

- It is a physically based, semi-distributed watershed/water quality model.
- SWAT requires a wide range of physical properties that were not available for this region.
- Regional soil and land cover databases for SWAT were developed that are publicly available from the Purdue University Research Repository (PURR):
    1. Daneshvar, F., Frankenberger, J. R., Bowling, L. C., Cherkauer, K. A., Vera Mercado, J. A. (2020). Estimated land cover properties for hydrologic modeling in Arequipa, Peru. Purdue University Research Repository. doi:10.4231/GYN8-W684. (https://purr.purdue.edu/publications/3627/1)
    2. Daneshvar, F., Frankenberger, J. R., Bowling, L. C., Cherkauer, K. A., Villalta Soto, M. J. (2020). Estimated soil physical properties for hydrologic modeling in Arequipa, Peru. Purdue University Research Repository. doi:10.4231/N5MX-9W30 (https://purr.purdue.edu/publications/3626/1).

Model Inputs:

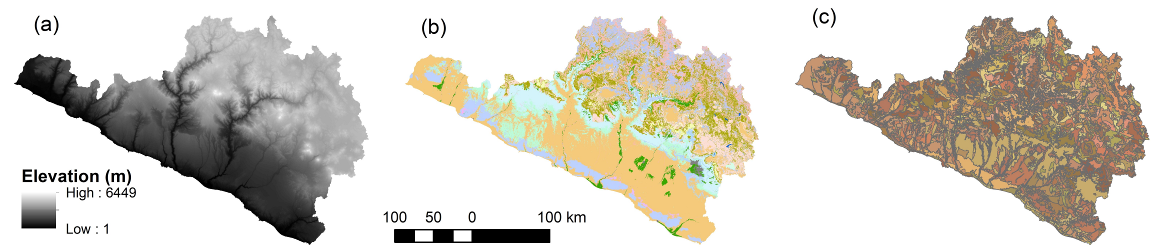

Figure 2. SWAT input data layers including (a) elevation (12.5 m), (b) 23 land cover classes, and (c) 172 soil classes

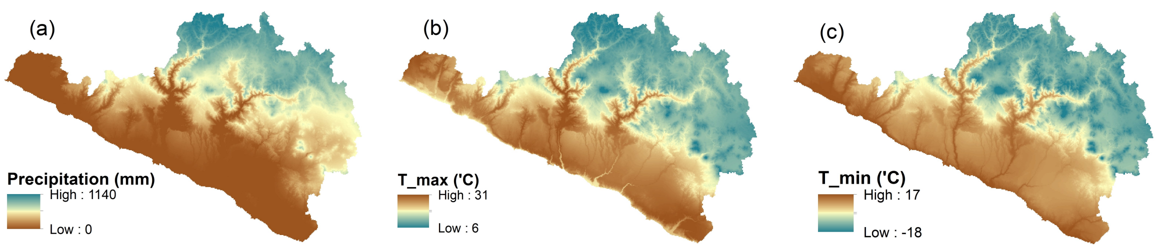

Figure 3. Arequipa Climate Map (ACM (https://purr.purdue.edu/publications/3378/1)) weather data (1 km) were used to extract precipitation, maximum and minimum temperatures as subbasins' centroids.

MODEL SETUP

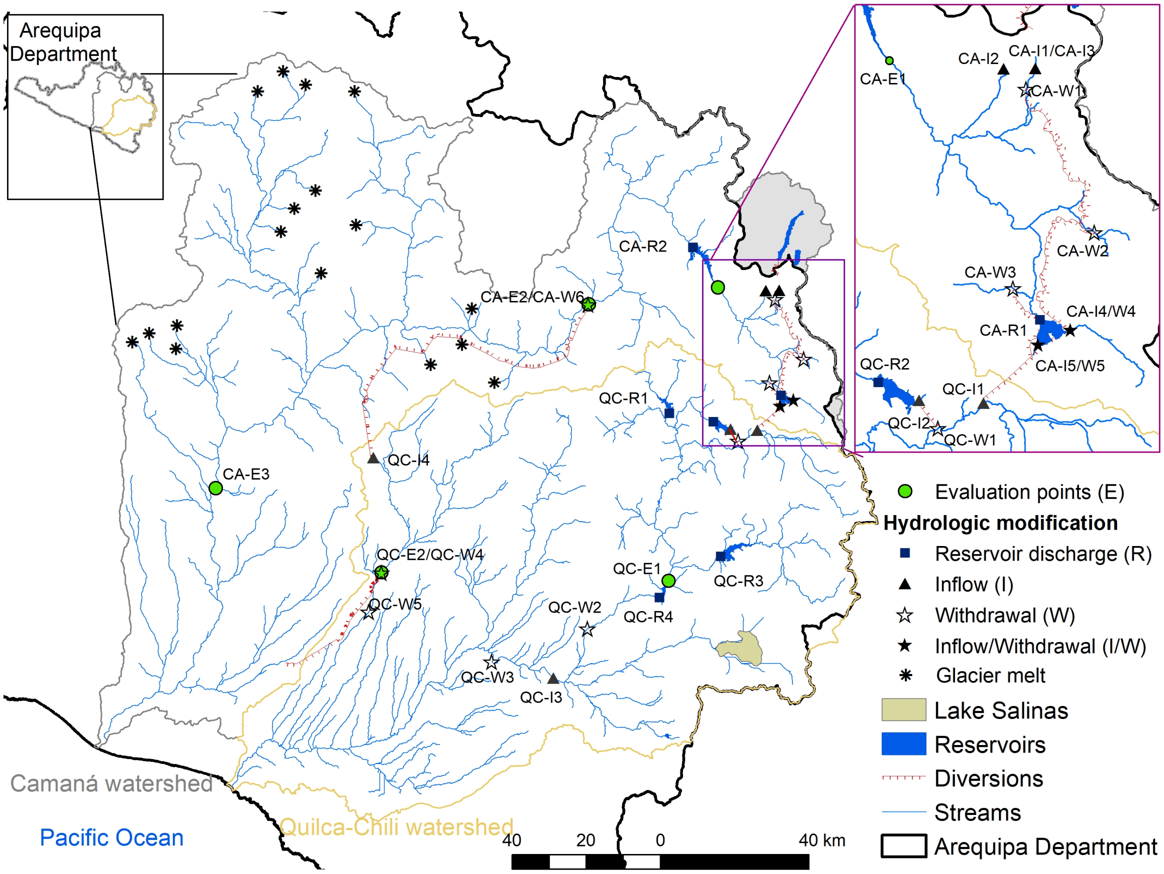

Figure 4. Study area, evaluation and hydrologic modification points in the Quilca-Chili (QC) and Camaná (CA) watersheds.

Reservoirs:

- Measured daily releases of eight reservoirs that are available from the Autonomous Authority of Majes (AUTODEMA) were used.

Diversions:

- Two separate major water diversions transfer water from the headwaters of the Camaná to the Quilca-Chili.
  - The one shown in the purple box moves water from three reservoirs and three rives in Camaná to QC-I1 in the Quilca-Chili.
  - The other one moves water from the Camaná (CA-W6) to the Quilca-Chili (QC-I4) first and then moves it back to the Camaná (QC-W4) for agricultural use in Majes.
- Inflows and withdrawals were simulated as positive and negative point sources respectively.

Other hydrologic modification points:

- In addition to two major water diversions, there are some other hydrologic modifications such as inflow from a water treatment plant, or withdrawal for the City of Arequipa. These modification points were also represented as positive or negative point sources accordingly.

Glacier melt:

- Stream baseflow appeared to be much higher in the Camaná River basin than in the Quilca-Chili Basin, to account for the potential contribution of glacier melt on low flows, seven existing glaciers and snowfields were simulated as point sources using an external two-layer snow model.

Lake Salinas:

- It is an endorheic lake and does not contribute to the downstream river system. Therefore, it was modeled as a reservoir with zero discharge that contributes to the groundwater.

RESULTS

Model Performance Assessment:

- Developed models provided a satisfactory prediction of daily streamflow

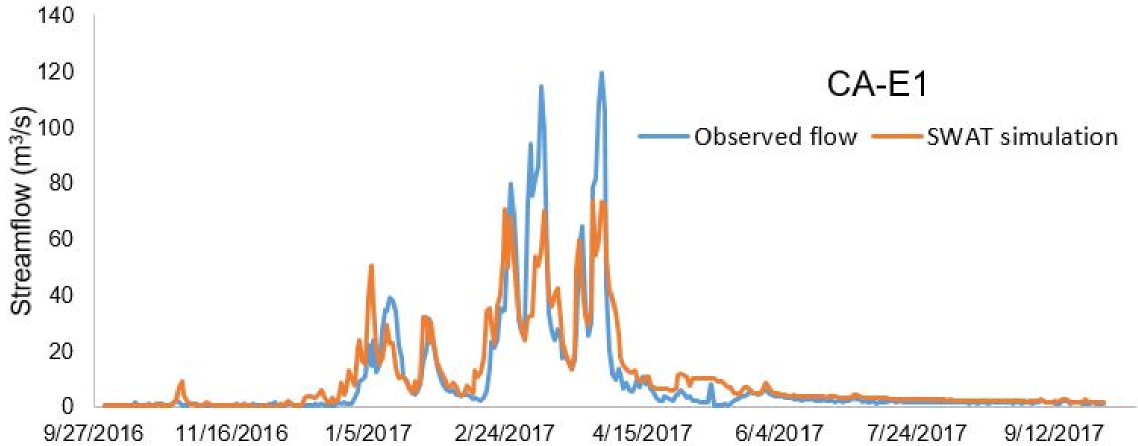

Figure 5. Comparison of observed and simulated daily streamflow for one water year (October 2016 - September 2017)

Table 1. SWAT model performance evaluation (2009-2017)

	R^2	NSE	PBIAS (%)
CA-E1	0.74	0.72	9.33
CA-E2	0.75	0.74	6.74
CA-E3	0.61	0.59	17.03
QC-E1	0.77	0.55	-16.35
QC-E2	0.56	0.27	-9.43

Impact of water infrastructure on natural hydrology:

- Comparison of the average annual flow of the current and natural flow scenarios showed the overall degree of impact on downstream of regulation points (Figure 6).
- Flow withdrawal could change peak flows even 140 km downstream of the regulation point.

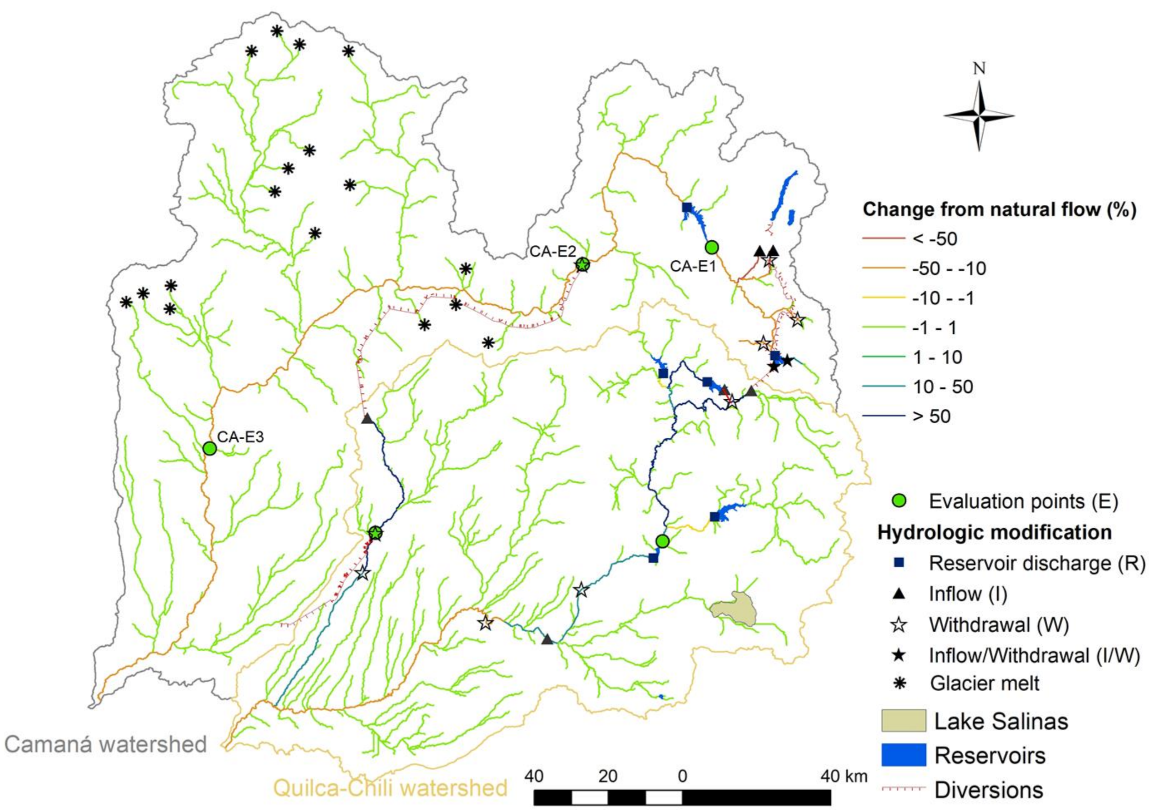

Figure 6. Percent change in average annual flow compared to natural flow (no hydrologic infrastructure)

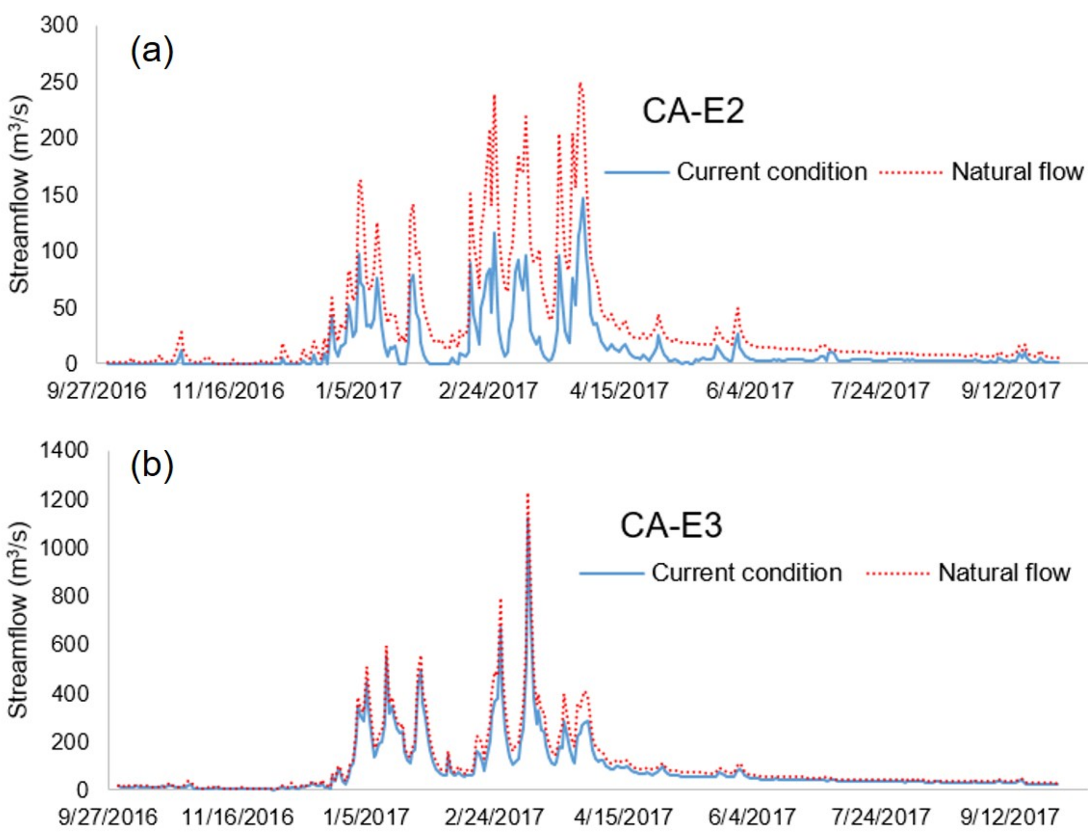

Figure 7. Comparison of current and natural flow (a) at a major regulation point (CA-E2), and (b) 140 km downstream of the regulation point (CA-E3), for one water year (October 2016 - September 2017).

SUMMARY AND FUTURE WORKS

- Developed methodology and incorporated modifications provided a satisfactory prediction of streamflow.
- Current hydrologic status and impacts of hydrologic modifications were evaluated.
- Developed models will be used for ecological flow assessment.
- Results will be shared with the public on HidroAQP (https://mygeohub.org/groups/water-hub/swatflow/Arequipa).

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ABSTRACT

Freshwater is limited in the semi-arid Arequipa region in Southern Peru that is home to more than 1.3 million people, agricultural and industrial sectors. To address water demand, eight reservoirs and more than 200 km of water diversion tunnels and canals have been implemented in the Quilca and Camaná river basins, resulting in severely modifed hydrology and interconnection of the two basins. The Soil and Water Assessment Tool (SWAT) was used to simulate the current hydrological status and potential alternative management scenarios for the two interconnected basins. Simulation challenges include scarcity of data on soil and land cover to run SWAT, which was addressed by developing publicly available regional soil and land cover databases. A representation of water infrastructure required a complex model structure incorporating point sources to represent water transfers and reservoir outfows and water withdrawals at 18 locations. The developed model is used to provide a comprehensive understanding of water availability in the region under current and alternate scenarios for water regulation. The impact of current water infrastructure on minimum streamfow is explored in the Quilca and Camaná river basins. Results were shared with the local water authorities and the public via an online tool called HidroAQP to support water allocation and related water resource decisions.