Hydrological Impacts of Climate Change in Peru's Eastern Central Andes: Future Development Scenarios

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MOTIVATIONS AND OBJECTIVE

Water and climate change

Extreme events (floods and droughts)

Watershed systems in the Peruvian Andes are facing significant challenges due to climate change

Ayacucho's economy depends largely on agriculture

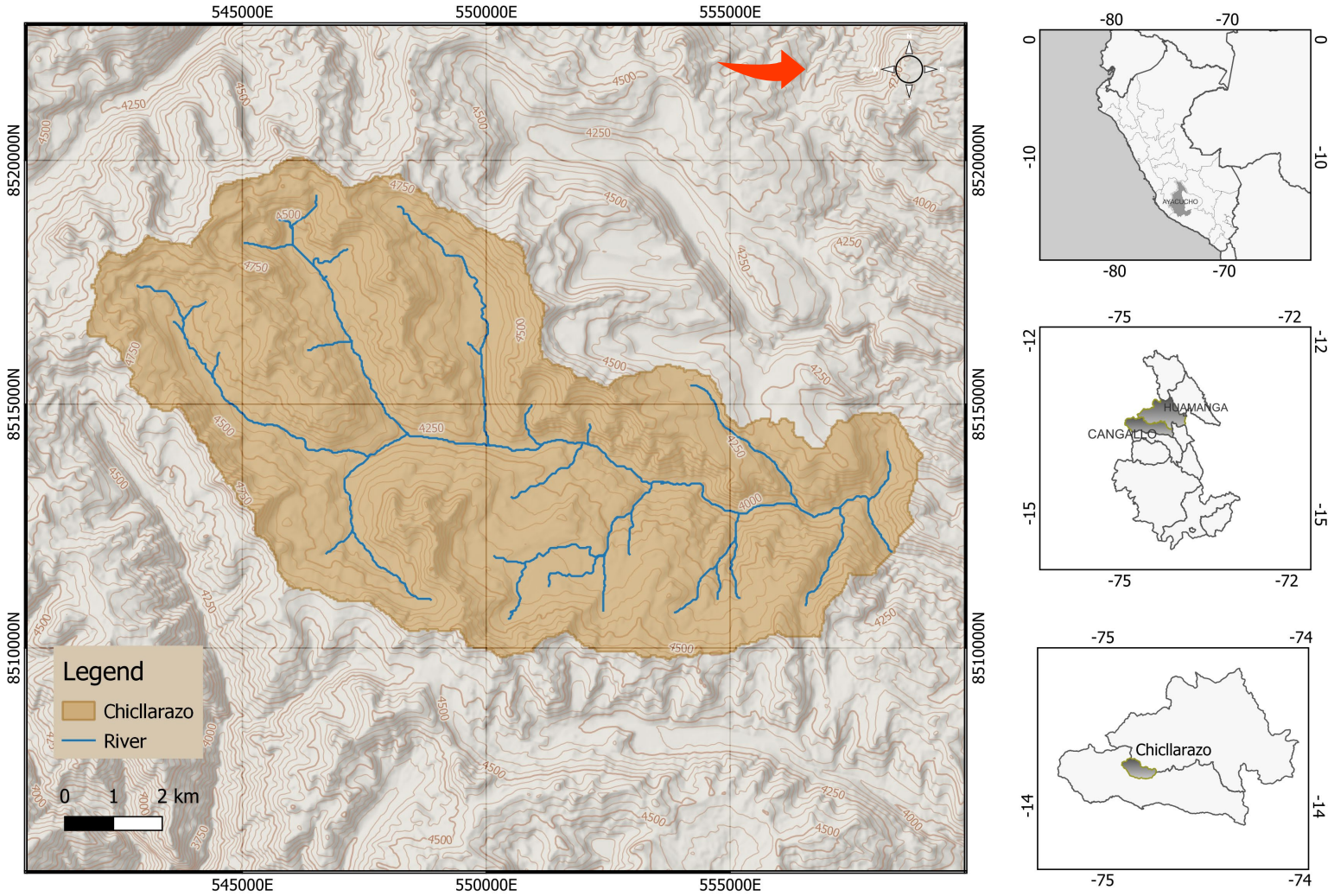
To assess the impacts of climate change on hydrological cycle in the Chicllarazo River watershed

Fuente: https://revistafal.com/arboles-kieviyeme/

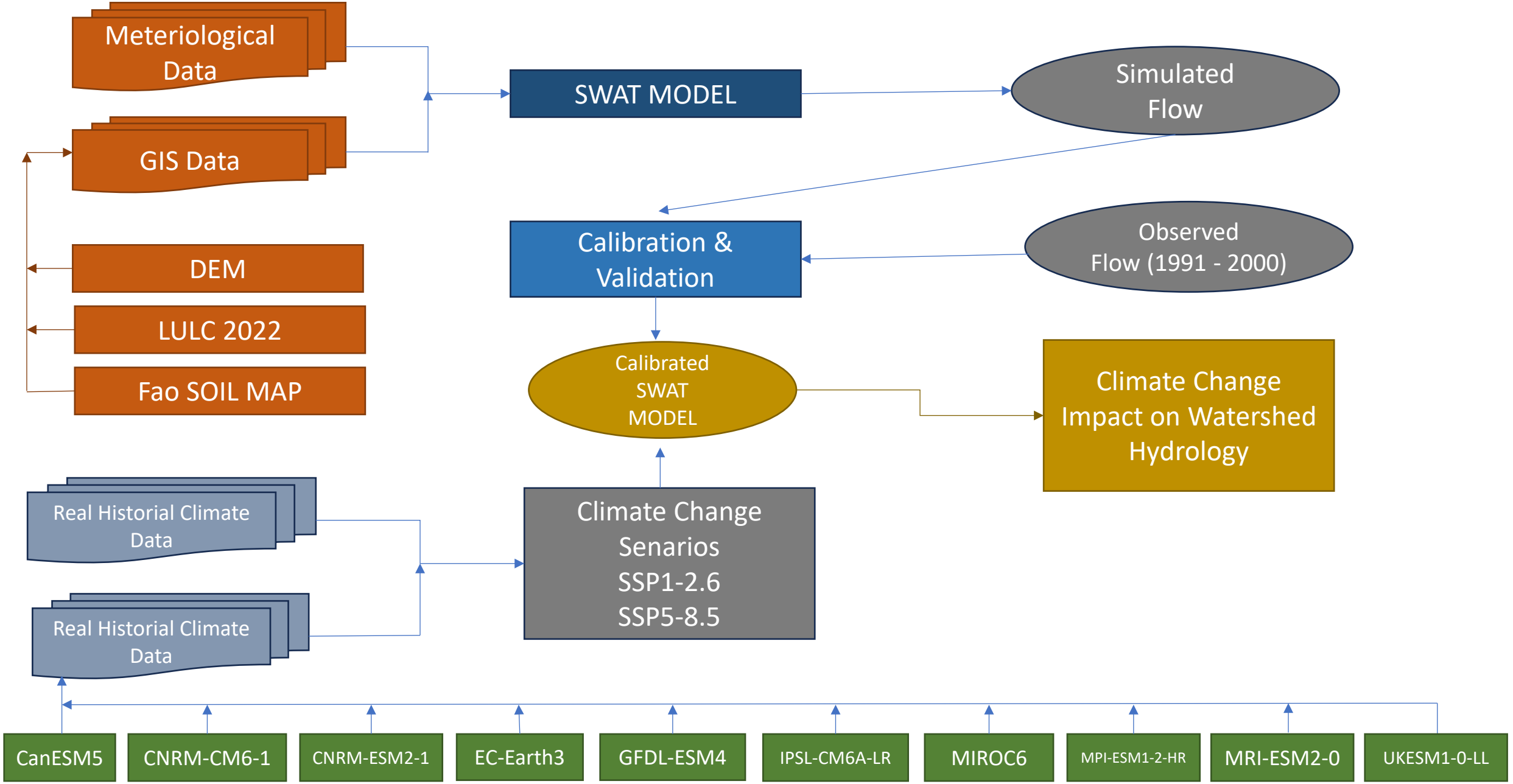
METODOLOGY

Study Area

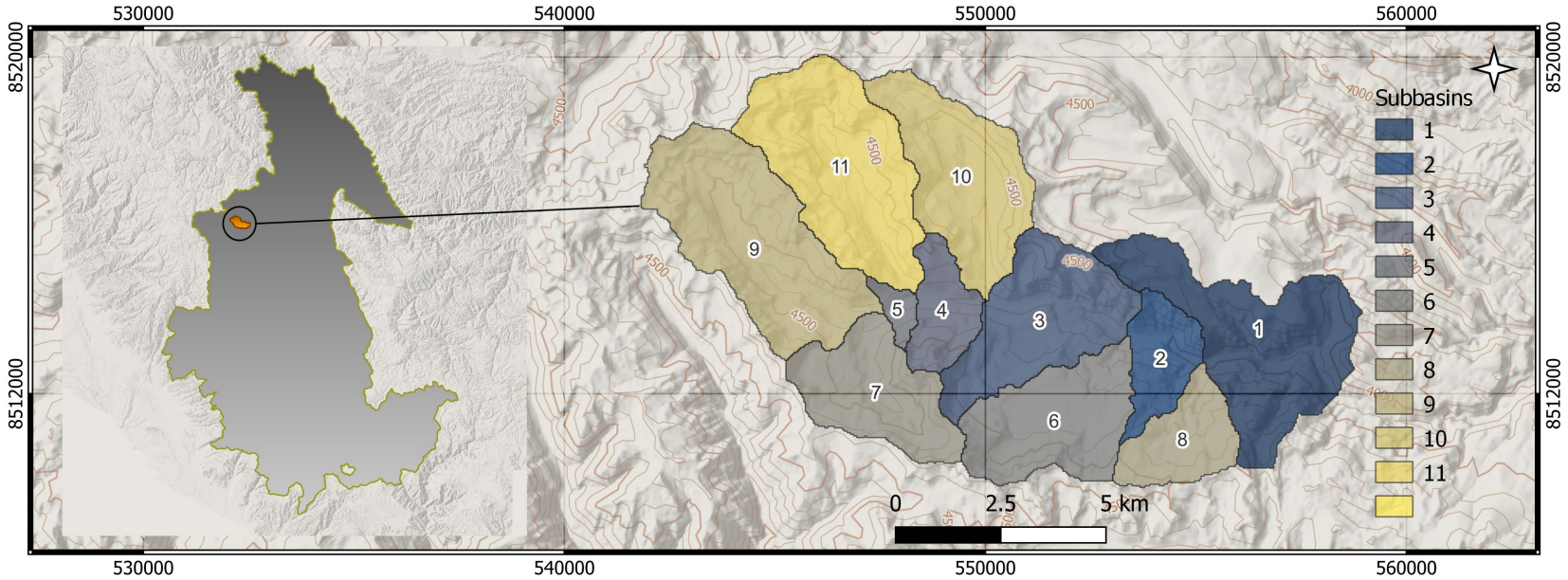
- The Chicllarazo River flows along with the Cachi, Mantaro, Apurimac, Ene, Tambo, and Ucayali rivers
- Is part of the Cachi Hydraulic System (CHS)
- The CHS provides water for multiple purposes:
  - irrigation of 14,500 hectares
  - supply the instream flow and the city of Ayacucho
  - 1.8 MW of hydropower
- In the Chicllarazo River Basin (CRB), the density of surface rain gauges is low, which affects the quality of hydrological research in the region.



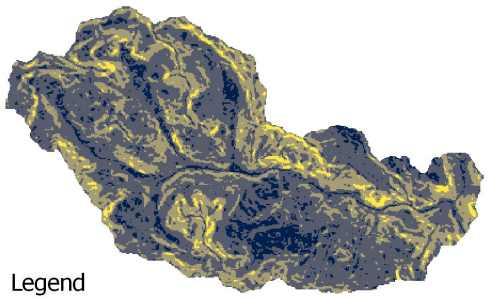
Workflow


Meteriological Data
GIS Data
DEM
LULC 2022
Fao SOIL MAP
SWAT MODEL
Simulated Flow
Calibration & Validation
Observed Flow (1991 - 2000)
Calibrated SWAT MODEL
Climate Change Impact on Watershed Hydrology
Real Historial Climate Data
Real Historial Climate Data
Climate Change Senarios SSP1-2.6 SSP5-8.5
CanESM5
CNRM-CM6-1
CNRM-ESM2-1
EC-Earth3
GFDL-ESM4
IPSL-CM6A-LR
MIROC6
MPI-ESM1-2-HR
MRI-ESM2-0
UKESM1-0-LL

Input variables

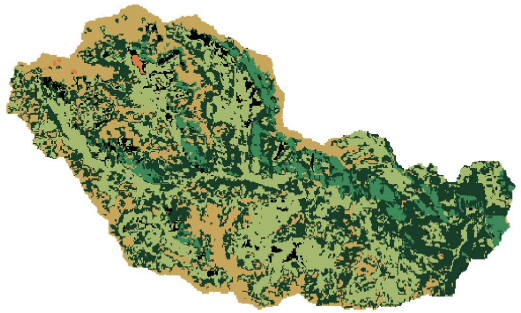


a)



Legend
Slope %
0-5
6-20
21-35
>36

b)



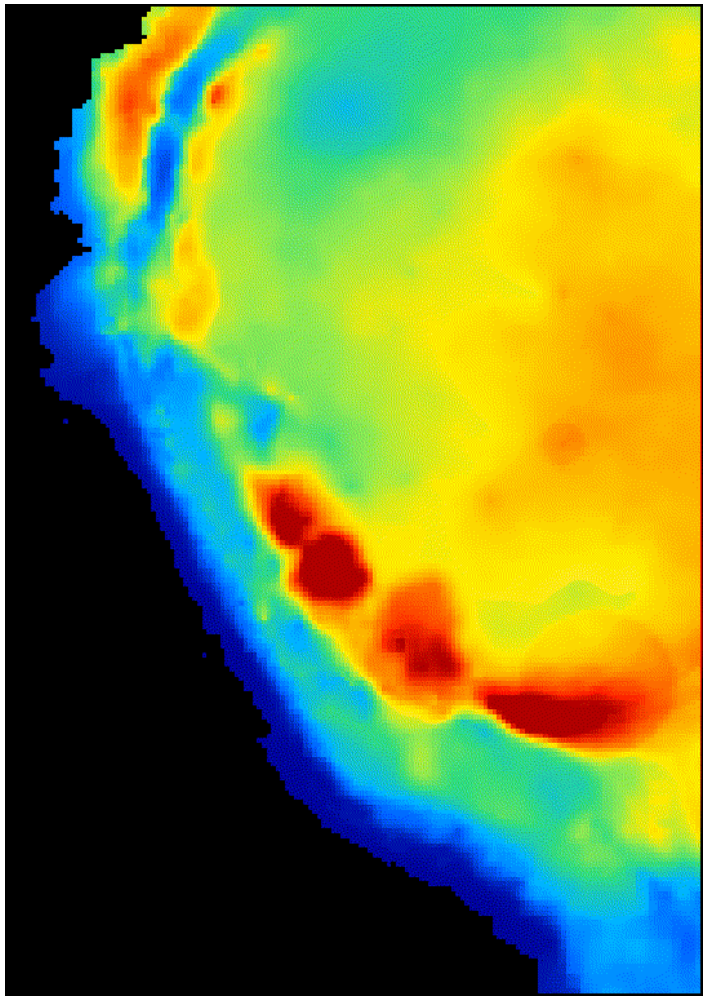
Legend
LULC
Flooded grassland /shrubland
Grasslands / herbaceous
Scrubland and other non-forest formations
Pasture
Other non-vegetated area
River, lake or ocean

c)

Legend
Soils
5497
5518

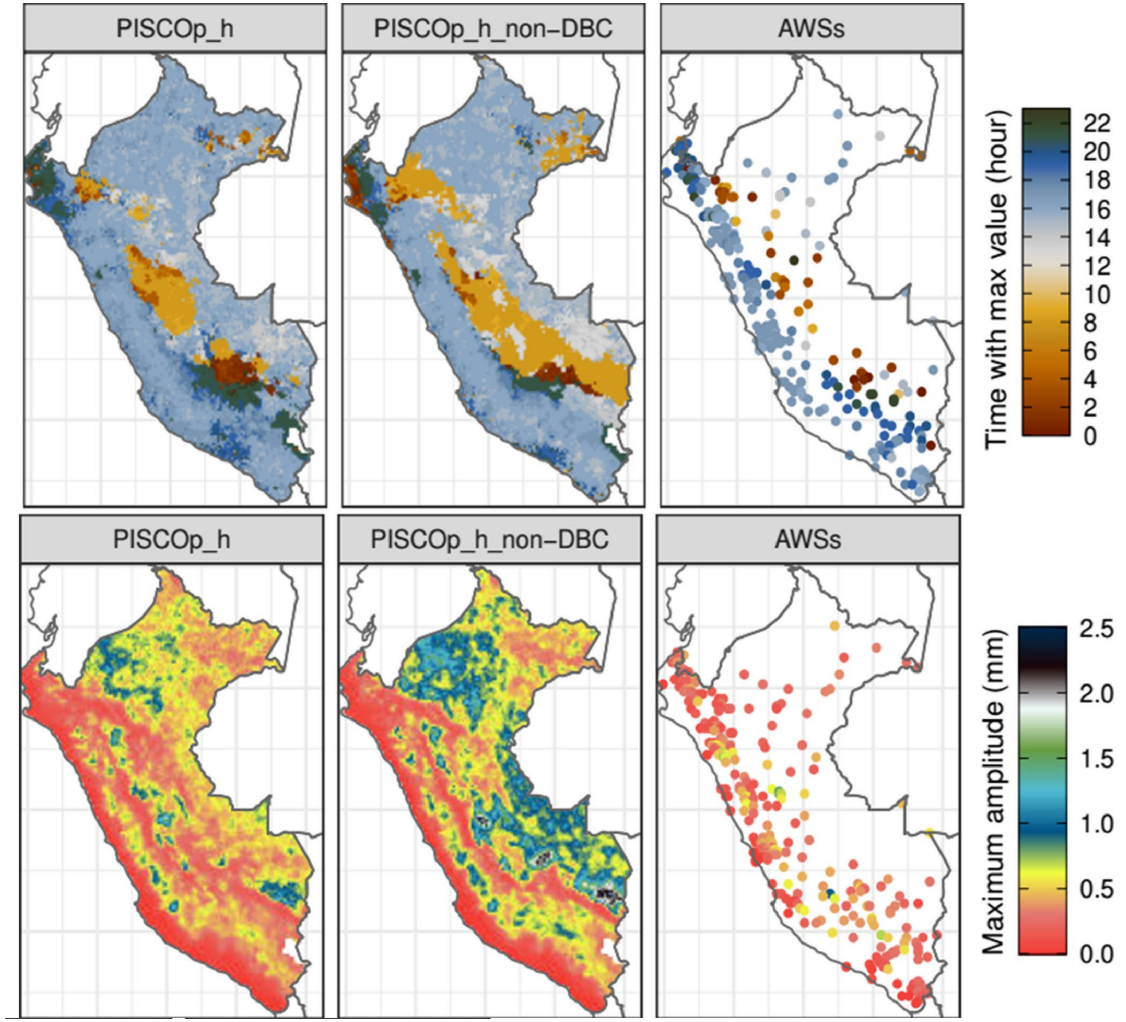
Climate Data

- **Precipitation: Rain4pe**



Source: (Fernandez-Palomino et al., 2021)

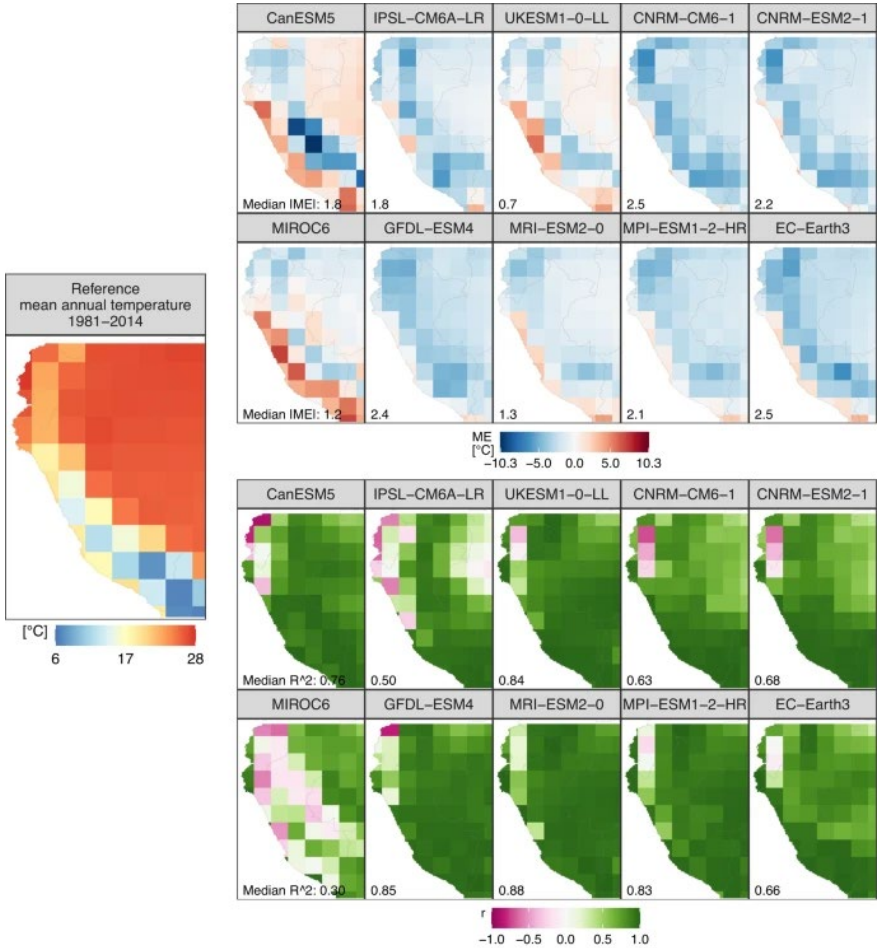
- **Temperature: Pisco**

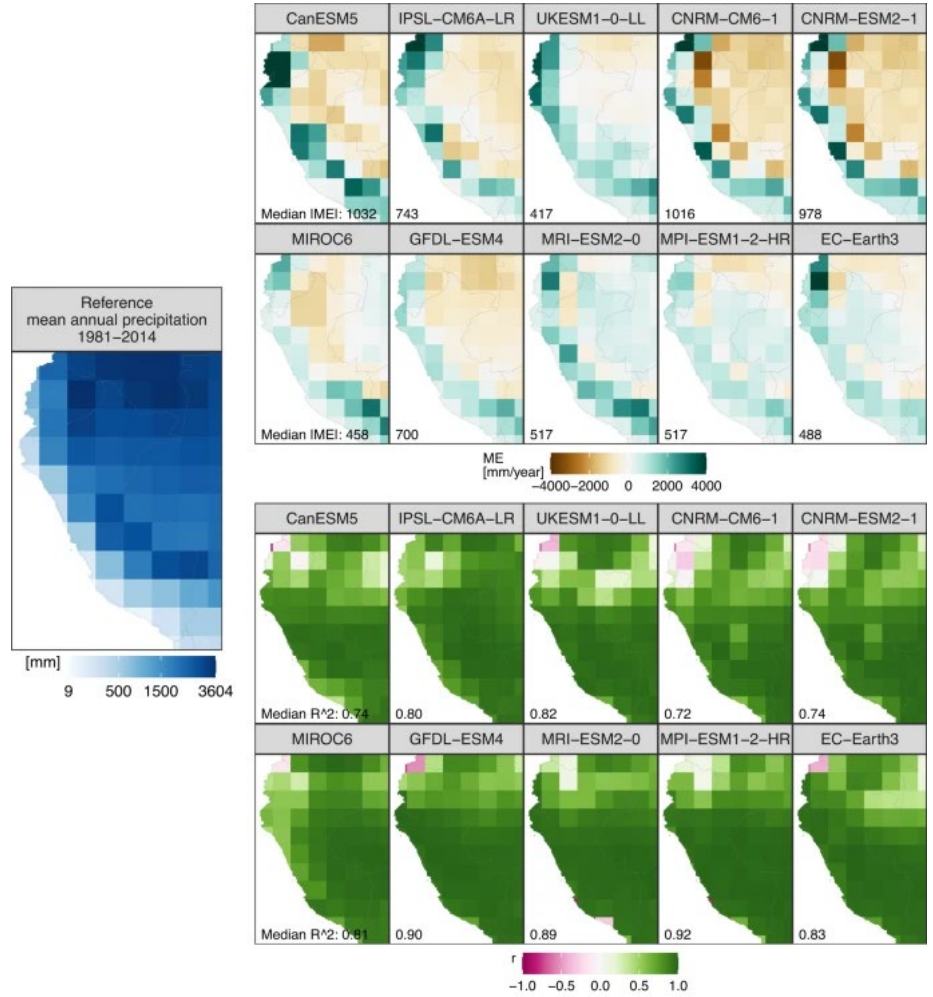


Source: (Aybar, C et al., 2017)

Climate projection

BASD-CMIP6-PE (1d, 10 km). It includes models with low (GFDL-ESM4, MPI-ESM1-2-HR, MRI-ESM2-0) and high (IPSL-CM6A-LR, UKESM1-0-LL) climate sensitivity, with mitigation policy (SSP1-2.6) and without mitigation (SSP5-8.5)





Source: (Fernandez-Palomino et al., 2024)

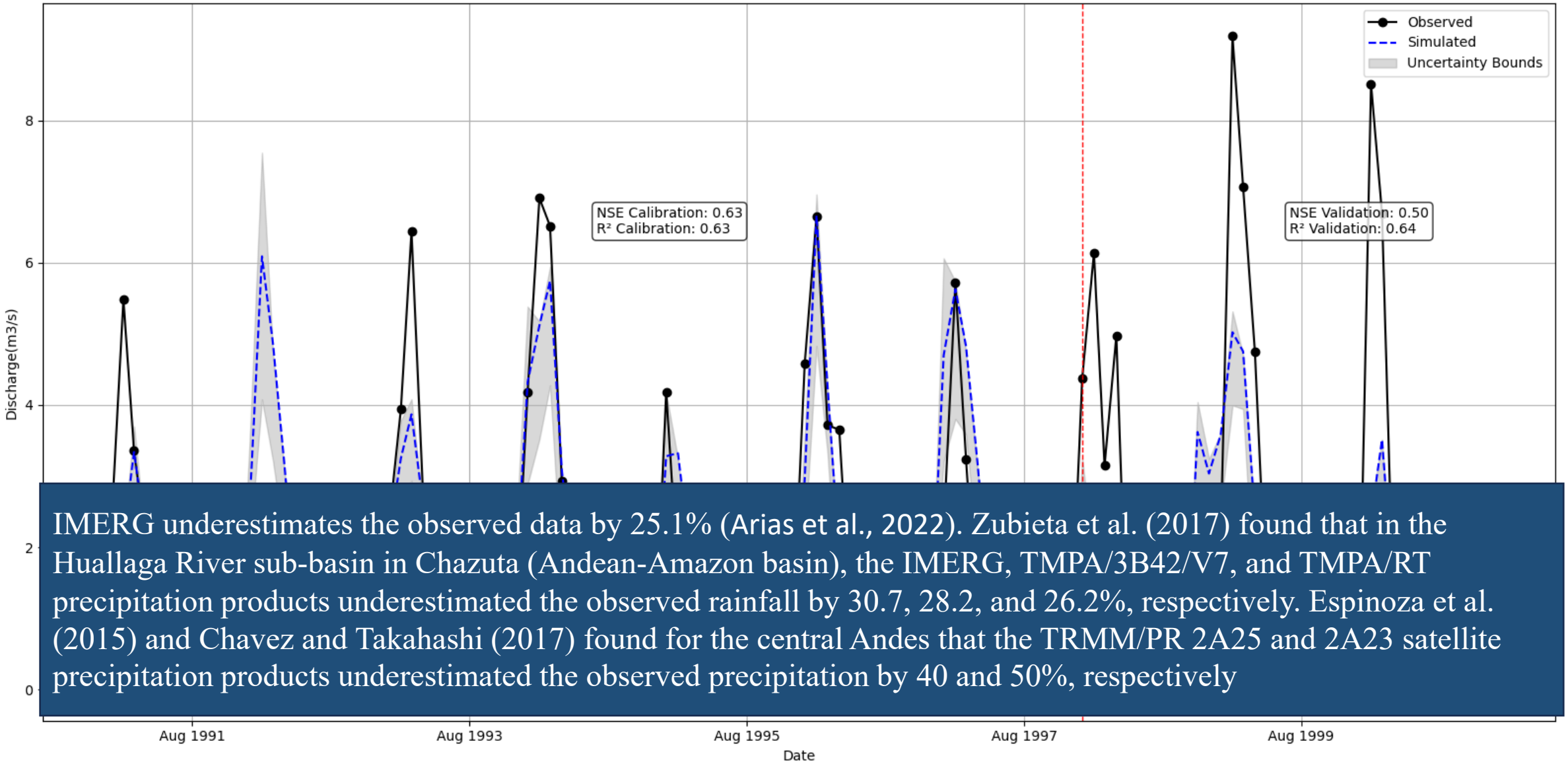
Model performance

N°	Performance criteria	Description	Threshold
1.	$R^2 = \left(\frac{\sum_{i=1}^{n}(q_i^{obs} - \mu_{obs})(q_i^{sim} - \mu_{sim})}{\sqrt{\sum_{i=1}^{n}(q_i^{obs} - \mu_{obs})^2}\sqrt{\sum_{i=1}^{n}(q_i^{sim} - \mu_{sim})^2}} \right)^2$	Linear dispersion between observations and simulations.	> 0.60
2.	$NSE = 1 - \frac{\sum_{i=1}^{n}(q_i^{obs} - q_i^{sim})^2}{\sum_{i=1}^{n}(q_i^{obs} - \mu_i^{obs})^2}$	Mean square error (MSE) of observed and simulated data, compared to the variance in the measured value.	> 0.50

Source: Abbaspour, 2015.
Moriasi, Gitau, Pai & Daggupati, 2015.

RESULTS AND DISCUSSIONS

Time Series Plot for Calibration and Validation Periods



IMERG underestimates the observed data by 25.1% (Arias et al., 2022). Zubieta et al. (2017) found that in the Huallaga River sub-basin in Chazuta (Andean-Amazon basin), the IMERG, TMPA/3B42/V7, and TMPA/RT precipitation products underestimated the observed rainfall by 30.7, 28.2, and 26.2%, respectively. Espinoza et al. (2015) and Chavez and Takahashi (2017) found for the central Andes that the TRMM/PR 2A25 and 2A23 satellite precipitation products underestimated the observed precipitation by 40 and 50%, respectively

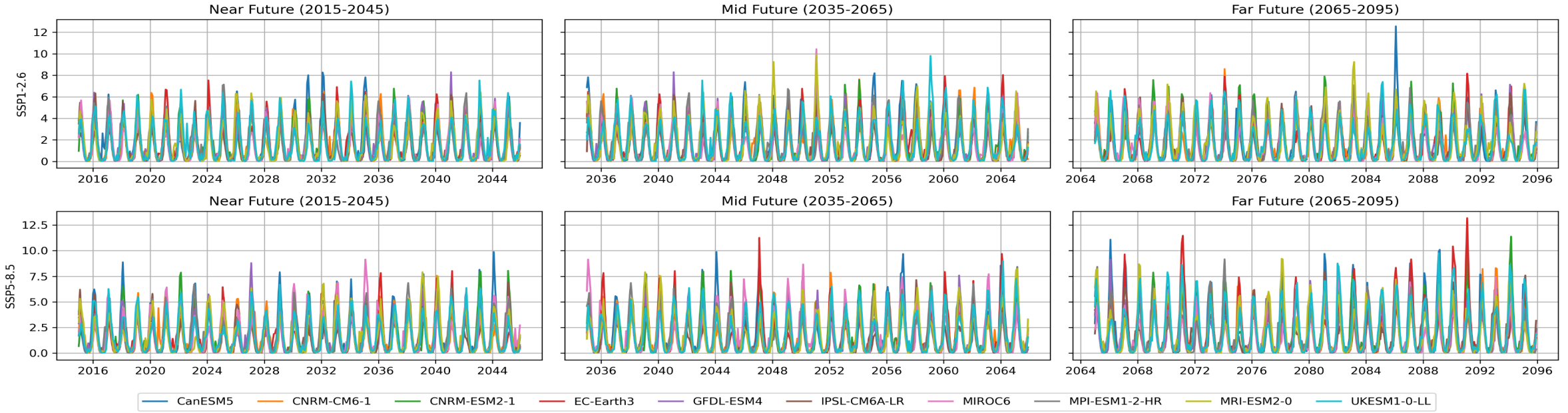
Calibration parameters

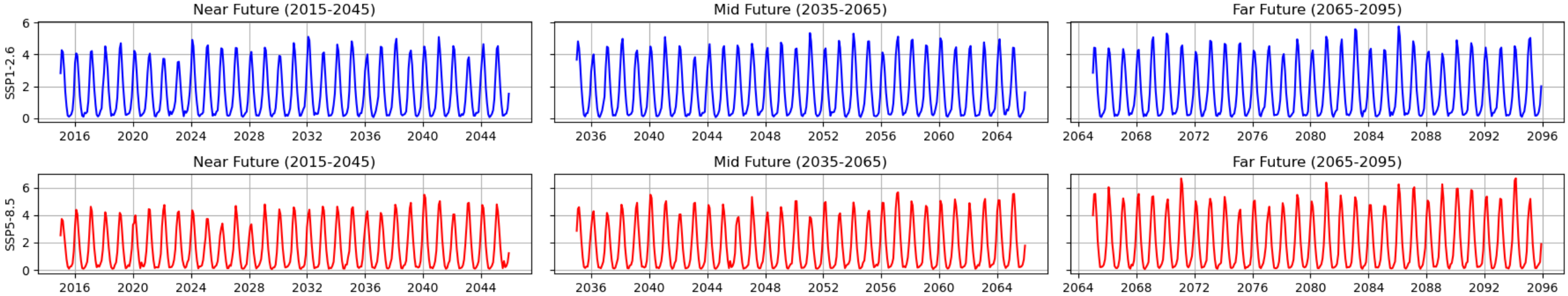
SWAT hydrological model parameters adopted in the calibration step (Adapted from Fernandez-Palomino et al., 2022 and Daneshvar et al., 2021), and best fit of values.

Parameter	Description	Range	Best fit
ALPHA_BF.gw (^{v})	Baseflow recession constant (day^{-1})	0 – 1	0.15
GW_DELAY.gw (^{v})	Groundwater delay time (days)	0 – 100	25
GWQMN.gw (^{v})	Threshold depth of water in shallow aquifer required for return flow to occur (mm)	500 – 1000	625
RCHRG_DP.gw (^{v})	Deep aquifer percolation fraction	0 – 0.5	0.425
GW_REVAP.gw (^{v})	Groundwater “revap” coefficient	0.02 – 0.2	0.83
SOL_AWC.sol (^{r})	Soil available water capacity (mm H_2O/mm soil)	-0.8 – 0.8	0.12

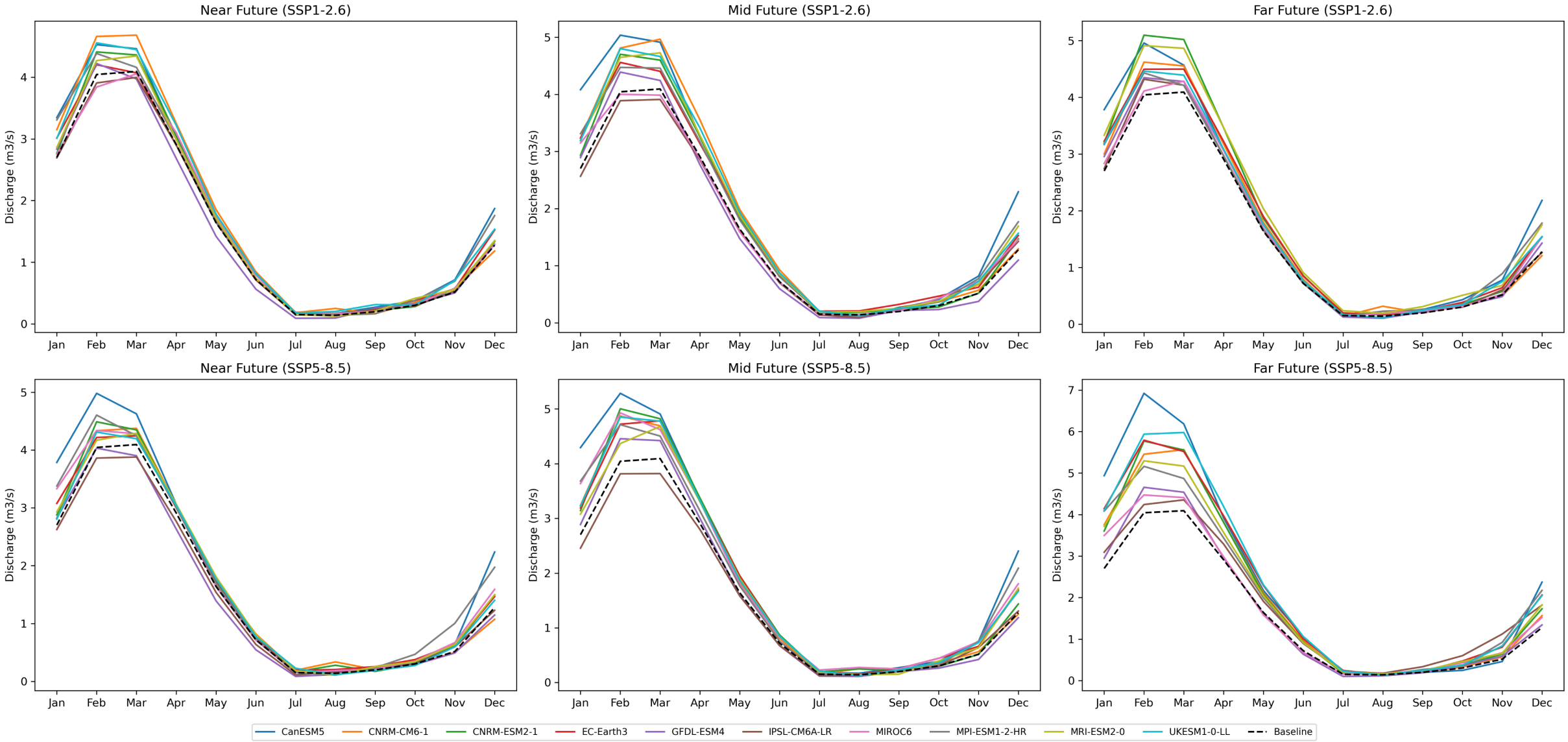
$^{(v)}$ $^{(r)}$ correspond to the replacement changes and relative, respectively

Time Series Plot for Near, Mid, and Far Future

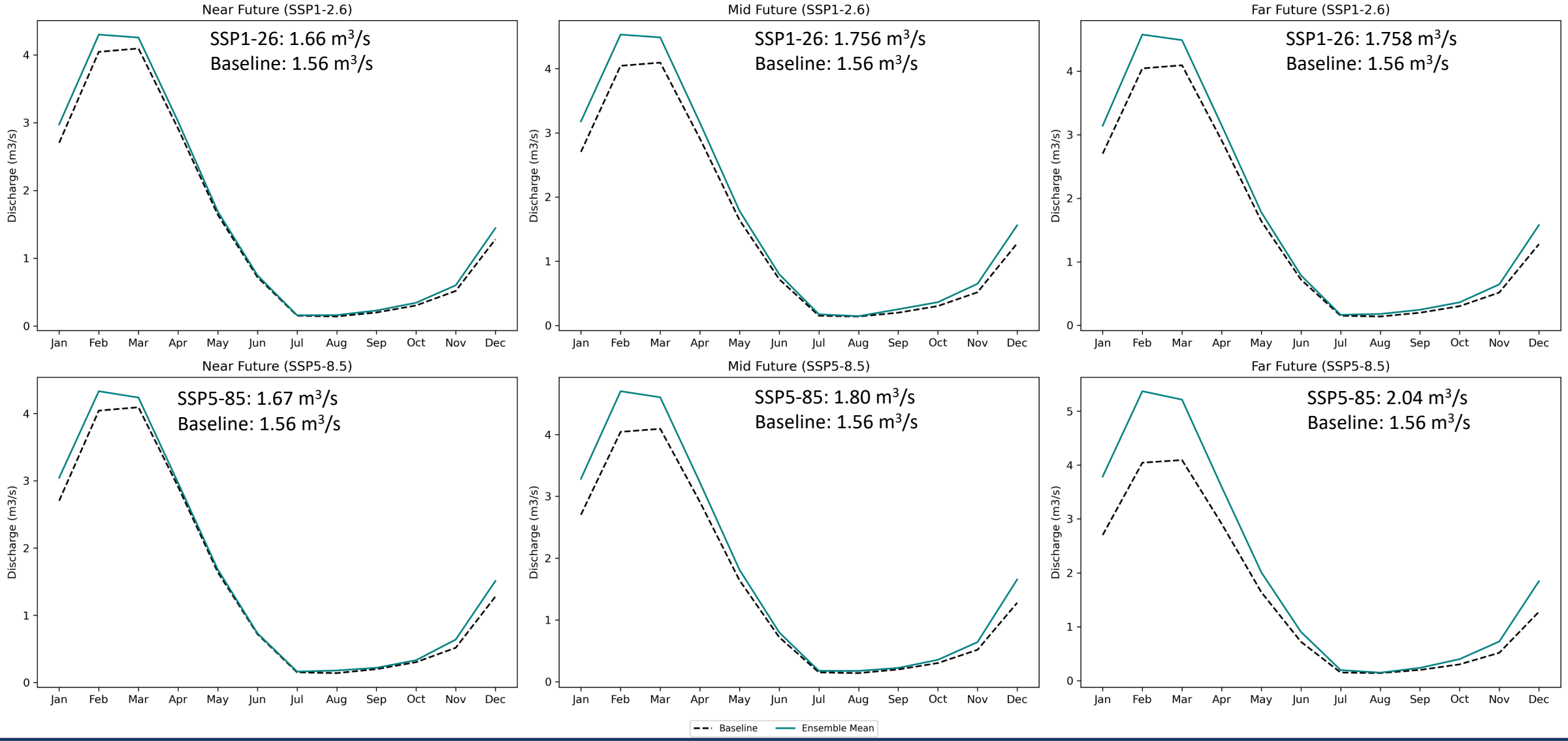




Monthly Discharge for Near, Mid, and Far Future - Individual GCMs



Monthly Discharge for Near, Mid, and Far Future - Ensemble Mean



CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- Model results can be considered acceptable given lack of rain gauges and the sparse observed data for Chicllarazo Basin.
- Climate projections indicate an increased precipitation during the rainy months (December - March), projecting higher water availability and increases in high-flow events.
- The impacts are expected to be more severe under the fossil-fuel-driven development scenario, particularly as we move towards the late-century.
- The findings of this study contribute important insights to planners and decision-makers by providing with a quantification of the water availability, that is vital in the development of effective climate change adaptation plans for water resources in Andean watersheds.

Recommendations

- The lack of data from hydrometric stations limits the calibration and validation process for the most recent years. It is recommended to implement more hydrometric stations in situ.
- In this study, the land cover map corresponds to 2022 and was assumed constant for future projections. Therefore, it is recommended to use future land use coverage scenarios.
- It is recommended for the following hydrological modeling to assess local gridded precipitation PISCO - Peruvian Interpolated data of the SENAMHI's Climatological and hydrological Observations.

THANK YOU

References

- Aybar, C.; Lavado-Casimiro, W.; Huerta, A.; Fernández, C.; Vega, F.; Sabino, E. & Felipe-Obando, O. (2017). Uso del Producto Grillado “PISCO” de precipitación en Estudios, Investigaciones y Sistemas Operacionales de Monitoreo y Pronóstico Hidrometeorológico. Nota Técnica 001 SENAMHI-DHI-2017, Lima-Perú.

- Daniel N Moriasi, Margaret W Gitau, Naresh Pai, and Prasad Daggupati. Hydrologic and water quality models: Performance measures and evaluation criteria. *Transactions of the ASABE*, 58(6):1763–1785, 2015.

- Fernandez-Palomino, C. A.; Hattermann, F. F.; Krysanova, V.; Lobanova, A.; Vega-Jácome, F.; Lavado, W.; Santini, W.; Aybar, C.; Bronstert, A. (2021). Rain for Peru and Ecuador (RAIN4PE). V. 1.0. GFZ Data Services. https://doi.org/10.5880/pik.2020.010

- Fernandez-Palomino, C.A., Hattermann, F.F., Krysanova, V. et al. High-resolution climate projection dataset based on CMIP6 for Peru and Ecuador: BASD-CMIP6-PE. Sci Data 11, 34 (2024). https://doi.org/10.1038/s41597-023-02863-z

- KC Abbaspour. Swat calibration and uncertainty programs: A user manual. *Swiss Federal Institute of Aquatic Science and Technology: Eawag, Switzerland*, 2015.

- KC Abbaspour, Elham Rouholahnejad, Srinivasanb Vaghefi, Raghavan Srinivasan, Hong Yang, and Bjørn Kløve. A continental-scale hydrology and water quality model for europe: Calibration and uncertainty of a high-resolution largescale swat model. *Journal of hydrology*, 524:733–752, 2015.

Agriculture (no cons. measures) and livestock (infiltration & runoff)