FUNCEME

CEARÁ
GOVERNO DO ESTADO
SECRETARIA DOS RECURSOS HÍDRICOS

Operational Implementation of SWAT in Large Basins of Brazil's Semi-Arid Region: Methodologies and Challenges

Dário Lima
João Dehon Filho
Renan Rocha
Gilberto Möbus
Alyson Estácio
Daniel Cid
Caio Silva

FUNCEME

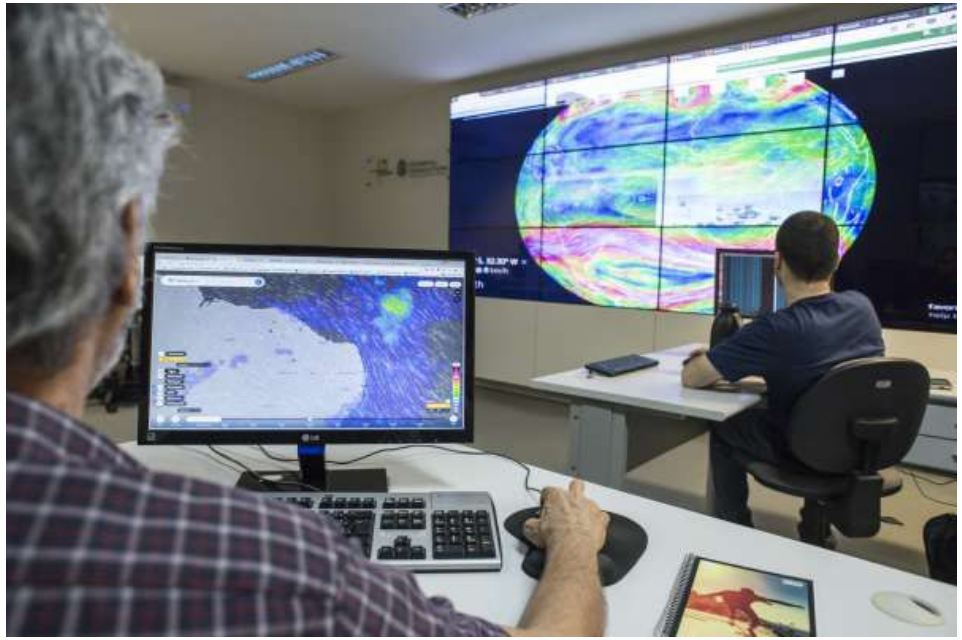
CEARÁ
GOVERNO DO ESTADO
SECRETARIA DOS RECURSOS HÍDRICOS

Summary

1. State of Ceará
2. Reservoirs of Ceará
3. SWAT implementation
4. Initial results
5. Conclusions and next steps

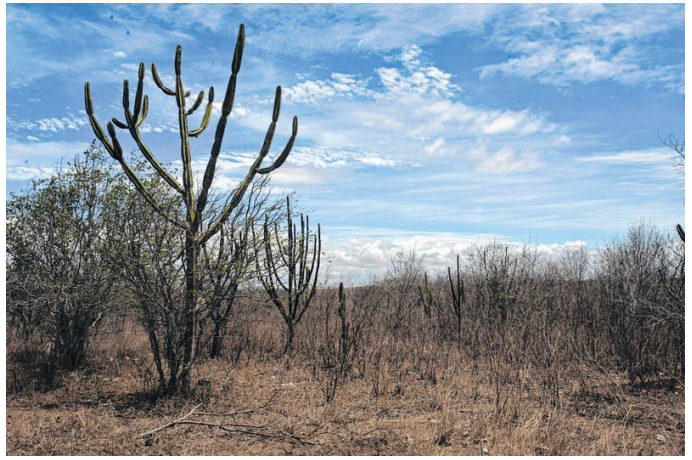
FUNCEME

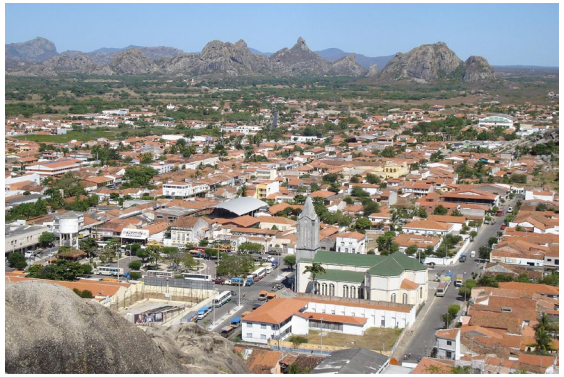
- Research Institute in Meteorology and Water Resources
- Founded in 1972
- Seasonal climate forecasting
- Weather forecasting
- Atmospheric and Hydrological modeling
- Soil survey
- Mapping of small reservoirs
- Rain gauges and weather stations
- Decision support systems for the water resources sector



STATE OF CEARÁ

Location

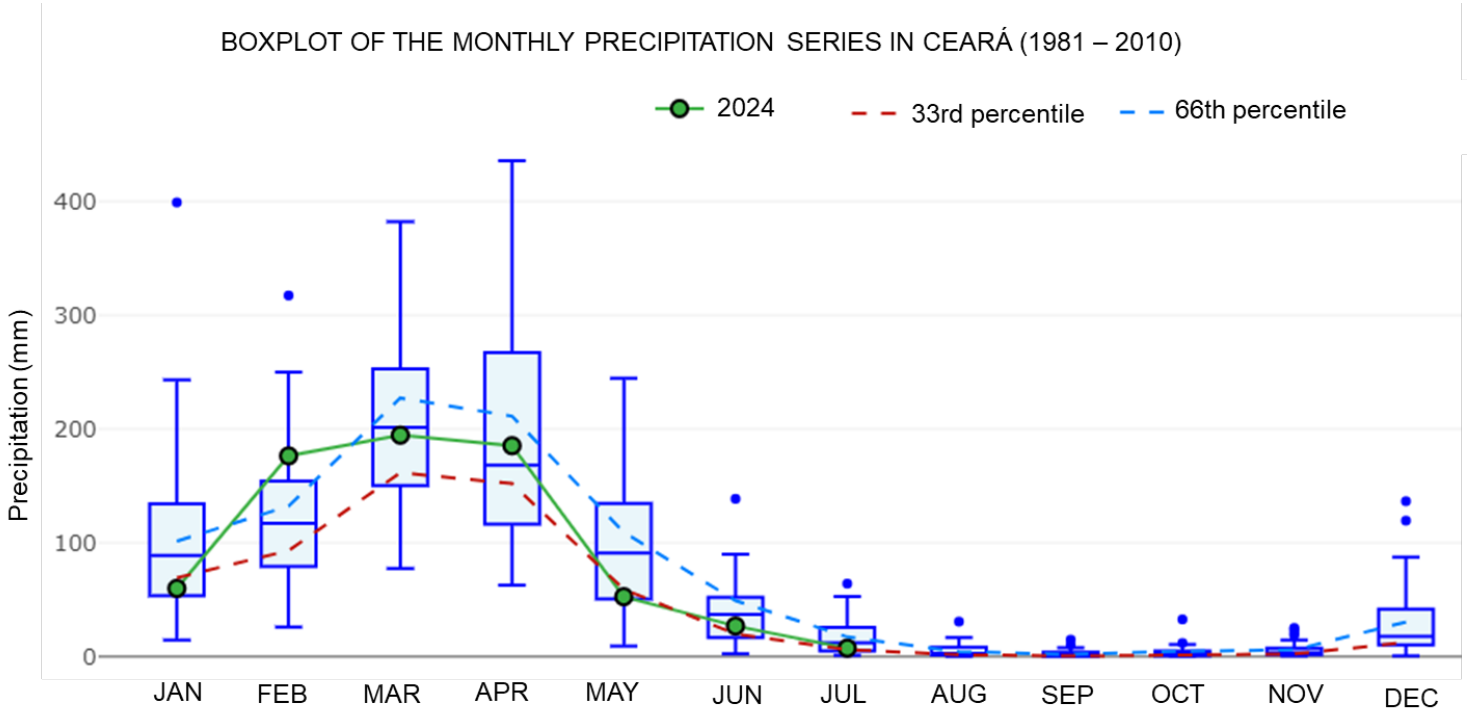




STATE OF CEARÁ

Negative water balance

- Mean annual rainfall: 800 mm
- Rainy season: February-May
- High temperatures and solar radiation
- Annual potential evaporation: 2200 mm
- Crystalline bedrock and shallow soils
- Intermittent rivers

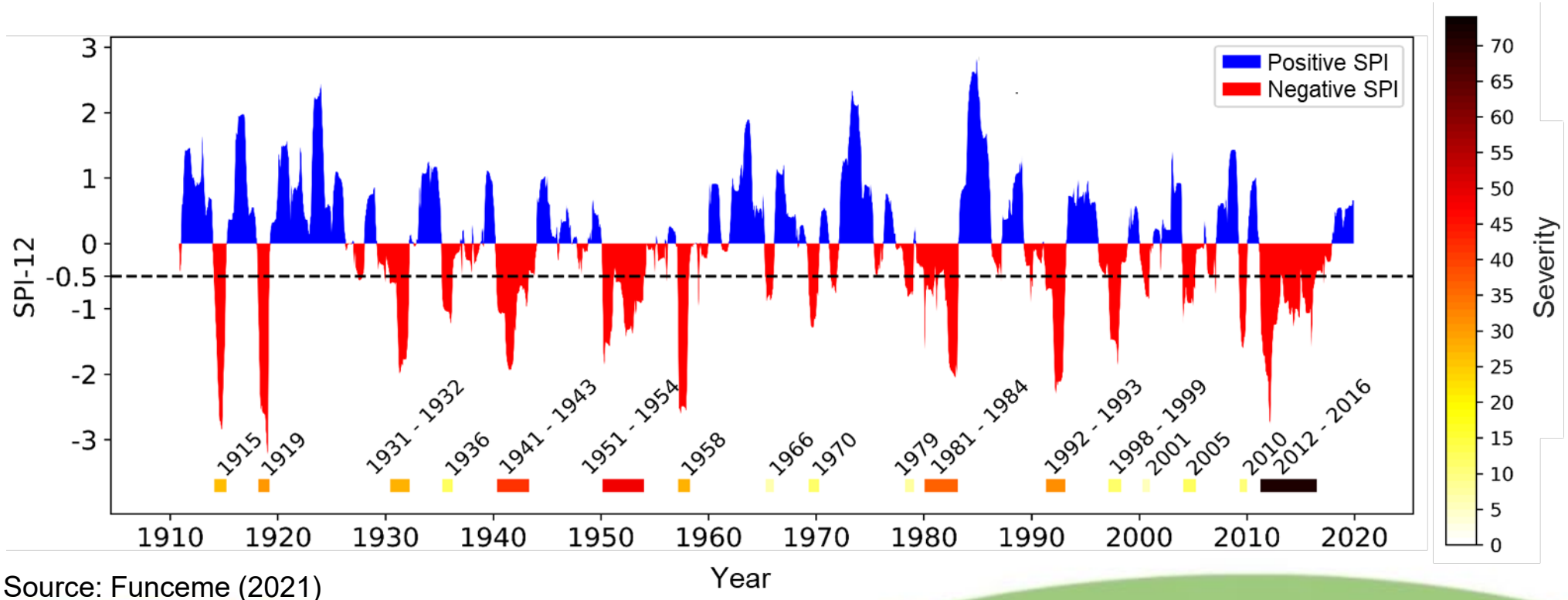


Source: http://www.funceme.br/dashes

STATE OF CEARÁ

High recurrence of drought events

- 17 drought events since 1910
- 1.5 events per decade



Source: Funceme (2021)

STATE OF CEARÁ

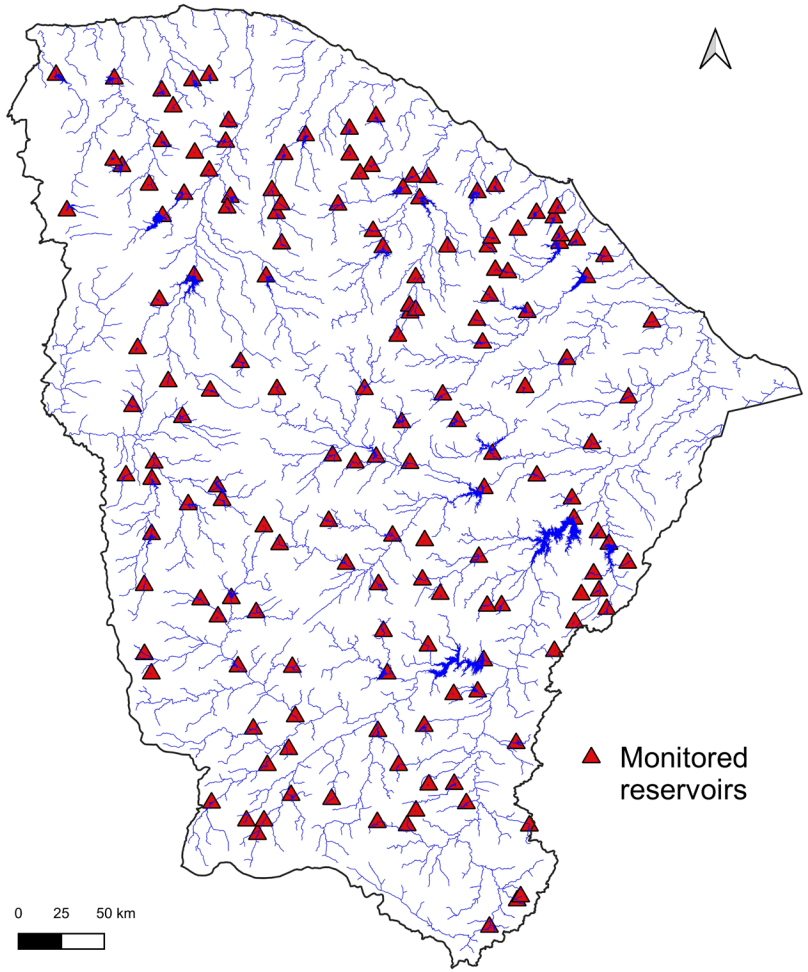
Population

- Population in 2022: 8.7 million
- Fortaleza, the capital, has a population of 2.6 million, making it the 4th largest city in Brazil.)

STATE OF CEARÁ

Reservoirs

- 157 monitored reservoirs



Castanhão Reservoir: 6.7 bi m³

Banabuiú Reservoir : 1.5 bi m³

Orós Reservoir : 1.9 bi m³

RESERVOIRS OF CEARÁ

Principal challenges

- Water availability
- Water quality

Eco-Hydrological modeling

Forecasting

- Seasonal Eco-Hydrological Forecasting
- Real-Time Forecasting System

Regulation Capacity

- Historical inflow series
- Flow with 90% reliability

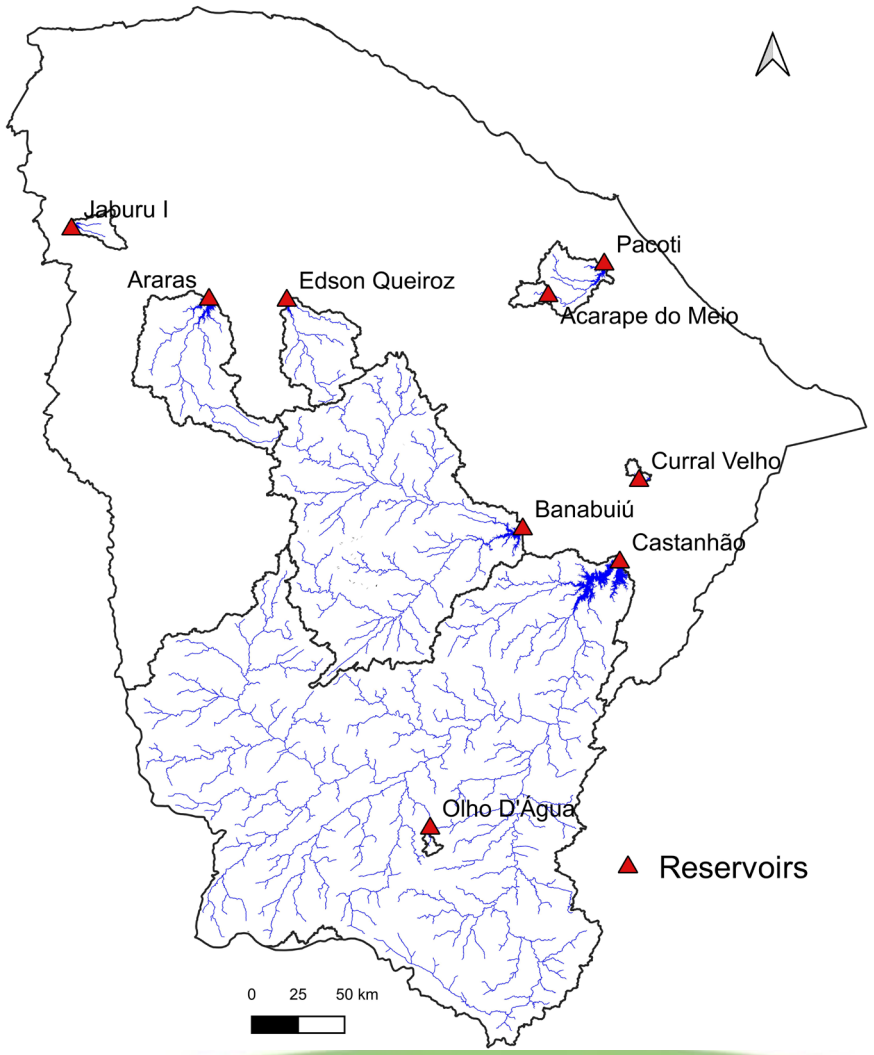
Scenarios

- Land Use and Land Cover changes
- Soil conservation practices
- Expansion of access to the sewage collection network
- Impacts of new reservoir construction

SWAT IMPLEMENTATION

Study area

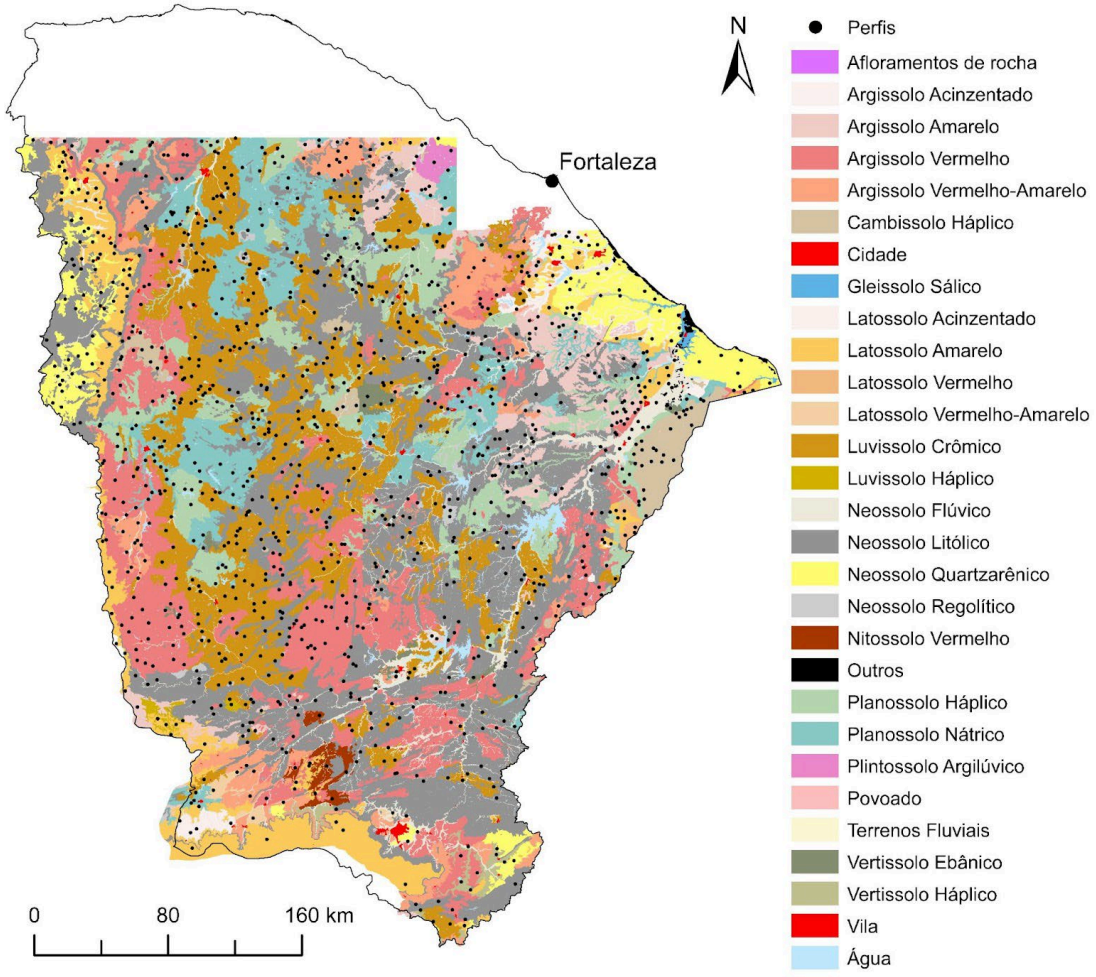
- Funceme has implemented SWAT operationally in 9 strategic reservoirs in Ceará State
- Combined drainage area: 66,000 km² (44% of the total area of Ceará)
- Combined storage capacity: 10 bi m³
- They are crucial for Ceará water supply
- Version: SWAT 2012



SWAT IMPLEMENTATION

Soil database

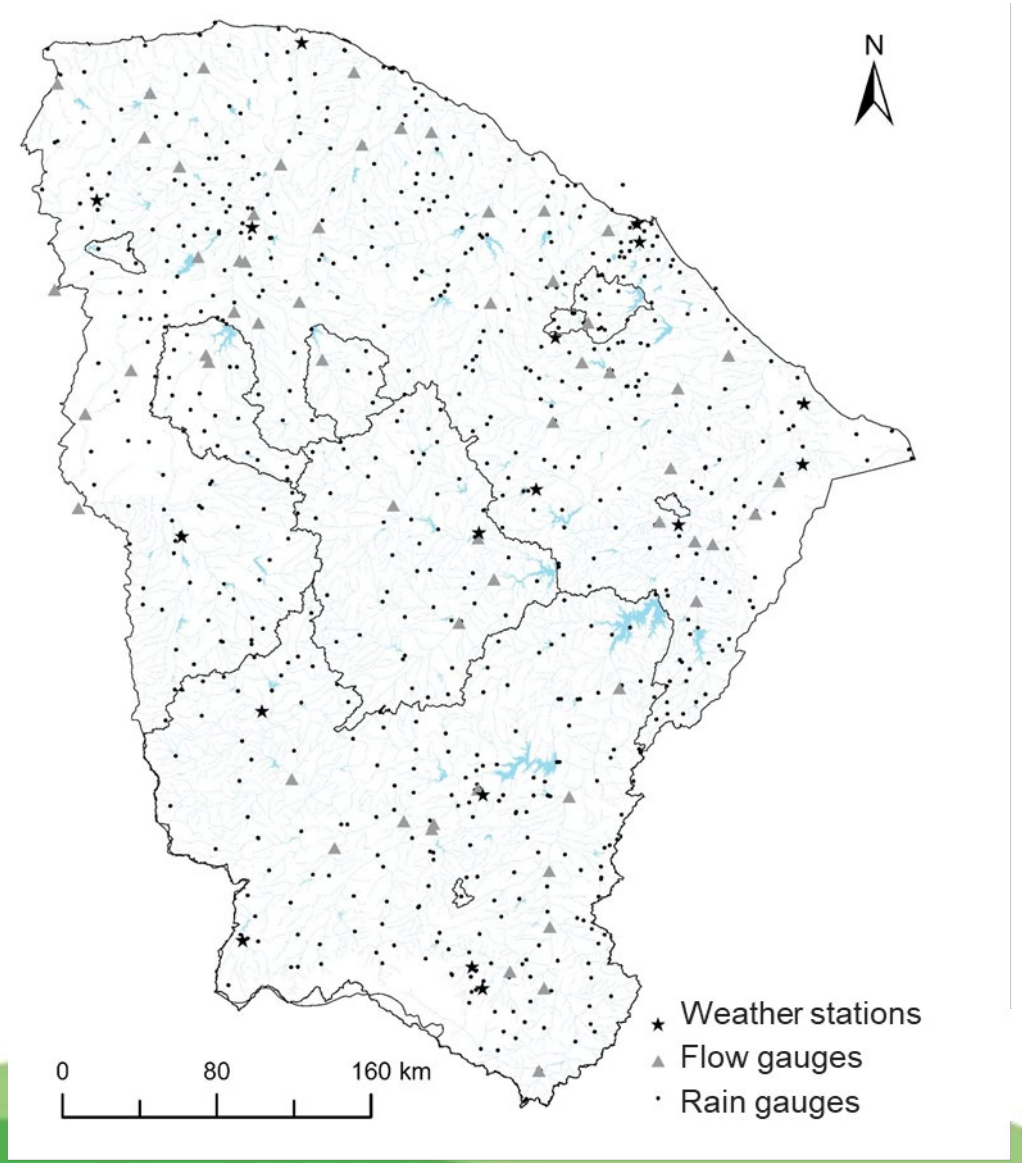
- Funceme is conducting a soil survey for the entire state of Ceará, based on field surveys and satellite image analysis



SWAT IMPLEMENTATION

Weather database and Observed flow

- **Weather database**: developed from data provided by Funceme and the Brazilian National Institute of Meteorology (INMET)
- Daily temporal resolution
- **Observed flow data**: Brazilian National Water and Sanitation Agency (ANA)

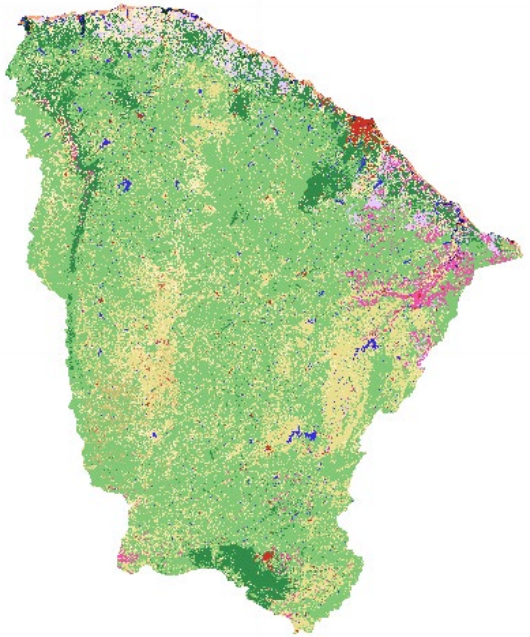


SWAT IMPLEMENTATION

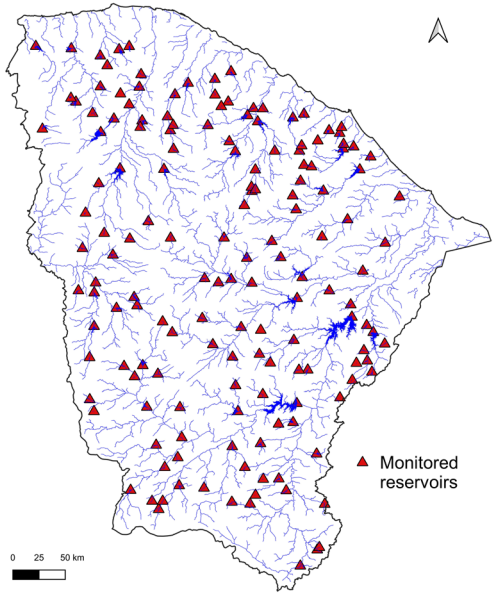
Other input data

- **Land Use**: Mapbiomas (Souza et al., 2020)
- **Reservoirs**: Funceme database
- **Point-source pollution**: estimated based on city population and the typical per capita contribution of each wastewater parameter (Sperling, 1996)
- **Non-point source pollution**: the predominant agricultural crop in each watershed was identified, and we aimed to replicate its production cycle, including fertilization

Land Use



Reservoirs



Point-source pollution

Non-point source pollution

SWAT IMPLEMENTATION

Sensitivity analysis

- Algorithm developed in R language
- **Sampling technique:** Latin Hypercube (LH) (McKay et al., 1979)
- **Sensitivity analysis method**: Multivariate linear regression (Abbaspour, 2015)

SWAT IMPLEMENTATION

Calibration

- Algorithm developed in R language
- **Algorithm**: Particle Swarm Optimization incorporating Crowding Distance (MOPSO-CD) (Raquel and Naval, 2005)
- Evolutionary algorithm
- Multi-objective

3 objective functions

$$NSE = 1 - \frac{\sum_{t=1}^{N}(Qobs_t - Qcal_t)^2}{\sum_{t=1}^{N}(Qobs_t - \overline{Qobs})^2}$$

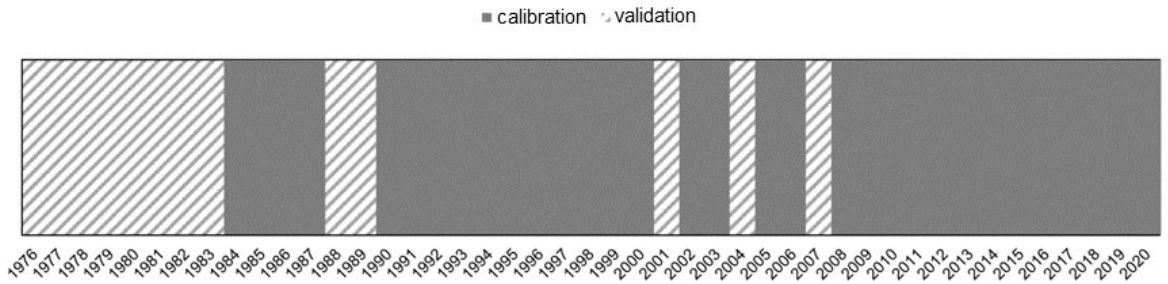
$$NSE_{log} = 1 - \frac{\sum_{t=1}^{N}(\ln(Qobs_t) - \ln(Qcal_t))^2}{\sum_{t=1}^{N}(\ln(Qobs_t) - \overline{\ln(Qobs)})^2}$$

$$PBIAS = \frac{\sum_{t=1}^{N} Qcal_t - \sum_{t=1}^{N} Qobs_t}{\sum_{t=1}^{N} Qobs_t} \cdot 100$$

SWAT IMPLEMENTATION

Calibration and validation periods

- **Calibration**: 70% of total period
- **Validation**: 30% of total period
- An effort was made to balance the number of dry and wet years in both the calibration and validation periods
- Years were classified based on Standardized Precipitation Index (SPI) (McKee et al., 1993)



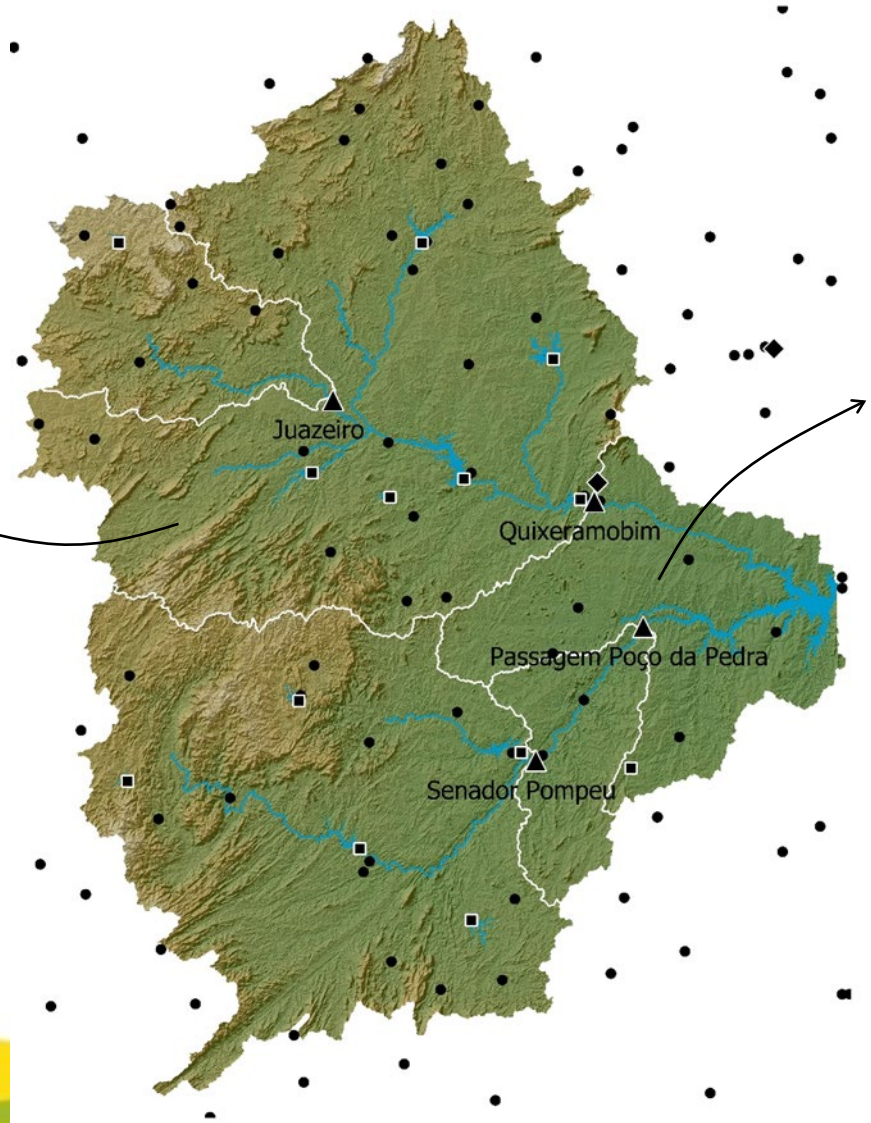
Class	Description	Range	Probability (%)
1	extremely wet	SPI >= 2	2%
2	severely wet	2 > SPI >= 1.5	4%
3	moderately wet	1.5 > SPI >= 1	9%
4	wet	1 > SPI >= 0.5	15%
5	normal wet	0.5 > SPI >= 0	19%
6	normal dry	0 > SPI >= -0.5	19%
7	dry	-0.5 > SPI > -1	15%
8	moderately dry	-1 >= SPI > -1.5	9%
9	severely dry	-1.5 >= SPI > -2	4%
10	extremely dry	SPI <= -2	2%

We aimed to maintain this proportion during both the calibration and validation periods

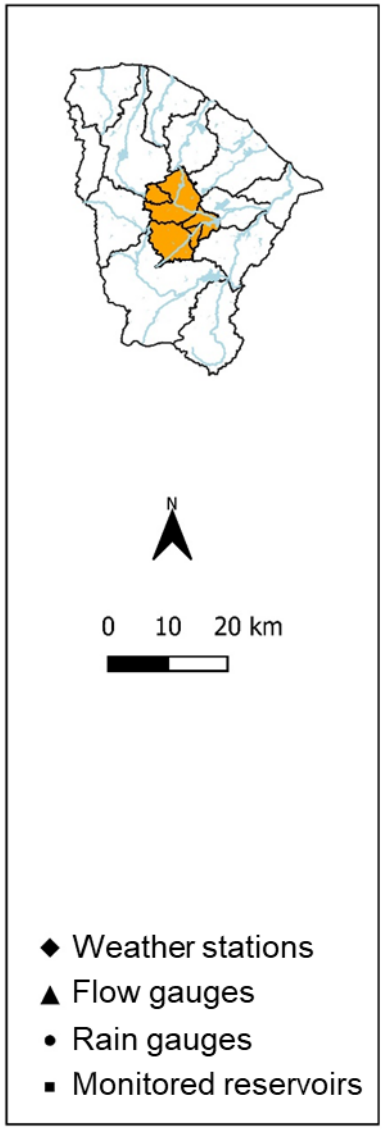
SWAT IMPLEMENTATION

Calibration strategy

Calibration of each incremental watershed



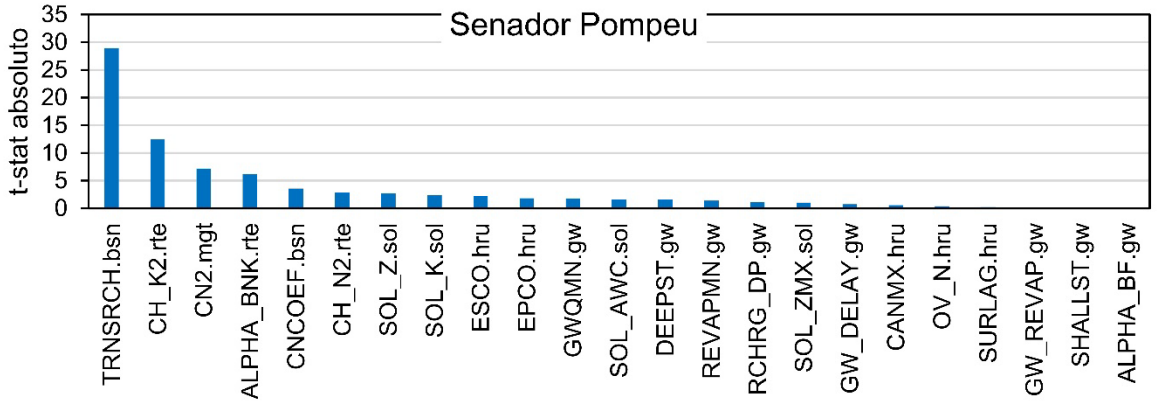
Calibration is performed using inflow estimates to the reservoir

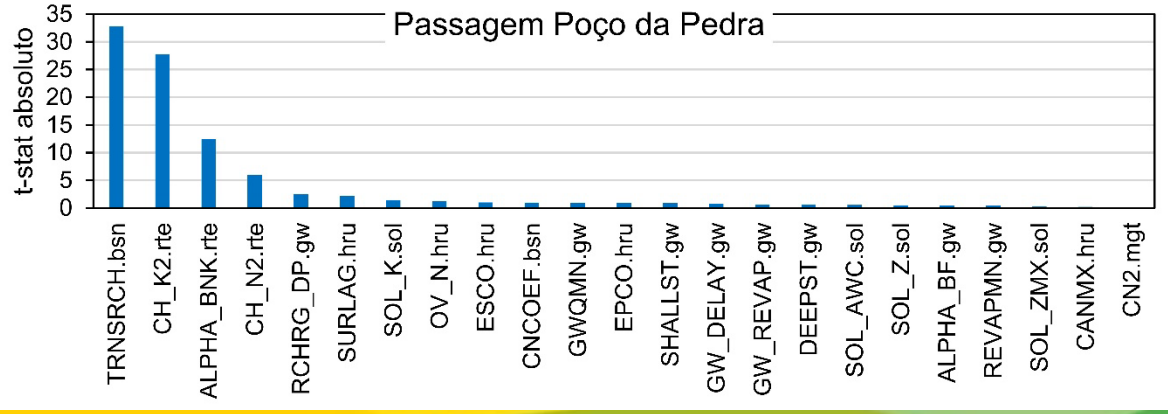


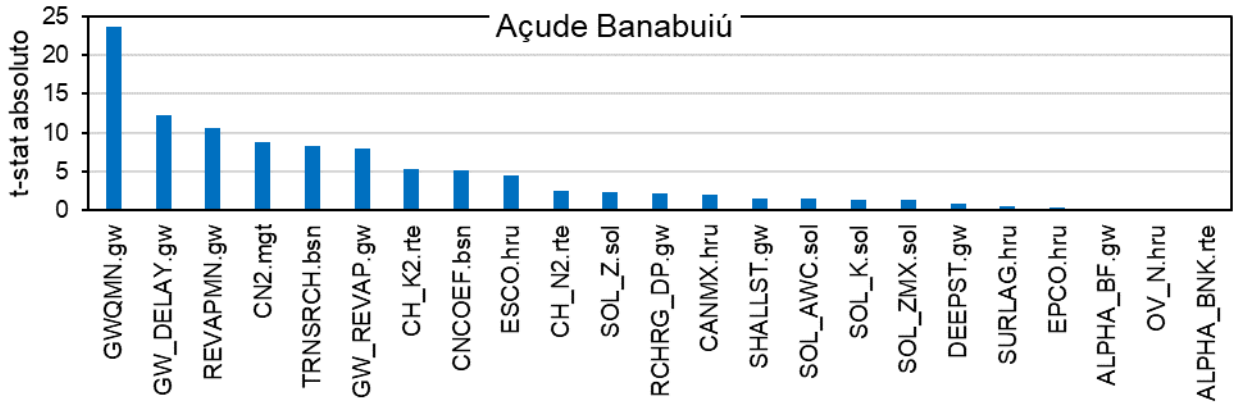
INITIAL RESULTS

Sensitivity analysis

- Parameters with higher sensitivity are usually related to losses from the channel due to transmission through the sides and bottom



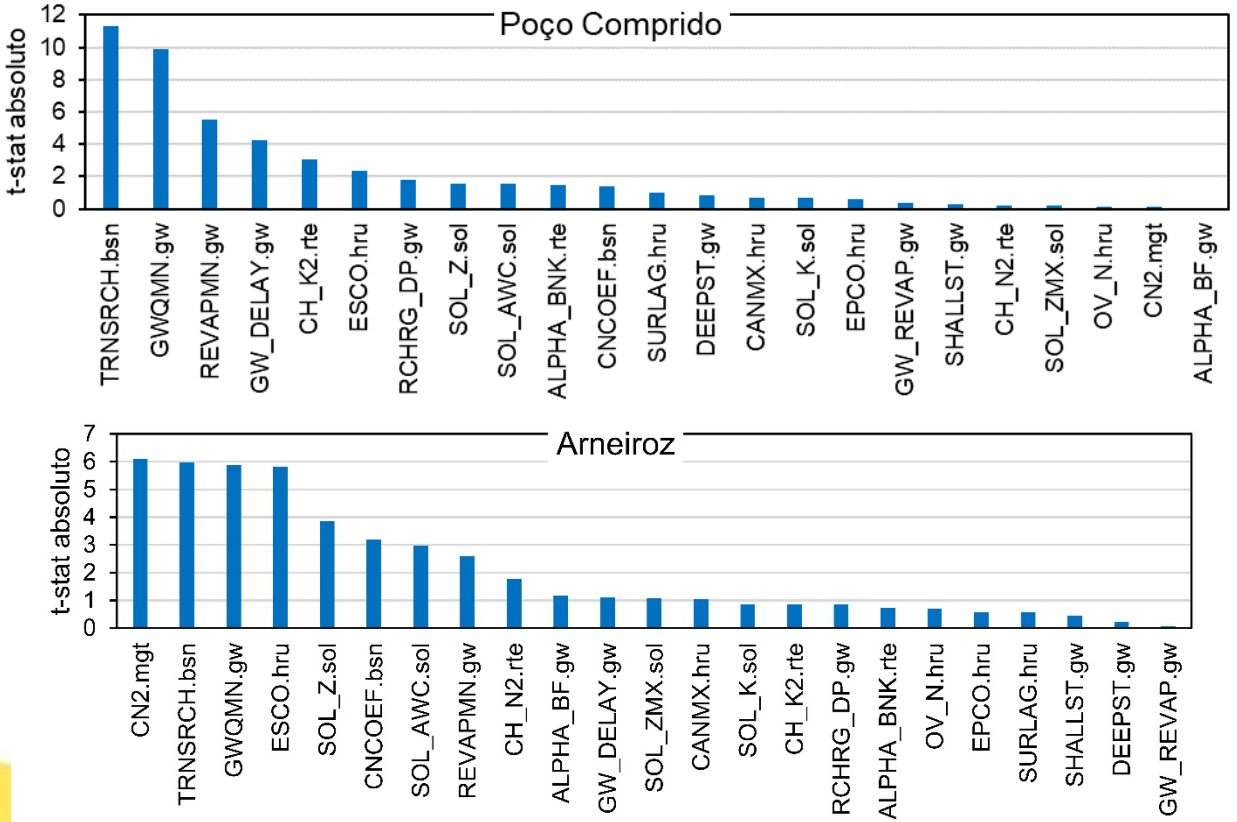


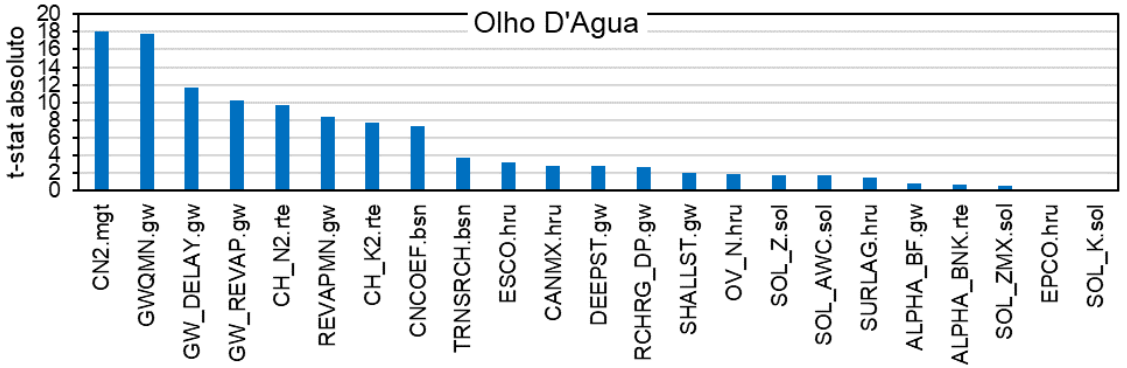


INITIAL RESULTS

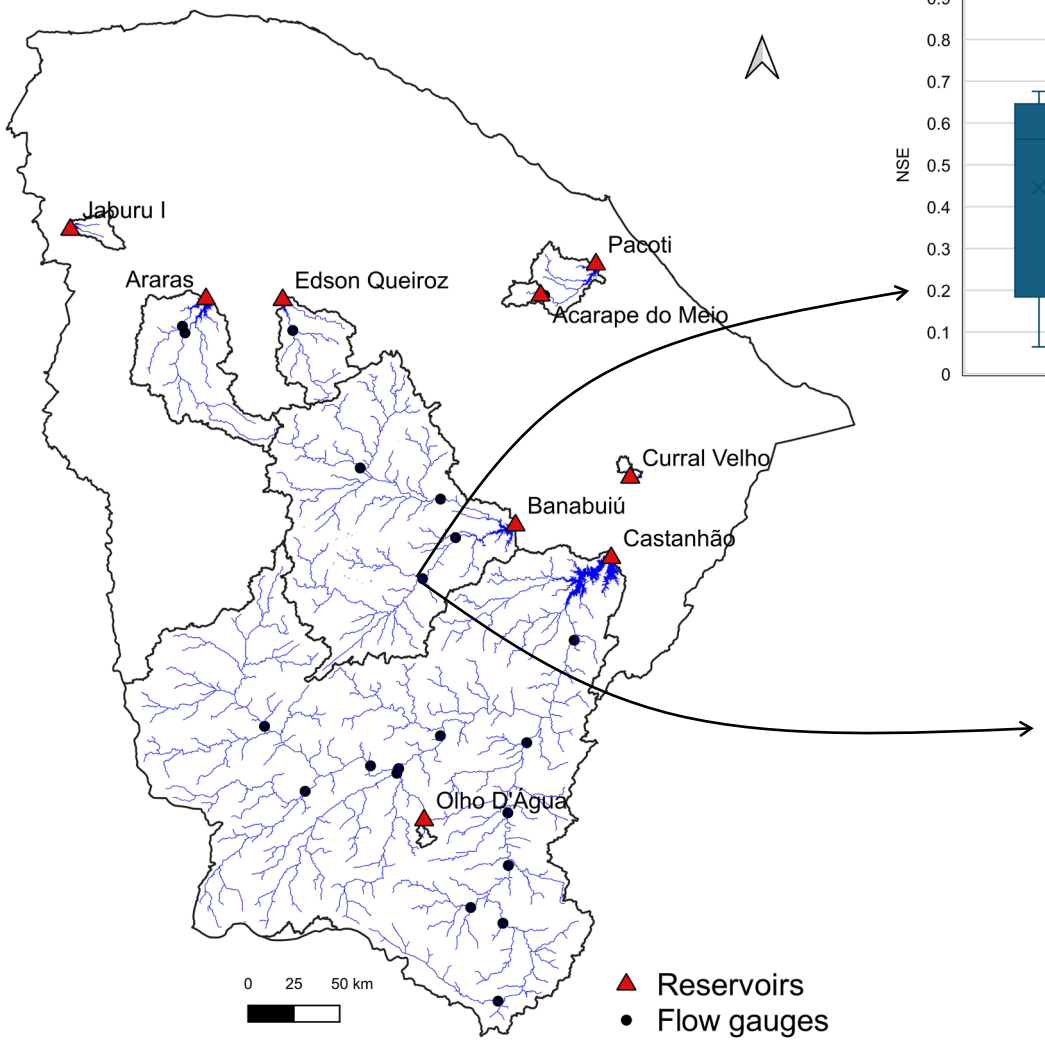
Sensitivity analysis

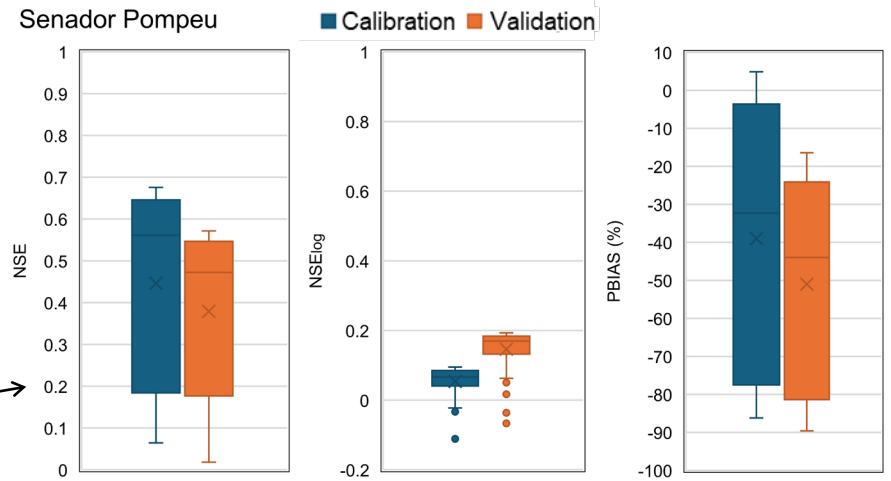
- CN2 and GWQMN also presented a high sensitivity for some watersheds

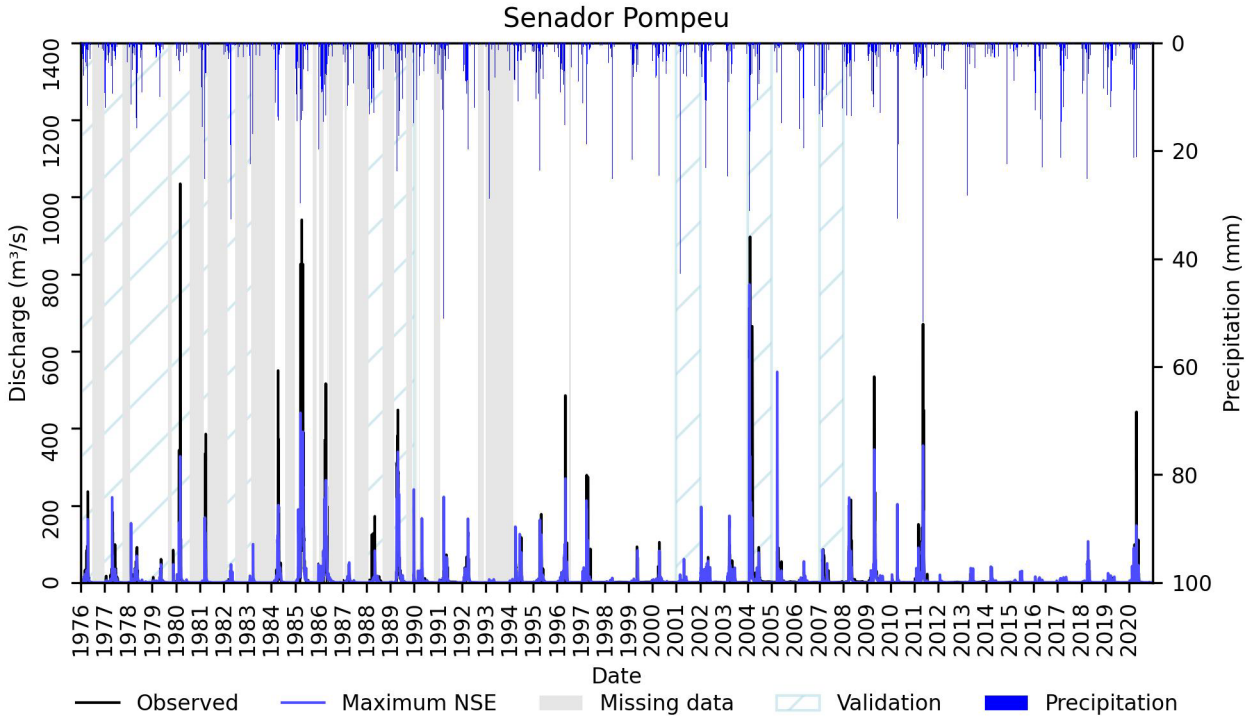




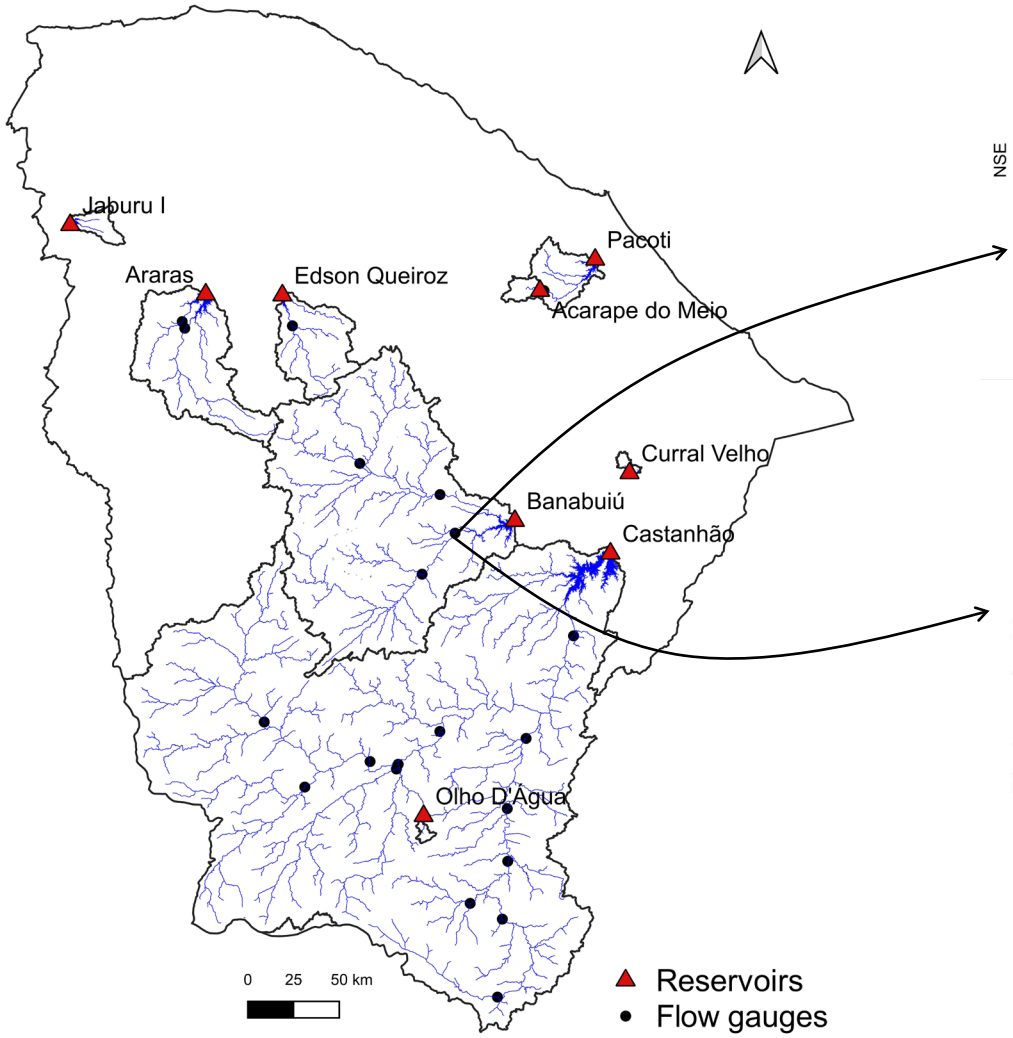
INITIAL RESULTS

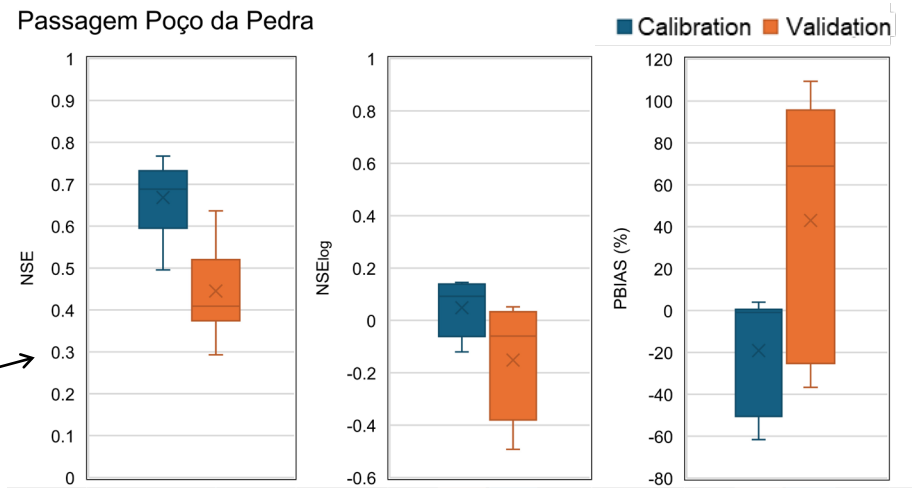


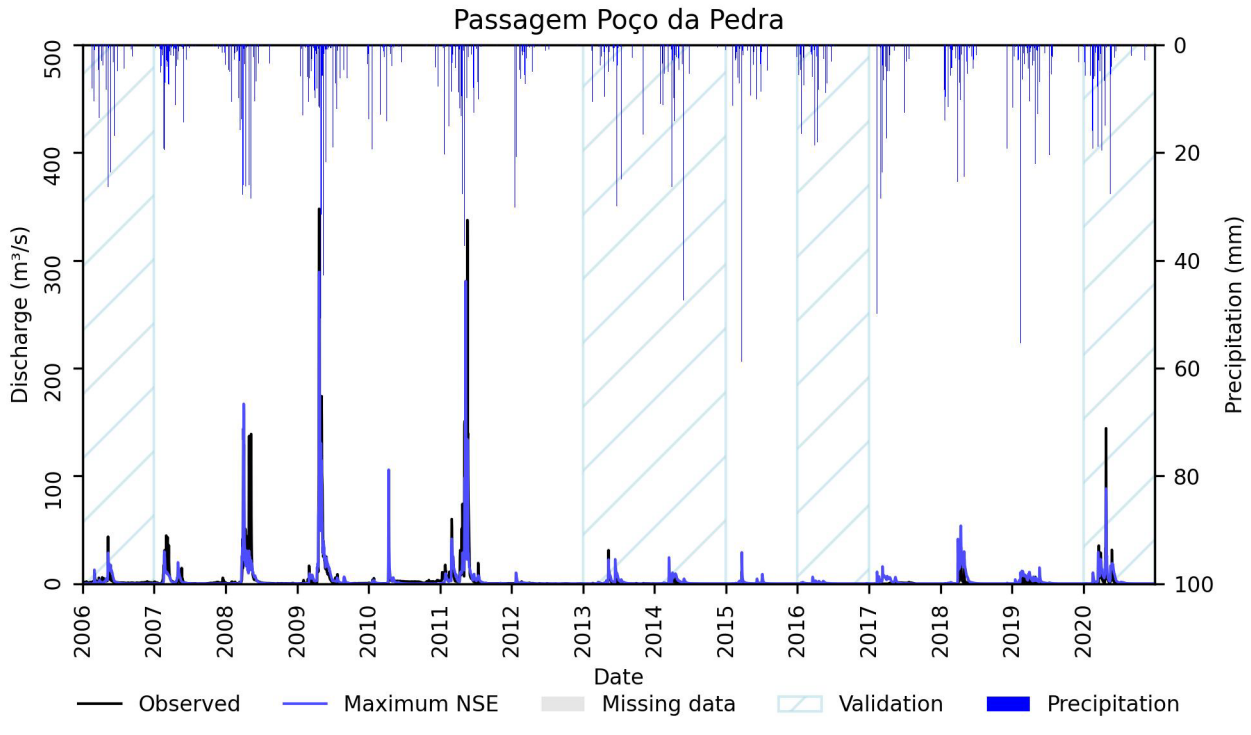




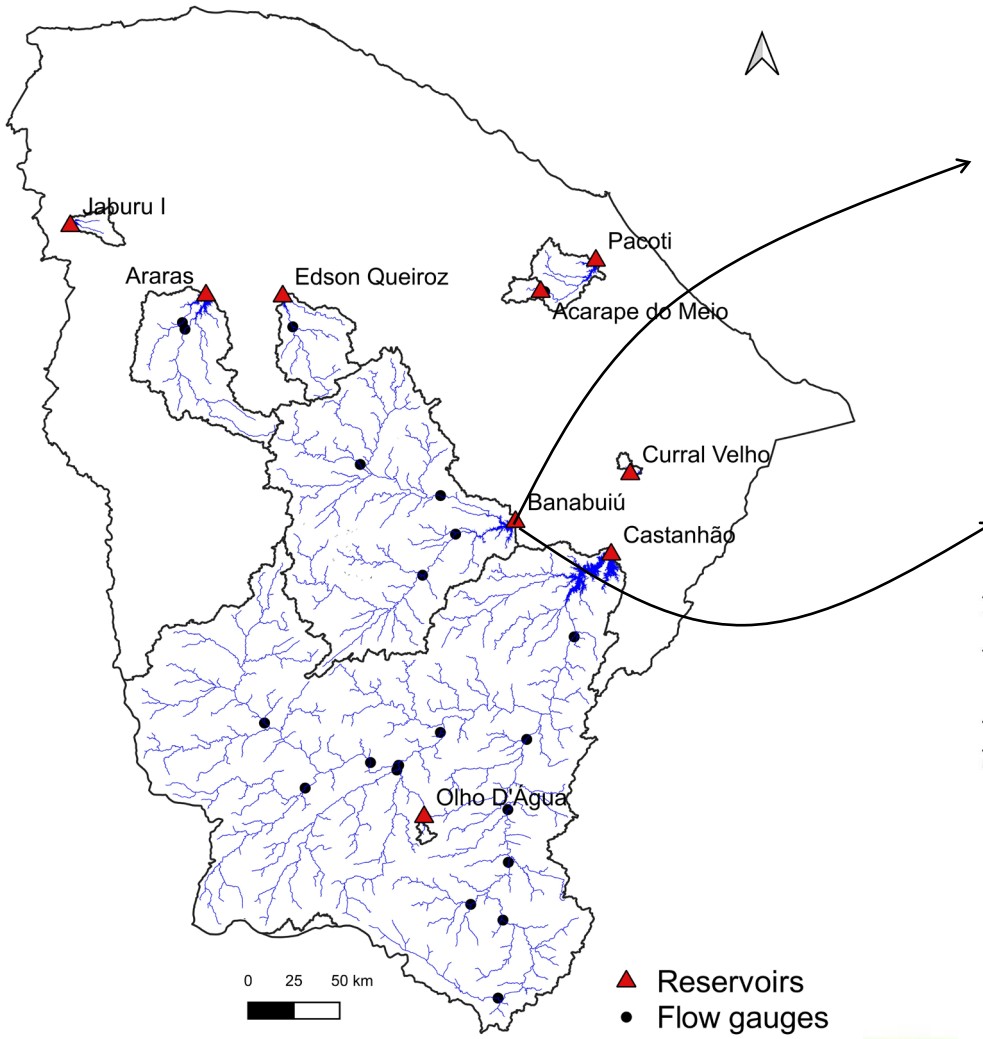
INITIAL RESULTS

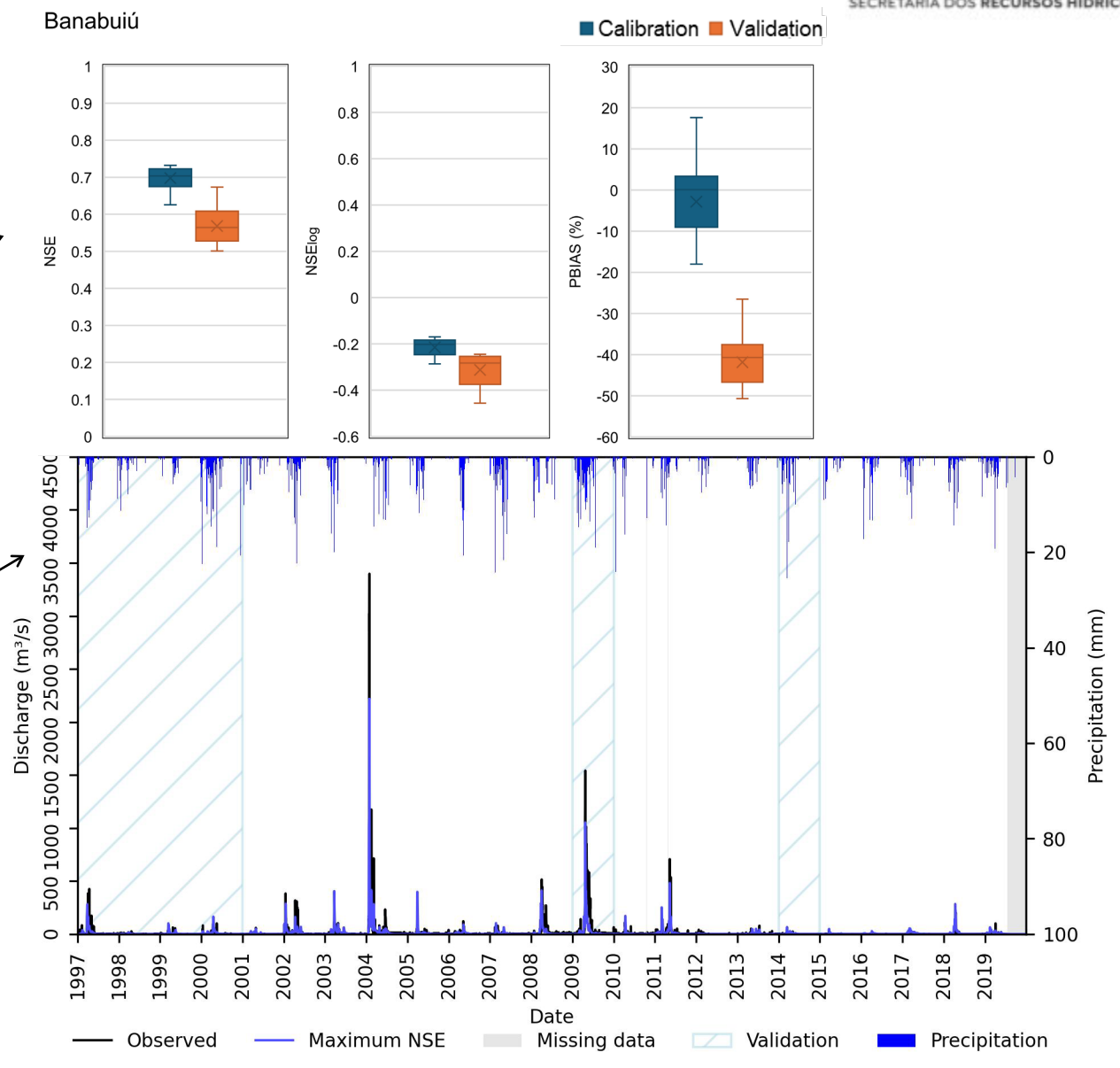




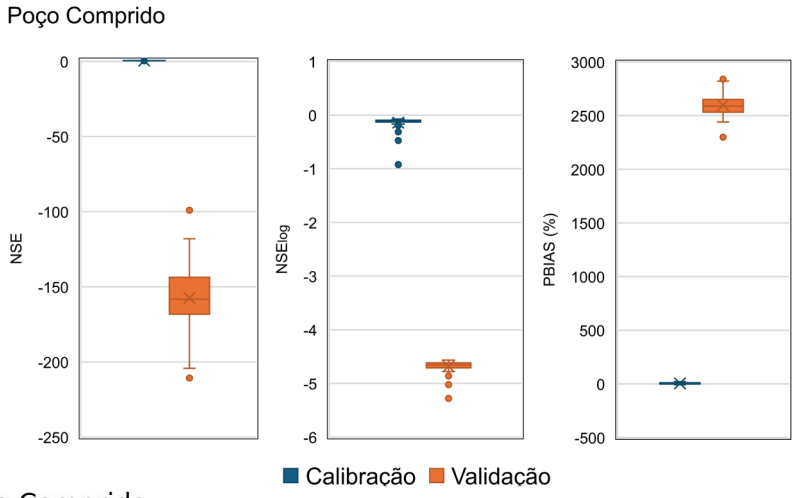


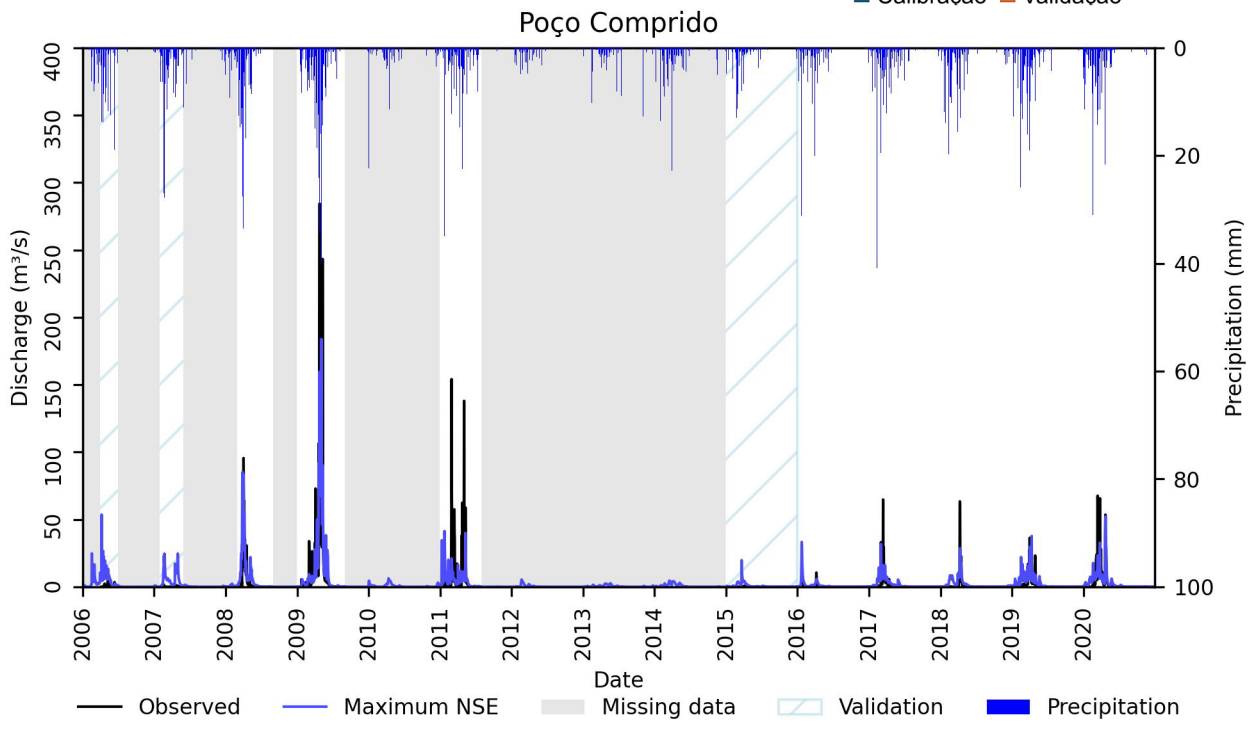
INITIAL RESULTS

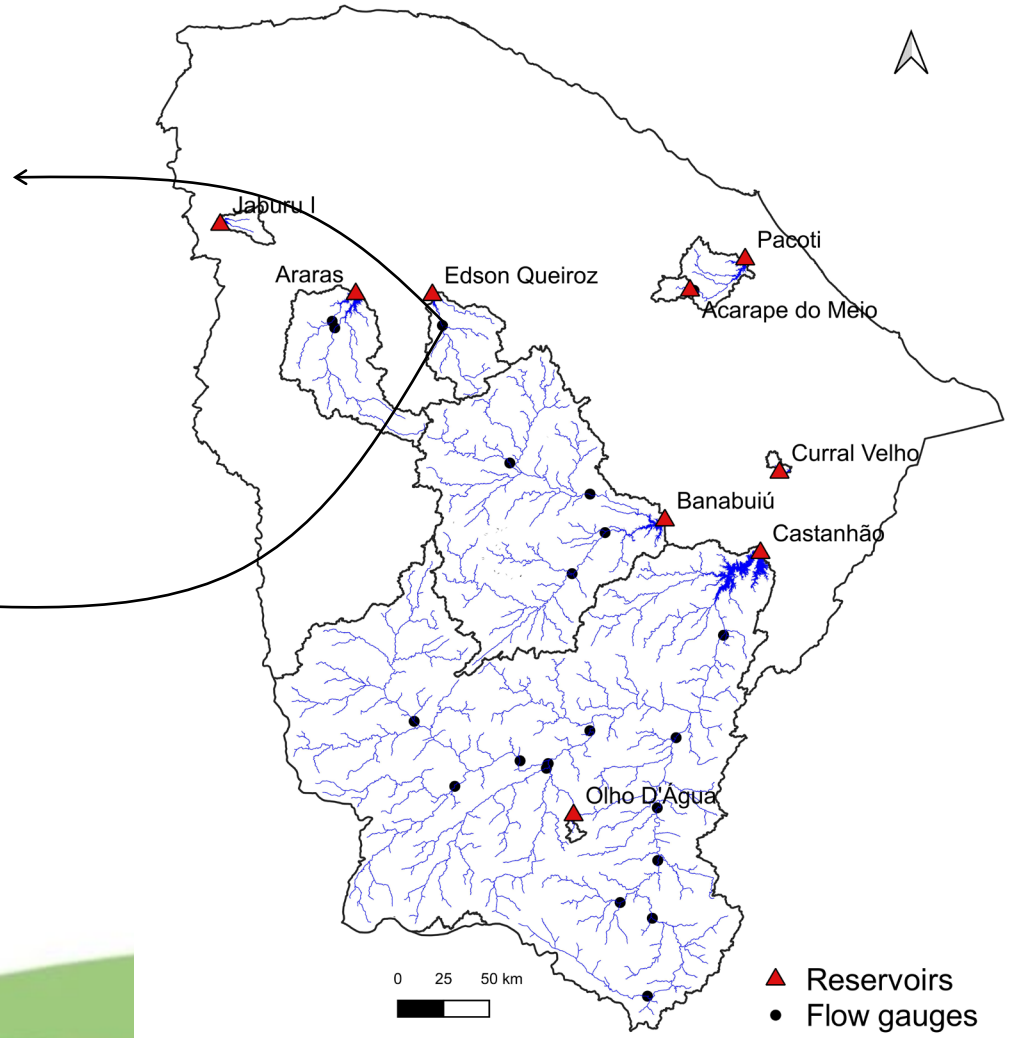




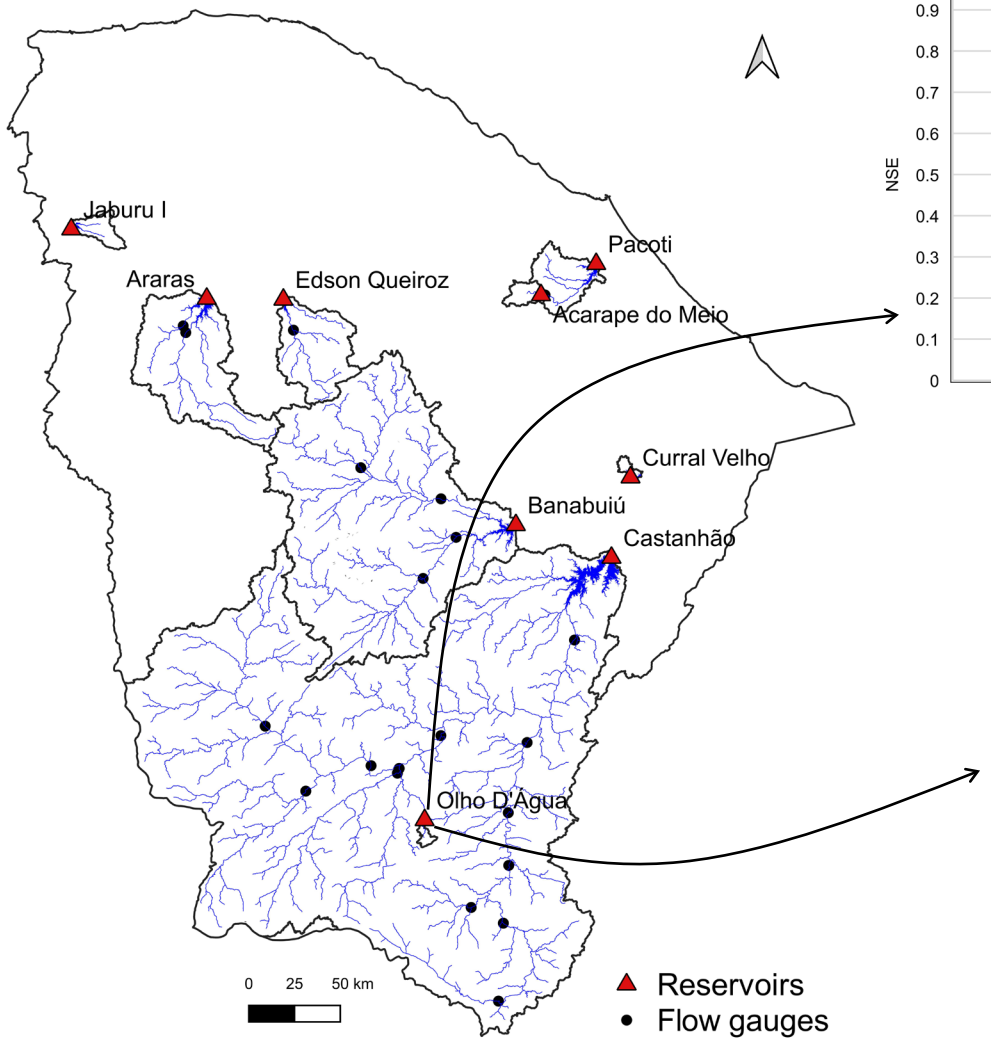
INITIAL RESULTS

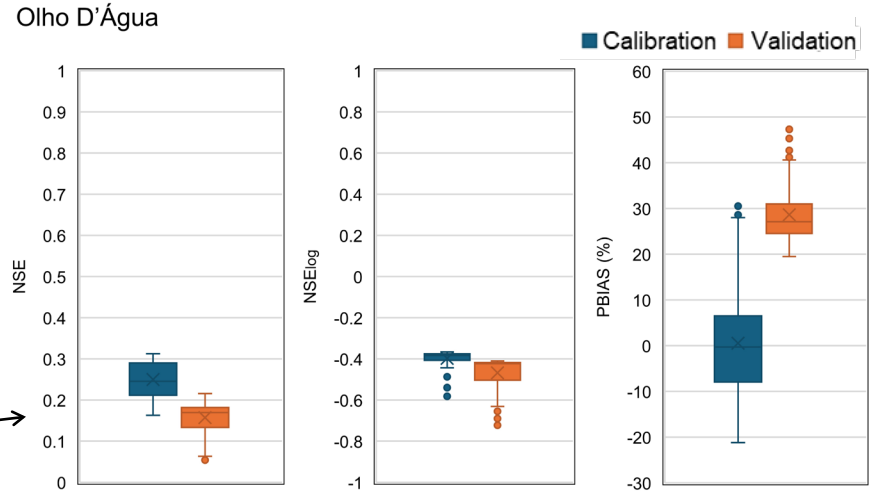


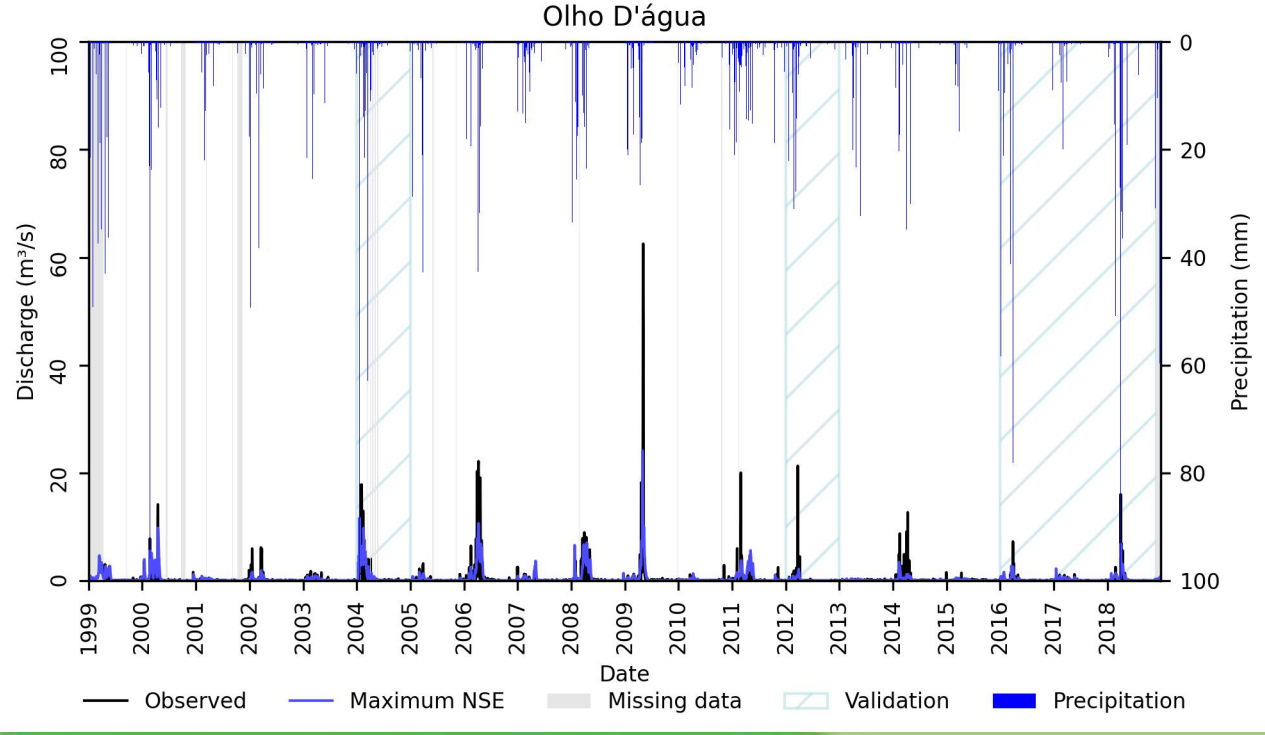




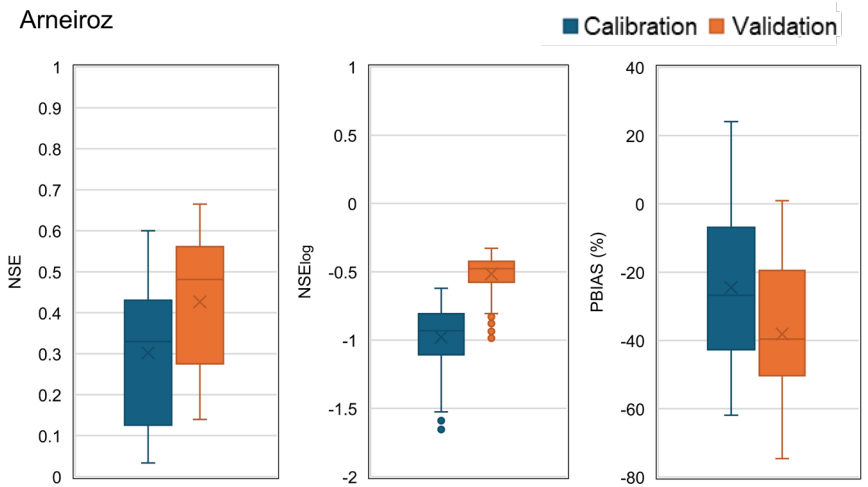
INITIAL RESULTS

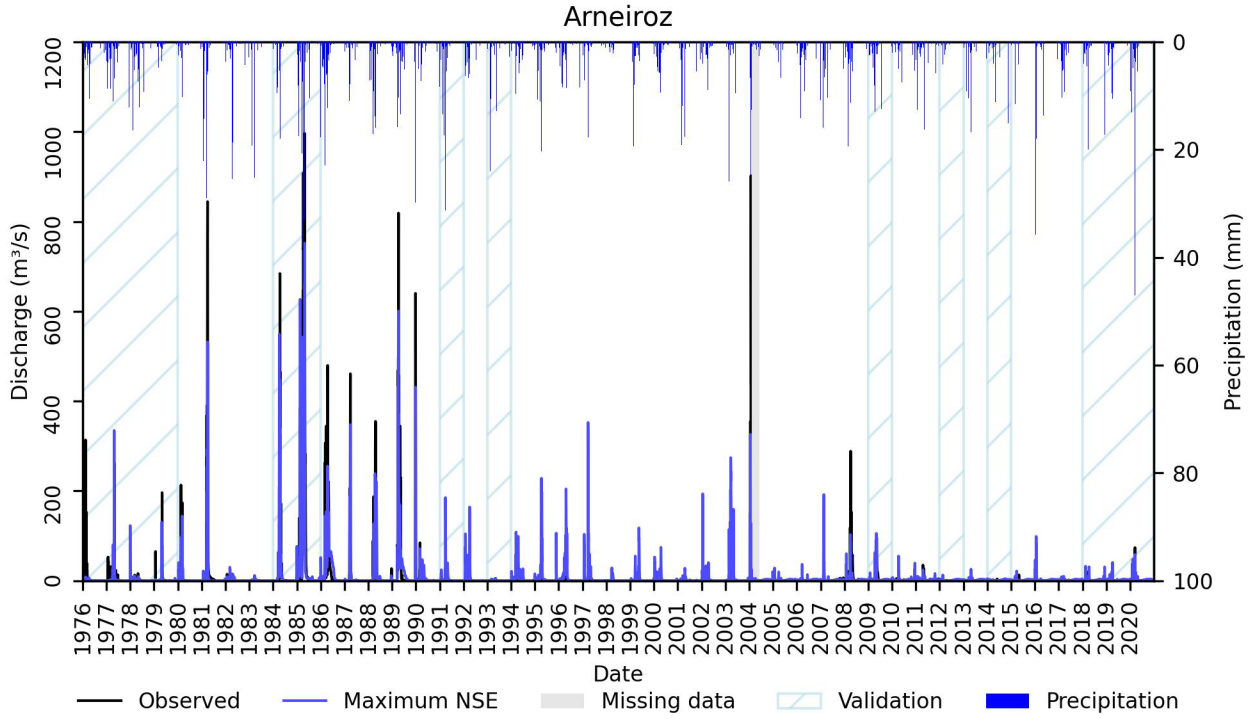


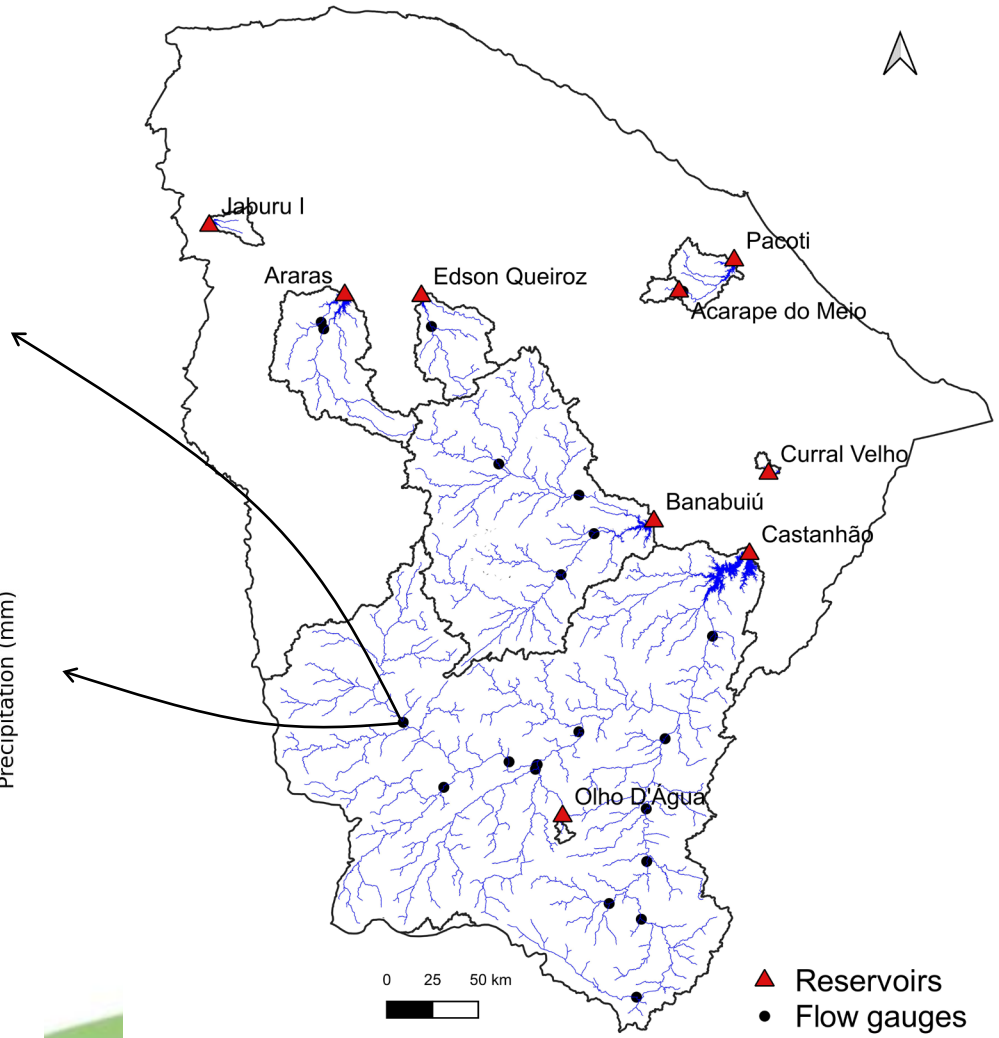




INITIAL RESULTS







CONCLUSIONS AND NEXT STEPS

- For certain watersheds, the SWAT model demonstrated good performance

- However, the poor performance observed in some watersheds may be attributed to various factors, such as the limited number of rain gauges, issues with observed discharge data, and other uncertainties

- The next step involves completing the calibration of the nine reservoirs. One significant challenge is the high processing time required for model calibration.

- After calibrating the parameters related to hydrology, our focus will shift to calibrating the parameters associated with water quality.

- However, a big challenge is the scarcity of data related to water quality

CEARÁ
GOVERNO DO ESTADO

@funceme

THANK YOU!

dario.lima@funceme.br