# Modeling the potential impacts of climate change on streamflow in a headwater of the Grande River Basin, Southeastern Brazil

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Purdue University

UNIVERSIDADE FEDERAL DE LAVRAS

TEXAS A&M UNIVERSITY

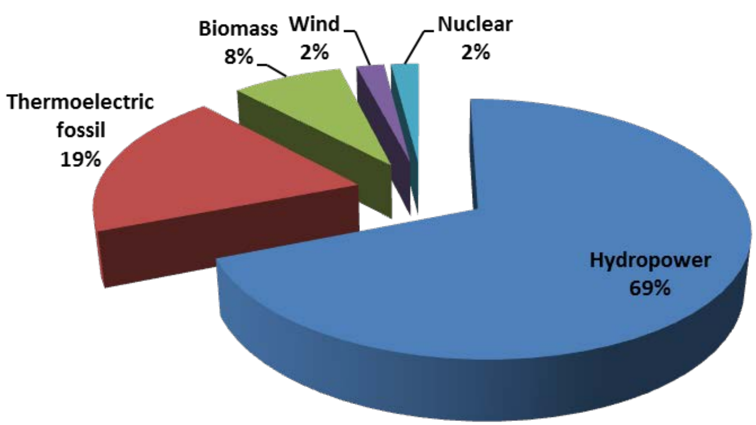
# Outline

- Introduction
- Objectives
- Material and Methods
  - Study area;
  - Database;
  - Climate change database;
  - Climate change data source.
- Results
- Conclusions

# Introduction

- According to the Intergovernmental Panel on Climate Change (IPCC, 2013) the precipitation pattern and the temperature will significantly change by the end of 21st century, which will affect the hydrologic regime.

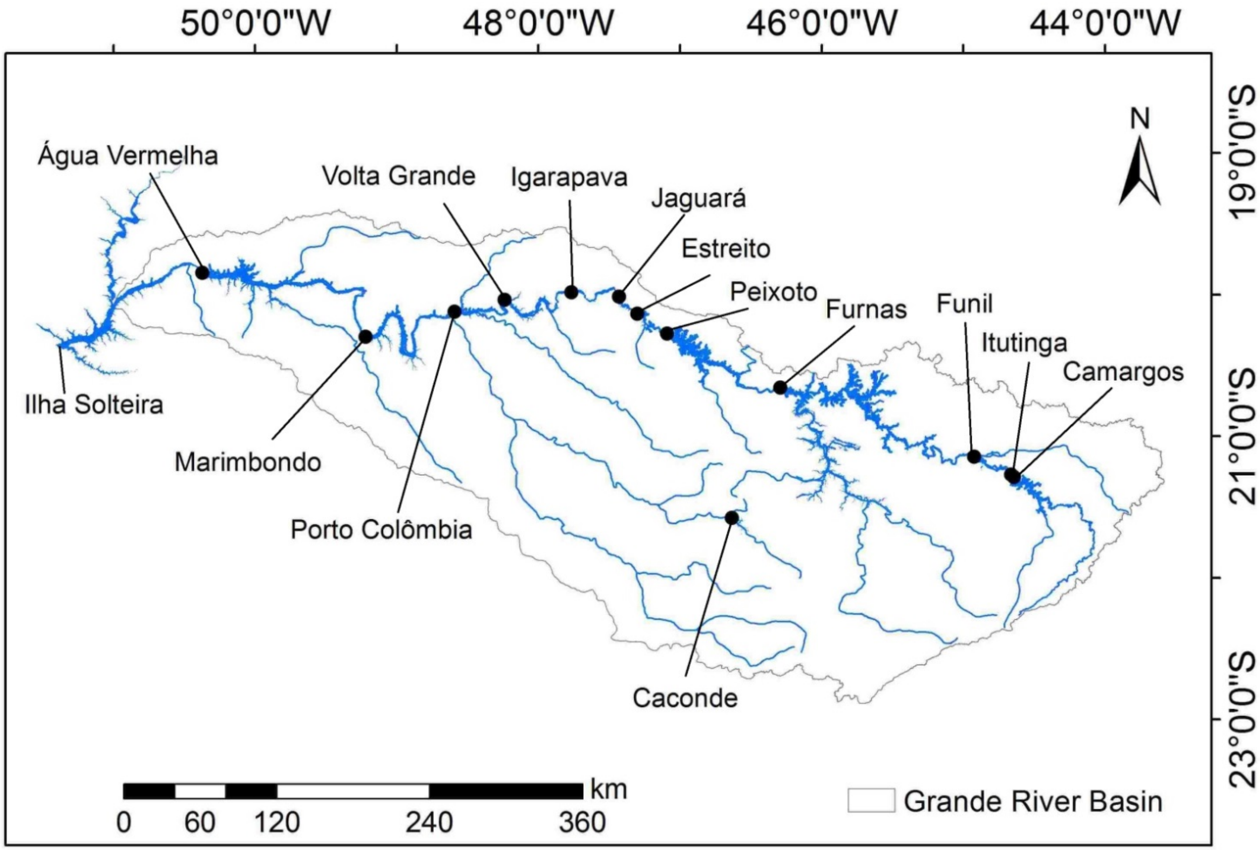
- Importance of the assessment of climate change in Brazil:
  - Extremely dependent of the water resources to produce electric power;




Source: ANEEL

# Introduction

- Main hydropower plants installed in Grande River Basin




- Electricity generation capacity (by hydropower plants)
  - Brazil = 89,200 MW
  - Grande River Basin = 7,800 MW

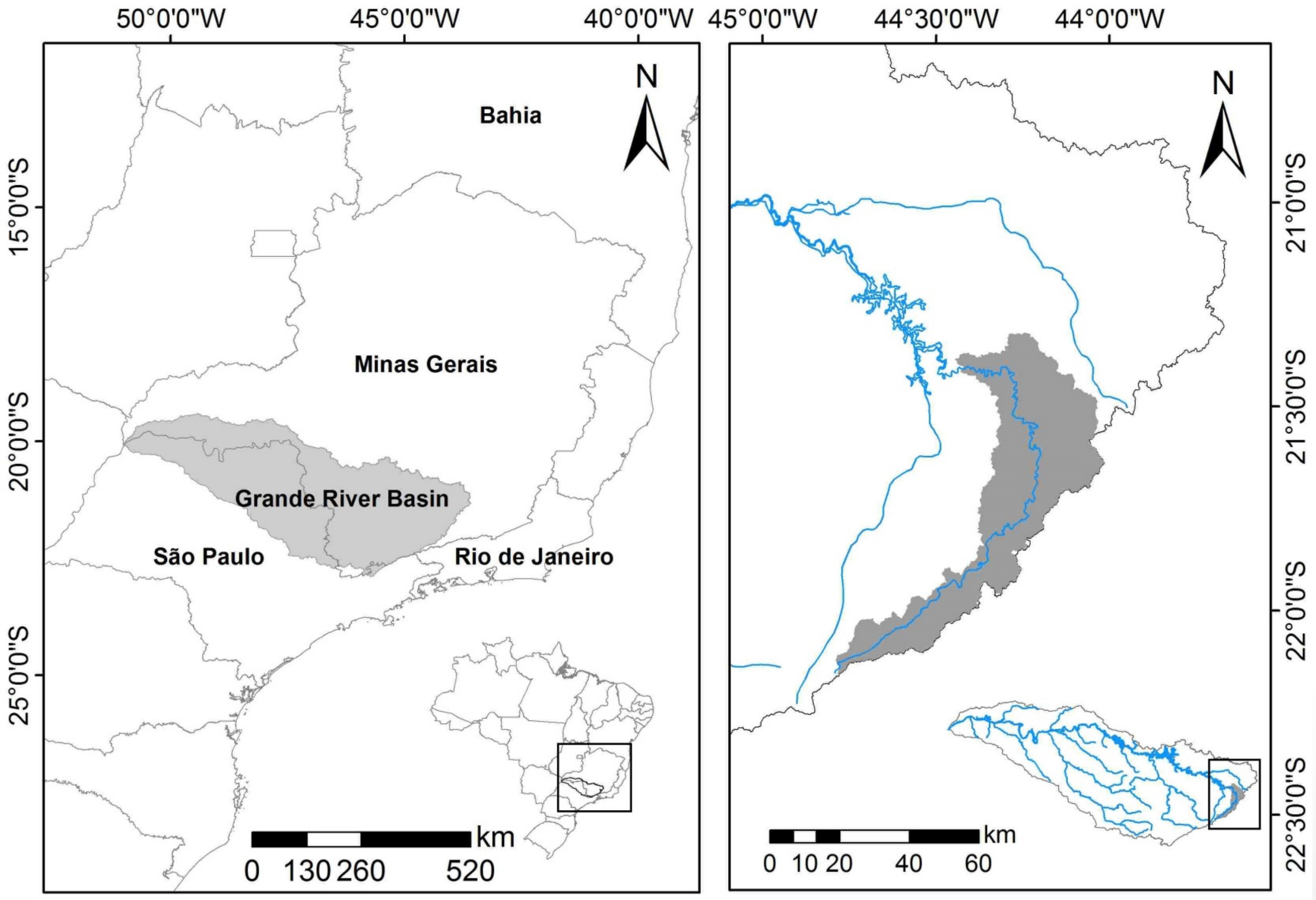
**8.7 %**

# Objectives

- Calibrate and validate, in monthly basis, a headwater of Grande River Basin in Minas Gerais state, Brazil, in order to evaluate the impacts on hydrology under a future climate change scenario.

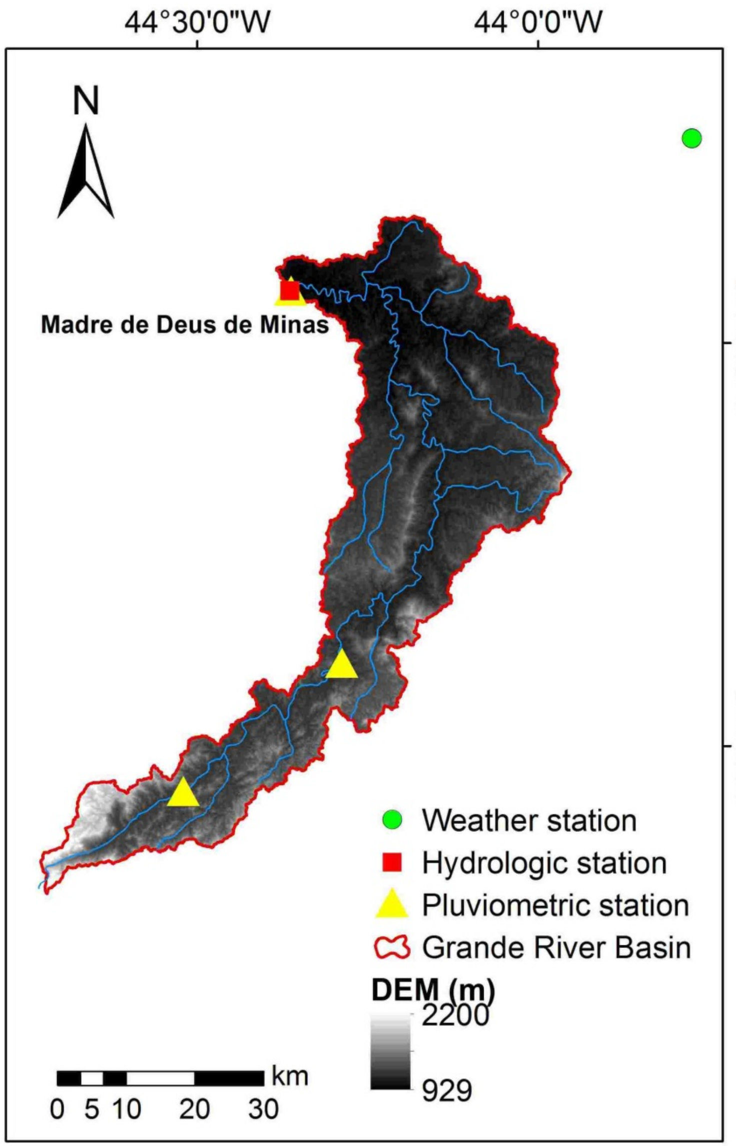
# Material and Methods

- Study area



# Material and Methods

- **Grande River Basin**
  - Area: 2077 km$^2$
  - Precipitation: 1400-2000 mm/year
  - Mean temperature: 19 - 21 °C
  - Hydrologic station: Madre de Deus de Minas
  - DEM:
    - Aster. Resolution 30x30 m



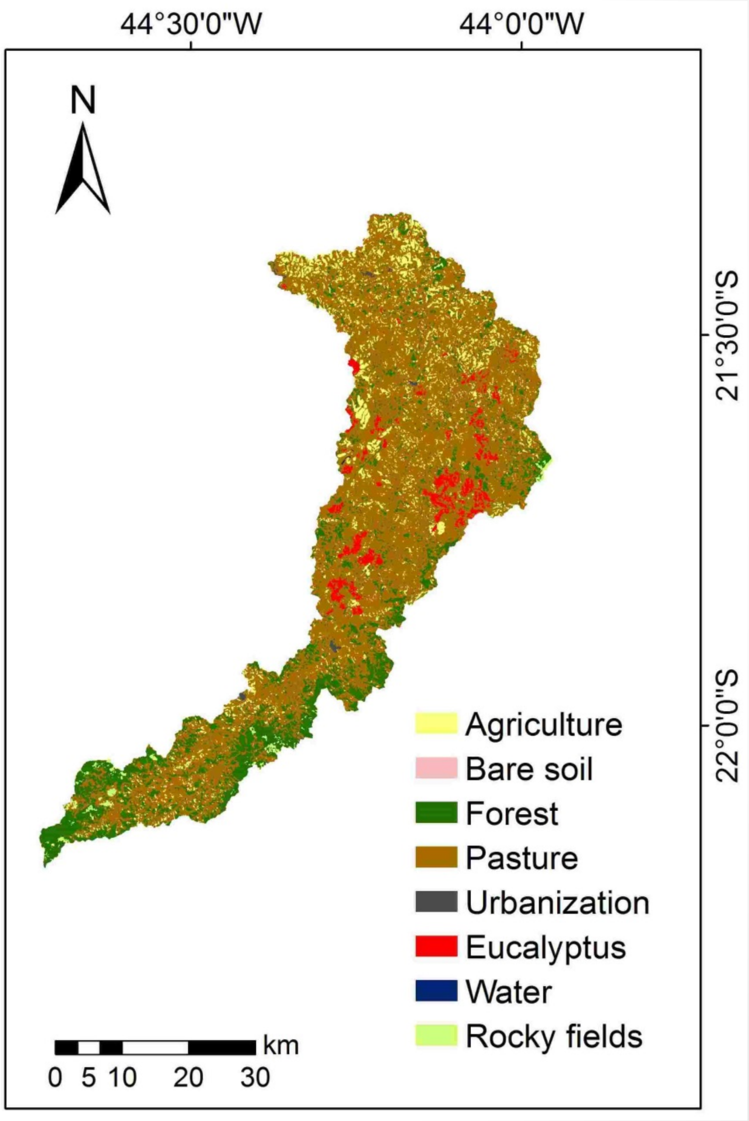
# Material and Methods

- **Database**

  - The land use map was derived from Landsat 8 images (2013, 30m resolution);

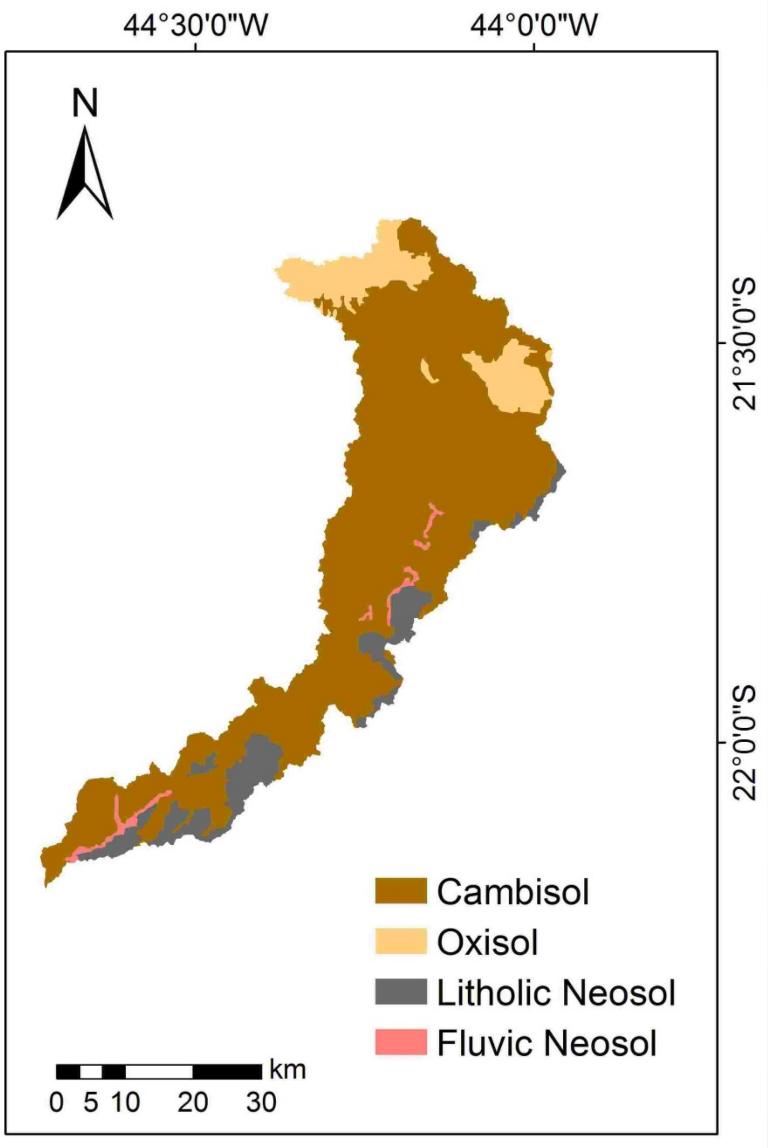
  - Pasture is the predominant land use in the Grande River Basin, with 69.8% of the area;

  - Forests are concentrated in high altitudes (**Mantiqueira Range**), covering 17.5% of the area.



# Material and Methods

- **Database**
  - The soil map was obtained from the Araújo (2006);
  - Cambisol is the predominant soil type in the Grande River Basin, with 78.5% of the area;
  - Soil parameters for each soil type were obtained from the Brazilian Agricultural Research Corporation (EMBRAPA).



# Material and Methods

- **Climate change database**
  - Precipitation and maximum and minimum temperatures from downscaled Regional Climate Model (RCM) Eta-HadGEM2-ES (Chou et al., 2014 [a,b]);
  - Coverage period: 1960-2005 (baseline); 2007-2040; 2041-2070; 2071-2099
  - Grid size: 20 km;
  - Scenarios:
    - In the IPCC Fifth Assessment Report (AR5) the scenarios are based on total anthropogenic radiative forcings at the end of the 21st century;
    - Economic models can take different paths to reach four different radiative forcings that are equivalent to different concentration paths of the greenhouse gases:
      - **RCP 8.5**
      - RCP 6
      - **RCP 4.5**
      - RCP 2.6

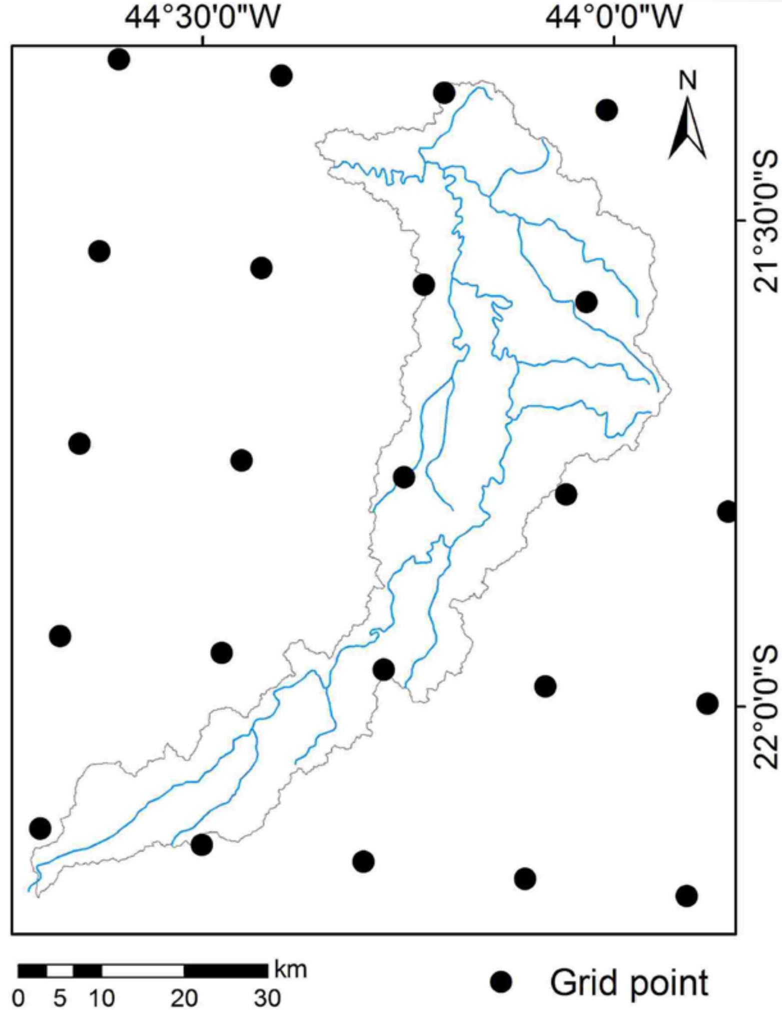
Representative Concentration Pathway (W $m^{-2}$)

| **AR5** | | **AR4** |
|---|---|---|
| RCP 8.5 | ≈ | A2 |
| RCP 4.5 | | B1 |

# Material and Methods

- **Climate change database**
    - Bias correction method:
        - Linear-scaling approach

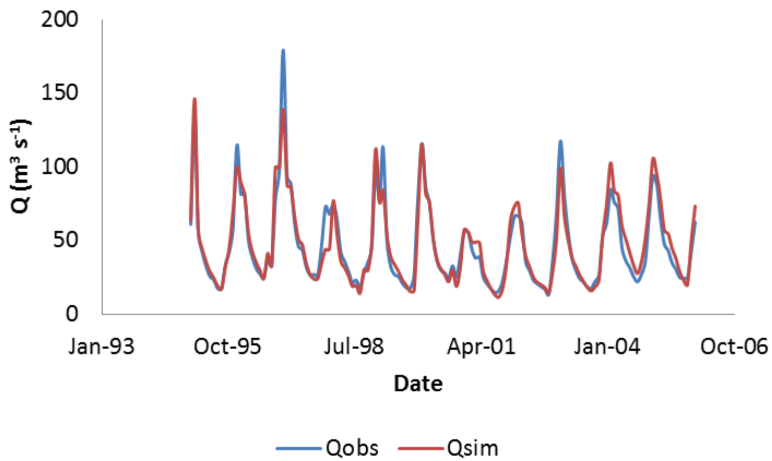
The linear-scaling approach (Lenderink et al., 2007) operates with monthly correction values based on the differences between observed and present-day simulated values. By definition, corrected RCM simulations will perfectly agree in their monthly mean values with the observations. Precipitation is corrected with a factor based on the ratio of long-term monthly mean observed and control run data.



# Results

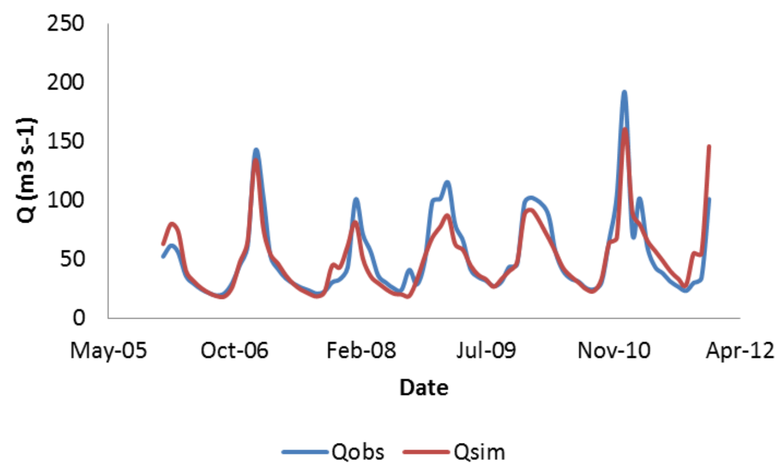
- **Calibration and Validation**

**Calibration**: 1995-2005




NS: 0.90
$R^2$: 0.90
Pbias: -1.6

**Validation**: 2006-2011




NS: 0.82
$R^2$: 0.82
Pbias: -2.7

**Very good performance**
**Moriasi et al. (2007)**

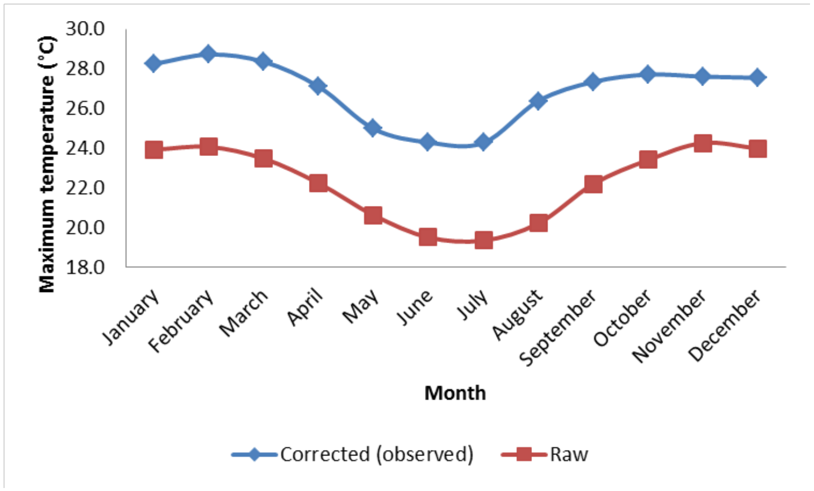
# Results

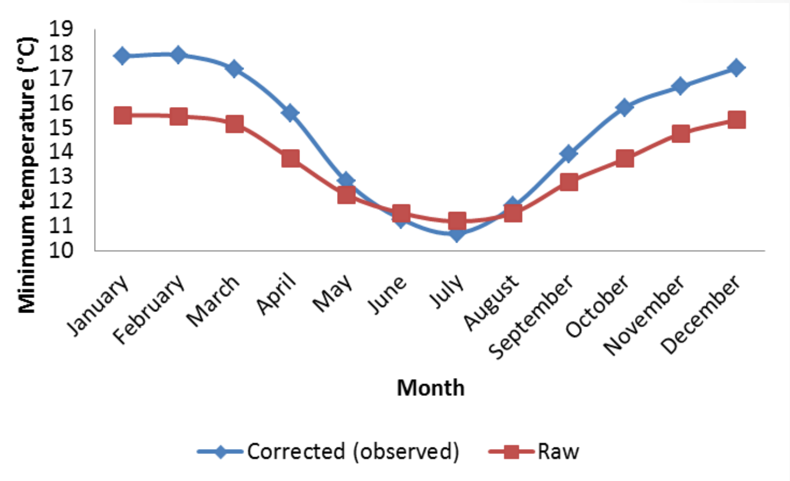
- **Parametrization**

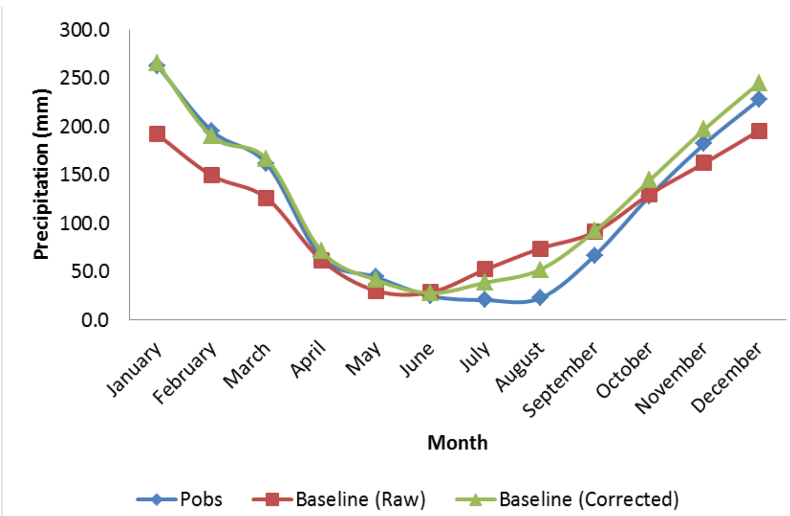
| Parameter | Max | Min | Fitted value |
|---|---|---|---|
| v__ESCO.hru | 0.5 | 0.95 | 0.79 |
| r__CN2.mgt | -0.1 | 0.1 | -0.096 |
| v__ALPHA_BF.gw | 0.004 | 0.009 | 0.0075 |
| a__GW_DELAY.gw | -30 | 60 | -29.13 |
| a__GWQMN.gw | -1000 | 1000 | -670 |
| v__CANMX.hru | 0 | 30 | 2.61 |
| v__CH_K2.rte | 0 | 10 | 8.41 |
| v__CH_N2.rte | -0.01 | 0.2 | 0.058 |
| v__EPCO.bsn | 0.01 | 1 | 0.52 |
| v__GW_REVAP.gw | 0.02 | 0.2 | 0.037 |
| a__REVAPMN.gw | -1000 | 1000 | 314 |
| r__SOL_AWC().sol | -0.05 | 0.05 | -0.015 |
| r__SOL_K().sol | -0.05 | 0.05 | -0.0009 |
| v__SURLAG.bsn | 0.01 | 24 | 20.43 |

# Results

- Bias correction



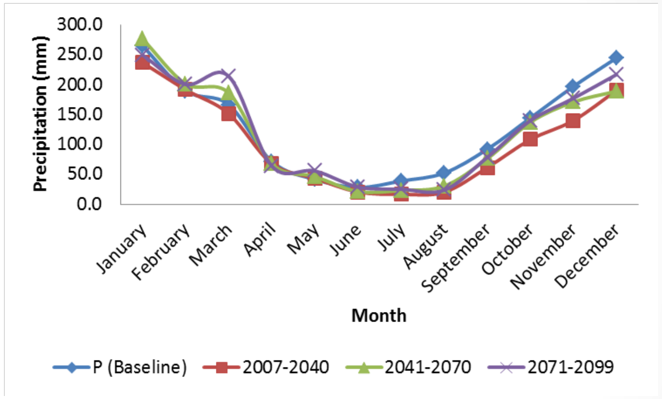



# Results

- Mean annual precipitation

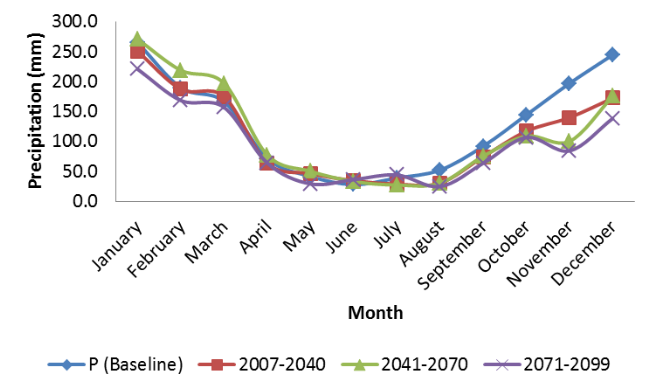
**RCP 4.5**

| | Control | 2007-2040 | 2041-2070 | 2071-2099 |
|---|---|---|---|---|
| **Precipitation (mm)** | 1526.6 | 1249.5 | 1422.1 | 1456.8 |
| **$\Delta p_{\text{time slice – control}}$ (mm)** | - | -277.1 | -104.5 | -69.8 |
| **$\Delta P_{\text{time slice - contro}}$ (%)** | - | -18.1 | -6.8 | -4.6 |




**RCP 8.5**

| | Control | 2007-2040 | 2041-2070 | 2071-2099 |
|---|---|---|---|---|
| **Precipitation (mm)** | 1526.6 | 1319.6 | 1366.6 | 1134.3 |
| **$\Delta P_{\text{time slice – control}}$ (mm)** | - | -207 | -160 | -392.3 |
| **$\Delta P_{\text{time slice - contro}}$ (%)** | - | -13.6 | -10.5 | -25.7 |



# Results

- Mean temperatures

**RCP 4.5**

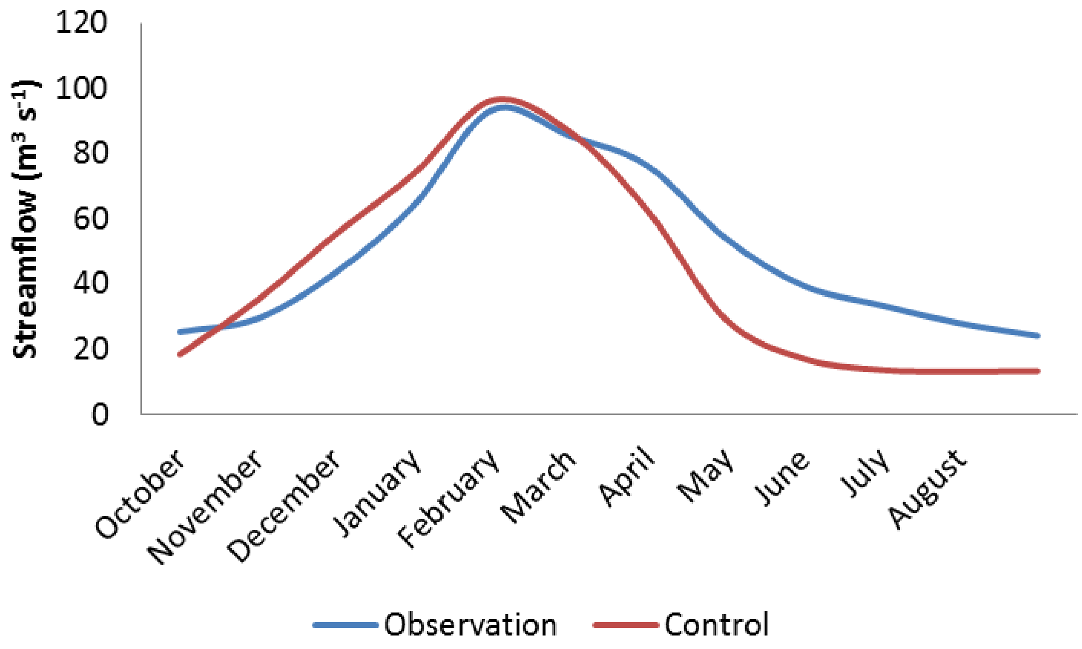
| | Control | 2007-2040 | 2041-2070 | 2071-2099 |
|---|---|---|---|---|
| $T_{max}$ (°C) | 26.9 | 30.9 | 31.7 | 32.3 |
| $T_{min}$ (°C) | 14.9 | 14.6 | 15.7 | 16.2 |
| $\Delta T_{max}$ (°C) | - | 4.1 | 4.8 | 5.4 |
| $\Delta T_{min}$ (°C) | - | -0.3 | 0.8 | 1.3 |

**RCP 8.5**

| | Control | 2007-2040 | 2041-2070 | 2071-2099 |
|---|---|---|---|---|
| $T_{max}$ (°C) | 26.9 | 31.5 | 33.1 | 35.9 |
| $T_{min}$ (°C) | 14.9 | 15.0 | 16.6 | 18.4 |
| $\Delta T_{max}$ (°C) | - | 4.6 | 6.2 | 9.0 |
| $\Delta T_{min}$ (°C) | - | 0.1 | 1.6 | 3.5 |

# Results

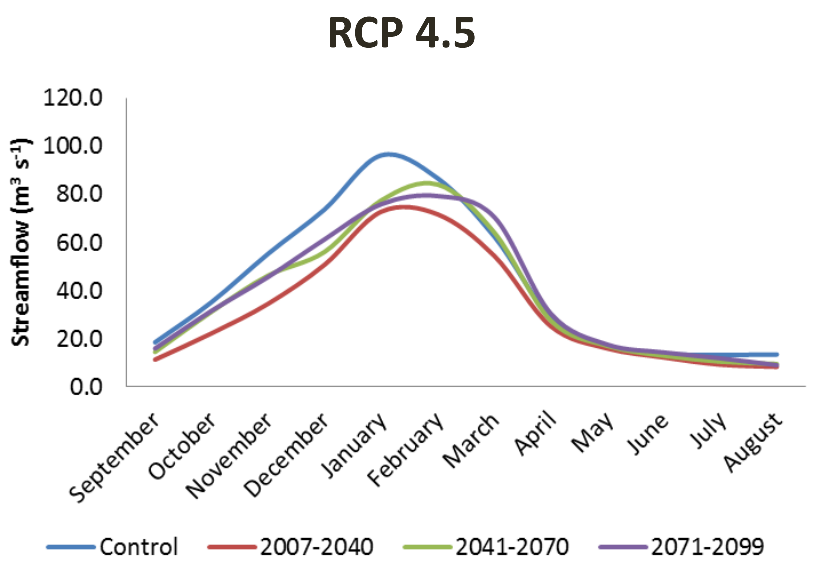
- Hydrological impacts
  - Mean monthly streamflow

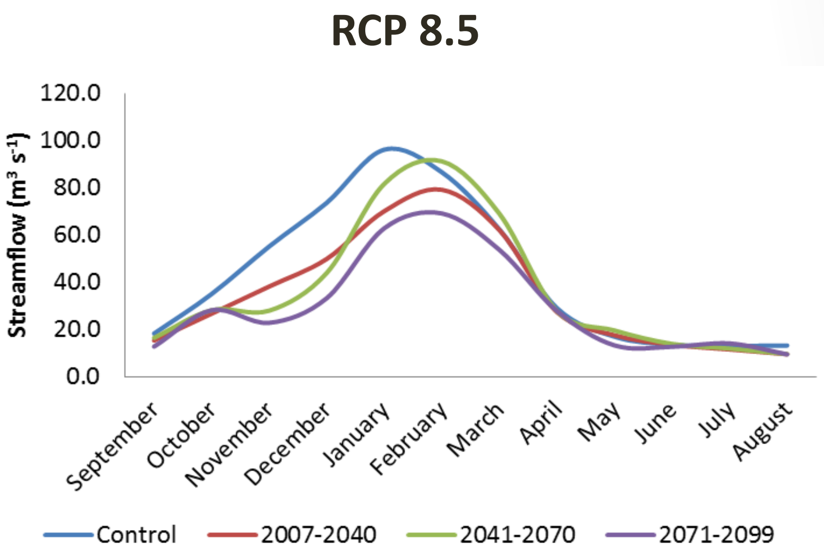



- ➢ Good estimation of the simulated flow in the summer (wet period);
- ➢ Underestimation of the simulated flow in the winter (dry period).

# Results

- Hydrological impacts
  - Mean monthly streamflow



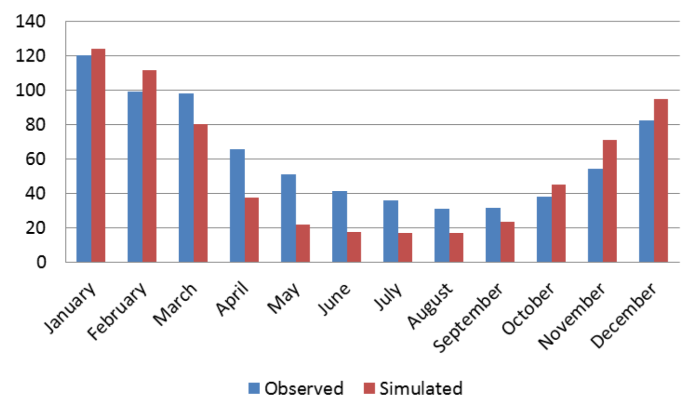




- Reduction of the mean monthly streamflow for all time slices and both scenarios, especially during the summer (wet period);
- Greater reduction of the mean monthly streamflow for RCP 8.5 scenario in the end of the $21^{st}$ century (2071-2099).

# Results

- Hydrological impacts
  - Mean annual water yield

| Month | Observed | Simulated | Relative error |
|---|---|---|---|
| **January** | 120.3 | 124.1 | 0.03 |
| **February** | 99.5 | 111.8 | 0.12 |
| **March** | 98.3 | 80.6 | 0.18 |
| **April** | 65.9 | 37.7 | 0.43 |
| **May** | 51.0 | 22.2 | 0.57 |
| **June** | 41.8 | 17.7 | 0.58 |
| **July** | 36.2 | 17.2 | 0.53 |
| **August** | 31.2 | 17.3 | 0.44 |
| **September** | 31.7 | 23.9 | 0.25 |
| **October** | 38.0 | 45.4 | 0.19 |
| **November** | 54.4 | 71.4 | 0.31 |
| **December** | 82.7 | 95.2 | 0.15 |
| **Mean** | - | - | **0.31** |




- Slight overestimation in the summer (wet period);
- Underestimation in the winter (dry period).

# Results

- Hydrological impacts
  - Water Yield

| Scenario | Water yield (mm) | | | |
|---|---|---|---|---|
| | Baseline | 2007-2040 | 2041-2070 | 2071-2099 |
| **RCP4.5** | 664.5 | 488.9 | 567.5 | 580.9 |
| **RCP8.5** | | 532.1 | 557.1 | 454.2 |

| Scenario | 2007-2040 | | 2041-2070 | | 2071-2099 | |
|---|---|---|---|---|---|---|
| | $\Delta_{\text{Scenario - Baseline}}$ (mm) | % | $\Delta_{\text{Scenario - Baseline}}$ (mm) | % | $\Delta_{\text{Scenario - Baseline}}$ (mm) | % |
| **RCP4.5** | -175.5 | -26.4 | -97.0 | -14.6 | -83.6 | -12.6 |
| **RCP8.5** | -132.4 | -19.9 | -107.4 | -16.2 | -210.2 | -31.6 |

- Significant reduction of the water yield for all time slices in both scenarios;
- Reductions of the mean annual water wield of 26.4, 14.6 and 12.6% for RCP 4.5 and 19.9, 16.2 and 31.6%

# Results

- Hydrological impacts
  - Flow duration

| Duration | Control | RCP 4.5 | | | RCP 8.5 | | |
|---|---|---|---|---|---|---|---|
| | | 2007-2040 | 2041-2070 | 2071-2099 | 2007-2040 | 2041-2070 | 2071-2099 |
| $Q_{95}$ | 7.22 | 4.58 | 5.11 | 5.28 | 4.64 | 5.20 | 4.29 |
| $Q_{90}$ | 9.87 | 6.39 | 7.20 | 7.42 | 6.54 | 7.27 | 5.95 |
| $Q_{80}$ | 14.43 | 9.58 | 10.89 | 11.22 | 9.91 | 10.90 | 8.83 |
| $Q_{20}$ | 61.59 | 45.05 | 53.08 | 54.49 | 48.64 | 51.40 | 40.01 |
| $Q_{10}$ | 90.00 | 67.52 | 80.30 | 82.36 | 73.72 | 77.09 | 59.38 |
| $Q_{5}$ | 123.10 | 94.31 | 113.03 | 113.03 | 103.93 | 107.74 | 82.28 |

- Reduction of the low flows for all time slices in both scenarios, when compared to the baseline;
- Slight low flow increase after abrupt decrease in the first time slice for RCP 4.5;
- Greater reduction by the end of the 21$^{st}$ century (2071-2099) for RCP 8.5;

**INDICATE WATER AVAILABILITY PROBLEMS IN THE FUTURE!!!**

# Conclusions

- Although there was an underestimation in the dry period, SWAT model forced by RCM Eta-HadGEM-ES was able to simulate the baseline flow in a reasonable manner;
- Significant reduction of the streamflow and therefore a reduction of the annual water yield for the three time slices;
- Reduction of the low flows for all time slices, when compared to the baseline period;
- The hydrological behavior of the watershed may be negative affected, especially the ground water recharge capabilities and therefore the base flow, reducing the water availability of the region in the dry periods.

# Acknowledgements

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