Climate and land-use change impacts in the São Francisco Basin (SFB), Brazil

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SWIM vs. SWAT

Are there many differences?
There are some, but… (SWIM is based on SWAT’93 & MATSALU)

• Same model structure
• Basic assumptions and equations comparable

Some specific functionalities are different:
  - Wetlands
  - Dams and reservoirs
  - Agriculture (Irrigation, crop rotations,…)
...

SWAT more user-friendly… (interfaces etc.)
SWIM rather “pure” scientific tool…
Overview

- Introduction
- Calibration and validation
- Results:
  - Climate scenarios
  - Land-use scenario
  - Water management scenario
- Summary

Figura 1. Bacia hidrográfica do rio São Francisco dividida e suas principais usinas hidrelétricas e postos fluviométricos.

ANA (2004)
Overview

• Introduction

• Calibration and validation

• Results:
  • Climate scenarios
  • Land-use scenario
  • Water management scenario

• Summary

INNOVATE: INterplay among multiple uses of water reservoirs via inNOVative coupling of substance cycles in Aquatic and Terrestrial Ecosystems ⇒ Focus area: Itaparica Reservoir, Brasil
Overview

Drought in the São Francisco river basin (SFB), lasting for more than 3 years ...

Minimum discharge:     $500 \text{ m}^3/\text{s}$     $1300 \text{ m}^3/\text{s}$

Overview

Dec. – Apr.: rainy season!!!
Introduction: observed discharge at gauge Traipu / São Francisco

![Graph showing observed discharge over the years 1951-1960 and 1991-2000.](http://www.ons.org.br/)

Data: ONS [http://www.ons.org.br/]
Introduction: observed discharges

São Francisco River basin: 640,000 km²

Discharge measurements from 175 gauges (ANA - Agência Nacional de Águas)

Criteria for selection: catchment area, time series length, no large gaps in time series ⇒ 65 gauges selected

For some gauges naturalized discharges (calculated by subtracting reservoir effects & water uses from measured discharges) are available from ONS (Operador Nacional do Sistema Elétrico) and other sources
Introduction: discharge at gauge Traipu / São Francisco

Data: ONS (http://www.ons.org.br/)
Introduction: data used

• **SRTM-Digital Elevation Model**
• **Soil** data: EMBRAPA (Brazilian Enterprise for Agricultural Research)
• **Land-use**: MODIS2001 & 2010; adapted to land use classes in SWIM
• **Climate**: daily (re-analysis data; e.g. Tmax, Tmean, Tmin, precipitation, solar radiation) from WATCH-project (http://www.eu-watch.org/) grid cells of 0.5° (approx. 50x50km)
Introduction: data used

Water use data from 2002-2013 from ANA (Agência Nacional de Águas)

Withdrawal (max.)
- 0.01 – 0.50 m³/s
- 0.51 – 1.00 m³/s
- 1.01 – 2.00 m³/s
- 2.01 – 5.00 m³/s
- 5.01 – 10.0 m³/s
- 10.01 – 20.0 m³/s
- 20.01 – 50.0 m³/s
- 50.01 – 100.0 m³/s

Land-use (MODIS, re-classified)

Sub-regions
Water
Settlement
Cropland
Grassland (meadow)
Grassland (pasture)
Forest (mixed)
Forest (evergreen)
Forest (deciduous)
Wetland
Heather (brashland)
Bare soil
Introduction: SWIM; delineation of Sub-basins (1627)

23 Sub-catchments with different parameter sets

<table>
<thead>
<tr>
<th>Reservoirs</th>
<th>Drainage Area [km²]</th>
<th>Capacity [Hm³]</th>
<th>Dead storage [Hm³]</th>
<th>HPP, inst. [MW]</th>
<th>HPP, yield [MW]</th>
<th>Qmin. [m³/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Três Marias</td>
<td>50,560</td>
<td>19,528</td>
<td>4,250</td>
<td>396</td>
<td>250</td>
<td>500</td>
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<tr>
<td>Sobradinho</td>
<td>498,425</td>
<td>34,117</td>
<td>5,448</td>
<td>1,050</td>
<td>510</td>
<td>1,300</td>
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<tr>
<td>Itaparica</td>
<td>587,000</td>
<td>10,782</td>
<td>7,233</td>
<td>1,500</td>
<td>900</td>
<td>1,300</td>
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</tbody>
</table>

Koch et al.:
- Water management modeling in SWIM: new features and applications (2013 International SWAT Conference, Toulouse)
- Modelling of water availability and water management for the São Francisco Basin, Brazil (2014 International SWAT Conference, Porto de Galinhas/Brazil)
Climate and land-use change impacts in the São Francisco Basin, Brazil; Hagen Koch et al.

SWIM: Calibration & validation for natural discharge

reservoir Três Marias

NSE 0.77

NSE 0.76

PBIAS 16%

PBIAS 14%

Climate and land-use change impacts in the São Francisco Basin, Brazil; Hagen Koch et al.
SWIM: Calibration for natural & managed discharge

Gauge Traipu

<table>
<thead>
<tr>
<th>Date</th>
<th>Naturalized (observed)</th>
<th>SWIM, natural</th>
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<tbody>
<tr>
<td>Jan/ 88</td>
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<td>Jan/ 95</td>
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Climate and land-use change impacts in the São Francisco Basin, Brazil; Hagen Koch et al.
Climate and land-use change impacts in the São Francisco Basin, Brazil; Hagen Koch et al.

SWIM: Calibration for natural & managed discharge

Gauge Traipu


Postos
- excluded
- analysed
- naturalized (ONS)
- naturalized (other sources)

Rios
- Bacia
Climate projections of five CMIP5 ESMs ([http://cmip-pcmdi.llnl.gov/cmip5/](http://cmip-pcmdi.llnl.gov/cmip5/)); bias-corrected (Hempel et al., 2013)
Scenarios: Climate

Sub-basin of reservoir Três Marias

Legend
Difference in [mm]
-400
-200
-100
-50
-25
0
+25
+50
+100
+150
+200

Climate and land-use change impacts in the São Francisco Basin, Brazil; Hagen Koch et al.
Results: SWIM, historical runs (1981-2000)

Q natural

Tres Marias

Month / Mês

0 1 2 3 4 5 6 7 8 9 10 11 12

Q [m³/s]

0 1000 2000 3000 4000

MIROC-ESM
Nor_ESM
Had-GEM2
IPSL-CM5A
GFDL-ESM2
WATCH

Q managed

Tres Marias

Month / Mês

0 1 2 3 4 5 6 7 8 9 10 11 12

Q [m³/s]

0 1000 2000 3000 4000

MIROC-ESM
Nor_ESM
Had-GEM2
IPSL-CM5A
GFDL-ESM2
WATCH

Climate and land-use change impacts in the São Francisco Basin, Brazil; Hagen Koch et al.
Results: SWIM, climate scenarios (2021-2050)

Q natural, RCP2.6

Tres Marias

Q natural, RCP8.5

Tres Marias

Traipu

Traipu

Climate and land-use change impacts in the São Francisco Basin, Brazil; Hagen Koch et al.
Results: SWIM, climate scenarios (2021-2050)

Q managed, RCP2.6

Q managed, RCP8.5

Climate and land-use change impacts in the São Francisco Basin, Brazil; Hagen Koch et al.
Results: SWIM, climate scenarios (2021-2050)

Hydro-power generation, RCP2.6

Hydro-power generation, RCP8.5

Climate and land-use change impacts in the São Francisco Basin, Brazil; Hagen Koch et al.
Land-use scenario: increase in agricultural land-use

Suitability for rain-fed and irrigated agriculture

Adapted land-use map

Climate and land-use change impacts in the São Francisco Basin, Brazil; Hagen Koch et al.
Land-use scenario: increase in agricultural land-use
Land-use scenario: increase in agricultural land-use

Assumption: strict observation of minimum discharges
Land-use scenario: increase in agricultural land-use

Assumption: strict observation of minimum discharges
Water management scenario: new reservoirs (hydro-power generation)

- Pedra Branca (installed: 320MW; firm energy: 195MW)
- Riacho Seco (installed: 240MW; firm energy: 145MW)
Results: SWIM, discharge (2021-2050)
Results: SWIM, hydro-power generation (2021-2050)
Summary

• Climate change simulations using a selection of climate models and climate scenarios (RCPs) were carried out

• Effects of climate change on runoff (⇒ water availability, hydro-power generation) depend mainly on selected climate model (⇒ different directions: drier or wetter future!!)

• New reservoirs, mainly used for hydropower generation, and new irrigation schemes were included in the scenario analysis

• Wet scenario: high safety of water supply (also for increased water demand)
• Dry scenario: even for the reference scenario high deficits

• Impacts of irrigation water requirement on hydropower generation low compared to climate impacts (strict observation of minimum discharges assumed in the simulations)
Grazie!

Thank you!

Vielen Dank!

OBRIGADO!

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Scenarios: Climate scenarios (RCP: Representative Concentration Pathway)

CMIP5 GCM ENSEMBLE MEAN TREND (RCP8.5), 2006-2100

- 80% agreement in TREND direction

Climate and land-use change impacts in the São Francisco Basin, Brazil; Hagen Koch et al.
Scenarios: Climate (extreme floods)

Annual precipitation

1961-1990; Agência Nacional de Águas (ANA), 2004

1961-1999; WATCH-data set

Precipitation causing extreme flood in climate scenario (example)

Precipitation sum 30d [mm]

(17.02.-19.03.2031), Nor_ESM, RCP 8.5

Climate and land-use change impacts in the São Francisco Basin, Brazil; Hagen Koch et al.
Scenarios: Climate (extreme floods)
SWIM: Climate data for calibration / validation

- daily climate data (re-analysis data corrected by using monthly observations; e.g. Tmax, Tmean, Tmin, precipitation, solar radiation) from the WATCH-project (http://www.eu-watch.org/)

- grid cells of 0.5° (approx. 50x50km)
SWIM: simulated runoff (mean 1981-2010)