Assessing the hydrologic impacts of land use change in the Upper Paraná River Basin between 1985 and 2015

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La Plata River Basin
Area: 3.1 million km²
Upper Paraná River Basin

Area: 900,480 km²
Average streamflow: 14,000 m³/s
Population: 65 million

Energy generation (MW)

- ≤ 82.5
- 82.5 – 264
- 264 – 807.5
- 807.5 – 3444
- ≥ 7000

Paraná state
Research Questions

What are the potential changes in the hydrological processes and discharge in the Upper Paraná River Basin between 1985 and 2015?

What extent they are associated with the observed past land use changes?
SWAT Hydrological Model

- Soil and Water Assessment Tool (SWAT, Arnold et al., 1998)

- **Simulation period:** 1979 – 2015
  - Warm-up: 1979 – 1983
  - Calibration: 1984 – 2004
  - Validation: 2005 – 2015
Flowchart of the steps for the execution of SWAT hydrological model

Pre-Processing (Data preparation)

Weather variables

Precipitation
Temperature
Relative Humidity
Solar Radiation
Wind speed

SWAT HYDROLOGICAL MODEL

Processing

Post-Processing and Visualization

Rain Gauge
Data Available (%)
- 0 - 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100

**Flowchart of the steps for the execution of SWAT hydrological model**

- **Pre-Processing (Data preparation)**
- **Weather variables**
  - Precipitation
  - Temperature
  - Relative Humidity
  - Solar Radiation
  - Wind speed

- **SWAT HYDROLOGICAL MODEL**
- **Processing**
- **Post-Processing and Visualization**

**Source:** Climate Forecast System Reanalysis (CFSR).
Flowchart of the steps for the execution of SWAT hydrological model

Pre-Processing (Data preparation)

Weather variables
- Precipitation
- Temperature
- Relative Humidity
- Solar Radiation
- Wind speed
- Topography

Physical variables
- Topography
- Land use and land cover
- Types of soil

Source: Shuttle Radar Topography Mission (SRTM).
Flowchart of the steps for the execution of SWAT hydrological model

Pre-Processing (Data preparation)

Weather variables
- Precipitation
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- Relative Humidity
- Solar Radiation
- Wind speed
- Topography

Physical variables
- Land use and land cover
- Types of soil

Flowchart of the steps for the execution of SWAT hydrological model

Pre-Processing (Data preparation) → Weather variables

Physical variables → Processing

Post-Processing and Visualization

Source: Brazilian Agriculture Research Corporation (EMBRAPA); HWSD.
Flowchart of the steps for the execution of SWAT hydrological model

1. Pre-Processing (Data preparation)
   - Weather variables
   - Physical variables

2. Processing
   - Basin discretization
   - Land use/soil characterization
   - HRUs definition
   - Import the weather data

   - Digital Elevation Model (DEM)

3. Post-Processing and Visualization
   - Hydrologic Response Unit (HRU)
     Combination of soil, land use types, and slope

Variables included:
- Precipitation
- Temperature
- Relative Humidity
- Solar Radiation
- Wind speed
- Topography
- Land use and land cover
- Types of soil

- Physical variables
- Weather variables

- SWAT HYDROLOGICAL MODEL
- Flowchart of the steps for the execution of SWAT hydrological model
5,187 sub-basins
44,635 HRU
Flowchart of the steps for the execution of SWAT hydrological model

Pre-Processing (Data preparation)
- Weather variables
- Physical variables

Post-Processing and Visualization
- Digital Elevation Model (DEM)
- Hydrologic Response Unit (HRU)
  - Combination of soil, land use types, and slope

Processing
- Basin discretization
- Land use/soil characterization
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- Import the weather data

Physical variables
- Precipitation
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- Topography
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SWAT HYDROLOGICAL MODEL
Flowchart of the steps for the execution of SWAT hydrological model

Pre-Processing (Data preparation)
- Weather variables
- Physical variables

Processing
- Basin discretization
- Land use/soil characterization
- HRUs definition
- Import the weather data

Post-Processing and Visualization
- Verification of initial model simulation
- Sensitivity analysis
- Calibration (Fluviometric data)
- Validation (Fluviometric data)
- Analysis of efficiency calibration
- Analysis of efficiency validation

Digital Elevation Model (DEM)
- Types of soil
- Land use and land cover
- Topography
- Wind speed
- Solar Radiation
- Relative Humidity
- Temperature
- Precipitation

SWAT HYDROLOGICAL MODEL
Leaf Area Index (LAI)

Default mode

Modified plant growth module
Source: Strauch and Wolk (2013)
Simulation performance for monthly discharge values

Source: Abou Rafee et al. (2019)
Flowchart of the steps for the execution of SWAT hydrological model

**Pre-Processing (Data preparation)**
- **Physical variables**
- **Weather variables**

**Processing**
- **Basin discretization**
- **Land use/soil characterization**
- **HRUs definition**
- **Import the weather data**

**Post-Processing and Visualization**
- **Verification of initial model simulation**
- **Sensitivity analysis**
- **Calibration (Fluviometric data)**
- **Validation (Fluviometric data)**

**SWAT HYDROLOGICAL MODEL**

**Digital Elevation Model (DEM)**
- **Hydrologic Response Unit (HRU)**
  - Combination of soil, land use types, and slope

**Data**
- Precipitation
- Temperature
- Relative Humidity
- Solar Radiation
- Wind speed
- Topography
- Land use and land cover
- Types of soil

**Analysis of efficiency validation**
**Analysis of efficiency calibration**
**Analysis of land use change scenarios**
Scenarios

1985

2015 (Baseline)

Classes
- Forest
- Cropland
- Grassland
- Water
- Urban
- Cerrado

Subbasins

1. São Bartolomeu
2. Dos Bois
3. Paraná - Meia Ponte
4. Claro
5. Upper Paranaíba
6. Paraná - Preto
7. Paraná - Peixe, and others
8. Tijuco
9. Araguari
10. Sucuriú
11. Verde
12. Lower Grande
13. Paraná, Quitêria, and São José dos Dourado
14. Middle Grande
15. Pardo
16. Upper Grande
17. Lower Tietê
18. Paraná - Feio or Aguapeí
19. Mogi-Guaçu
20. Sapucaí
21. Paraná, Peixe, and others
22. Invinheima
23. Paraná, Samambaia, and others
24. Lower Parapanema
25. Upper Tietê
26. Paraná, Laranjal, and outros
27. Paraná, Iguatemi, Maracai, Amambaí
28. Upper Parapanema
29. Ivaí
30. Tibagi
31. Piquiri
32. Paraná, Guaçu, and others
33. Lower Iguaçu
34. Upper Iguaçu
Land use changes: Difference between scenarios 2015 and 1985

Forest

Wet season: October - March
Dry season: April - September

Total forest loss – Ivaí subbasin
1,937 km$^2$
Land use changes: Difference between scenarios 2015 and 1985

Forest

Total forest gain – Upper Grande subbasin
3,068 km²
Land use changes: Difference between scenarios 2015 and 1985

**Cropland**

Total cropland gain – Lower Tietê subbasin
10,299 km²
Land use changes: Difference between scenarios 2015 and 1985

Cropland

Total cropland gain – Invinheima subbasin
13,610 km²
Percentage change in discharge for the year 2015 with respect to year 1985 at the final outlet of the basin.

Paraná River
mean = 1.2; 4.2; -2.2


Bars indicate:
- Annual
- Wet
- Dry

%: -5.0, -2.5, 0.0, 2.5, 5.0
Green water flow
(soil evaporation plus transpiration)
Concluding Remarks

- Deforestation (afforestation) mainly increases (decreases) the wet season discharge along the main rivers of the Upper Paraná River Basin; the opposite happens in the dry season.

- Land use changes between 1985 and 2015 affected increases (decreases) in the wet (dry) season discharge up to 7% (-6%) at the final outlet of the basin.

- Future land use changes may have potential impacts on the main economic activities developed in the basin such as hydropower generation, agricultural, and livestock.
Thanks for your attention!

Iguazu Falls
(18 km before the Iguazu flows into the Paraná River)

Source: Guia Geográfico Paraná