The hydrological environmental services of Permanent Preservation Areas (PPA): a case study with numerical modeling in the Ribeirão das Posses watershed

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Introduction

Main water producer of São Paulo metropolitan region (~50% do abastecimento)
Flood in Atibaia City (2010)

Land use change in Piracicaba River Basin

Water shortage in 2014
Introduction: How to coexist with land change pressure?

► With environmental conservation. In Brazil, it is helped by the Forest Act

- Legislation for the protection of natural vegetation, including the Permanent Protection Areas (PPA)

Limits of riparian PPAs

► The Forest Act Challenge

PPA’s deficit

- deficit: 44 Mha (43%)  
Sparovek et al. (2012)

► Riparian PPAs maintain:
- Streamflow regulation
- Encourage infiltration
- Reduce erosion

This set of benefits, among others, are the Hydrological Environmental Services (HES)

The effects of the extent of riparian vegetation vary from basin to basin. What are the effects of varying the extent of these ranges in HES?
Study area

► Ribeirão das Posses Watershed

Drainage area ~ 12 km²
Rural watershed – smallholder agriculture
Payments for Env. Services (PES) -
Conservador das Águas proj. (ANA, TNC and Extrema (MG) City Hall)

► DEM
(source: ASTER resampled to 15 m)

Elevation ~ 950-1450 m
16% watershed with slope > 25°

► Hidroclimatology

Annual rainfall: 1600 mm (highest occurrences oct-mar)
Mean Streamflow: 250 litros s⁻¹
(~ 1% of streamflow arriving at Resev. Jaguarí-Jacareí)
Mean Temperature: 14 °C (jun)
21 °C (feb)
Input data

► Data from DEM
  - rede de drenagem
  - sub-bacias
  - slope, channel width, channel depth, ...

► Land use

► Soil
  - soil parameter:
    ✓ Soil Properties – Soil Map
    ✓ Available Water Capacity (sol_awc) – Minasny & Hartemink (2011)

► Hidrometeorological
  - Streamflow
  - Rainfall
  - Temp. Air, UR, Vel. Wind and Irrad. Solar
  - Energy fluxes (H,LE), net radiation (Rn), ...
Input data

► Data from DEM
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► Hidrometeorological
- Streamflow
- Rainfall
- Temp. Air, UR, Vel. Wind and Irrad.
  Solar
- Energy fluxes (H,LE), net radiation (Rn), ...

Adapted from Azevedo (2008):
20 m resolution

Adapted Azevedo (2008) and Calheiros (2009): 1:5:10^4 scale
Input data

- **Land use**
- **Soil**
  - soil parameter:
    - Saturated Hyd. Cond. \( \text{sol}_k \) – PTFs Saxton & Rawls (2006)
    - Soil Properties – Soil Map
    - Available Water Capacity \( \text{sol}_\text{awc} \) – Minasny & Hartemink (2011)

- **Hidrometeorological**
  - Streamflow
  - Rainfall
  - Temp. Air, UR, Vel. Wind and Irrad.
  - Solar
    - Energy fluxes \( H, LE \), net radiation \( R_n \), ...

**Daily Data**

- Rainfall (source: ANA/CPRN)

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![Stage-Discharge Rating Curve (Preliminary) equation: \( Q = 11.4725(h - 0.287)^{2.03908} \)]
Calibration – Evapotranspiration of Ecosystems

Data from DEM
- rede de drenagem
- sub-bacias
- slope, channel width, channel depth, ...

Land use

Soil
- soil parameter:
  ✓ Soil Properties – Soil Map
  ✓ Available Water Capacity ($sol_awc$) – Minasny & Hartemik (2011)

Hidrometeorological
- Streamflow
- Rainfall
- Temp. Air, UR, Vel. Wind and Irrad. Solar
- Energy fluxes (H,LE), net radiation ($R_n$), ...

Flux towers (Eddy Covariance)

Sources: Tatsch (2006), Bruno (2009), Rocha (2009), Cabral et al (2010, 2011), Freitas (2012), and preliminary data of the Projet Carbon Tracker and Water availability FAPESP (Program Global Climate Change)
**Numerical experiment setup**

▶ **Calibration**
- manual sensitivity analysis parameters: soil, groundwater, evapotranspiration
- manual calibration of evaporative fraction
- auto-calibration of streamflow using hydroPSO (Zambrano-Bigiarini & Rojas, 2013)

▶ **Setup simulation**
- Simulation period: 2006-2012
  *warm up*: 5 years (2006-2010)
  calibration: 2 years (2011-2012)
  *analysis*: 2011-2012

- Resolution
  spatial (DEM, Land use and Soil): 15 m
  temporal: daily
Reforestation Scenarios

► Experimental design

- Riparian buffer
  - 03 sizes buffer width:
    - buffer width 15 m (Refl_L15)
    - buffer width 30 m (Refl_L30)
    - buffer width 45 m (Refl_L45)

- Step slope areas
  - slope areas with slope > 25° (Step_area)

► Land use maps

- Reflo_L15
- Reflo_L30
- Reflo_L45

- 28.4% floresta
- 34.2% floresta
- 41.9% floresta

- 32.6% floresta
SWAT Vegetation parameters

► Modification – Seasonal LAI

(default SWAT)

► Vegetation parameters - ET manual calibration

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<th>Vegetação</th>
<th>gsi</th>
<th>canmx</th>
<th>chtmx</th>
<th>rdmx</th>
<th>esco</th>
<th>blai (m² m⁻²)</th>
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</table>

sources LAI:
Cana-de-açúcar: Cabral, et. al (2012)
Eucalipto: Maire (2011)
Calibration of Evaporative Fraction (EF)

\[
    \frac{EF}{EF} = \frac{ET}{Rn}
\]

HRU mean of EF on Piracicaba River Basin for 3 types of land cover

- Manual calibration of seasonal Evaporative Fraction (EF) through adjustment of vegetation parameters

SWAT HRU mean

observed

Cana-de-açúcar

Eucalipto

Cerrado
Results: Calibration streamflow (daily)

Calibration:

NSE: 0.50
PBIAS: 2.3%
Results – AVE ANNUAL - Ribeirão das Posses Watershed

Evapotranspiration, Water Yield and Total AQ. Recharge

Buffer width 45 m
ET $\rightarrow + 6\%$
Water Yield $\rightarrow - 8\%$
Recharge $\rightarrow + 2\%$

Step slope areas
ET $\rightarrow + 3\%$
Water Yield $\rightarrow - 4\%$
Recharge $\rightarrow + 1\%$
Results - Percentage change (%): $Q_m$, $Q_{1\%}$ and $Q_{95\%}$

- Slight reduction in the minimum streamflows
- Significant reduction in maximum streamflows

Hydrological environmental services
Conclusions

► Ave Annual

— Evapotranspiration: increased ~ 4.5% with reforestation.
— Water Yield: decreased ~ 6%. Especially runoff superficial that reduced the maximum streamflow.
— Recharge: increased ~ 1.5% → increased base flow.

► Extreme streamflow

— Reduced floods events ~ 18% and did not adversely affect the streamflow during low-flow periods.

► Limitations of estimates

— parameter uncertainty
— HRU: not explicitly represents the location vegetation and are not hydraulically connected

⚠ Areas of permanent preservation (riparian reforestation and in steep areas) promoters are predominantly favorable hydrological environmental services in Brazil
Next Steps

► Versions: SWAT-VSA / grid-based SWAT obtain scenarios consist of combinations APP and BMPs that optimize hydrological environmental services

► Measurements (Hillslopes)
Evapotranspiration
Soil moisture

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Martin, et al. (2014)