Trade-off assessment in the Senegal River Basin

ICID
Saskatoon 2018

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The Senegal River basin

- Located in western Africa
- Drainage area = 337000 km²
- Shared by four countries: Guinea, Mali, Mauritania and Senegal
- Traditional uses:
  - transportation (navigation)
  - food production: fisheries + flood recession agriculture
- More recently: hydroelectricity
- Significant year-to-year variability of river discharges:
  - exposes water users to a high hydrological risk
- Significant development potential in the basin. Coordination through the river basin authority: OMVS
The Senegal River basin

Artificial flood (AF)

4.5 km³

By Bourrichon (https://creativecommons.org/licenses/by-sa/3.0)
HEM for the Senegal River basin

- As river basins develop it becomes more and more relevant
  - To seek efficient allocation policies
  - To understand the linkages between
    - Economic sectors
    - Water users
    - Water users and their biophysical and social environment

- In the Senegal River basin, the following hydro-economic principles apply:
  - Water should be used where and when its user value is the greatest
  - Water should be stored in reservoirs upstream
  - Water for consumptive uses should be withdrawn downstream

- How to find the balance between these principles?

  Hydro-economic modelling (HEM)
- Maximizes expected net benefits from hydropower generation and irrigated agriculture
  - **Constraints:** M&I uses, artificial flood (eflows), navigation
- Up to 10 reservoirs / 12 hydropower plants
- 11 irrigation demand nodes / 52 crops
- Maximizes expected net benefits from hydropower generation and irrigated agriculture
  - **Constraints:** M&I uses, artificial flood (eflows), navigation
- Solved using Stochastic Dual Dynamic Programming (SDDP)
- Generic HEM coded in MATLAB + efficient Gurobi solver
Scenarios - Senegal River basin

- Development scenarios represent alternative levels of water resources’ commitment in the basin

<table>
<thead>
<tr>
<th>Baseline 2015</th>
<th>Mid-development 2030</th>
<th>Full-development 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 reservoirs</td>
<td>5 reservoirs</td>
<td>10 reservoirs</td>
</tr>
<tr>
<td>2 hpp</td>
<td>6 hpp</td>
<td>12 hpp</td>
</tr>
<tr>
<td>74 kha</td>
<td>255 kha</td>
<td>402 kha</td>
</tr>
<tr>
<td>5.9 million inhabitants</td>
<td>9.7 million</td>
<td>16.8 million</td>
</tr>
</tbody>
</table>

- Management scenarios reflect alternative allocation policies between competing uses
  - Food security: flood recession agriculture, fisheries and irrigation
  - ...
  - Energy security: hydropower generation
Hydropower generation

- Annual energy generation

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<td>Reservoirs</td>
<td>2</td>
<td>5</td>
<td>10</td>
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![Graph showing energy generation and reservoirs](image)
Cultivated area – flood recession agriculture

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Marginal value of water

Legend
- ROR
- Reservoir
- nodes
- River

Water value
$/1000m^3$
- 0.00
- 0.01 - 0.03
- 0.03 - 5
- 5 - 6
- 6 - 19
- 19 - 33
Water accounting (2030)

- Short-run values and costs (million US$/y)

<table>
<thead>
<tr>
<th></th>
<th>Guinea</th>
<th>Mali</th>
<th>Senegal</th>
<th>Mauritania</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fisheries</td>
<td>0.4</td>
<td>0.6</td>
<td>3.6</td>
<td>8.4</td>
</tr>
<tr>
<td>Irrigation</td>
<td>17.4</td>
<td>3.0</td>
<td>187.7</td>
<td>78.2</td>
</tr>
<tr>
<td>Hydropower</td>
<td>199.3</td>
<td>142.9</td>
<td>2.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Evaporation</td>
<td>-4.7</td>
<td>-5.8</td>
<td>-0.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Storage services</td>
<td>57.4</td>
<td>35.6</td>
<td>3.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Natural inflows</td>
<td>117.0</td>
<td>29.6</td>
<td>1.1</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Indicators

- Satisfaction level = degree to which one objective is achieved in a particular scenario (compared to the max achievable performance in the corresponding “best” scenario)

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<tr>
<th>Indicator</th>
<th>Scale &amp; units</th>
<th>« best » management scenario</th>
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<tbody>
<tr>
<td>Flood recession ag</td>
<td>Flooded area (ha)</td>
<td>Food security</td>
</tr>
<tr>
<td>Energy</td>
<td>Energy (MWh)</td>
<td>Energy security</td>
</tr>
<tr>
<td>Navigation</td>
<td>Probability of exceeding min flow (-)</td>
<td>Navigation</td>
</tr>
<tr>
<td>Fisheries</td>
<td>Fish catch (T)</td>
<td>Food security</td>
</tr>
</tbody>
</table>
Trade-off (2030)

- The thick lines = the average performance of a particular scenario
- Thin lines = performance for a particular hydrological year → give an indication of the year-to-year variability
Basin-wide net revenues (2015, 2030, 2050)
Conclusions and recommendations

- Future developments of the basin will exacerbate the existing trade-offs between competing uses.
Conclusions and recommendations

- Future developments of the basin will exacerbate the existing trade-offs between competing uses
- Inter and intra-country trade-offs
Conclusions and recommendations

- Food production sector more vulnerable to hydro-climatic variability
- The performance of the Senegal river system can be significantly improved through the coordinated operation of the multireservoir system
- Impact of climate change on trade-offs has yet to be carried out