Impact Assessment Modeling of Low-Water Management Policy

Modelagem para Avaliação de Impacto de Política de Gestão da Agua Baixa

IV FUNASA Seminar of Public Health Engineering, march 18 – 22, 2013 - Belo Horizonte (MG Brazil)

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1. Issues in Water Management

2. Knowledge Representation & Sharing

3. Simulator Development

4. Simulating
Contemporary issues of IWRM

- Management of a scarce resource
- Maintenance of ecological equilibrium & services
- Impacts of Climate Change
- Manage both the water quantity and quality
- Design basin-scale water management
- Account for competing and inter-related uses
- Specificity issues in urban / rural water
- Improve the monitoring of the resource
Incentive

Governance issue is key for the sustainable development of the water resource

- « Resource » implies « actors »
- Water is a « local » resource implies “actors’ coordination is required for resource management”
- « Coordination of actions » implies « rules » and « norms » (policy, law, etc.)
- *Ex ante* impact assessment of environmental norm implementation is very necessary
MAELIA: « Multi-Agents for Environmental norms Impact Assessment »

2009 - 2013

- **Consortium**
  - GET Midi-Pyrénées Observatory Toulouse
  - IRIT: Institut Recherche en Informatique de Toulouse
  - MSHS: Maisons des sciences Humaines et Sociales
  - AGIR/Institut Nat. Recherche Agronomique

- **Sponsor [2009-2013]**
  - Foundation RTRA STAE « Science and Technology for Aeronautics and Space” [www.fondation-stae.net/](http://www.fondation-stae.net/)
Objectives

• Develop an hybrid modeling platform (multi-agent system, equations, GIS) in order to explore the following questions:

  What are the impacts of a given corpus of norms in different socio-economical & environmental contexts?

  What are the impacts of different normative corpus in a given socio-economical & environmental context?

  Are these impacts consistent with the expectations of the policy- or law-makers?
Case Study: Adour-Garonne Basin

- **Natural resources**
  - Basin ~ 120 000 km², 120 000 km of waterways
  - Rainfall: 600 mm to 2000 mm / year
  - Potential of 90 km³ for flow & very large volumes in the groundwater

- **Artificial reserves**
  - 2.5 km³ of hydropower reserves of which 0.136 km³ under agreement with EDF to support low-flow
  - 0.356 km³ dedicated to supporting low water (dams, etc.).
  - 0.290 km³ accumulated in approximately 15,000 small dams for irrigation

- **Average yearly withdrawal: 2.5 km³**
- **~Equally distributed between drinking water, industry, farming (~ 645 000 ha irrigated)**
With a priority issue …

• But very uneven distribution over the year
  – Concentration of agricultural levies in times of low flow (up to 80%)
  – During the 2003 heat wave, 1.2 km³ diverted for irrigation (about twice the average yearly withdrawals for irrigation)

• Deficit of about 250 MCM in the Adour-Garonne

  Recurring conflicts of uses (and users)

  Negative impact on aquatic ecosystems

  Enforce limitation of water uses

  Economy: insecurity and loss of production income

→ We focus on the modeling of low-water management
**Crisis Management -> Structural Management**

- During low-water periods (étiage in French), rivers reach their lowest levels of the year.

- These last years, flows were regularly measured **under the minimal threshold** (DOE) which guarantees a normal functioning of the ecosystem.

- **LEMA (2006)** is a law dedicated to reform the management of these situations, the definition of water volumes quotas, their control by local authorities, etc.

Measuring the « crisis flows » (crisis management)

Define abstraction volumes (structural management)
Context: New Management Device

Application of the 2006 Water Law (LEMA):

• Implementation of the new regulation on abstraction volumes for agricultural irrigation

• **Authorized abstraction water volumes for agriculture (AWV):** water available in the basin, considering the needs for ecosystem functioning (DOE) and the priority uses: domestic and industrial

• **Single Organizations for Collective Management (2012):** (CA, CACG, CG, EPTB,...): be responsible for the management of agricultural water in each sub-watershed (consistent hydrologic units).
4 Priority Scenarios

• Contrast 2 ways of evaluating the water volume legally available for irrigation

• Contrast 2 climate change scenarios (mainly rainfall forcing)

• And many other possible options (e.g.):
  – Contrast agriculture EU policy (aids to farmers)
  – Contrast markets (water prices, prices of farm production, energy prices, land prices)
  – Contrast water monitoring systems?
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Abstraction / Instantiation Levels
Meta-Model of Social-Ecological Systems
“Limit” to the Model

Internal / External

Graphical Language

- An ecological or socio-economic process that impacts resource \( R_2 \) is dependent on the state of resource \( R_1 \).
- An ecological or socio-economic process impacts resource \( R \) (material or cognitive).
- An ecological or socio-economic process being dependent on the resource state it impacts.
- Actor A performs an activity that impacts the resource \( R \).
- Actor A uses the resource \( R \) to execute at least one of his activity; the relation can be labeled or not.
- Actor A performs an activity that simultaneously impacts resources \( R_1 \) and \( R_2 \), their respective states being inter-dependent.
- Actor A performs an activity that changes the realization of a process being dependent on the state of resource \( R_1 \) and impacting resource \( R_2 \).
Hydrological Sub-System
Agronomic Sub-System
Sub-System of Other Uses
Normative Sub-System
Structure of Low-Water Management System (Adour-Garonne)
Detailed Representation of the Processes & Activities

Each knowledge holder of products:

- Class, interaction or process diagrams
- Equations
- Algorithms
- Rules of change

... any form of representation that allows the researcher to formalize and share knowledge on biophysical and social processes.
Space & Time Scales of Dynamics

Direct process interactions (fitting equations)

⇒ Temporal and spatial scales are structuring elements for all processes

Interactions are set at the level of entities (resources)

⇒ Each (set of) process has its own logical representation of space and time.
⇒ Consistency is ensured at the level of entities (as integrity constraint)
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Modeling Processes & Activities

- Ecological Processes
- Socio-economical Processes
- Activities
- Decision-taking
Ecological Processes

- **Soil / Plant expert model** (INRA)
- **SWAT modules for quantitative hydrology**
- **Weather & CC**: historical data and model projections (CERFACS)
- **Land Cover / Land Use changes**:  
  ✓ Corine Land Cover 2000 – 2006  
  ✓ RPG 2006-2010  
  ✓ 2010-2050: statistical model (cellular automata)
- **Demographic changes**: INSEE model (Omphale) disaggregated at the level of Municipalities
- **Technological innovations**: process of knowledge diffusion over social networks
Examples of Process Modeling

**Soil / Plant**

*Easily usable water reserve* $R_{eu}$: amount of water available in the soil that cannot exceed a certain maximum amount specific to soil type

$$R_{eu} = W_{irrigation} + W_{rainfall}$$

**Maximum Evapotranspiration** $ETP_{Max}$: Maximum value of the ETP of a given culture at a vegetative stage in given climate context

**Potential Evapotranspiration** $ETP_{Pot}$: water that may be lost through plant transpiration (soil $\to$ atmosphere)

$$ETP_{Max} = ETP_{Pot} \times K_c$$

**Crop coefficients** $K_c$: the plant will take a certain amount of the water depending on its phenological stage of development
Drinking Water Consumption

All the processes that are used to estimate:
• water withdrawals and discharges;
• their likely evolution up to 2050.
Industrial Water Consumption

All processes for estimating the industrial water withdrawals and discharges:

• Logging homogeneous year
• Discharges indexed on withdrawals via a factor
• Evolution in time is not taken into account
Water storage in dams and releases for the support of low water periods:
• Rules for water release and storage
• Optimization \textit{wrt} hydropower production (and demand)
LUCC – Hydrology Multi-scales coupling

Hydrologie: dépend du LULC

Hte Résolution: bilan hydrique fin sur parcelle (échelle métrique)
Locate the Available Resources (1)

BD Carthage®
Sections of watercourses
• Toponyms
Surface hydrology
• Resource type (river, lake, reservoir,...)

• Toponym of the resource
• Code of the resource
Locate the Available Resources (2)

Water Information System

Groundwater masses

• Type, Toponym

• Toponym of the resource

• Code of the resource
Locate the Available Resources (3)

**BD TOPO®**

**Under-water surfaces** = surfaces > 20 m de long, Watercourse > 7,5 m (width) 
masonry basins > 10 m 
floodplains > 20 m (width)

- Nature (basin, surface of water)
- Regime (intermittent, permanent)


![Map](image)

AEAG typology of water mass to extract the hill dams

- form (stretching, convexity)
- area
- Localization (salted littoral zones)
- **BD Carthage® classification**
Activities

Key actors in the quantitative management of water (endowed with a model of rationality)

- Farmers
- Prefects
- dam managers
- managers of low water

Main activities related to a decision-making process

- Crop rotation
- Crop management
- Irrigation
- Decree of water-use restriction
**Crop rotation**

**Yearly rotation:**
- Activities implemented by the farmer of choosing a system of culture (culture + associated strategies) for each parcel
- Rational decision by evaluating various cognitive resources

**Corp Management**

Sowing, harvesting: decision-making process resulting from the strategies of the technical itinerary associated with the parcel.
Irrigation of the parcels

Irrigation

- Decision-making process based on the irrigation strategy attached to the technical itinerary
- Take into account the restrictions on irrigation

Water withdrawals are done at the scale of the hydrographic zone
Locate irrigators and irrigated areas


**Culture Islets** from CAP statements = contiguous set of cultivation parcels exploited by the same farmer
- Surface of different culture classes
- Farm characteristics
- Irrigated?: y/n

- Positioning of the irrigated islets
- Municipality of implantation of the farm
Locate the reported withdrawn volumes

**Water Information System**

*Points of agricultural levies* (2003 à 2010)

- Municipality centroid
- Nature of the resource
  - Surface water
  - Confined groundwater
  - Groundwater
  - Hill reservoirs
- N° de SIRET of the farm or company
- Toponym of the resource
- Code of the resource
Locate the authorized abstraction volumes

Towards a “regulatory map”? 

Management reference units
• Water courses
• Withdrawn volumes
• Authorized volumes

↓
• Withdrawn volumes
• Authorized volumes
The whole farmer’s behavior is a set of decisions at various time scales:

- **Strategic behavior** (year): choice of the cropping plan and of the culture strategies associated
  - Sowing strategy
  - Irrigation strategy
  - Harvest strategy

- **Operational behavior** (day): application of the culture strategies taking into account workload time
Representing Actor’s Rationality

Multi-criteria decision-making method based on the belief theory, (Shafer 1976) and evidence theory (Dempster)

Approach allowing to manage:
- incompleteness and imprecision of knowledge of the criteria
- the consequences of choices on these criteria
- conflicts between decision criteria

- **Plans**: agent’s strategic vision (ex.: list of culture rotation on each parcel)
- **Desires**: formalized as a set of criteria that will be used to evaluate the plans (ex.: max expected profit, min workload, etc.)
- **Beliefs**: agent’s beliefs about the system functioning.
- **Intention**: the chosen plan.
Activity Diagrams: Farmers
Decision-making procedure for restricting water uses

Convening actors of the drought cell

Low-water period stars

Survey of Situation

Definition of a Restriction Strategy

Enactment of Prefectural Decrees

Activity diagram of a Departmental Direction (Tarn-et-Garonne)
Strategy for Restriction Level
Mapping the Extension of Decrees

Decrees of restriction of water uses
• Recovery from the DDT 31 of a corpus of 50 decrees between 2001 and 2011

Control / Verbalization
• Activity of the « water police » agent
• Much rational behavior

Principles
• Upstream-down stream solidarity
• Continuity of restrictions
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Data Model

Identification / discussion with the owners / collection

Preprocessing and harmonization

GIS / GAMA integration

Consistency constraints

Use (inputs, outputs)

- RPG / LPIS [irrigable parcels]
- BD Carthage [hydrological network]
- BD topo [hill lakes]
- SIEau [withdrawals & releases]
- INSEE, Omphale ...[démography projections]
- EDF / dams
- Administrative limits
- ...
Intégration des données: exemple

1 - Association géographique guidée par les chroniques de prélèvements

2.a - Association par analyse de la table attributaire

2.b - Association par analyse spatiale

3 - Fusion des couches SIG

4 - La relation entre îlots irrigués et réserves d'eau est finalement établie par croisement des 2 couches SIG.
Plateforme de Simulation

Environnement GAMA (IRD)
Multi-agents + SIG + équations
Développements interfaces usagers & modélisateurs
Production des indicateurs sociaux & env.
Hydrological Flow

Resolution: hydrological zone

Red to deep blue: no water to saturation

Includes withdrawals (irrigation, drinking water, industry)

Time step: day
Crop Growth

We here do not distinguish the different kinds of crops

Intensity of **BLUE** increase when the phenological state is more advanced

1 image / day

Period ~6 months
Agricultural Islet Disappearance

Urbanization + Fallow

Green: forest, pastures
Orange: agricultural islets
Red: Urbanized areas

1 image / year
Period ~70 years
Farmers’ Activities

1 tractor = 1 farmer

Islet color = main plot sown (wheat, maize, barley, etc.).

The farmer is always on the islet he is working on (sow, irrigate or harvest).
# Scenarios & Main Indicators

- Water flow at DOE points
- Surplus / deficit of water (wrt DOE)
- Water crisis frequency
- Yield of Irrigated corps
- Agricultural production
- Sustainability of Farms
- Patterns of crop rotation

- Total and irrigated surfaces of farms
- Number of farms
- Cost of implementation / operation of alternative management policy (€)
- Acceptability (norm compliance, satisfaction level of various actors)

<table>
<thead>
<tr>
<th>CLIMATE CHANGE</th>
<th>WATER MANAGEMENT</th>
<th>By WATER FLOWS</th>
<th>By ABSTRACTION VOLUMES</th>
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</thead>
<tbody>
<tr>
<td>« BAU »</td>
<td>S11</td>
<td>S12</td>
<td></td>
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<tr>
<td>REDUCED PRECIPITATION during LOW-WTAER</td>
<td>S21</td>
<td>S22</td>
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Near Future

On-Going (2013)

• Sensitivity analysis & calibration
• Simulation of scenarios & analyses

Next steps

• Modeling water « small cycle »
• Scenarios of urban water demand and supply
Thank you for attention

Web Site of the Project:

http://maelia1a.wordpress.com/

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