Integration of Land Cover & Land Use Multi-Scale Information Layers
In a Model of Low-Water Management

Van Bai Nguyen1
David Panzoli2
Anne-Elisabeth Laques3
Olivier Thérond4,5
Pierre Mazzega1,6

1 GET UMR5563, IRD-UPS-CNRS-CNES, OMP, 14 av. E. Belin 31400 Toulouse France
van_bai.nguyen@get.obs-mip.fr

2 Université Toulouse 1- Capitole, IRIT, F-31042 Toulouse cedex, France
panzoli@irit.fr

3 ESPACE-DEV, Maison de la Télédétection, 500 rue Breton 34093
Montpellier cedex 5, France
anne-elisabeth.laques@ird.fr

4 INRA, UMR 1248 AGIR, F-31326 Castanet Tolosan, France

5 Université de Toulouse; ENSAT; UMR 1248 AGIR, F-31326 Castanet Tolosan, France
olivier.therond@toulouse.inra.fr

6 Joint Mixt Laboratory OCE, UnB / IRD, LAGEQ, Instituto de Geociências - Universidade de Brasília, Campus Darcy Ribeiro, Brasília - DF, Brasil
pierre.mazzega@ird.fr

Abstract. We present a methodology for the integration of multi-scale information and modeling of hydrological processes (low resolution), of the dynamics of land cover and land use (medium resolution) and of agricultural islets (high resolution) into a multi-agent platform for simulating the impacts of public policies of low-water management.

Keywords: Land cover and land use, multi-scale information, low-water management, agriculture, integrated modeling, impact assessment

1. Introduction
As part of the interdisciplinary MAELIA project, we develop a based-agent platform (CSSIS, 2000; Berger and Ringler, 2002; Amblard and Phan, 2006) for the numerical simulation of the social, economic and environmental effects induced by the implementation of new low-water management policies under various scenarios (impacts of climate change, regulatory changes, etc.; March et al., 2012; De Girolamo and Lo Porto, 2012). The platform is potentially exploitable in many basins nevertheless its concrete instantiation is being performed on a sub-basin of the Adour-Garonne basin (South-West of France), the Upstream Garonne basin.

In low water period (June-October) the main challenge is to fill the demand for agricultural irrigation (70% to 80% of the withdrawals in ordinary years) once are met the priority needs like the supply of drinking water, the industry needs, and maintaining the ecological functioning of aquatic ecosystems as required mainly by the European Water Framework Directive (Directive 2000/60/EC), its transposition into national law and other French legal and regulatory devices (Mayor et al., 2012; Mazzega et al., 2012).
To simulate the direct or indirect effects of implemented policies - including new regulation on abstraction volumes for agriculture and the creation of single organisms of collective management, a modeling methodology has been developed, based on a meta-model of social-ecological systems (Sibertin Blanc et al., 2011) whose use in the case of the Upstream Garonne basin involves:

- identifying and representing the key actors, material resources, cognitive resources and the dynamics at play across the considered basin (Fig. 1);
- simulating all the dynamics at play (biophysical and ecological processes, socio-economic processes and human activities) and the induced evolution of the state variables of actors and resources up to the 2030 time-horizon.

Here we present more specifically the strategic choices and the methodology developed to take into account the multi-scale information on the one hand on the land cover / land use (LCLU) and their changes, on the other hand on the agricultural irrigated parcels, these two levels affecting the basin-scale hydrological processes and state of the water resource.

In the following sections we present briefly the choice of representation of hydrological flows in the platform (Sec.2), the choice of representation of the land cover and land use classes (Sec. 3), the integration of information on agricultural parcels (sec. 4), how to take into account LCLU changes (Sec. 5), few opportunities related to the development of the platform (Sec. 6).

2. Hydrologic Processes in the MAELIA Platform

Modeling of the main hydrologic processes is essential to represent flows in the rivers and the filling of reservoirs (water from dam under agreement for the support low water periods, private hill-reservoirs, etc.) having a role in low-water management and agricultural activity. The hydrographic zone (HZ) is the hydrologic unit scale for which we model the water cycle in the platform (Fig. 1). The (modeled) hydrology depends strongly on (the representation of) the land cover and land use in the considered territory (e.g. Hernandez et al., 2003; Houet, 2006; Wheater and Evans, 2009).

We develop a standard rainfall-runoff model but with two nested scales of resolution. Indeed, the blade of water falling on each hydrographic zone is divided between agricultural areas
(metric resolution, cf. Sec. 4) and non-agricultural areas (HZ resolution) as illustrated in Figure 2.

Figure 2: left) Schematic view of the rainfall-runoff model; right) Interaction diagram of the different resources involved in the water flow process, and other processes of influence.

Three main processes are controlling surface runoff: a) the rainwater that falls on a non-agricultural area runs off in the water reserves of the hydrographic zone; b) the water that falls on an agricultural area fills the useful reserve of the plot and feeds the cultures. Excess runoff flows into the water reserves of the HZ; c) water at the outlet of a HZ flows into the reserve of the downstream hydrographic zone.

Urban expansion is the main factor (and the only one we model) that accounts for the disappearance of agricultural islets (CAP islets) in the basin, mainly in favor of building and housing, which indirectly alters runoff of rain-water in the hydrographic zone. Changes in land cover (updated on an annual basis) accounts for the other transitions between polygons of LCLU classes (see Sec. 5).

3. Tailored Representation of Land Cover / Land Use

We obtain the coverage of the MAELIA study area, by using the Corine Land Cover database (CLC, 2012). Constructed from satellite images, it includes major types of land cover (mapped as polygons of a few hundreds of m²). These data have allowed us to build GIS layers by aggregation of CLC land cover classes in classes useful for the needs of our platform (hereinafter called "MAELIA classes"; Figure 3).

<table>
<thead>
<tr>
<th>Classe MAELIA</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>équiv. CLC</td>
<td>RPG</td>
<td>111</td>
<td>1-111</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>31</td>
<td>33</td>
<td>4, 51</td>
<td>52</td>
</tr>
</tbody>
</table>

Figure 3: Correspondence between the MAELIA classes and CLC classes of LCLU (and color codes of the MAELIA classes). Areas corresponding to the French Land Parcel Information System (LPIS, 2010) form a separate class (class 2) for specific treatment of the processes taking place there.

The name of the CLC classes, their grouping into MAELIA classes and the corresponding surfaces are listed in Table 1.
### Table 1: Surface of the CLC and MAELIA classes in the Upstream Garonne basin, year 2006.

<table>
<thead>
<tr>
<th>Corine Land Cover Classe</th>
<th>Surface (ha)</th>
<th>MAELIA Classe</th>
<th>Surface (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ø Out of the study area</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ø French Land Parcel Information System LPIS</td>
<td>281988,1</td>
<td>2</td>
<td>281988,1</td>
</tr>
<tr>
<td>111 Continuous urban area</td>
<td>146,0</td>
<td>3</td>
<td>146,0</td>
</tr>
<tr>
<td>112 Discontinuous urban area</td>
<td>13316,0</td>
<td>4</td>
<td>16500,7</td>
</tr>
<tr>
<td>121 Industrial and commercial areas</td>
<td>1033,1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>122 Road and rail networks and associated spaces</td>
<td>105,2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>124 Airports</td>
<td>158,0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>131 Extraction of materials</td>
<td>1175,9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>141 Urban green spaces</td>
<td>143,6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>142 Sports and leisure areas</td>
<td>568,8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>211 Arable land outside irrigation perimeters</td>
<td>17434,6</td>
<td>5</td>
<td>17434,6</td>
</tr>
<tr>
<td>221 Vineyards</td>
<td>13,8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>222 Orchards and small fruits</td>
<td>6,5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>321 Natural pastures and lawns</td>
<td>12599,3</td>
<td>6</td>
<td>19655,0</td>
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<tr>
<td>322 Moors and heathland</td>
<td>3316,9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>324 Forest and changing shrub vegetation</td>
<td>3718,5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>231 Meadows / grasslands</td>
<td>28718,0</td>
<td>7</td>
<td>28718,0</td>
</tr>
<tr>
<td>242 Cultural systems and complex parcels</td>
<td>28408,0</td>
<td>8</td>
<td>41888,7</td>
</tr>
<tr>
<td>243 Predominantly agricultural areas, interrupted by important natural areas</td>
<td>13480,7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>311 Deciduous forests</td>
<td>152871,6</td>
<td>9</td>
<td>192520,4</td>
</tr>
<tr>
<td>312 Coniferous forests</td>
<td>24750,2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>313 Mixed forests</td>
<td>14898,6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>332 Bare rocks</td>
<td>9407,8</td>
<td>10</td>
<td>15547,0</td>
</tr>
<tr>
<td>333 Sparse vegetation</td>
<td>5791,1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>335 Glaciers and perpetual snow</td>
<td>348,1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>511 Water courses and water ways</td>
<td>369,1</td>
<td>11</td>
<td>2349,9</td>
</tr>
<tr>
<td>512 Water bodies</td>
<td>1980,8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

One of our objectives being to evaluate the effects of new low-water management regulations on the economic development, especially on farms that will be submitted to them in the first place, the modeling accuracy is expected on irrigators behavior (Taillandier et al., 2012) and on the dynamics of crop rotation and crop growth on agricultural land, but not so much on hydrology for which a large-scale and low-resolution modeling is sufficient. The coverage of non-agricultural areas is based on the use of the Corine Land Cover data base. The aggregation of certain CLC classes of land cover and land use has been performed to simplify the representation (Fig. 4) of the cover and of the hydrological processes.
Figure 4: Maps of land cover from Corine Land Cover (left) and from the MAELIA platform (right) over the Upstream Garonne basin, year 2006 (see Table 1).

4. Integration of the French Land Parcel Information System

Each year, in particular in order to benefit from subsidies, farmers addressed to the Public Administration a declaration file that describes surfaces of the culture islets they operate and cultures they are practicing. An islet is a contiguous set of farming plots operated by the same farmer. Geo-referencing of the islets is updated each year by farmers on the basis of the ortho-imagery of the National Geographic Institute (BD ORTHO © from IGN). This information is recorded on the GIS parcel register called French Land Parcel Information System (LPIS, 2010).

Figure 5a: 2006 Distribution of the LCLU of the MAELIA platform in the Upstream Garonne basin.

Figure 5b: Example of the high resolution agricultural parcel "overlay" (class 2) in the low-resolution LCLU layer.

To avoid superimposing layers used for the representation of agricultural and non-agricultural surfaces, we performed in ArcGIS an overlay of the land parcel information (LPIS, 2010) in
the GIS layer representing the distribution of the MAELIA classes of land cover and land use (LCLU). Figure 5 illustrates the type of results we obtain. This figure is especially exhibiting the high resolution (metric) representation of agricultural parcels embedded in the low-resolution representation of the land cover in the hydrographic zones (Fig. 1).

After this treatment, each hydrographic zone comes in the form of a partition of MAELIA classes (see Sec. 3). In the simulation platform, areas of Class 2 (LPIS data) are associated with specific processes and activities modeled in detail, such as the decision-making process of farmers about crop rotation and irrigation (water tours), the process of growing crops according to their type, etc., all these processes having an impact on the larger scale hydrological dynamics.

5. Accounting for LCLU Changes
Simulation of evolutionary trajectories of the Adour-Garonne basin, of its resources and activities that are developing there, is conducted over the 2000-2030 period. A scenario of change of land cover and land use is constructed for this time-horizon, and its impact on water resources considered (Chery and Jarrige, 2011).

The 2000 - 2010 sub-period allows for the "calibration" of process parameters based on a set of ecological, economic, administrative and social data. Comparing the 2000 and 2006 Corine Land Cover maps of land cover and land use, we build the matrix of annual transition rates between LCLU classes. These transition rates are then aggregated to obtain the transition rates between MAELIA classes. Figure 6 simply shows the changes in area of some CLC classes between 2000 and 2006 in the Upstream Garonne basin (surfaces are given in Table 1).

![Figure 6: Evolution (in ha and %) of some CLC classes of land cover in the Upstream Garonne basin between 2000 and 2006. CLC_133 is the class of "construction sites", all recorded in 2000 being completed in 2006. Classes CLC_121, CLC_131 and CLC_512 are respectively the industrial and commercial areas, areas of extraction of materials and water bodies, three classes with significant % of growth.](image)

These results indicate surface changes of only a few percent of certain classes of land cover in the Upstream Garonne basin, except in the peri-urban area of the city of Toulouse, where growth continues mainly at the expense of agricultural surfaces or farms.
Rates of transitions between MAELIA classes are then used to project the evolution of LCLU year after year until 2030. The spatial distribution of the transition is randomly generated, possibly with the use of a few simple rules (e.g. the loss of agricultural islets is in the immediate vicinity of urban centers, etc.) in order to preserve the spatial cohesion of territories.

Indeed, the data show that urbanization only is significant with regard to changes in land cover. In the platform, urbanization is represented through the disappearance of agricultural areas converted into building and housing. The quantification of this loss on the scale of each hydrographic zone is performed using a quantitative spatial analysis carried out on the basis of 5 years available on the French Land Parcel Information System (Fig. 7).

![Surface changes islets in the ZHO027 hydrographic zone](image)

**Figure 7:** Example of the evolution of the surface of crop islets and meadows / grassland islets between 2006 and 2010 on a hydrographic zone (ZHO027). Information retrieved from an analysis of LPIS data (2010).

### 6. Conclusion

The use of multi-agent modeling to simulate the effects / impacts of scenarios of evolution of land cover and land use on water resources (Parker et al., 2010; Mehdi et al., 2012), integrated with a representation of natural and anthropogenic processes and socio-economic activities is the basis of the development of the MAELIA platform to support policy design and decision-making. The MAELIA platform will be also coupled with a platform modeling the strategy of the key actors involved in the low-water management and representing the social acceptability of the implemented regulations and policy (Sibertin-Blanc et al., 2006; Adreit et al., 2011)

We pursue this objective by coupling a representation of the evolution of land cover / land use and a high resolution representation of irrigated agricultural plots (and modeling activities and processes that take place). The multi-scale approach is required to produce relevant scenarios from both an environmental perspective and from the perspective of social and economic development (Evans and Kelley, 2004). In the Upstream Garonne basin, we observe low transition rates between LCLU classes in the period 2000 - 2006, except in peri-urban zones where agricultural islets disappear mainly in favor of urban built. However, the modeling methodology presented here is generic and will be applied to the entire Adour-Garonne Basin (or to other basins).

*Acknowledgments. This research is funded by the Thematic Network for Advanced Research “Sciences & Technologies for Aeronautics and Space” (RTRA STAE Foundation http://www.fondationstae.net/) in Toulouse, France, under the MAELIA Project (http://maelia1.wordpress.com/).*
7. References


