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Abstract:
In Europe, many water resources systems are in structural water deficit, with limited or non-existent opportunities to store more water. Often, the agricultural sector is blamed for taking water when it is least available. This paper describes a fine, spatially and temporally explicit agricultural model which was built specifically to support the design and the assessment of alternative cropping system spatial distributions to face water scarcity issues at river basin level. We focus on the description of decision making process and spatio-temporal organization of irrigation at farm level. Information available in the French “Land Parcel Identification System” (LPIS) geographical database was crucial to the modeling process. The agricultural model is coupled to a hydrological and a normative model in the MAELIA multi-agent simulation platform which aims at representing of the structure and dynamics of a particular social-ecological system: a socio-agro-hydro-system.
We give an overall description of the model components and present the main simulation results used to assess the models’ performance. We discuss the model’s ability to figure inter and intra annual irrigation withdrawal dynamics.

***Keywords**: cropping system, farming system, irrigation, decision-making, social-ecological system.*

1 INTRODUCTION

The need to integrate water issues into spatial planning emerges as a cornerstone for integrated water management at all levels of governance. This requires that actors in charge of land management and of water management should craft tomorrow’s governance and practices together (Gober et al., 2013). In rural areas the main land managers and practitioners are farmers or their representatives. For irrigating farmers, stakes in using water are high, going as far as the economic viability of their farm. In France, this paradigm of *spatial water management* has been a failure up to now, as it mainly triggered conflict situations and water policy lock-ins. Getting actors of opposite opinion to sit together and overcome their differences has shown to be very difficult. Also, the social-ecological systems at stake are complex adaptive multi-level systems, therefore information and knowledge about them are dispersed and hard to objectify. We believe that intervention science (Hatchuel, 2001) is a way to manage the science-society interface and elaborate tools and methodologies to assist stakeholders in representing this complexity, designing solutions to natural resources management problems, while favoring co-learning along the way.
More precisely, we argue that design activities allow sciences to be more credible, salient and legitimate (Cash et al., 2002; Nassauer and Opdam, 2008). In line with this, we developed and implemented a participatory methodology to design and assess a new organization of what we call a “socio-agro-hydro-system”, a particular type of so-called social-ecological systems. In collaboration with stakeholders, we design and then assess alternatives of agricultural activities and water resources management in a basin experiencing water quantitative imbalance. Our approach is built on three iterative participatory steps (i) co-representation of system in a spatially explicit multi-agent simulation (MAS) model, (ii) co-design of alternatives of spatial distributions of cropping systems and

water resources management strategies, and (iii) integrated co-assessment of the different alternatives via the MAS model (Murgue et al., in revision). This design-and-assessment methodology was implemented on the downstream Aveyron River watershed, one of South Western France' most controversial areas for quantitative water issues. It is an irrigated landscape of more than 800 km^2, of mainly cereal and maize cropping, fruit production, and numerous seed-production contracts. The usable agricultural area is about 40,000 ha. There are about 1,150 farms, of which 43% irrigated, with an average farm irrigated area equal to 38% of the farm agricultural area (French Land Parcel Identification System in 2009).

Dealing with land and water management issues in social-ecological systems cannot be addressed by just balancing overall demand vs. supply at river basin level. In fact, water levels at outlet are generally determined by a great variety of spatial and temporal interactions between cropping systems (CS), pedo-climatic situations, water resource types (private dams, aquifers and rivers) and water management practices (dam releases, water use restrictions). One cannot represent such a dynamic problem as flow variations by just an overall seasonal appraisal. To face this complexity we developed a spatially explicit model, fine enough to represent interactions at spatial and temporal scales that make sense for the different stakeholders involved in the project. One of the main challenges in modelling very place-based interactions within a river basin is to represent the structure and dynamics of the agricultural activities.

This paper is focused on step (i) of our design-and-assessment methodology. It describes the agricultural model we built to simulate the effect of changes in the agricultural activities and their interactions with hydrological dynamics, specifically for (summer) low-flows management. The model was developed into the multi-agent MAELIA platform (Gaudou et al., 2013) dedicated to the simulation of interactions between agricultural activities, water resources management and regulatory water use restrictions. We hereby describe all elements of the platform's agricultural domain i.e. the "agricultural model". We present the components and their interactions, and then provide simulation results to discuss their ability to retrace spatial and temporal patterns of irrigation practices at different levels and in turn corresponding withdrawals.

Our modeling trajectory was guided by the principles of mixing hard and soft methods (Pahl-Wostl and Hare, 2004) and the objective of retracing patterns rather than exhaustively representing mechanistic processes (Grimm and Railsback, 2012). The model we describe here combines scientific and empirical knowledge, local expertise and large scale census data. Information available in the French "Land Parcel Identification System" (LPIS) geographical database (Inan et al., 2010) was crucial (see section 2.2).

2 MODEL DESCRIPTION

2.1 Overall description and concepts used

The agricultural model simulates spatial and temporal dynamics of agricultural activities within the river basin. It includes 3 main dynamic components representing (i) the crop growth, (ii) farmer agents' decisions on crop management and irrigation at field level, and (iii) the irrigation organization at farm level.

To simulate on-farm spatial and temporal organization of cropping and irrigation activities, we use the concept of cropping and irrigation blocks, two types of field group. Cropping blocks are groups of fields within the same farm which feature identical CS and pedoclimatic conditions. Fields within blocks therefore undergo the same crop sequences, possibly in different orders, and the same crop management strategies. The irrigation block concept is presented in section 2.5. Those spatial units are manipulated by farmer agents (hereafter referred to as *farmers*) to allocate their activities. The model is therefore able to represent interactions between the field, field blocks and farm levels.

A virtual farmer is associated to each farmland and equipped with crop management and irrigation strategies i.e. formal representations of the corresponding decision-making processes. Model outputs such as working time, yield or withdrawal levels can be provided for all individual entities of each level and be aggregated based on geographical or parametrical date e.g. a type of farms, fields of a Water User Association (WUA), a river sub-basins.

The agricultural model is coupled with the hydrologic and normative models within the MAELIA platform to simulate impact of the different agricultural activities on the different water resources.

2.3 Description of the system structure

The representation of the system's entities and relations between them in our agricultural model is based on spatial and tributary data on water resources (dams, aquifers, rivers), pedo-morphology (soil types, digital elevation model), climate (daily temperature, precipitation and evapotranspiration series), hydraulic infrastructure and information provided by the French LPIS. All of those elements are stored in a GIS and used as entries of the agricultural model.
The LPIS provided us with the location and delineation of spatially continuous farmers' cropping blocks, hereafter called "islets", and with the annual crop acreage within them from 2006 to 2009. Islets contain one or many annual agricultural parcels, hereafter called "fields". The LPIS dataset also provides the affiliation of islets to each farm, and therefore the spatial extension of farmlands.
Agricultural fields (about 15,000) are geo-localized at islet level. One of the key challenges to achieve a fine spatial representation of agricultural activities was to affect a CS to each field, i.e. a typical rotation and crop and irrigation management strategies. To do so we integrated information about crop rotations coming from the analysis of the LPIS crop acreage data from 2006 to 2009 and crop management from participatory mapping and farm surveys.
We define on-farm labor availability using farm size as proxy. Based on expert knowledge, we allocate labor units proportionally to the farm size, considering that one annual labor unit is necessary to farm 120 ha. We also define a daily working time of 12 hours with the possibility to over work for maximum 1/3 of this time as to finish a technical operation that a farmer has already started in a field.
Each irrigated islets are explicitly connected to water resources in order to identify the resource from which irrigation water is withdrawn. To make this connection, hereby called "hydraulic linkage", we developed an algorithm based on expert knowledge and farm surveys in two steps: (1) link withdrawal points to the closest resource of their type, (2) link withdrawal points with irrigated agricultural islets using famers' description of possible combination between resources.

2.4 Crop growth model: AqYield

We use a semi-empirical crop model (*AqYield*, adapted from Nolot & Debaeke, 2003) to simulate crop growth and soil water dynamics given soil characteristics, climate and farmer practices. The purpose of *AqYield* in our simulation platform is (i) to provide daily information on water dynamics in soil and plant growth as to interact with farmers' decisions on irrigation and (ii) to estimate crop yields in each field as a function of water satisfaction during the whole growth cycle. Required inputs are crop, soil characteristics, crop sequence and (annual) crop management (CM), daily rainfall, temperature, and evapotranspiration. CM is provided by the farmer decision model (see section 2.3).
Crops correspond not only to species, but also to cultivar (e.g. flowering precocity for maize) and final product destination (e.g. maize for grain harvest vs. maize for forage production). Hence we refer to crop/cultivar to define a unique crop parameterization in the model. The crop/cultivar parameters can easily be adapted by model users locally, to ensure that model outputs fit with locally observed performances of crop-soil-CMS combinations. For example they include the crop maximum yield in an optimum water availability situation, the sum of degree-days to flowering and to physiological maturity, a coefficient of crop emergence speed. Twelve crop species were integrated, covering about 92% of the usable agricultural area of our case study in the 2009 LPIS, and 100% of irrigated crop. Maize being the most intensively irrigated species, it is considered under 7 crop/cultivar ranging in 3 usage types (seed, grain or forage) and 5 earliness categories (very late, late, regular, early, very early). Other simulated crops are: sunflower (early, regular), wheat, barley, peas, rapeseed, sorghum, soya, temporary and permanent meadows, apple (water intensive fruit production), plum (water extensive fruit production).
The soil is represented with a nested reservoir approach. Soil moisture varies as a percentage of water contents (WC) from wilting point (0%) to field capacity (100%). The water content of the soil surface layer (WC_{surf}) represents the reservoir subject to evaporation. In order to figure the closing of exchange surfaces, the size of WC_{surf} decreases every day until a minimum is reached (WC_{surf_min}). Tillage reinitiates the WC_{surf} to the tillage depth's corresponding water content, as to figure reopening of soil and exchange surfaces. Tillage water content (WC_{till}) represents water content in the deep tillage depth (e.g. 30 cm). Root water content (WC_{root}) represents water content available for crop absorption. WC_{root} increases along with crop roots development. At a given development stage, given the soil depth explored by the roots, the WC_{root} reaches a maximum water content (WC_{max}) corresponding to soil moisture at field capacity.

Those water contents are filled by rainfall and irrigation and emptied by evaporation, transpiration, drainage and runoff. We estimate runoff using field's average slope, current moisture level in WC_{surf}, a surface roughness indicator (WC_{surf_day} / WC_{surf_min}), and a soil parameter for maximum daily intake capacity. Drainage is calculated as the excess amount of water in WC_{max} after considering all other water fluxes. AqYield also represents capillarity fluxes as a function of WC_{surf} and WC_{till} differential (i.e. difference between moisture levels in surface and tillage soil layers).
Crop development is estimated according to the temperature sum from emergence (°Cd). Temperature sum correspond to the accumulation of mean daily effective temperature during the crop development. The daily effective temperature is the average temperature above a crop's base temperature (e.g. 6° C. for maize). Crop development at field level is represented through a vegetative scale for all crops ("Vscale", flowering = 1). This allows to characterize and monitor key development stages from sowing to harvest. AqYield also represents crop biomass growth through the crop coefficient (Kc) and roots development. Kc dynamics is a function of current day temperature and daylight length, crops' vigor potential and cumulative transpiration. It increases before flowering stage and then declines until harvest. Root development depends on cumulative temperature modulated by a crop roots development parameter.
Evaporation (EVA) is estimated through a function of ETP, Kc and WC_{surf} size and moisture level, considering EVA null when Kc > 1. This also allows to estimate a current day theoretical maximum transpiration (TR_{max}) being the other share of ETP. The model then calculates crop transpiration ("real transpiration" *TRr*), modulating TR_{max} by WC_{root} moisture level and the clay percentage in soil. The daily ratio between TRr and TR_{max} is summed over the cropping season as to calculate a global water satisfaction index according to the following, empirically established equation ("water function"): $IRsh = (1-\alpha).\left[1-\left(\frac{\sum TRr}{\sum \mathrm{TRmax}}\right)\right]^2$ *where* α *is a crop parameter.*
This index (IRsh) is then used as a coefficient to estimate crop yield at harvest by moderating a locally defined maximum yield for a crop conducted at optimum water availability, using $Yield_{real} = IRsh \,.\, Yield_{max}$.
This soil-crop model is coupled with the farmer decisions model described in following sections. Soil, crop and water dynamic state variables are influenced by farmers' actions (i.e. technical operation), and in return farmers' actions are decided according to, among others, crop and soil variables provided by the biophysical model. Mainly:

- Tillage, sowing, irrigation, fertilization and harvest are triggered by soil moisture and crop physiology among others;
- Soil structure is modulated positively or negatively depending on (i) soil moisture at tillage or harvest date, (ii) inter annual crop rotation practices.

2.5 Farmer decisions: cropping and irrigation practices

The farmer decision component represents decision-making processes which trigger technical operations, taking into account on-farm labor availability and spatial characteristics of field, islets, cropping and irrigation blocks and farms. More precisely, farmers activate their daily technical operations considering the priority between them, their execution time (ha/hr) and the fields' spatial distribution as to minimize distance when changing field. Every day, they start with the priority operation or a prior operation to be finished and stop when their daily work time availability is reached. Simulated activities are, in order of priority: (1) tillage of various intensity and depth, (2) Sowing, (3) Irrigation, (4) Harvest, (5) Fertilization, (6) Plant protection.
Farmers' strategies are coded as a set of decision rules (DRs) using the typical syntax: "IF INDICATOR OPERATOR THRESHOLD AND INDICATOR OPERATOR [...] THEN ACTION (ELSE ACTION)", for example "if it is later than 1st of May and it rained less than 15 mm in the last 5 days and WC_{root} humidity is lower than 80% of soil water holding capacity level and […] then sow maize". Variables used as indicators are provided by AqYield (e.g. plant development stage, soil moisture level), climatic data (e.g. rainfall in the previous and next days), hydrological data (e.g. levels of water resources provided by the hydrological model; Therond et al., this conference), and the normative context (i.e. withdrawal restrictions provided by the normative model; Therond et al., this conference).
There are about 30 individual rules per crop/cultivar. Such a set of DRs should be seen as a pre-established strategy to trigger a sequence of technical operations depending on soil-plant-climate-water resources conditions at field level. For the same crop/cultivar, DRs can be different if thresholds are different or if indicators are deactivated/activated. We use the notion of crop management in CS (CMiCS) to differentiate management strategies of the same crop/cultivar under different CS i.e. a

CMiCS is the set DRs associated to a crop/cultivar within one CS. Each CS is therefore described through a sequence of CMiCS. In our case study we represent 18 CS, combining 27 CMiCS. DRs sets are described by CMiCS in a text format file (CSV) used as an entry to the farmer decision component. In order to represent farmers' aversion to fail at carrying out a technical operation (e.g. sowing), DRs modeling architecture allows to release conditions using primary, secondary or tertiary etc time or physiological windows. For each superior window, the conditions (thresholds of DRs) change in order to trigger action anyway. This allows to represent that a farmer is less exigent on conditions as time passes. For example in a CS based on maize/wheat annual rotation, maize harvest constraints become very low as the end of sowing time window for wheat approaches.

2.6 Spatial and temporal organisation of irrigation at farm level

At the heart of the farmer decision component is the concept of irrigation block. It is a spatial management unit, defined by farmers every year in order to structure the delivery of water to fields according to an irrigation turn delay (ITD) i.e. the number of days between each water delivery in a given field. By managing irrigation block(s), farmers thus intend to make sure water is delivered to crops regularly. Hereafter, we detail how the concepts of irrigation blocks and ITDs are modeled.
In the model, depending on the area of irrigated crops they sow each year, farmers have a yearly irrigated area to manage (A_{irr}^{farm}). They divide it into irrigation blocks, corresponding to the area managed with one irrigation equipment under the ITD (specific to every CMiCS). In addition, to correctly figure the repartition of irrigation withdrawals over days, farmers can only irrigate a maximum area per day and per irrigation equipment (A_{irr}^{day}), determined by the irrigation equipment performance (ha/day). The size of the irrigation block (A_{irr}^{Block}) is then the area that is irrigable with the given equipment during the ITD: A_{irr}^{Block} = ITD x A_{irr}^{day}. Most of the time, A_{irr}^{Block} is smaller than A_{irr}^{farm}, which means that irrigation blocks are irrigated simultaneously with different equipment. The model annually creates irrigation blocks within farms by grouping nearest fields with identical CMiCS crop/cultivar. Fields can possibly belong to more than one irrigation block, if their area is bigger than A_{irr}^{Block}. To avoid the creation of small irrigation blocks, at least 10% of a field's area should be within one group.
The farmer decision component also takes into account the priority of use of the potential different water resources of each farm, day after day, according their filling state. Farm surveys showed that farmers prioritize resource types as follows (1) collective network, (2) river, (3) aquifer, (4) dams. In our model, farmers start with the most priority resource and if it turns either dry or normatively restricted, farmers tap in the less priority one.
Finally, the farmer decision component also represents the effects of withdrawal restrictions. It seeks to limit the effect of these restrictions by reducing the ITD (see Gaudou et al., 2013 for more details).
At each time step, the farmer screens his fields and lists which can be irrigated. This decision is multi criteria based, calling parameters from DRs table and variables from AqYield and other modeling components of the platform:

- Current date is within time window for crop irrigation
- Vscale is within physiological window for crop irrigation
- Current date rainfall is less than 10 mm
- The field was not irrigated since at least a ITD
- The field is not connected to a withdrawal point subject to water use restrictions

3 RESULTS AND DISCUSSION

The agricultural model we present here was designed to be used in interaction with the hydrological and normative models of the MAELIA platform (Therond et al., this conference). We thus run the whole MAELIA platform to assess whether simulations fit with observed data of our case study, mainly the withdrawal dynamics. In the platform, groundwater and surface water hydrology are simulated through the formalisms of the SWAT model (Arnold and Srinivasan, 1998; http://swat.tamu.edu/).
Here we present results from an 8 years simulation using observed climatic data. We then discuss the platform's capacity to relate real world withdrawals dynamics and irrigation practices at field and river basin levels. We look at annual and inter annual as well as day-to-day withdrawal dynamics.

3.2 Annual balance at water basin level

We use data on agricultural water withdrawals from the regional water basin agency to assess the quality of our simulation outputs. These data are derived from farmer's mandatory reporting on their annual withdrawals. Results are shown in Figure 1.

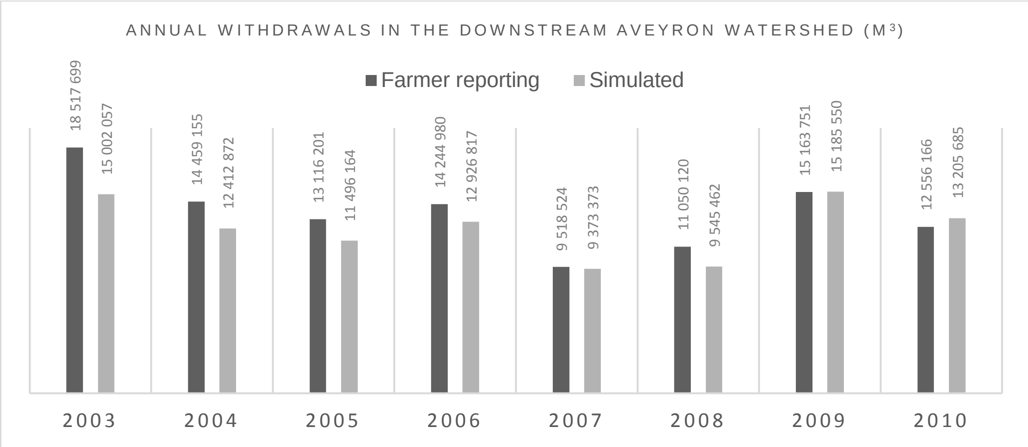

Figure 1. Annual withdrawal volume comparison over 8 years (m^3)

The results show that our model is able to retrace relatively finely patterns of annual water withdrawal volumes and inter annual differences with an average -10% difference and maximum of -23% in 2003, the strongest drought for decades. This level of similarity is also observed when analyzing results at the scale of reference hydrological units i.e. the finest watershed level defined by local state services in charge of water management. The offsets observed in 2003 show a current weakness of our model: the DRs developed for irrigation management do not retrace practices in extreme climatic situations. 2003 was extremely hot and dry. Our clue to explore and solve this offset is to adapt farmer strategies to take into account early edaphic drought to set off irrigation in post sowing i.e. in March - April.

We point out that, because the agricultural model simulates agricultural activities at a very fine spatial (islet) and temporal (day) resolutions, such results can be displayed at any levels over these resolutions, depending on the expectation of model users.

The table 1 shows the relative distribution of withdrawals in each type of water resource. Again, data from the regional water basin agency is used for comparison. We over estimate withdrawals in aquifers and underestimate them in dams, with an average of 7%. This offset can be due to the hydraulic link algorithm, which would link too many fields to aquifer withdrawal point based on distance, or to our model component simulating farmers' choice between resources.

	Aquifers	Dams	Rivers
Simulated	17%	23%	60%
AEAG	10%	30%	60%

Table 1. Repartition of withdrawn volumes between resource types. Both data are an average between the year 2003 and 2010.

3.3 Withdrawals dynamics

Figure 3 below shows the monthly withdrawal dynamics for year 2004, resulting from the simulation of farmers' irrigation practices and irrigation blocks and turns within farms. We show the daily average withdrawal level to demonstrate that our model simulates the repartition of irrigation withdrawals over days thanks to the implementation of the ITD concept. The withdrawals peaks correspond to the starting of water turns. In our model, farmers who sowed the same crop within the same cropping system on the same day will start their irrigation turn on the same day. However, depending on the irrigation block area, some might stop irrigating in the middle of the irrigation turn duration.

Also, the figure shows the example of an indicator used to regulate irrigation activities in maize alluvial soil monocropping systems: the precipitation accumulation during the past 5 days. Under 15 mm, the normal ITD is kept, between 15 and 35 mm the ITD is delayed for x days (where x =

$Rain_{5\_previous\_days}/5$), above 35mm the ITD is cancelled. Note that these thresholds are specific of maize CS whereas the curve aggregates the demand for all CS.

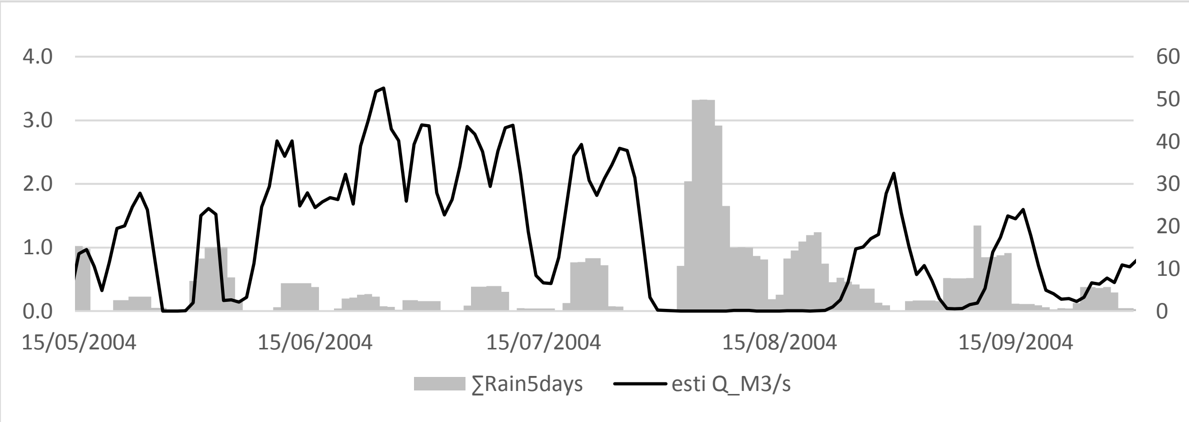

Figure 2. Simulated withdrawal demand dynamics and 5 days precipitation accumulation during the summer 2004 (avg. Q [m^3/s]), all resources and all irrigated fields

3.4 Irrigation practices at field level

Table 2 below shows a synthesis of simulated average irrigation practices for grain maize monocropping systems in alluvial soils. The results are coherent with data on irrigation practices collected through a dedicated survey in 27 farms of our case study (Hipolito, 2012). The difference in dates between years shows that our farmer decision model simulates variability for beginning and end dates depending on yearly climatic conditions and plant development, which also depends on earlier farmer choices (e.g. sowing). The number of irrigation turns and total dosage show that farmers also adapt to seasonal precipitations.

	Average date of first irrigation	**Average date of last irrigation**	**Average irrigation turn number**	**Average dose [mm]**
2003	23/5	15/9	14	288
2004	4/6	1/10	13	287
2005	3/6	4/10	13	305
2006	25/5	2/9	12	263
2007	23/6	21/9	10	255

Table 2. Summary of yearly average irrigation practices for grain maize in alluvial soils and in maize monocropping system

CONCLUSIONS

In conclusion, we note that our agricultural model is able to retrace annual withdrawal estimations and dynamics provided by the regional water basin agency with an average 10% error. Looking more in detail, our model is also able to simulate irrigation practices accurately for the most irrigated crops (fruit cultivation and maize). We guess that we underestimate the withdrawal level for other crops. We also note that hydraulic leaks in pipes transporting water to the fields and on-field losses by evaporation are currently not taken into account in the agricultural model. Experts consider that one could therefore adjust results through a coefficient increasing withdrawals of 15 to 20%.

The simulation results show that in the case of an extreme climatic event, the farmer decision model may not be robust enough. This is to be explored with longer time series and will be corrected by including decision rules to adapt to these extreme climatic events.

Globally, we assume that the agricultural model presented here has the required potential to be used in our design-and-assessment project (see Murgue et al., in revision). When embedded in the MAELIA platform, we argue that it may provide a worthy boundary object both for design and for assessment at the river basin level. On one hand, the fine spatial description of the agro-systems' structure and of

day-to-day dynamic decision making provide flexibility to represent a great variety of changes expressed by stakeholders in the design phase. Indeed this fine representation should enable the researchers to formalise alternatives for whatever spatial or temporal scales participants may manipulate, and for whatever levels, including farm level decision-making.
One the other hand, thanks to the agricultural model, the MAELIA platform is able to produce relevant information on hydrological and socio-economic consequences emerging from changes in CS. This information can be useful discuss the impact of alternative organization of farming activities in the basin with local stakeholders during the assessment phase of our project. There again, this level of precision gives free reins to participants of our design-and-assessment project to display assessed indicators whatever the organizational levels or spatio-temporal scales expected.
Nevertheless, although the representation of the current situation is quite satisfactory, difficulties can be anticipated when using the model to simulate alternative CS spatial distributions. We make the hypothesis that participants may question the outputs of an unreal situation. Making this model useful will first of all require that its functioning and outputs are accepted by participants. Although all data and subcomponents were co-constructed with participants and/or validated locally, their articulation into one integrated model may trigger dis-trust. For this reason, we need to elaborate on stakeholder interaction strategies which will stress model transparency and put forward model weaknesses.

REFERENCES

Arnold, J., Srinivasan, R., 1998. Large area hydrologic modeling and assessment part I: Model development1. JAWRA J. … 34, 73–89.

Cash, D., Clark, W., Alcock, F., Eckley, N., Jäger, J., Kennedy, J.F., 2002. Salience, Credibility, Legitimacy and Boundaries: Linking Research, Assessment and Decision Making. KSG Work. Pap. Ser. RWP02-046.

Gaudou, B., Sibertin-blanc, C., Therond, O., Amblard, F., Arcangeli, J., Balestrat, M., Sauvage, S., Taillandier, P., 2013. The MAELIA multi-agent platform for integrated assessment of low-water management issues, in: MABS 2013 - 14th International Workshop on Multi-Agent-Based Simulation. Saint Paul, Minnesota, pp. 1–12.

Grimm, V., Railsback, S.F., 2012. Pattern-oriented modelling: a “multi-scope” for predictive systems ecology. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 367, 298–310.

Hatchuel, A., 2001. The Two Pillars of New Management Research. Br. J. Manag. 12, S33–S39.

Hipolito, J., 2012. Spatial distribtuon and description of cropping systems in the Lower reaches of the Aveyron River - INTERNSHIP. Supagro Montellier.

Inan, H.I., Sagris, V., Devos, W., Milenov, P., van Oosterom, P., Zevenbergen, J., 2010. Data model for the collaboration between land administration systems and agricultural land parcel identification systems. J. Environ. Manage. 91, 2440–54.

Murgue, C., Therond, O., Leenhardt, D., n.d. Towards sustainable water and agricultural land management: participatory design of spatial distributions of cropping systems in a water-deficit basin. Land use policy.

Nassauer, J.I., Opdam, P., 2008. Design in science: extending the landscape ecology paradigm. Landsc. Ecol. 23, 633–644.

Nolot, J.M., Debaeke, P., 2003. Principes et outils de conception, conduite et évaluation de systèmes de culture. Cah. Agric. 12, 387–400.

Pahl-Wostl, C., Hare, M., 2004. Processes of social learning in integrated resources management. J. Community Appl. Soc. Psychol. 14, 193–206.

Therond, O., Sibertin-blanc, C., Lardy, R., Balestrat, M., Hong, Y., Louail, T., Mayor, E., Bai, V., Taillandier, P., Vavasseur, M., Mazzega, P., 2014. Integrated modelling of social-ecological systems : The MAELIA high-resolution multi-agent platform to deal with water scarcity problems.