Agricultural viability in a water-deficit basin : can participatory modelling and design activities trigger collaboration between water management and agriculture stakeholders?

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Keywords: spatial planning, system design, participatory approaches, boundary object, modeling, multi agent modeling

Abstract

Some hydro-systems are in structural water deficit: human water uses are too high to allow a good ecological status of aquatic ecosystems. The Adour-Garonne watershed (116.000 km2, South-West France) is emblematic of such situations, with recurring occurrence of quantitative water management crises due to high agricultural withdrawals during the low flow period. Since opportunities to store more water is limited, authorities require the agricultural sector to reduce its demand, which results in a conflicting situation as irrigation is a key production factor for farming systems in this area. Our study is embedded in the governance challenge of conciliating water resources protection and economic viability of agriculture by re-thinking agricultural land use in interaction with both agricultural land managers (i.e. mainly farmers) and water managers. Our objective was to design and assess alternative agro-hydrosystem (i.e. new cropping systems and/or new distribution of cropping systems over fields and new water resource management strategies). We developed a problem-oriented approach based on a variety of modeling methods and on the participation of actors. We used models to integrate local knowledge with scientific and statistical information in order to specify the problem (system and question) and then formalize the proposed alternatives. We then used their computational potential to simulate the consequences of designed alternatives on a complex system, with precise spatial and temporal insight on a 10-15 years' time horizon, taking into account the climate variability. This communication describes the participatory process that allowed two groups of local stakeholders in opposition to each design alternatives for water management strategies and cropping systems, specifying the spatial, economic, organizational and technical constraints of their implementation. The groups involved farmer representatives on one hand and representatives of the aquatic environments law on the other hand. We present a formalized alternative from each group and discuss their potential to prevent quantitative water management crisis, and to be integrated into a consensual one.

Abbreviations

AGB: Adour-Garonne Basin
CS: Cropping System
GIS: Geographic Information System
LWAE: Law on Water and Aquatic Environments
LIPS: Land Parcel Identification System
MAS: Multi-Agent Simulation
NRM: Natural Resources Management
QWM: Quantitative Water Management
SAH: Social-Agro-Hydrosystem
UAA: Usable Agricultural Area

Introduction

In Europe, even though water resources have relatively high natural availability and storage capacity are well-developed, shortages and conflicts over the resource are common (EEA, 2012). Today, with growing environmental and societal considerations, and changing natural availability, water resources management can no longer rely only on storing more water. Policy makers and water operators must also reflect on the type of human activities and their distribution over landscapes. The need to integrate water issues into spatial planning emerges as a cornerstone for integrated water management at all levels of governance.

In line with this, a recent report by EEA (2012) highlights two challenges for water management: (i) take into account the types of land use that influence water flows in hydrosystems and (ii) bring policy makers and practitioners of territories closer together to think land and water resources governance in an integrated way. In the scientific community, spatially explicit assessment and modeling of interactions between land use and natural resource use have developed since the 2000s, focusing on agricultural uses (Debolini et al., 2013; Ewert et al., 2009; OECD, 2009; van Berkel and Verburg, 2011). These studies do aim to produce knowledge for resource management, but the questions to address and the methods used, mainly computer-based models, are most often developed in an analytical situation with weak or without interactions with stakeholders. However, as Olsson and Andersson (2007) pointed out, the methodological questions associated to using such models in NRM decision-making processes are not often addressed in the literature. The utility of these tools in sharing scientific knowledge and in promoting communication between stakeholders can thus be called into question. Through design and assessment activities (Hatchuel and Weil, 2002), we undertake the social and technical challenge of using spatial modeling with stakeholders to solve a water problem.

We experiment a participatory approach to design and assess alternative socio-ecological systems in a basin experiencing water quantitative imbalance. We believe that design activities allow to bring sciences within action processes to guarantee that scientific knowledge will be useful to decision making i.e. credible, salient and legitimate (Cash et al., 2002). Our methodology is built on three iterative cycles of (i) co-representation of the “socio-agro-hydrosystem”, (ii) co-design of alternative spatial distributions of cropping systems (CS) and of water resources management strategies, and (iii) integrated co-assessment of different alternatives via a multi-agent simulation (MAS) model. Taking into account the tense political context of our case study, the challenge was to implement this methodology in a situation of conflict between environmental groups and the agricultural world. In this paper, we describe the methods and results of the first two phases of the project: modelling and designing. We then discuss on the potential of both results and process in moving towards spatial management of water.

1 Methodology

1.1 Study area

In the Adour-Garonne basin (AGB) in south-western France, the local state services regularly steps in to manage what are commonly called “quantitative water management crises”, i.e. when water flows fall below legal thresholds that are supposed to ensure proper functioning of aquatic environments. They use two main levers to protect water flow: releases from large collective reservoirs and restrictions of withdrawals on agriculture. In the AGB, irrigation allows to crop maize, which has well-known economic and organizational advantages for farmers and agricultural supply chains, in fields considered unsuitable for winter cereals or non-irrigated spring crops (mainly hydromorphic, locally called “*boulbènes*”). Debates about irrigated systems impacts on water resources focus on maize mono cropping.

We implement our study on the lower reaches of the Aveyron River (**Erreur ! Source du renvoi introuvable.**), one of the most controversial first level watersheds of the AGB. It is one of the areas with the greatest gap between water resources and water needs for irrigation; therefore water-management crises are frequent and recurrent (many times per year, year after year). The volumes withdrawn for irrigation in the study area reach about 18 hm³, which represents 70% of the agricultural withdrawals of the whole Aveyron watershed for only 16% of its area. The landscape is dominated by cereal and maize cropping with numerous seed-production contracts, and fruit production. Animal production, especially bovine, is in decline and pushed to the less-productive outlying of hills and plateaus. The area of the study site is approximately 840 km². The usable agricultural area (UAA) is about 40,000 ha of which 26% was permanent forage and 34% was irrigated in 2009. There are about 1,150 farms, of which 43% irrigated, with an average irrigated area equal to 38% of their UAA.

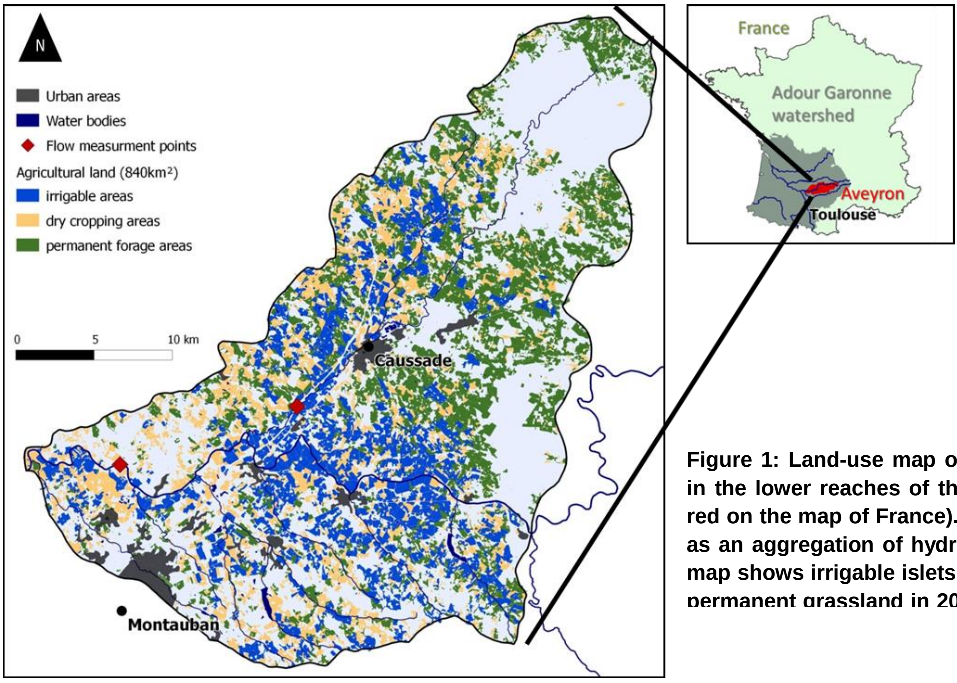


Figure 1: Land-use map of the study area, located in the lower reaches of the Aveyron watershed (in red on the map of France). The area was delineated as an aggregation of hydrological units. The detail map shows irrigable islets, dry cropping areas, and permanent grassland in 2009 (data from the French

1.2 Co-representation of the social-agro-hydrosystem

During this initial step, we constructed a spatially explicit model with local actors which represent the current structure and dynamics of the socio-ecological system. To ensure credibility and legitimacy of our approach and of the simulation model, we started at this stage to interact with actors who would participate in the design workshops described in the next section. Hereafter, the investigated social-ecological system is called "socio-agro-hydrosystem" (SAH system) as we address interactions between water governance, agriculture and hydrology domains. We represent it conceptually as a complex hierarchical nested system in which the hierarchical organization levels are composed of multiple subsystems in those three domains. Key interactions regarding water management issues occur between subsystems within and between levels and domains (Ewert et al., 2011). Key organization levels for each domain are: (i) agriculture domain: field, irrigation block, farms, pedoclimatic zones, and zones of seed production, (ii) water governance domain: zones for withdrawal restrictions, combination of stock-river sections for water release and (iii) hydrology domain: field groups connected to the same irrigation network, different nested watershed levels, ground water entities, small private dams and large collective reservoirs.

General approach

Our modeling approach was based the use of various methods and inputs to valorize all sources of information available. We follow the argument of Yeager and Steiger (2013) who explain that although powerfull, quantitative datasets and hard models developed in silico are not sufficient to apprehend the complexity of geographical phenomena. We therefore intendended to valorize both local knowledge and available datasets. On one hand, we made an analysis, selected and integrated existing georeferenced data on hydrology and agriculture, dynamic computer-based models and existing locally produced data; and on the other hand we organized 2 participatory collective workshops where relevancy of these informations were discussed, amended, corrected and completed with local actors and experts. The nature and level of knowledge issued from the participatory workshops varies for each domain, depending on the quantity, nature and relevancy of available scientific or statistical information. All elements included and how they were obtained are described briefly in Table 2. To illustrate our approach, in the following section we detail the modelling process of the agricultural domain.

This SAH model developed in this step of our design-and-assessment approach takes the form of a geographic information system (GIS) linked to a multi-agent simulation platform. It is an adaptation and implementation of the platform developed by (Gaudou et al. 2013) to assess environmental and socio-economic impacts of water-resource management regulations at the watershed level. From a technical viewpoint, the entities of the system's structure (soils, cropped fields, farms, hydrography and water resources, and withdrawal locations) and their characteristics are represented in the GIS. Dynamics, like ecological processes (crop growth and surface hydrology), are modeled through adaptation and calibration of pre-existing equations and data in interaction with local actors. Decision processes describing crop, water-release and restriction management strategies where elicited through dedicated semi-directive interviews with respectively farmers (27), dam managers and state services in charge of water-use restrictions (2 offices, 5 persons). These strategies were coded in the form of mathematical equations and a set of IF-THEN decision rules (e.g. Bergez et al., 2012) in the MAS model.

Modelling the cropping systems and their spatial distribution

One of the main challenges in modelling the social-agro-hydrosystem was to represent the structure and dynamics of the agricultural domain. We had to propose a spatially explicit model which would be fine enough to represent interactions at scales that makes sense for the different stakeholders involved in the project. For example for farmers manipulate the field and hydraulic equipment levels, whereas state services deal with water restriction zones corresponding to an aggregation of hydraulic equipment linked to islets. For this reason, we intended to describe and locate CS exhaustively in all fields of the considered area. One of the great difficulties when working in large agricultural areas (Leenhardt et al. 2010) is to describe and locate farming systems and CS (crop sequences and crop management i.e. the sequence of field operations). To achieve such challenging objectives, we implemented a methodology that hybridize knowledge from local agricultural and irrigation experts with information available in the French "Land Parcel Identification System" (LPIS) geographical database (Inan et al., 2010). The LPIS is crucial to both modelling of the current agricultural systems described in this section, and to the formalization of designed alternatives (see below). It includes geographical position and spatial delineation for block of fields, hereafter called "islet", which contains one or many agricultural annual agricultural parcels, hereafter called "fields" (**Erreur ! Source du renvoi introuvable.**).

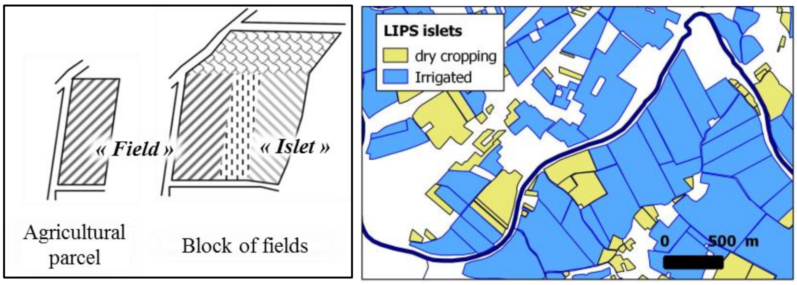


Figure 2 :

Example view of the French “Land Parcel Identification System” geographical database, and corresponding terminology used in this article.

The LIPS dataset provided the spatial structure of our model and the attribute information was. This information on crop acreage was iteratively consulted and processed according to local experts' knowledge to describe the CS and their location. Mainly, we made spatial and algorithmic treatments of LPIS of 2006 to 2009 to identify crop sequences of each field in each islet. Given the wide diversity of crop sequences in the fields recorded in the GIS, we develop a typology of crop rotations. This typology evolved as we moved through the steps of the participatory modelling process, with the input of local knowledge. The modeling of the agricultural domain is structured as follows:

1. Exploration of the available information in LIPS and soil databases;
2. Participatory mapping exercise to identify CS and their spatial determinants (Figure 5 p.18);
3. Survey in representative farms for elicitation of crop management strategies (CMS);
4. Allocation of a crop sequences and CMS to every field in every islets of the area.

We first explored both LIPS and soil databases to familiarize with the case study area and identify and characterize crop sequences and systems and soil diversity. This provided us with ~~necessary~~ sufficient overall knowledge on the agricultural systems to interact efficiently and with relevance with local stakeholders and experts during the collective modeling process.

We then organized a participatory mapping workshop (Saqalli et al., 2009) where we asked local agriculture experts to identify the main rotations in the area and map their spatial predominance on a blank map. Those experts, a group of 8 people from irrigation collectives, cooperatives, syndicates and state extension services, were selected to be representative of the agricultural diversity in the study area as well. We did not provide any information from the databases in order not to bias their view of the area. They concluded with a list of about 20 main CS to cover the area's diversity. In a second part of the workshop, we asked participants to identify determinants of CS occurrence (e.g. "maize is sold as seed when in a seed production zone"), and if possible to map them. The objective was to determine descriptive criterion of the geographical, ecological, hydrological contexts or farming system of a field which strongly determine the type of CS implemented on it. The participants identified 4 key criteria categories: rotation type, soil, farming system, and seed production areas. Although we also built a map of local seed production zone, the mapping exercise focused mainly on refining the soil information. Participants mobilized geographical space by drawing new limits for soil units, which we later integrated through digitizing methods. They also made descriptions of soils limits in parametrical space (Shi et al., 2009), i.e. describing elements of the environment to locate them. We integrated those elements by crossing the soil data with other geographical information. For example, stakeholders explained emergences of silt soils in clay units of the soil map could be located by observing fields with two years of irrigated maize in a row. Using the data on crop sequences we could update the soil map. With this participatory mapping exercise, we had a spatial typology of CS: a list of main CSs and detailed map of their determinant(s).

Following this, in order to model farmers decisional process regarding crop management, we made a dedicated farm technical and economic surveys. We used criteria of the spatial typology of CSs (see previous paragraph) to determine the range of farming system types that should allow covering the whole range of pre-identified CSs types. The survey provided us with necessary data to formalize farmers' crop management strategies under rules and decisions criteria farmer use to trigger their technical operations (e.g. tillage, seed, fertilization, irrigation, harvest). Decisions criteria are mainly based on climatic and soil conditions, crop phenological stages and withdrawal restrictions.

In a final step, in the laboratory, we developed allocation rules that assign a crop rotation types and management strategies to each of the 16,000 fields considered, based on determinants of cropping system (collected during the mapping workshop). This allocation algorithm analyses for each field (1) the observed sequence, (2) the soil type, (3) the farming system type, and assigns a CS type i.e. a crop sequence and a crop management strategy to each crop of the sequence.

To tackle changes in the SAH system for quantitative water management purposes, we used this representation of CS spatial distribution as the main entry. We asked local stakeholders what could change in it and in the operational water management decision rules.

1.3 Framework for co-designing and formalizing alternatives

The co-design step should allow the explicit description and formalization of visions that actors hold ("visioning" in Salter et al. (2010)) about solutions to QWM problems in their territory that address their concerns (e.g. viability and technical nature of production systems, protection of aquatic environments). The hypotheses that guided organization of this co-design step are (i) QWM stakeholders have a vision of possibilities for change to resolve their problems that draws upon, among other things, the spatial distribution of agricultural practices; (ii) they can express these visions at the socio-agro-hydrosystem level by putting aside the contingencies of their own level of activity (e.g. production systems for farmers) while considering the economic, technical, and organizational issues of their sector of activity; and (iii) spatially explicit modeling, used as an intermediate object, can help to express and formalize these visions. To ensure a certain degree of openness, we selected participants who had expressed an interest in our approach during the co-construction of the SAH model.

To overcome the conflict situation, we chose to lead discussions within two distinct groups of stakeholders having, in theory, divergent positions in debates about QWM: one with representatives of the agriculture, the other with representatives of the environmental issues addressed by the LWAE ("LWAE guarantors") (Table 1). There was quite a diversity of agricultural practices and strategies in the agricultural group, but the agricultural profession is politically united around the issue of quantitative water management. Conscious of the need to assemble water-management and land-management actors, we still considered this separation necessary in order to ease the expression of innovative options for change, not only those corresponding to the traditional elements of existing conflicts: creating reservoirs vs. reducing the volume available for withdrawal.

Table 1 : Participants of the two workshops, separated into two interest groups

Agricultural group	Law on Water and Aquatic Environments guarantor group
• Farmers • Presidents of Farmer Associations • Representatives of farmers' unions • Civil-servant technicians (departmental Chamber of Agriculture)	• Water policy bureau of the local administrative authority (policy-maker for withdrawal rights, water use restrictions, and water releases) • Local water police office: agency in charge of monitoring the state of French watercourses • Local general counselors: operational and financial managers of low-water replenishment • Local actors involved in protecting aquatic environments (fishery federation, associations of municipalities)

For clarity, we present the design process as a two-step approach: (i) participatory work to reveal actors' visions and then (ii) formalization of these visions in the laboratory

Revealing actors' visions and making them explicit

We held our design workshops successively with each of the two groups using the same approach. The detail of the workshop facilitation methodology is not given here. It was based on directed brainstorming techniques, using visible and mobile index cards placed and moved on a board to render participant ideas concrete (**Erreur ! Source du renvoi introuvable.**). This approach allows participants to freely express individual ideas however with a constant formalization of ideas so that the whole group agrees on the content of the idea.

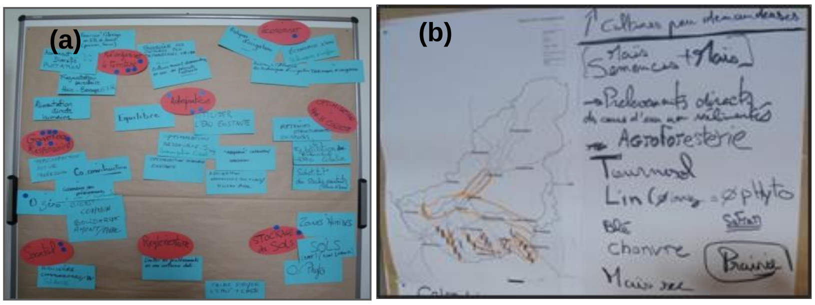


Figure 3: Participatory design workshop photographs of (a) brainstorming and organization of ideas by the agricultural group and (b) simplified mapping to detail an option by the guarantor group.

We conceived the workshops in a way that the design objectives would be tackled progressively, around three framing questions, each giving the opportunity to open up and then narrow the space of possibilities:

1. *What do you expect from this research project?*

This sequence allowed the group to turn the question we had previously developed into a question accepted by the entire researcher-actor collective. For example, with the agricultural group, we added the "farm viability" notion explicitly in the question. This phase was particularly useful to raise the inevitable debate over increasing agricultural water supply, giving us the opportunity to explain why this subject was not included in workshop objectives, without denying the need to debate it.

2. *What changes in cropping systems' nature and spatial distribution, as well as in water management practices, could limit the risk of crises occurrence?*

We asked the group to express individual ideas for change compared to the current situation (e.g. replace one CS with another). The facilitator's role was to allow all participants to express themselves, and to frame the discussions to identify convergent ideas and minimize off-topic subjects. We asked participants to collectively organize their ideas into groups of similar ideas, that is, ones that aim to attain the same objectives or use the same types of action to attain them (**Erreur ! Source du renvoi introuvable.**a).

3. *Which of these ideas do you find most interesting? In what production and environmental contexts could they be applied?*

This phase aimed at building a list of selected change options with details on why and where to implement them. We organized the collective selection of the ideas that seemed most interesting, then asked the group to detail the implicit objectives of each one (i.e. what concerns can it satisfy?). Finally, we asked participants to identify the elements of the system which could be concerned by change, both in terms of location (location description criteria, or drawing on a simple map e.g. **Erreur ! Source du renvoi introuvable.**b), and to express the degrees of change acceptable i.e. thresholds of technical, economic, and organizational acceptability for farms (e.g. the maximum area concerned for a crop in a farm). This degree of acceptability triggered much discussion in the agricultural group. The selected degree of acceptability is a minimum i.e. it could be acceptable in any candidate farm.

~~During all discussions with stakeholders, the researchers' objective was that the descriptions of participants approached the format of model input as closely as possible.~~ During all discussions with stakeholders, the researchers' had to make sure that their descriptions would be possibly coded as inputs for the models. For this, keeping the model formalisms in mind, ~~T~~they had to~~must~~ help the participants to specify and, if possible quantify, as precisely as possible all descriptive variables they use in their discourses. This process is later called "defuzzification" of stakeholder' narratives (Alcamo, 2008). We call "options for change" the collective identification of an idea or group of ideas for change in a form that is explicitly detailed, stable and accepted by the group.

Formalize alternatives in the laboratory

This step aimed to determine what practices were to change and where during the implementation of options in future simulations. It is based on the identification of elements of the system which match the groups' description of a change. We call "alternatives" the formal representation of one or a combination of options for change through a selection of the GIS data. First, we identified the potentially impacted fields, islets and farms, hereafter called "candidate elements", using spatial and attribute GIS queries based on participants' selection criteria. We created a list of candidate elements, with information on their location at the islets level. Second, we estimated average areas and number of fields impacted annually when taking into consideration the current or proposed rotation practices. To do so, we assumed that the annual crop acreage of farms reflect the rotation practices implemented by farmers, and used the information on crop rotations typology developed from the LPIS observed sequences. For example in those options which aim at changing rotation practices, to estimate the impacted area annually, we used the difference between the proportion of maize in the existing rotation and that of the rotation to be implemented. Finally, we took into account the degree of acceptability expressed by participants as a maximum percentage of the area in maize or the UAA of farms, depending on the option. We could thus estimate an average area impacted annually, and finalize the formalization by randomly selecting candidates until the annual estimated impact area was fulfilled.

Quantify and characterize the impacts of alternatives

In the design-and-assessment project, the MAS platform will be used to assess alternatives. It will calculate a set of indicators representing the assessment criteria produced by stakeholders. Alternatives such as the one presented below can be used as input to this platform. To initially quantify the mean impact of the alternatives on water withdrawals for irrigation at the territorial scale, we used mean estimates of the water used for maize irrigation by soil in the investigated zone: 2500 m^3/ha/year on alluvial terraces and 1800 m^3/ha/year on clayey limestone slopes. These values come from data collected from farm surveys performed during step (i) of the design-and-assessment approach.

2 Results

2.1 A shared model to represent the system

The co-constructed model is in itself a result of our research. It is considered a shared representation, because all elements were discussed with or presented to a diversity of stakeholders of the quantitative water management problem. For the most controversial elements i.e. hydrological dynamics, pedology and spatial distribution of CSs, stakeholders held a crucial role: their views on the SAH system were collectively discussed and formalized ~~into a~~'in silico'.~~ representation that suits all participants.~~ Some of those elements were modeled only with stakeholders who hold the required expertise (e.g. the crop growth model was discussed with local farmers) and then presented to other stakeholders to ensure their acceptability.

In its current state of development, the model takes as entry parameters: an alternative i.e. a set of CS assigned to each of the 16,000 fields (4 years sequence and decision rules for field management practices), a set of decision rules on dam releases and withdrawal restrictions, and a 10 years hydro-climatic dataset. With this, it is able to calculate hydrological, environmental and economic indicators at different scales and organization: from day to years, at field, farm and other chosen zoning levels. The last phase of our design and assessment methodology will focus on eliciting which levels of aggregation would be of interests for stakeholders to assess the alternatives.

2.2 Results of the participatory workshops

The detailed list of ideas for change generated in the two workshops are not presented, instead we chose to provide a general view of each groups' production. The selected and detailed options, then formalized into alternatives are presented in Table 3**Erreur ! Source du renvoi introuvable.**.

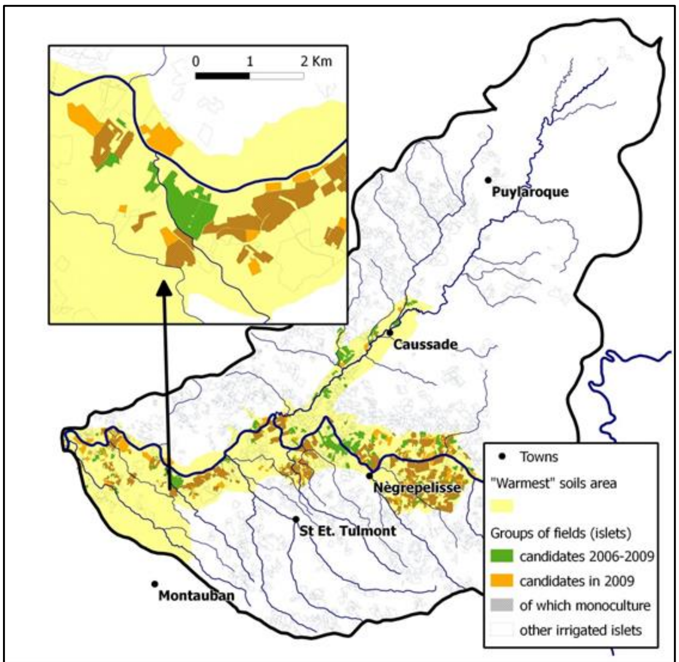
Ideas and options

The agricultural group sought (i) to reduce water demand for irrigation or distribute it over the growing season, and also (ii) to improve management of water releases from dams by improving exchange of information with the dam manager about agricultural needs. The group's ideas covered all levels at which water quantity is managed within an irrigated landscape: technical aspects at the plant or field level, agronomic aspects at the farm level, and socio-organizational aspects at the territorial level. However the detailed options for change deal only with CS and their distribution within the landscape. They involve choice of maize planting date and precocity, crop choice and rotation practices (option 2), and even the design of an innovative CS (option 3). The agricultural group provided detailed description on the technical and spatial constraints to implement these changes (mainly soil criteria), as well as on their socio-economic acceptability on farm. For this latter, they produced an acceptance degree criteria based on work-organization and gross margin per CS (and thus farm revenue), expressed in terms of a maximum per year area impacted.

The LWAE guarantor group focused its ideas for change on irrigation situations that it considers incompatible with sustainable water management, such as watersheds of tributary streams where irrigation cannot be compensated by water releases (“non-recharged” streams). Their option for change described (option 4)**Erreur ! Source du renvoi introuvable.** involves few agricultural practices, limiting itself to species choice. Instead, the group worked to identify the most important action zones for change by citing location criteria based on the type of water resource and the landscape zones concerned. The group also proposed aspects of operational water management to optimize water releases as a function of agricultural needs. For simplicity, we do not present the formalization process of this last option, which involves decision rules integrated into the MAS platform, instead we focus on options linked to farmer practices.

Example of a formal and spatially explicit representation

To provide an example, we present an *Alternative 1a: advance peak in irrigation needs of maize*, built from the formalization of an option from the agricultural group (**Erreur ! Source du renvoi introuvable.**, option 1a). It focuses on choices of maize variety and sowing dates and is illustrated in Figure 4.



Candidate fields (ha)	Impact (ha)	
	Annual estimate	2009
2 268	**614 (23%)**	**508 (19%)**

Figure 4: Location of candidate islets for alternative 1a, including those impacted every year (monoculture) and those impacted in the 2009 spatial crop distribution configuration. The table shows the area of candidate fields, the estimated mean yearly impact, and the 2009 example for alternative 1a.

This alternative concerns agricultural land that warms up the fastest at the end of winter, i.e. two soil types locally called "alluvial soils" and "good *boulbènes*". On these, the agricultural group proposed to replace the current variety of irrigated maize with early varieties, with the aim of advancing the flowering period and thus the peak of water withdrawals. The objective is to advance maize flowering from the middle of the low-water period (end July) to just before the low-water period, when flows tend to be higher. We identified candidate areas by selecting fields whose observed crop sequence included maize and that were located in the "alluvial" or "good *boulbène*" soils.

The table below Figure 4 shows results for Alternative 1a. We estimated the number of fields and hectares impacted in 2009, considering a degree of acceptability of 20% of the annual area in maize of the farms concerned, specified by the group. Based on the reconstituted crop sequences, we estimated the average annual impact of Alternative 1a to be 23% of the candidate areas (614 ha), whereas looking at the 2009 crop acreage, 19% of the candidate areas would have been impacted. This offset is due to the fact that our estimation of the average annual impact considers the observed crop sequences as repeated rotations. In reality, rotation practices are adapted to climatic and price annual variations. The acceptability threshold strongly influenced the area of candidate fields impacted: bringing it from 1870 ha to 508 ha in 2009. Concerning the farms, 136 were candidate and about 112 are annually impacted, that is about 10% of the total number of farms of the considered system.

We evaluate that alternative 1a have the potential to impact 1.10 hm3 of the annual demand. This volume is about 16% of the estimated imbalance between supply and demand in the watershed in a five-year dry period (6.7 Mm^3 Daubas and Dupuis, 2009). We highlight that volumes that would be saved with this type of alternative depend on the natural water availability at the beginning of the season, statistically higher, but nevertheless different for each climatic year. However spreading demand also aims at limiting the intensity of dam releases during the low-water period. In contrast, the quantitative effect of other options which are not presented here can be lower but represents an absolute decrease in demand regardless of the climatic year.

3 Discussion

On the Importance of a gradual process

We stress the importance of moving step by step into the design-and-assessment methodology to ensure its success. Investing in the first step, co-constructing a representation of the SAH system, appears to be a key for success at the design stage. Beyond co-constructing a computer-based model for dynamic simulations, it allowed the researchers and local stakeholders collective to learn to work together and to build trust and a so called “community of practice”. In the tense context of our case study, this process was very valuable: not only for bilateral relationship between the researches team but also to initiate dialogue and curiosity between the opposed parties.

We also purposely decoupled the co-design phase from the integrated-assessment phase in our project, for two reasons: (i) to give free rein to participants’ creativity without participants having to think about model use when describing their ideas, (ii) because the complexity of the object to design, i.e. the socio-agro-hydrosystem, renders formalization of the options difficult to make directly during design workshops. Our design-and-assessment process is preferably organized in successive and iterative phases of participatory design followed by laboratory assessment. The alternatives described here correspond to the first level of design, and their formalization creates the need for feedback from actors to assess their credibility and acceptability and refine the conditions for implementing them. We assume that the researcher-actor group can perform several iterative loops. The knowledge analyzed would thus become increasingly quantitative and factual, and the degree of assessment complex, targeted at the levels of organization that interest the participant group.

On the role of alternatives

The alternative presented here, example of the first design round with stakeholders, is intended to provide intermediate thinking aids during future design-and-assessment cycles. In future workshops, we will re-design new alternatives of greater degrees of complexity on the basis of the existing ones and the results of the first simulations. Existing formalized alternatives will therefore serve as input information to help participants identify areas where change would be the most desirable according to criteria related to target production systems (e.g. farm size or type, eco-efficiency, economic acceptability, magnitude of the break with existing farm CS). Once those agricultural dimensions of alternatives are stabilized, hydraulic, biophysical and even social elements can be manipulated by participants to describe and refine options for change. In that sense, previous formalized alternatives are intermediate objects for a next design cycle. Iteration of design cycles should allow the complexity of the socio-agro-hydrosystem studied to be addressed gradually.

One goal for the next part of the project is to bring the two groups together for mixed designs. Beers et al. (2006) explain that the construction of shared knowledge in a multiparty and/or multidisciplinary group requires each member to externalize his or her knowledge and internalize the knowledge of others, then to negotiate to build a shared knowledge base. Using shared formalisms makes this process easier. We consider that the formalized alternatives correspond to externalizable knowledge, which can be internalized during a future mixed workshop. Acceptance of each group’s proposals will be facilitated by the fact that participants will already have integrated the formalization process during single-party workshops. We hypothesize that the alternatives can help groups come closer, if not toward universally accepted strategic decisions, at least toward a shared understanding of the problem and a shared representation of the system.

Design for learning

Performing a design process on an object as complex as a socio-ecological system poses many problems. The difficulty resides in the fact that each actor understands this complex system according to his/her own logic of management, decision, and action, and as a function of his/her activities and interests. From an agricultural viewpoint, agricultural practices are the result of decisions of independent production systems or socio-professional networks. From the viewpoint of water managers, agricultural practices are considered at the territorial scale only via their expected shortterm impact on streams: withdrawal peaks. To surpass this problem, we set up a facilitation framework that allowed the groups to move gradually, following its own logic, towards understanding the different levels of organization. As foreseen, the agricultural group began the design process by defining options for change in rotation practices and crop management at the field level and then, prompted by the researchers, described production systems and soil and climate zones in which the changes in practices could occur. This climbing of hierarchical levels allowed farmers to gradually understand the whole system dimension, little considered in their decision-making process. In contrast, members of the guarantor group started by breaking down the territory's hydrological network, beginning with the highest levels. They then integrated, little by little and only partially, other domains and organization levels, such as production systems and CS.

A side effect of our framework

We envisioned participation not as a goal but as a way to incorporate actors' knowledge and values. The objective was to reveal and formalize the diversity of viewpoints, not to obtain a consensus (Marjolein et al., 2002). We performed the exercise in two distinct groups of a priori opposed views on the problem. One could see this as anti-progressive, but we decided to proceed this way in order to overcome the conflict situation and facilitate abstraction and imagination during the workshops.

Having formalized each groups' alternatives, we presented the main points to the other group. Both groups then clearly expressed a desire to know more and to discuss them during a meeting mixing participants of the two groups. Separation of the two interest groups, rather than reinforcing barriers between them, seems on the contrary to have piqued each group's interest in the results of the other. We posit that the framework implemented is in itself a type of tool to increase understanding by interest groups in debates. Even though it was not designed as such, it thus turns out to have the potential to be a mediation framework that can give stakeholders involved in the QWM conflict the desire to share their ideas for change.

Conclusion

The results presented here, two alternatives for CS and their spatial distribution, are sample products of the application of our participatory design-and-assessment methodology to a given socio-agro-hydrosystem. They are based on the use of spatially explicit modeling methods in a participatory framework and explore means of coordinating the management of water with that of agricultural land use. These alternatives were formalized by the research team from visions of change produced by two interest groups with, in theory, divergent opinions about the issue of QWM. These are intermediate results of the project, their main utility being to serve as a set of input data in a simulation model of interactions between the spatial distribution of CS and hydrology, for integrated assessment.

This initial design step also produced a knowledge base common to participants and researchers committed to the design-and-assessment process, necessary for increasing the complexity and accuracy of design, as well as of assessment. In particular, this knowledge base includes the reference model corresponding to the shared representation of the territory in its current state, but also the intermediate "alternative" objects for their functional characteristics throughout the process.

We expected, and the results confirm, that co-designing alternatives laid the shared, foundation knowledge required to identify the key elements of the system that impact QWM at the sub-watershed level. The process highlighted which interactions were to be explored for addressing greater levels of complexity in subsequent design loops. Nonetheless, we did not expect that the framework implemented, which separated the two interest groups, would raise each group's curiosity about the other. We now make the hypothesis, which needs to be tested, that the formal representation of visions as spatially explicit, quantified, and detailed alternatives is an intermediate object effective for laying the foundations of a multiparty discussion and introducing a mixed-design exercise.

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Table 2: Synopsis of the entities (system structure) and processes (dynamics) represented into the model of the investigated socio-agro-hydrosystem (case study), corresponding data and knowledge sources and methods used to integrate them.

		Entities and processes	Data and knowledge sources	Methods to collect/integrate data and knowledge
Structure	Agriculture	- Spatial distribution of cropping systems (rotations + practices) in fields/islets - Farm types (irrigability, animal production, feeding methods, crop distribution, age class, legal form) - Zones of seed production	- 2006-2009 LPIS[1] (spatial distribution of crops) - Corine Land Cover - actors, agricultural experts and farmers of the case study	- Actor-based zoning (ABZ) [2]: identification of influential biophysical and socio-economic factors of CS distribution in the watershed; ABZ of homogeneous CS zones, combining landscape and farm type - 27 technico-economic surveys in representative farms of the ADZ' homogeneous CS zones to describe CSs types - Analysis of the LPIS: allocation of observed crop sequence of the LPIS to CS types built from farm surveys
Structure	Hydraulic	- Link between islets and water resources via spatially explicit withdrawal points - Irrigation networks of farmer associations	- Local irrigation experts - Presidents of farmer association - Manager database on withdrawals - 2006-2009 LPIS (irrigation status)	- Interviews with experts to understand the hydraulics logics behind water withdrawals - Description of the administrative databases by their manager - Application of spatial algorithm to LPIS and water resources databases using proximity-based logic developed from farm surveys
Structure	Biophysic & hydrology	- pedo-landscape units (6 classes, 2 sub-classes) - Elementary hydrological (watershed) units - Main streams and other water resources: water bodies, rivers, groundwater	- Soil map (1/350,000) (Cavaillé, 1950) - National water resources database - Local actors and experts - Spatial distribution of CS	Refining of the soil map and integration into the GIS: - ADZ, to refine soil units - Updating of certain parts of soil units based on information from experts, observed crop sequences and topography
Dynamics (daily step)	Agricul-ture	- Farmer practices (decision rules): tillage, seeding, irrigation, harvest - Plant growth and water dynamics (semi-empiric models)	- farm surveys to describe in detail decision rules regarding CSs - crop-model developed by INRA Toulouse - hydrology datasets on main streams[3] - SWAT model[4] for simulating hydrology of tributaries (vs. principal streams)	- Presentation of the crop models functioning and participatory calibration and validation of outputs - Presentation and validation of the natural water flow reconstruction method
Dynamics (daily step)	Hydro logy	Water withdrawal restrictions and water releases	specific surveys to elicit decision rules of state services in charge of setting up water withdrawal restrictions and water releases	Collaborative formalization (researchers-model-managers) of managers' practices of water restriction and low-water replenishment
Dynamics (daily step)	Gover-nance	- Flows of principal streams and interaction with alluvial groundwater - Filling of water bodies, drying of tributaries	- hydrology datasets on principal streams BRGM study on alluvial groundwater [5] - Water release records	Collaborative formalization of interactions between stream flow and water-release practices

[1]LPIS: Land Parcel Identification System, [2]Actor-based zoning see (Caron and Cheylan, 2005)), [3](Nolot and Debae ke 2014), [4](Neitsch et al., 2005),[5] Gandolfi (1997)

Table 3 : Options for change selected and detailed by the agricultural group (1, 2, 3) and the LWAE guarantors group (4a, 4b, 4c).

Options	Objectives	Change in practice	Location criteria	Acceptability threshold
1. Adjust planting dates and precocity of grain maize	**1a.** Advance peak water needs (flowering)	Early planting / early varieties	Terraces, the “warmest” fields	20% of a farm’s annual area of grain maize
	1b. Advance peak water needs (flowering) and aim for end-of-season storms; higher yields	Early planting / late varieties	Terraces, except for hydromorphic “boulbène*” soil	20% of a farm’s annual area of grain maize
	1c. Dry cropping	Early planting / very early varieties	Limestone slopes, deep soil	20% of a farm’s annual area of grain maize
2. Turn maize monocultures into rotations	**2a.** Limit withdrawals and work peaks during summer; keep a useful margin potential	Maize (1-5 times) / wheat	Terraces, except for hydromorphic “boulbène” soil	40% of a farm’s area of grain maize monoculture
	2b. Limit withdrawals and work peaks during summer; higher yields	maize (2-4 times) / sorghum	Terraces, except for hydromorphic “boulbène” soil	20% of a farm’s area of grain maize monoculture
3. Intensify dry cropping	Increase the dry cropping margins	Two crops per year (e.g. barley-sunflower)	Terraces, the “warmest” fields	20% of a farm’s annual area of winter cereal
4. Decrease the area irrigated in watersheds with non-recharged streams	Minimize withdrawals from sensitive streams and thus risks of severely low flow: **4a.** Stop irrigated monocultures **4b.** Regulate the time until maize replanting **4c.** Stop irrigation from non-recharged rivers: dry cropping	**a)** Irrigated maize monocultures become maize/cereal(/oilseed)	Irrigable islets next to small tributaries identified as sensitive	Fewer direct withdrawals, few dry periods
		b) Irrigated maize monocultures and pseudo-monocultures become maize/cereal(/oilseed)	Selection of streams according to their sensitivity	Fewer direct withdrawals, few dry periods
		c) All irrigated maize becomes maize/cereal(/oilseed)	All tributaries of the Lère and Aveyron Rivers	No direct withdrawals

*Boulbène: silty-clayey textured soil that has developed on old alluvial plains; Characterized by a bad structure and subject to hydromorphy

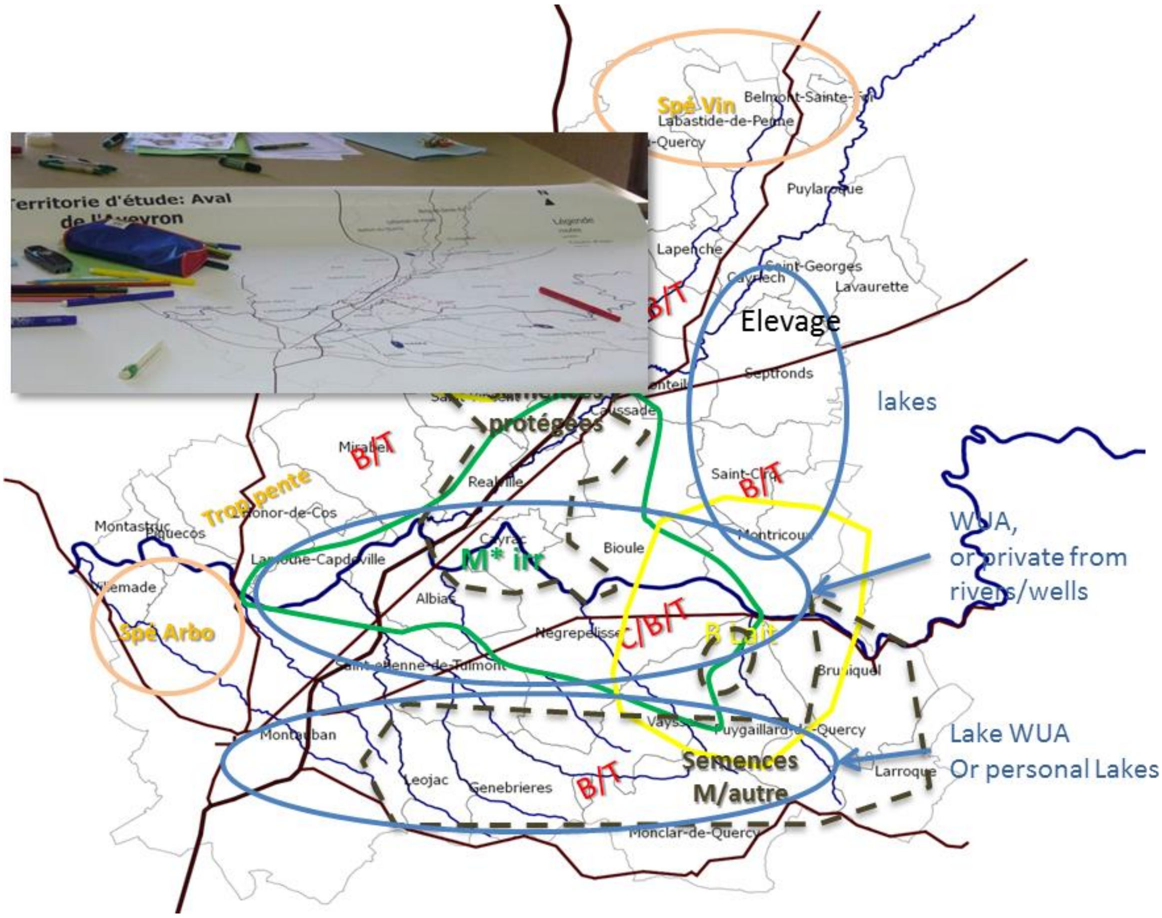

Figure 5: illustration of the participatory mapping workshop material before the exercise and of the digitized results