Accompanying The adaptation of irrigated agriculture to climate CHAnge

Table of contents

Abstract

Agriculture is increasingly relying on groundwater irrigation. **The Indian context is an extreme case: the "groundwater revolution"** which started three decades ago and induced a well identified "groundwater crisis" with tremendous impacts on water resources and ecosystems, is the result of millions of very small farmers owning individual borewells, with a large diversity of practices and strategies. Groundwater depletion is expected to worsen with climate change. Thus, it is critical to **develop reliable and practical methods for assessing the sustainability of agricultural systems under climate change**. The ATCHA project aims to combine an integrated biophysical model with a participatory approach to help adapt farming systems to climate change in a network of experimental watersheds in Southern India.

A wide variety of models have been developed for *ex-ante* evaluation of management policies or assessment of the impacts of land-use changes. They are commonly used to support decision making by stakeholders through participatory approaches. However, the models rarely represent both the complex biophysical processes at stake in agricultural watersheds and the farmer adaptation strategies to changes. Consequently, these models are not able to adequately account for the spatial and temporal interactions and feedback between these two components. Through a unique trans-disciplinary approach, involving hydrologists, geochemists, soil scientists, agronomists, geographers, economists and sociologists with a strong participation of Indian scientists and stakeholders, we aim at demonstrating the ability of researchers and stakeholders to share knowledge for building together and assess scenarios of sustainable development of agriculture.

The ATCHA project is based on (1) a **15 years partnership** through the International Joint Laboratory "Indo-French Cell for Water Sciences" (IFCWS, involving the Indian Institute of Science, Bangalore) (2) a **Critical Zone Observatory** (ORE BVET) which has built an extensive hydro-geochemical database in the Berambadi experimental watershed and (3) a **preliminary version of an integrated model** combining hydrology (AMBHAS), agronomy (STICS), economy (MoGire) and farmer decision (Namaste) that was developed for the Berambadi in a former Indo-French project (IFCPAR AICHA, 2013-2016). The ATCHA project will complement the Sujala III project (2014-2019), led by the **Karnataka Watershed Department** and in which IFCWS takes part in the coordination of the hydrological monitoring carried out in 14 experimental watersheds across the Karnataka state.

The project is composed of 3 challenging work packages: i) development of novel methodologies to gather information on soils and land use at high spatial and temporal resolution by using both ground and multi-satellite data ii) provide a realistic biophysical model based on a thorough study of nutrient cycles in tropical irrigated agro-systems iii) development of a participatory approach to build and assess scenarios of adaptation to climate change. WP1 and 2 will provide information that will sustain the scenario construction in WP3. WP3 will provide integrated assessment of scenarios and feedback to WP1 and 2 for an iterative process.

The ATCHA project is expected to produce significant scientific advances on the functioning of agro-hydrosystems under high anthropogenic pressure. It will also have a strong socio-economic impact, particularly in improving the relevance of public policies and of advice given to farmers by extension services.

People involved in the project.

Partner	First Name	Surname	Status	Implication person.month	Role & Responsabilies in the projet, main task
INRA UMR SAS RENNES	Laurent	RUIZ	IR1	28	**Project Coordinator Leader Task 4.1** Agro-hydrologist, Modelling
	Chantal	GASCUEL	DR2	8	Task 2.2, Hydrology, geochemistry, nutrient cycles
	Ophélie	FOVET	CR2	8	**Leader Task 2.2** Hydro-geochemical modelling
	Claire	AUBRON	MC1	8	Task 3.2 UMR SELMET, Montpellier Agro-economist, Agrarian System Diagnosis
	Patrick	DURAND	DR2	4	Task 2.2, Distributed hydrological modelling
INRA UMR AGIR – TOULOUSE	Jacques-Eric	BERGEZ	DR1	8	**Coordination WP3** ***Scientific resp. AGIR*** Agricultural system modelling
	Magalie	WILLAUME	MC	8	Task 3.1 & 3.2, Agronomist
	Gael	PLUMECOCQ	CR1	8	Task 3.1, Economist, innovation, spatial dynamics
	Eric	CASELLAS	IE2	8	**Leader Task 4.2**, UMR MIAT, RECORD Team Toulouse Computer science
	Delphine	BURGER-LEENHARDT	DR2	8	**Leader Task 3.1** Agronomist, agricultural systems, spatial modelling
	Eric	JUSTES	IRHC	1	task 2.1, Agronomist, Crop modelling
	Hélène	RAYNAL	IR1	8	**Coordination WP4** UMR MIAT, Head of RECORD Team Toulouse Computer science
	Julie	CONSTANTIN	CR2	8	**Leader Task 2.1** Agronomist, Crop modelling
INRA UMR TSE-R - TOULOUSE	Alban	THOMAS	DR1	8	**Project co-coordinator** **Leader Task 4.3** ***Scientific resp. TSE-R,*** Economist
	Arnaud	REYNAUD	DR2	8	Task 3.1, Economist
	Stefan	AMBEC	DR2	8	Task 3.1, Economist
	Stéphane	COUTURE	CR1	4	Task 3.1, Economist
	Stéphane	CEZERA	IE2	8	Task 4.2, Computer science
UR2 UMR LETG-COSTEL - RENNES	Samuel	CORGNE	PR2	8	**Leader Task 1.1** ***Scientific resp. UR2*** Geographer,Remote sensing, land use
	Laurence	HUBERT-MOY	PR1	5	Task 1.1, Geographer, Remote sensing, land use
IRD UMR GET - TOULOUSE	Jean	RIOTTE	CR1	12	**Coordination WP2 *Scientific resp. IRD-GET,*** Chairman IJL CEFIRSE, SOERE BVET Isotopic Geochemistry, nutrient cycling
	Sylvain	MANGIAROTTI	CR1	10	Task 1.1, UMR 5126 CESBIO, Toulouse Environmental modelling, Chaos theory
	Claire	DELON	CR1	8	Task 2.2, UMR 5560 LA, Toulouse Geochemist nutrient cycling, GHG emissions
	Dominique	SERÇA	MC1	8	Task 2.2, UMR 5560 LA, Toulouse Geochemist, nutrient cycling, GHG emissions
INRA UMR EMMAH - AVIGNON	Samuel	BUIS	IR2	8	**Coordination WP1** ***Scientific resp. EMMAH*** Applied mathematics, inverse modelling
	Dominique	RIPOCHE	IE2	8	Task 2.1, US 1116 AGROCLIM, Avignon Computer science, Crop modelling
	Philippe	LAGACHERIE	IRHC	8	**Leader Task 1.2** UMR 12221 LISAH Montpellier Soil Scientist, Digital Soil Mapping
	Nicolas	BEAUDOIN	IR1	4	Task 2.1, UR 1158 AgroImpact, Laon Agronomist, Soil scientist, Crop modelling
IFP – Pondichery	Audrey	RICHARD-FERROUDJI	CR2	8	**Leader Task 3.2** ***Scientific resp.* IFP**, Sociology, water management
	Govindan	VENKATASUBRAMANIAN	IR1	4	Task 3.2, Socio-economist

Evolution of the full proposal in comparison with the pre-proposal

No significant changes have been introduced compared to the pre-proposal. Minor changes in the WP3, where the 3 tasks have been reorganized into 2 tasks, allowed clarifying the major role of Social Sciences throughout the project. The budget is within the permitted range.

1. Context, positioning and objectives of the full proposal

1.1 Challenges in agriculture and groundwater resource management in India

In the context of climate change and of agriculture increasingly relying on groundwater irrigation, it is crucial to **develop reliable and applicable methods for sustainability assessment of current and alternative agricultural systems**, i.e. providing answers to generic questions like "how to assess and manage soil and water resources availability and quality?", "what would be the impact of climate and anthropogenic changes on water and nutrient cycles?", "which agricultural systems would provide at the same time adequate food production, adequate income for farmers and preserve the environment?". The problem is complex and requires an integrated approach (Savenije and Vand der Zaag, 2008). The awareness that **water resource management must account for interactions and feedback between biophysical processes determining movement of water, and human behaviour in a given socio-economic context** has gained significant recognition among scientists in the past few years (Sivapalan et al., 2012) and "Change in hydrology and society" was proposed by IAHS as the main research theme for the decade 2013–2022 (Montanari et al., 2013). However, as reviewed recently by Barthel et al. (2012) very few attempts have been made to really combine the critical aspects of climate, water, and socio-economic interactions and feedback in an integrated modeling framework coupling Soil-Vegetation-Atmosphere Transfer (SVAT) models to groundwater and stakeholder decision models).

Finding answers to such questions in the case of India is both urgent and extremely challenging: the **"pump revolution"** (Molle et al. 2003) which started four decades ago, after the "green revolution", induced a well identified "groundwater crisis" with tremendous impacts on water resources and ecosystems. India account for one third of world's total irrigated area, about 60% of which is from groundwater (Thenkabail et al. 2009; Bhaduri et al., 2012). Agriculture currently accounts for 92% of the water consumption and groundwater irrigation represents 39% of it, i.e. about 260 km^3/year. This positions India as the first groundwater consumer in the world and also the place where groundwater decline is the fastest (Fishman et al., 2011), threatening the food security of the country (Smilovic et al., 2015) but to date, true **trans-disciplinary approaches** aimed at dressing the problem **are lacking** (Srinivasan et al., 2012[1]).

Hydrogeologists have highlighted the vulnerability of hard-rock aquifers in Peninsular India, whose storage capacity is low and decreasing with depth (Dewandel et al. 2006; Perrin et al. 2011): as climate is mostly semi-arid, slight shifts in rainfall annual amount or seasonal distribution have a major impact on groundwater recharge (Sekhar et al., 2006, Mangiarotti et al., 2012). Consequently, groundwater availability varies from year to year, which means that farmers constantly need to adjust their practices. **Projected trends of climate change** are expected to worsen the situation (e.g. Mujumdar and Kim, 2010), with higher evapo-transpiration (Kumar et al., 2006) and negative impacts on the groundwater recharge, even if many uncertainties remain about projections, such as the intensity of monsoon rainfall.

Considering the huge amount of energy needed to extract this water India is an extreme case of the **water-energy-alimentation nexus** and a transition towards a more sustainable system is expected to have large impacts for climate change mitigation and adaptation (Shah, 2009a). The challenge for engaging in such transition is linked with i) **the complex nature of the groundwater resource**, which is both a common pool and a private good since access rights are *de facto* tied to land rights (Ostrom, 1990) and ii) the fact that borewells (more than 25 millions) are owned by **very small farmers cultivating 1.15 ha on average**, with a large diversity of practices and strategies, and currently facing a deep agrarian crisis (Dorin and Aubron, 2016).

Most of the research in **humanities** focuses on economics, groundwater management and governance aspects (e.g., Ostrom, 1990). It highlights the individual, fragmented and diffuse use of groundwater and the **urgent need for better governance** (Kulkarni et al., 2015, Shah, 2009b). Contribution from sociological approaches remains low (Mitchell et al., 2012): Socio-economic and anthropological studies demonstrate the

[1] *References in blue are from members of the proposing consortium (see literature cited p 25)*

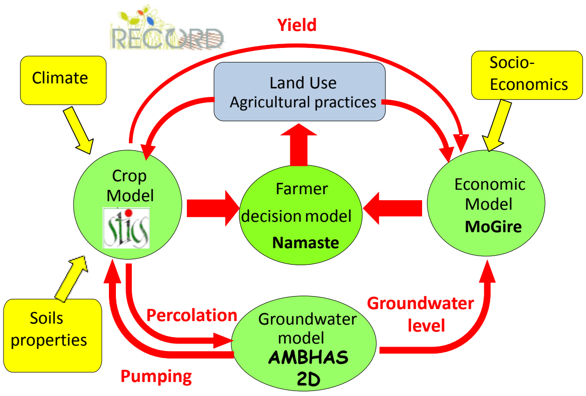
ambivalence of groundwater, being both an endangered heritage and a resource for development and the existence of multiple values, interests, and attachments among stakeholders, evidenced through plural narratives and ways of wording, picturing and measuring groundwater. Differential access to groundwater affects farmer's vulnerability (Janakarajan et al., 2006), knowledge and social status (Aubriot, 2013, Aubron et al., 2015). Even if the "pump revolution" clearly mostly benefited the small farmers (Shah et al., 2012), whether it has decreased or increased inequity remains unclear (Srinivasan & Kulkarni, 2014 ; Srinivasan et al., 2015).
However, groundwater resource is not necessarily condemned by the "tragedy of the commons" (Schlager & Lopez-Gunn 2006) and few examples of **participatory, community-based groundwater management have been described in India** (Shah, 2012; Kulkarni et al., 2015). Researchers can inform these initiatives, but merely promoting agricultural water use efficiency without taking into account the whole system, including farmer's choices, is likely to be inefficient as shown for example by Fishman et al. (2015) for irrigation technologies.

1.2 Experience of the proposing team and Indo-French partnership: a unique opportunity for a broad transdisciplinary project

Important insights on the processes and drivers governing groundwater sustainability and farmer adaptation were gained through the ending project AICHA[2] (2013-2016) funded by CEFIPRA, the Indo-French bilateral research funding agency. This project benefited from the strong partnership initiated with the International Joint Laboratory Indo-French Cell for Water Sciences (IJL IFCWS, IRD France)) located at Indian Institute of Science (IISc, Bangalore). IFCWS developed since 2003 the Kabini river Critical Zone Observatory (ORE BVET) (http://bvet.omp.obs-mip.fr) which belongs to the SOERE RBV and EQUIPEX CRITEX. It allowed building a strong partnership with the socio-hydrology group at ATREE, Bangalore. The CEFIPRA project focused on the **Berambadi watershed** (84 km^2 sub-watershed of Kabini), looking both at biophysical and socio-economic aspects. The monitoring of this watershed, started in 2010 (more details at http://ambhas.com/ and http://geowww.agrocampus-ouest.fr/portails/?portail=aicha for spatial data) include climate (automatic weather station, 2 flux towers for water, carbon and energy fluxes), soil moisture and crop parameters (LAI, biomass) using both field and satellite (Optical, radar) measurements and groundwater level and quality in about 200 farmer wells. An extensive socio-economic survey was carried out in 2014-15 on 660 households, out of 5000. We found (Ruiz et al., 2015) that the **introduction of deep boreholes since the 80s induced dramatic changes in the cropping patterns**: traditional crops as finger millet, sorghum and pulses were substituted with water-intensive crops like sugarcane, turmeric, banana and vegetables. Groundwater depletion is such that today, about two-third of the wells are defunct and many of the remaining ones provide water only for short periods. However, groundwater decline was not homogeneous in the watershed: because intensive pumping started in the villages of the valley, the valley regions exhibit very deep groundwater levels, which is non-classical in hydrogeology. The subsequent disconnection between groundwater and stream bed induced stream drying, as it happened to others rivers in the region (Srinivasan et al., 2015). Similarly, groundwater contamination it is widespread and also exhibits large spatial variations, with NO_3 hot spots up to 350 mg/L. As lateral fluxes are found control significantly this groundwater system (Sekhar et al., 2006 ; Mangiarotti et al., 2013), one of the main output of the project was to highlights **the importance of accounting for spatial interactions at the watershed scale for the assessment of agriculture sustainability.**

The CEFIPRA project allowed developing under the modelling platform RECORD the **integrated model** AICHA (Bergez et al., 2014) which combines models of hydrology (AMBHAS 2D, Sat Kumar et al., 2011), agronomy (STICS, Brisson et al., 2003), economy (MoGire, Reynaud and Leenhardt, 2008) and farmer decision (Namaste, Robert et al., submitted). The model is distributed, i.e. it can account for the spatial interactions

[2] The fact that two projects acronyms sound very much alike might confuse the reader. We have decided that the name of the proposal **ATCHA** should clearly indicate its filiation with the previous project **AICHA**, to capitalize on the recognition and trust gained among scientific partners and stakeholders in India. For clarity, in the following text, we will refer to the "AICHA project" as the "**CEFIPRA project**".



mentioned above. Simulations at the farm level in Berambadi **confirm the importance of accounting for the feedback of temporal variations of groundwater availability on agricultural practices** (choice of crop, irrigation practices).

The next step is to go beyond the CEFIPRA project "proof of concept" and use this model for proposing realistic and acceptable solutions for groundwater resource management.

There is a **unique opportunity to seize for achieving this goal**: over the course of the CEFIPRA project, a strong connection was established with the project SUJALA-III (2014-2019, funded by the World Bank). SUJALA-III (http://watershed.kar.nic.in/SujalaIII.htm) is led by the Karnataka Watershed Development Department, a government body coordinating all the state administrations involved in watershed management. Its objective is to develop participative watershed management, and to design adequate extension services for local stakeholders by characterizing soil and water resources in micro-watersheds (villages). The research component involves, among other partners, the 4 agricultural universities of Karnataka (UAS Bangalore, Dharward, Raichur and Bangalkot), the National Bureau of Soil Science (NBSS-LUP, ICAR) and IISc. It aims at assessing groundwater management issues in a network of **14 research micro-watersheds** (about 10 km²) in 7 districts of Karnataka**.** In each of these watersheds, a **stakeholder consortium** has been gathered, which includes farmers, representative of farmers organizations, water user associations, watershed committees, local authorities (PRIs), NGOs and government departments and agencies. IISc and IFCWS were consulted to select the micro-watershed based on pedoclimate and agricultural diversity, and have a critical role for coordinating the experimental set up: Berambadi was taken as a model and all the equipment needed for water balance assessment (automatic weather station, point and continuous soil moisture sensors, LAI meters, water level sensors, etc.) are available in each micro-watershed. Training is provided by IISc and IFCWS (e.g. Agro-hydrological manual, http://watershed.kar.nic.in/Ambhas_manual_sujala.pdf). In October 2014 a training session on crop modelling (STICS and RECORD) was organized by the CEFIPRA project in Bangalore and generated a great enthusiasm (40 attendees) and expectations for a follow up. In addition to modelling Sujala-III partners are keen to implement the participatory processes in collaboration with the Indo-French team (see the support letter at the end of this document).

1.3 Objectives of the ATCHA project

The objective of the ANR project ATCHA ("good!" in Hindi) is to implement an **Integrated Modelling and Assessment approach with stakeholders to co-build and assess scenarios of sustainable development of agriculture in Karnataka in the context of climate change.** The strength of the project is to build on the truly trans-disciplinary Indo-French consortium described above, involving hydrologists, geochemists, soil scientists, agronomists, geographers, economists and sociologists and seize the opportunity given by the links developed with the Sujala-III project to expand this consortium to additional Indian partners including scientists, extension service engineers and stakeholders.

This project is based on two main scientific hypotheses derived from the experience gained during the CEFIPRA project **1)** in hard-rock aquifers, management of groundwater resources in a changing climate must take into account **spatial interactions and feedback between biophysical and socio-economic drivers influencing farmer decisions 2)** integrated models and scenarios are **boundary objects** that can help, through participatory processes, bridging the gaps between the **knowledge produced, used and needed both by scientists and stakeholders** and allow envisioning possible sustainable futures.

Using integrated assessment approaches (s.l.) for natural resource management is not novel, and a large body of literature already exists. **Integrated Assessment (IA)** is a trans-disciplinary and participatory process that involves many actors with divergent interests (hereby called stakeholders), at different levels of action (IAASTD, 2009) and enables better understanding of complex phenomena by combining, interpreting, and communicating knowledge from diverse scientific disciplines (Rotmans and Asselt, 1996). Different integrated assessment methods have been used to address water-management problems (Pahl-Wostl and Borowski, 2007). Model-based methods quantitatively describe causal relationships and interactions among system components (Jakeman and Letcher, 2003; Parker et al., 2002). They use **Integrated Assessment Models (IAMs)** consisting of coupled "disciplinary" modules (Tol and Velinga, 1998) and scenario analysis (Van der Sluijs, 2002), to assess performances of different interventions in social–ecological systems according to possible futures (Enfors et al., 2008) and related uncertainty (Valkering et al., 2011). They has been extensively used for issues related to agriculture (e.g. Ewert et al., 2009), land use (Audsley et al., 2006), and especially climate change (e.g. Moss et al., 2010). Participatory methods favour decision-maker and stakeholder participation in the assessment and decision-making process (Reed, 2008). Complex socio-ecological issues may require methods that combine both approaches. Indeed, complex water issues require the collaboration of policy makers, experts, lay persons and researchers (Newig et al., 2008), and to understand such situations where "facts are uncertain, values in dispute, stakes high and decision urgent", Funtowicz and Ravetz (1993) explain that society and science must move forward together through dialogue.

ATCHA takes the challenge of implementing such "research-oriented partnerships" or "intervention research" ("Mode III" in Hatchuel, 2001), in which scientists are in charge of **creating boundary objects** (e.g. maps, numerical or conceptual models, role playing games) and collective action processes that enable stakeholders to deal with their specific natural-resources management problem. ATCHA aims at bringing science into the action process, typically with approaches from the "Sciences of Design" (e.g. Martin et al., 2012; Nassauer and Opdam, 2008).

The proposing team has an acknowledged expertise in developing methodological frameworks for the representation of drivers including the use of modeling within scenario approaches (eg. March et al. 2012 ; Leenhardt et al., 2012, Moreau et al., 2013; Murgue et al. 2015) and implementing and analyzing foresight experiences involving farmers and question participatory settings (Richard-Ferroudji et al., 2013, Faysse et al., 2014, van Klink et al., forthcoming).

1.4 Challenges, scientific and methodological bottlenecks

The project has a clear **applied dimension**, with significant impact expected for local stakeholders. Moreover, as its success involves addressing **several scientific challenges and methodological bottlenecks**, it has a strong potential in terms of **academic production**.

Generating realistic and useful scenarios, and evaluating them, is a great challenge in the case of India, due to the great density of farmers implying a great number of farms, farms of small size and various agricultural practices. The participatory processes aiming at building and evaluating scenarios should involve the adequate stakeholders to account for the stakes, viewpoints and values of this great diversity of farmers while models must be able to account for this diversity of practices as well as for their spatial distribution.

First, new methodologies need to be elaborated or adapted for gathering and handling the large amount of high resolution information on soil properties and land use which is needed for model calibration.

Historical time series of land use and agricultural practices (LULC) are needed in Integrated Assessment and Modeling (IAM) approaches for model calibration. In addition to field surveys and government statistics, optical remote sensing has proven to be a very efficient way to retrieve such data for large areas at high spatial resolution (Atzberger, 2013; Corgne et al., 2014). However, In India, like in all tropical regions under monsoon regime, optical images are scarcely or not available during most of the cropping season, due to cloud cover (Asner, 2001). Furthermore, plots are very small (median size of about 0.2 ha) and crop duration are often very short, with up to 3 crops per year during the three main seasons of Summer (dry season, from

January to May), Kharif (South-West monsoon season, June to September) and Rabi (North-East monsoon season, from October to December). Therefore, **the challenge of the task 1.1 is to develop an original methodology to retrieve high resolution and high frequency LULC time-series based on the available remote sensing information.** To validate this methodology, we will use a unique satellite dataset which will combine optical and radar images at high spatial resolution together with a new classification technique specifically developed for the context (Mangiarotti et al. 2016a) based on the global modeling algorithm (Mangiarotti et al. 2012) which will enable us to establish an empirical link between the observed satellite multi-temporal data and the on-field dynamics (Letellier et al. 2009). This modeling approach has already proven to be well adapted for modeling crops cycles from optical satellite data both at high and low resolution (Mangiarotti et al. 2014; 2016b). Here the objective is to identify crop types, associated agricultural practices (irrigation) and phenology stages (LAI). These data will be used in the project not only to calibrate and validate the integrated model (especially the farmer decision model), but also to retrieve soil properties by crop model inversion (see below).

Soil properties determine largely crop production but also groundwater balance (Anuraga et al., 2006) and hence one common limitation of integrated watershed modeling is the lack of accurate spatialized values of soil properties (Pachepsky and Acock, 1998 ; Lawless et al, 2008). Digital Soil mapping (DSM) have been recognized as the suitable approach delivering spatial estimation of soil properties with associated prediction uncertainties (McBratney et al, 2003). There has been a growing use of DSM these past years with a clear move toward operationality, especially through the global project GlobalSoilMap (Sanchez et al, 2009, Arrouays et al, 2014). However, this approach requires mobilizing adequate legacy pedological information which is often missing in developing countries. **The challenge addressed in the task 1.2 is to adapt the Digital Soil Mapping (DSM)** method by performing the data fusion between the classical data used in DSM method and data specific to this project: high spatial resolution optical and radar images and multi-local estimations of soil parameters obtained by a novel methodology based of crop inverse modelling to obtain high resolution maps of soil parameters with the associated estimated uncertainties.
In soil survey activities, vegetation has always been considered has a good marker of soil variations. Vegetation indices retrieved from remote sensing data like e.g. NDVI have then been already considered in DSM as useful covariates for predicting soil (McBratney et al, 2003). However, up to now vegetation indices have been used in DSM models without any consideration of the factors that may disturb the soil-vegetation relation such as season, climate and type of crop. A recent study on Mediterranean vineyard have demonstrated the potential of accounting for such factors (Taylor et al., 2013). In parallel, recent studies have shown the potential of vegetation models inversion for estimating soil hydraulic properties from observations available from satellite (Varella et al, 2010 ; Charoenhirunyingyos et al. 2011 ; Sreelash et al, 2012). The principle is to extract information on root zone soil hydraulic properties from surface vegetation measurements thanks to the representation of the soil-plant interaction via root system description in the inversed model. This inverse modelling methodology has been implemented and evaluated on a set of monitored plots in the Berambadi watershed in the previous CEFIPRA project (Sreelash et al, submitted). In the present project, we will use the remote sensing information (Task 1.1) to provide estimation of soil parameter many sites, which would improve greatly DSM precision. The precise soil maps produced for Berambadi will be used in the WP2. The output of this task is to provide a generic framework for optimal use of vegetation remote sensing data in DSM. Training in DSM will be provided to the Sujala partners (NBSS&LUP) for producing digital soil map for modelling of the 14 watersheds of Suja-III.

Second, adequate knowledge for modelling crop and nutrient cycling in tropical agrosystems must be mobilized or acquired.

Using **crop models at the watershed scale in the Indian context** represents a scientific and technical challenge, due to the high diversity of crop species found in Indian farming systems. A large part of the effort in process-based crop modelling has been focus on few major crops used in intensive systems (maize, wheat, sunflower, rice…). Model accounting for a larger number of species are often based on only one process (i.e. FAO Aquacrop model for water balance, Raes et al., 2009). In project such as ATCHA, to simulate the response of various crops to climate or agricultural practice changes at the watershed scale, crop model should account for the effect of biotic and abiotic stressors and provide not only crop yield but also environmental outputs such as water, carbon and nitrogen. The specifications of the STICS model (genericity, robustness, operationnality) are in line with these requirements. The STICS crop model, collectively developed at INRA since 1996 (Brisson et al., 1998, 2003, 2009) can simulate complex cropping systems (single crop, associations and several successive crop cycles, Beaudoin et al., 2008; Launay et al., 2009), their response to future climate scenarios and their environmental impacts. Crop development depends on temperature and CO_2 atmospheric concentration, while growth depends on water, carbon and nitrogen stress. The model can be used alone (java interface) or integrated in modelling platforms for example for spatial applications (e.g. Beaujouan et al., 2001; Moreau et al., 2013). The model has been adapted to a large panel of crop species (annual, perennial and herbaceous plants) and environmental conditions. It has been shown to mimic well the response of agro-ecosystems to contrasted environmental conditions and management practices at various space and time scales (e.g. Constantin et al., 2012; Coucheney et al., 2015). **The challenge to be addressed in the task 2.1 is to calibrate several tropical crops in the model STICS and to foster the emergence of a network of crop modelers in India**. STICS have been already applied in tropical conditions and takes part to AGMIP project (Sierra et al., 2003; Affholder et al., 2003; Bassu et al., 2014), but tropical crops available, and properly calibrated, remains insufficient. Our objective to achieve a reasonable **calibration of at least 15 tropical crops** during the project, by mobilizing the experience and data sets acquired in India during the CEFIPRA project and the Sujala-III project. The generic equations used in the model should facilitate the calibration of new crops. The information gathered on soil and land use (WP1) and nutrient cycling (task 2.2) will facilitate this task. In addition, the French group developing and promoting the crop model STICS will organize training sessions for Indian scientists and students involved in the Sujala-III, in the objective of **fostering the emergence of a crop modelling community in India** that will continue this task after the project (see Sujala-III support letter, p 30)

Nutrient cycling is rarely taken into account in groundwater resource Integrated Assessment and Modelling. While models simulating the impact of irrigated agriculture on groundwater quality are common, they do not consider **feedback of groundwater quality on crop yield and agricultural practices**. Typically, the quality of irrigation water becomes a topic of interest only when irrigation water comes from urban waste water or drainage water (e.g. Mohammad Rusan et al., 2007; Qadir and Oster, 2004). However, strong feedbacks are expected even in the case of local groundwater recycling. For example, fertilization excess can induce groundwater salinity and it is well know that this can affect crop yield (e.g. Friedel et al., 2000; Sharma and Rao, 1998). However groundwater recycling affect the fate of many other elements which impacts on soils and crops, positive or negative, are largely overlooked. For example, nitrate-rich groundwater can contribute significantly to nitrogen fertilization of crops. In the case of Berambadi, the high nitrate contents in groundwater (on average 100 $mgNO_3/L$, up to 360 $mgNO_3/L$) induces a "hidden" supply by irrigation of 50 kg/ha/yr on average with extremes up to 200 kg/ha/yr (Buvaneshwari et al., 2016). On the other hand, as farmers are not accounting for these inputs for rationalizing their fertilization, this is likely to worsen nitrate leaching and probably lead to high NOx gaseous emissions. **The challenge of the task 2.2 is to model the processes governing element cycling, with major emphasis on C/N cycles and salinity, so that the feedback of groundwater quality can be taken into account in scenario assessment.** This is expected to provide a major contribution to the knowledge of nutrient balance in the tropics, where adequate information for rational use of fertilizer are often lacking, hampering the modeling of soil fertility (e.g. Hartemink, 2003). This will require characterizing the principal factors involved in the control of soil production potential such as Carbon content which interacts strongly with the cycling of other nutrients e.g. (Weyhenmeyer and Jeppesen, 2010). In addition, there is a need to better understand the factors driving gaseous emissions in the tropic, especially denitrification, which is expected to be more spatially and temporally variable than in temperate regions (Xu et al., 2013). Our objective is i) to estimate the different component of C and N cycles at the watershednt scale, including stocks in soils and groundwater ii) assess soil solute mass balances and gaseous emissions and iii) propose a calibration of the carbon, nitrogen (mineralization and denitrification) and salinity modules of the crop model STICS and of the groundwater model AMBHAS.

Third, while implementing a participatory process with researchers and stakeholders from different nationalities, native languages and cultural backgrounds, the risk of misunderstanding is particularly high. Here by combining the Integrated Modeling and Assessment methodology (Task 3.1) with a systemic approach of agrarian systems and an ethnographic assessment of the process (Task 3.2), we aim at improving the sharing of knowledge and dialogue among participants.

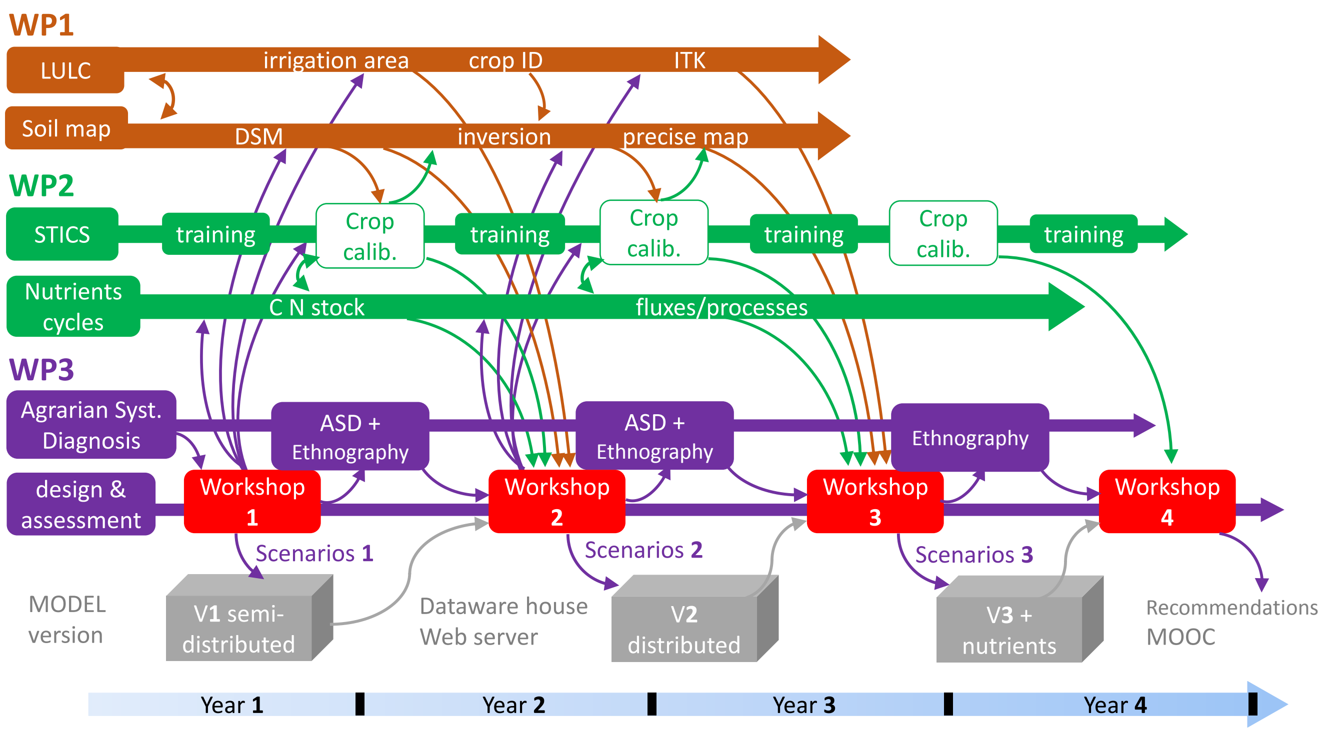
The agrarian system approach has been designed by the "comparative agriculture" French school of thought to study and compare agricultural development processes from different parts of the world and historical periods with the objective of both creating knowledge and help designing development projects and policies (Cochet, 2015). Its main originality is to consider jointly the biotechnical and socio-economic changes shaping agricultural development processes at different scales (Dufumier, 2007). To do so, it has developed a conceptual framework combining three interlocked scales of analysis and using specific concepts for each of them (agrarian system, production system and cropping / livestock farming system) (Cochet, 2012). The analysis of what defines and differentiates groups of farms having similar access to resources and implementing the same crop and livestock mix is at the core of the research. This diversity is captured empirically through the characterization of ecosystem resources and the reconstitution of the history of their tenure and use by the local population (Cochet et Devienne, 2006). The analysis of the structure of this fabric of farms as well as of the links between farms – through workforce flows or exchanges of products for example – brings forward several categories of farmers. The latter are seen as "strategic groups", who will broadly have the same attitude facing a similar problem (Olivier de Sardan, 1995).
The agrarian system approach has been used in a wide variety of situations worldwide, including in India (Aubron et al., 2015). In this project **such an analysis will be essential for replacing the different disciplinary analysis carried out in all the tasks in a broader perspective**.
On the other hand, this experience will allow testing the potential of the method within Integrated Modelling and Assessment processes as in the few cases where it was used (Castella et al., 2005 ; Barnaud et al., 2008 ;. Moreau et al. 2012) it merely served for initial assessment of the territory at the initial stage of the projects.

We will monitor and assess the participatory process in real time with an ethnographic approach. Today, the participation of local actors in the development of adaptive management to climate change is considered as a cornerstone to its success. Design and implementation of participatory processes are emphasized in reference to the dialogic democracy model (Callon et al., 2009) and frameworks for "future studies" (Fuller et al., 2009). Within dialogic democracy, collective decision-making emerges through a deliberative process which favours the exploration of problems, identities and the collective. Scientific experts, experiential experts and stakeholders come together in "hybrid forums" to deal with technical controversies. According to dialogic democracy, collaborative research only enables the exploration of multidimensional uncertainties. The different purposes and effects of participatory dialogic settings have long been debated for water issues (Von Korff et al., 2012). Experiences gathered by Von Korff et al. show that it is possible to respond to the various requirements in water management with a variety of approaches ranging from modelling to artistic and creative approaches. Crossover between the field of "future studies" and environmental research has proven instrumental in understanding long term environmental dynamics, and offers frameworks to make explicit the specific and fundamental choices. Recent studies have illustrated how participatory foresight approaches can be used to explore possible innovative water management practices, including considering radical paradigm changes (Faysse et al., 2012b). Studies however report difficulties in involving economic actors and stakeholders in discussions related to changes that may occur, with a certain degree of uncertainty, in the long (2030) or very long term (2050 to 2100). Planning is common in public policies at the national and state level with the definition of future 'visions' about agriculture (e.g. Government of Tamil Nadu, 2013). Yet foresight studies are not practiced often and most of these studies are carried out by policy makers on technology, industries, etc. **The observation of such process during this project will give interesting insights, as foresight approaches are unusual and participatory processes involving farmers are scarce in India** (van Klink et al,. forthcoming). Ethnographic analysis is commonly used to analyse participatory processes "post facto" (e.g. Levain et al., 2015). Here, the originality of the approach is that the analysis will contribute to the process itself: insights from the preliminary analysis will be shared with during each workshop, so that incomprehension or blocking situations can be identified and addressed, in "real time".

In summary, we expect this project to have a major impact on the adaptation of the Indian agriculture to climate change, by improving the relevance of public policies and advice given to farmers by extension services. Moreover, is expected to produce significant scientific advances on the functioning of agro-hydrosystems under high anthropogenic pressure.

2. Scientific and technical program, project structure

The project is composed of 3 challenging work packages: i) development of novel methodologies to gather information on soils and land use at high spatial and temporal resolution by using both ground and multi-satellite data ii) provide a realistic biophysical model based on a thorough study of nutrient cycles in tropical irrigated agro-systems iii) development of a participatory approach to build and assess scenarios of adaptation to climate change. WP1 and 2 will provide information that will sustain the scenario construction in WP3. WP3 will provide integrated assessment of scenarios and feedback to WP1 and 2 for an iterative process.
The project is structured by **four annual Project Meetings** involving all the project partners, including Participatory Workshops.
The working program comprises **field surveys, modeling and a participatory approach for conceiving and assessing scenarios**. Surveys include i) biophysical monitoring during the first 3 years, including groundwater chemical composition, land use, crop and soil parameters, and ii) socio-economic surveys during the first 2 years for agrarian system diagnosis and farmer decision model. For modelling activities, we will calibrate and use the existing V1 of the AICHA model to simulate the first and second set of scenarios. Two improved versions of the model, including new processes, new crops and improved spatial distribution of parameters will be proposed in year 2 (V2) and 3 (V3), according to knowledge advances and scenarios built with stakeholders.



WP1: Building methodology to collect adequate spatial database for modelling (Coord. S Buis)

Task 1.1: Modelling land use and land cover change using multi satellite high resolution data.

S. Corgne - S Mangiarotti ; L Hubert-Moy ; L Ruiz ; M Sekhar ; Coll KSRSAC

The main objective of this task is to develop a methodology which allows to identify not only the crop types but also to characterize the associated agricultural practices (irrigation), the phenology stages and the crop rotations (including intercrop and fallow periods) by processing an important radar and optical dataset at a fine scale.

Two temporal scales will be studied: (1) **A long term analysis of irrigated area evolution since 1990's**. We will focus here on data acquisition during summer (dry season, from January and May) when cloud cover is weak and optical data (Landsat archive) easily available to monitor irrigated area evolution in summer season from 1990 till 2015 (Sharma A. K. et al., in preparation). **(2) A short term analysis on land use from 2011 to 2015**. Land use monitoring will focus here on crop monitoring between the three main crop seasons (Summer, Kharif and Rabi). For that we will use high spatial resolution optical data (Landsat, SPOT5, SPOT6/7) during summer, SAR data during Kharif (Radarsat-2, RISAT-2) and jointly optical and SAR data during Rabi when cloud cover is lower than during the Kharif monsoon.

We will first extract biophysical variables from optical images (Leaf Area Index, LAI) and from radar images (backscattering coefficients, radar vegetation indexes, polarimetric parameters...). These multi-temporal indicators will be analyzed and classified at field scale. A new classification approach, using the global modeling technique (Gouesbet & Letellier 1994; Mangiarotti et al. 2012; 2016b) as a kernel, will be adapted to the present context. This technique is based on chaos theory (Bergé et al. 1984). Its ability to model cereal crops was recently shown (Mangiarotti et al. 2014; Mangiarotti 2014). Its interest for classification comes from its ability to model a global ensemble of solutions rather than single ones; preliminary tests on Berambadi watershed based on optical data have proved to be promising (Mangiarotti et al. 2016a).

This methodological approach will be first tested for its ability to identify crop, main phenology stages, and main land use management (irrigation, intercrop...) by using field data acquired on 60 monitored plots since 2011 on the Berambadi watershed. Improvement and validation of the methodology will be performed **based on a large survey (crop type and presence or absence of irrigation) that will be carried out in 2017 in each cropping season on about 5000 individual plots on the Berambadi watershed.** For the years 2017-2018, we will also apply this approach to the 14 watersheds of Sujala-III project, combining very high temporal frequency images from Sentinel-1 (SAR, C-band) and Sentinel-2 (Optical).

All results will be integrated in a GIS to provide vector and raster inputs for the model (at the end of the year 2). For the Berambadi watershed, two types of spatialized temporal information will be provided: (1) a long term survey of irrigated areas since 1990 during summer season and (2) land use monitoring since 2011 which will include crop successions monitoring, main phenology stages crop and main land use management (irrigation, intercrop...). LULC time series from 2017 to 2019 will be retrieved for the 14 watersheds of Sujala-III in collaboration with KSRSAC (Karnataka State Remote Sensing Application Center, member of Sujala-III). The methodology developed in this project is expected to find large application in the tropics.

Task 1.2: Digital Soil Mapping for spatial modelling

P Lagacherie - S Buis ; L Ruiz ; M Sekhar – Coll. NBSS&LUP

The objective of this task is to produce **exhaustive maps of STICS soil inputs over the watersheds** with the associated estimated uncertainties, using Digital Soil Mapping (DSM). This methodology is defined as the creation and population of spatial soil information systems by use of field and laboratory observational methods coupled with spatial and non-spatial soil inference systems. This task includes two steps:

A first Digital Soil Mapping will be performed by assembling a learning set of sites with legacy pedological data (measured textural soil properties, horizon thickness, carbon content,...) and the soil covariates, first those usually involved in DSM (soil maps, land use maps, Digital Elevation Model) and the specific inputs provided in this project, i.e. high resolution optical and radar images (T1.1.). Mapping of hydraulics soil properties for the STICS model will be performed by applying to this learning set appropriate algorithms of machine-learning, e.g. random Forest (Breiman, 2001) and geostatistics, e.g. regression kriging (Odeh et al, 1994) that deal with the soil-landscape relationships and the spatial structures of soil properties within the

Berambadi watershed. Training in DSM will be provided to NBSS&LUP Bangalore and the method will then be applied to the 14 micro-watersheds of Sujala III.

In a second step, the methodology of crop model inversion developed in the CEFIPRA project will be applied to a large set of plots spread in the watershed. Inputs required for these inversions are: (i) climatic data (from 2 weather stations in the watershed) ; (ii) farming practices (from the extensive field surveys performed in CEFIPRA) ; (iii) land use (from task 1.1) and (iv) LAI and surface soil moisture derived from radar and optical high-resolution satellite data (from task 1.1). Five years of data (2014-2018) will be available for choosing appropriate conditions bringing sufficient information on soil hydraulic properties as previously identified in the CEFIPRA project (Sreelash et al, submitted). Raw estimations of soil properties produced by DSM in the first step will be used as prior information for better constraining the inversion system. This will produce a great number of new sites with soil hydraulic properties estimations in the Berambadi Watershed that will be used as soil inputs in a second Digital Soil Mapping of soil hydraulic properties over the watershed. With this new source of soil data that remove the sparse soil input constraint, we expect enlarging the range of applicable DSM models and therefore dramatically increase the precision of soil hydraulic properties mapping.

WP2: Bridging knowledge gaps for agro system modelling in the tropics (Coord J Riotte)

Task 2.1: Calibration and evaluation of the STICS crop model for a sufficient variety of crops under tropical conditions. **J Constantin**, D Ripoche, N Beaudouin, E Justes, S Buis

The objective of this task is to develop and calibrate the STICS crop models to a variety of tropical crops cultivated in Indian agricultural systems. Crop can be affected by biotic as well as abiotic limiting factors of crop production. Here we will focus on biotic factors, as the main abiotic factor found in the studied (soil salinity) will be considered in the Task 2.2.

During the project CEFIPRA, the monitoring of 60 farm plots during 3 years allowed to ensure sufficient calibration of the STICS model (Sreelash et al., 2012, 2013) for 5 major crops found in the Berambadi watershed (turmeric, maize, sunflower, sorghum and marigold). This effort was sufficient to test simplistic scenarios to estimate the general behaviour of the system but building scenarios with stakeholders would require a larger degree of freedom (about 30 different crops are commonly found, classified in about 8 types (function of cropping duration, cost, water needs and end-use (cash crop or self-consumption). The many field experiments carried out by agricultural institutes in India are rarely used for modelling. Hence, the objective of this task is **to achieve the calibration/test of STICS applied to the maximum number of crops**. The task will include five steps: a) organize every year a training session on crop model calibration for agronomist within the Sujala-III project; b) define a generic strategy of STICS adaptation in tropical regions, relying on previous works (Flenet et al, 2004; Guillaume et al., 2011); c) build a database including experimental datasets and literature references about ecophysiology of the involved crop species; d) calibrate and test the STICS model, using companion STICS software, i.e., JavaSTICS optimizer, R routine of evaluation (Coucheney et al; 2015) and Optimistics (Guillaume et al.; 2011) e) write an synthetic report about each crop parameterization.

Generic scientific outputs are expected from extending the domain of validity of STICS to tropical situations: evaluating the robustness of the model formalisms in a context of water scarcity, hot temperature and short crop rotations; effect of salinity on soil-crop system; developing a method of calibration for a large panel of new species according to their functional traits.

Moreover, the objective is to contribute to build a **network between crop experimenters and crop modellers in India**. The group of agronomists gathered within the Sujala-III could be extended to scientist and students from other institutions (ICAR, ISRO…). This objective is ambitious but we believe it is reachable, considering the success of the first training session on STICS crop model crop held in October 2014 in Bangalore and the support of Sujala-III team.

Task 2.2: Modelling nutrient cycling in irrigated tropical agro-systems

O Fovet, J Riotte, D Serça S, P Durand, C Gascuel, L Ruiz, C Delon, M Sekhar

Element cycling can have a major impact on soil degradation and water quality and hence affect the sustainability of agricultural systems. The preliminary groundwater monitoring in the Berambadi watershed (200 farmer borewells) undertaken within the CEFIPRA project highlighted a huge spatial variability of groundwater composition with Cl and NO_3 contents spanning 3 orders of magnitude with the highest values (400mg/L NO3) found in the deepest groundwater. The mechanisms underlying such accumulation and its impact on crop production, both in terms of nutrient addition and increase in the soil salinity needs to be understood and modelled.

Estimation of the different component of C and N cycles at the watershed scale, including stocks in soils and groundwater. The C and N stocks in the soils of the Berambadi and the 14 watershed of Sujala-III are currently assessed by the National Bureau of Soil Science (NBSS&LUP). The C and N stocks in soils are a prerequisite for analysing the relation between the spatial variations of soil nutrient balance, groundwater quality and crop yield. We propose to extend the seasonal monitoring (level, major anions and cations, DOC) of 200 bore wells for the duration of the ATCHA project to estimate the temporal and spatial variability of groundwater composition and associated C/N stocks in groundwater. Nutrients that will be investigated here include Nitrates that are at major stakes for both water quality and agricultural production, Chloride and Sulphate that induce salinization and Carbon that is at major stake for both soil fertility and CO2 sequestration. Some other chemical species will be analysed during specific field campaigns as tracers (water isotopes 18O, 2H) or if needed for testing hypotheses about process dynamics e.g. via higher frequency sampling in groundwater focusing on recharge events. At the end of year 2 we will provide a gridded map of C and N stocks for the Berambadi watershed.

Assessment of solute mass balances and gaseous emissions a soil-plant scale. Analyzing nutrient cycling is needed for optimizing the efficiency of nutrient application and estimating the seasonal leaching of nutriments to the groundwater. We envisage monitoring 6 plots per year during the three first years of the project. We will select these plots based on crop type, soils (Ferralsol and Vertisol) and agricultural practices. In these plots, we will monitor the agricultural practices (fertilization, irrigation), crop variables (LAI, biomass), profiles of soil moisture and soil pore water composition (TDR, rhizon samplers), Carbon and Nitrogen gaseous emissions and denitrification potentials. Measurements should be performed on a fortnightly basis during each of the growing periods. The solute mass balance will be based on the chloride mass balance (CMB) method, configured for a soil in which anthropogenic Cl (KCl) is applied (Tyner et al., 2000) which, assuming that Cl is conservative within the soil layer and that $F_{Clinput}=F_{Cloutput}$, allows to deduce the soil output flux of water and chemical elements.

Calibration of the carbon, nitrogen (mineralization and denitrification) and salinity modules of the crop model STICS and of the groundwater model AMBHAS.

These data will be used to elaborate and calibrate a solute transport module in the hydrological model AMBHAS and to calibrate the carbon, nitrogen and salinity stress module in STICS. This work will be done in strong interactions with the task 2.1, so that successive calibrations of the STICS model will be shared between the teams. This will be facilitated by the different instruments developed in the WP4. A version of the integrated model including nutrient cycling will be implemented in the RECORD platform in the year 3. This will allow testing a wider range of scenarios while accounting for the feedbacks of groundwater composition on the sustainability of agricultural practices.

WP3: Sharing knowledge through scenarios (Coord JE Bergez)

Task 3.1: Scenario Design and Assessment

D Leenhardt - M Willaume, JE Bergez, A Thomas, A Raynaud, S Ambec, S Couture, Srinivasan V, S Badiger

The methodology used in this project is "Design & Assessment"(**D&A)** which was firstly developed by Murgue et al. (2015) to design scenarios of spatial distributions of agrosystems. It is based on the participation of local stakeholders and incorporates different sources of knowledge and supports a social learning process to enable social negotiation of satisfying solutions rather than computation of optimal ones (Giampietro, 2002; Newig et al., 2008; Pahl-Wostl and Hare, 2004; Sterk et al., 2009). The **D&A methodology**

is composed of three collaborative steps (Barreteau et al., 2010) (1) representation of the agricultural landscape in respect of water management issues, i.e. distribution of cropping systems in the landscape, (2) design of alternative landscapes (scenarios), and (3) integrated assessment of those alternatives via a simulation model. All three steps are participatory, i.e. they involve both researchers and stakeholders, and may constitute iterative cycles. Even if D&A methodology is well established and mastered by the proposing team, **the challenge of this task will be to adapt it to the complexity of South Indian agriculture**.
A series of annual workshops (4 workshops of 2 days each) will be organised **to design and assess scenarios in an iterative process**. Workshops participants will include all the scientists involved in ATCHA and Sujala-III projects, extension engineers and the consortium of stakeholders (including local authorities and farmer representatives) from the network of 14 micro watersheds. **To adapt to the case of ATCHA project, each workshop will include 5 sessions,** each followed by a discussion : i) a presentation of the main results of all the tasks of the ATCHA project ii) a presentation of the advance in the Sujala-III project, with a focus on 2 or 3 micro-watersheds, iii) a presentation of the evaluation of the scenario simulations with the integrated model iv) the elaboration of a new set of scenarios and v) a collective assessment of the participatory process.
During the first workshop, the integrated model elaborated during the CEFIPRA project (V1) will be presented. To illustrate the model features and the possible range of system responses, a set of simulations of over-simplified scenarios such as "business as usual", "100% rainfed agriculture" and "doubling irrigation area" will be presented. In addition, the effect of a simplified (semi-distributed) spatial distribution of these scenarios will also be presented to illustrate the spatial interactions within the watershed. Graphical representations of model outputs will be produced on GIS to enhance the discussion with stakeholders. Discussions about these first scenarios (their nature and their performance as simulated by the model) will enhance the co-design and formalization of a new set of scenarios, and possibly new requirements for the model (e.g. new evaluation indicators, new crops, new agricultural practices, new processes…). This will be repeated each year with increasing realism and pertinence of the scenarios, in pace with the increasing complexity and realism of the model. A fully distributed version of the model (with accurate soil map) will be used for workshop 3, while a version including nutrient cycling will be used for worshop 4.
These workshops will allow identifying local innovations, barriers and levers for improving agricultural systems, possible alternative crops/practices, overlooked processes, etc. Propositions will be made to include these new features in the analysis carried out in each of the tasks of ATCHA, if needed on the monitoring carried out in Berambadi and in the Sujala-III microwatersheds and if possible into the next version of the integrated model.
At the end of each workshop, the scenario assessment will be translated into a set of narratives, and possibly into recommendations for extension services. After the workshops, these narratives will be formalized, i.e. qualitative options for change will be translated into formal, quantified and spatially explicit, representations that will be used as inputs to the model. Note that adequate downscaled climatic scenarios (GCM) are already available for the study sites from previous projects.

Task 3.2: Agrarian system analysis and ethnographic approach to support the participatory process
A Richard-Ferroudji - C Aubron, M Willaume, D Leenhardt, JE Bergez, Srinivasan V, S Badiger

To insure the success of the participatory process, we describe the global context in which the groundwater management issue is analysed, and insure that a the various representation of the problem are shared among participants. For this we will use 2 approaches:
First, we will carry out "**Agrarian system analyses**". This involves a field work of about 4-5 month, combining observations and farmer surveys, and remobilizing data collected during surveys of the CEFIPRA project. At first, we will reconstruct the agrarian history of the last decades through interviews with elder people (about 20 persons, mostly retired farmers) complemented with ancillary data and published information. This spatial understanding of differentiated trajectories of agricultural holdings over the last decades will help us to develop a typology of local agricultural holdings. On a representative sample of farms, we will analyse the technical, social and economic functioning of each of these production systems in greater detail, drawing from about forty interviews with farmers. This information will complete previous farmer surveys performed

to identify farmers' decisions rules concerning crop management and adaptation to climate variability. A complementary survey on 50 households will also be done for validating this set of decisions rules. We will finally represent the diversity of production systems (by creating archetypes, representative of groups of holdings), their spatial distribution (maps), and a set of decision rules to simulate adaptive management to climate change.
The first diagnosis will be carried out in the Berambadi watershed and the knowledge produced will be presented and discussed during the first participatory workshop. This will allow replacing the water management issue in a broader perspective, and enrich the discussion on scenario building.
According to the discussion during each workshop, this methodology will be either applied to some of the Sujala-III micro watersheds or the diagnosis in Berambadi watershed will be complemented with additional surveys. These could serve to develop aspects of the agrarian system that would be identified during the workshops and not sufficiently addressed by the WP1 an WP2, for example livestock and milk production, issues related to land holding, man work availability and exchange, importance for farmer livelihood of activities other than agriculture, migrations.
As this would be the first time Agrarian System Diagnosis is part of an Integrated Assessment and Modelling approach, analysing how it influences this process will be particularly interesting.

Second, will use **an ethnographic approach to monitor and assess the participatory process** of scenario elaboration between researchers and stakeholders, Through observation of the workshops we will analyse the interactions between participants, the use of scientific knowledge and the co-creation of knowledge through iterative learning process. At several stages of the project, during and in between the workshops, interviews will be carried out with participants (stakeholders and researchers) dealing with their point of view of the participatory process that is underlined by their social and political agendas and local framing of the climate change issue. All interactions (workshops and interviews) will be recorded and we will track changes in narratives of irrigated agriculture.
The originality of this component of the project is that it will not only produce academic knowledge from the analysis of the participatory process, the use of the model and social learning within the process, but it will contribute to the process itself in "real time": insights from the preliminary analysis will be shared workshop participants during each workshop, so that incomprehension or blocking situations can be identified and addressed.

WP4: Coordination, modelling, dissemination and capacity building (Coord. H Raynal)

Task 4.1 Coordination:
L Ruiz, A Thomas, H Raynal, M Sekhar

Annual Project Meetings:
The project is structured by four annual Project Meetings involving all the project partners, including Indian scientists and stakeholders. Each meeting is composed of three sessions:

1) two-days scientific meeting on project advances, with focus on the links between the different tasks (see diagram of project structure)
2) three –days participatory Workshop on "design and assessment" with stakeholders
3) 1-day field visit of one of the experimental watersheds, including interactions with farmers.

Four video conferences will be held 6 month before each meeting to review the project advances.

Training sessions (one week) on environmental monitoring, data base maintenance and crop modelling for Sujala-III scientific partners will be organized every year one week before the Annual Project Meeting, to optimize the travel costs of French participants.

Task 4.2 Integrated modelling under the RECORD platform:
E Casellas, H Raynal, S Cézéra, JE Bergez, L Ruiz

Two of the key modelling challenges of this project are i) to **implement successive versions of the integrated model**, from the V1 developed in the CEFIPRA project and in pace with the development of the project: V2 will be a fully distributed version of the model and V3 will in addition include nutrient cycling and ii) to design a joint information system in order to run the model under **different scenarios while using updated inputs, parametrizations and model version**s.
These challenges can be taken as the integrated model will be developed under the **RECORD platform (INRA)** following an approach that integrates knowledge from different domains into a single framework" Nordhaus (2013).
The essential tasks will be integration and coupling of the different components of the model (taking into account i) feedback between modules, in particular between decision-making models and bio-physcal models, and ii) the multiple scales of the system, calibrations and scenarios running. These tasks will benefit of the abilities of the platform in model coupling, and intensive simulation (Bergez et al. 2013, Bergez et al. 2014, Bergez et al. 2016).
Model versioning will be based on collaborative tools (wiki). A special attention will be given to the **coherence of the modelling activities between WP** using computing and modelling standards, in particular spatial and temporal scales, data attributes and definition…)
Running spatially distributed scenarios at watershed scale require a large amount of input data and also will generate a lot of simulated data. So an information system will be designed in order to help in the management of this "big data", to facilitate the parameterization, the simulation of scenarios and the post-treatment of simulation outputs. Data base implementation will be based on the principles of **datawarehouses,** allowing easy access to data of various types (surveys, model inputs and outputs, maps scenarios, and narratives). Rigorous quality control of the data gathered trough the project will be carried out, using R routines.

Task 4.3 dissemination and capacity building:
A Thomas, H Raynal, JE Bergez, L Ruiz, M Sekhar

The coordination team will deploy a web portal to gather information on the project itself (news, events …), on the status of the different tasks. This web portal will be hosted in the INRA IT infrastructure. It will include open access to data and metadata (for observed and simulated data) using international standards such as INSPIRE (http://inspire.ec.europa.eu/) or AGROVOC (http://aims.fao.org/fr/agrovoc), to share the information required for reproducible and repeatable applications. Spatial data will be shared using GéoSAS, A modular and interoperable Open Source Spatial Data Infrastructure (Bera et al., 2015) on which a dedicated portal (http://geowww.agrocampus-ouest.fr/portails/?portail=aicha) was developed for the CEFIPRA project.
At the end of the Participatory process, scenario assessment will be translated into **narratives** and a **set of recommendations will be elaborated for policy makers**. A National workshop will be organized in the last year in India to disseminate the results.

Capacity building for Indian partners (scientists and extension service agents) is one of the main objectives of the project. Training session in field monitoring, soil mapping and crop modelling and learnings from the experience in Design and Assessment will be formalized and shared through **MOOCs** that will be proposed online for scientists, students and extension service agents. In this digital era, MOOCs (massive Open Online Courses) drive a new wave of learning, and procure the opportunity to expand the impact of the project.

In detail for academic production :

1. Each workpackage coordinator will have to propose plans for scientific publication and for dissemination in the international community that might be interested in ATCHA approaches (eg. International Congress on Environmental Modelling and Software, AGMIP (in particular the community working on regional assessment in South Asia http://www.agmip.org/southern-india/, MACSUR http://macsur.eu/). These plans that will be shared and debated at the different annual meetings

2. Data (from survey, monitoring or simulation) will be proposed as data papers in order to be published in data journals, in order to make them effectively discoverable, available and reusable by others. The data will be referenced with a DOI (Digital Object Identifier)
3. A general scientific book will be written to gather the overall scientific results (eg. Springer Verlag)
4. An operational guidelines will be written to explain the operationality of the ATCHA approach and share general concepts.

Management of scientific risks

Two major scientific risks are identified that are common in IAM approaches: 1) possible insufficient connection between the numerous scientific disciplines involved, in which case the project would be merely "multi-disciplinary" 2) possible insufficient involvement of stakeholders in the participatory approach.

We address the first risk by building a project structure (see diagram at the beginning of this section) with large connections between all the tasks. Interactions between WP1 and WP2 are obvious, and will be structured by the modelling objective. In addition, WP3 is placed at the core of the project, and strong interactions are expected with the other tasks. For example, the Agrarian System Diagnosis will describe historical LULC changes and might identify crops occupying small surfaces but of major importance for some farm types; this will guide the selection of LULC classes to be retrieved with remote sensing. Similarly, output from the WP3 will guide the choice (and possibly the definition of functional typologies) of soil types, crops and agricultural practices that must be studied and modelled in priority. On the other hand, WP1 and WP2 will inform WP3 by giving a quantitative assessment of the bio-technical processes at stake, such as the impact of nutrient cycles or salinity on crop yield.
The structure of the annual project meetings in Bangalore, combining training sessions, scientific meeting, participatory workshops and field visits, with sufficient time given to scientific, technical and informal exchanges, will facilitate "team building" across disciplines which is required to achieve such interactions.

For the second risk, we have decided not to base our approach on a direct participatory approach with farmers, as we believe that the risk would have been too high. Instead the participatory approach relies on the large consortium of stakeholders established for the Sujala-III project. As the teams involved in the project have a strong experience in implementing participatory approaches in France (AGIR, SAS) and in India (IFP, ATREE) we are confident that we can obtain active participation of a large range of stakeholders. Coupling the participatory process with other type of activities, such as training sessions, field visits, discussions on the agrarian system should also guarantee the active and regular participation of stakeholders. In addition, the monitoring and assessment of the participatory process with the ethnographic approach will allow identifying and addressing blocking situations in "real time".

Consortium and budget

This project will promote the emergence of a **unique trans-disciplinary consortium on sustainability assessment of agricultural systems, with a balanced representation of bio-physical sciences (hydrology, geochemistry, agronomy, remote sensing) and social sciences (geography, economics, sociology), and strong experience both in field observation and modelling.** The core of this consortium is constituted by the members of the previous CEFIPRA AICHA project, who all demonstrated their capacity to work as a real trans-disciplinary team, and have gained significant knowledge and experience on the challenges (both scientific and methodological) at stake in South Indian agriculture. Based on the analysis of the CEFIPRA project strengths and weaknesses, additional members have been added bringing competence in crop modelling, soil digital mapping and agrarian system diagnosis.
These teams are: **UMR SAS** (Hydrology, geochemistry, watershed modelling - L Ruiz, P Durand, C Gascuel, O Fovet), **UMR TSE-R** (Economic modeling - A Thomas, A Reynaud, S Couture, S Ammbec, S Cezéra), **UMR GET/LMI IFCWS** (Geochemistry, nutrient cycling - J Riotte), **UMR UR2-LETG** (Remote sensing, LULC - S

Corgne, L Hubert-Moy), **UMR EMMAH** (Soil properties, model inversion - S Buis), **UMR AGIR** (Integrated assessment, farmer decision, crop modeling - JE Bergez, D Leenhardt, M Willaume, E Justes, J Constantin, G Plumecocq), **UR MIAT** (Modeling platform RECORD, H Raynal, E Casellas). Based on the analysis of the CEFIPRA AICHA project strengths and weaknesses, additional members have been added: The INRA team developing and promoting **STICS crop model** (led by N Beaudoin, UR 1158; D Ripoche, US 1116), **UMR LISAH** (Digital Soil Mapping, P Lagacherie), UMR SELMET (Agrarian System Diagnosis, C Aubron) and **IFP Pondicherry** (A Richard-Ferrouji, Head of Social Sciences department, Govindan Venkatasubramanian).

The total cost of the project is **743k€**. Intensive work needed for model development and calibration, and for implementing and documenting the participatory process justifies the implication of 4 **non-permanent staff** (**317k€** see description of the positions below). The later amount also includes stipends for 14 Master students (84 Months, detail below). The participation of permanent staff amounts is large (**about 250 person.months**), and **precariousness ratio is only of 20%** (as per ANR rules, Master students are not included in the calculation of this ratio).
The project requires a large implication of French teams in India (and visits to France for Indian scientists and students), which explains why a large part of the budget (**163k€**) is dedicated to **travel costs**. As the project relies on established observatories, little **equipment** is required (**23k€**) mostly for computers. Other **external expenses** are for consumables, chemical analysis, and publication fees (**122.8k€**). External services (**75k€**) are required mostly for managing workshop logistics and field work in India.

The PI of the project is Laurent Ruiz (relevant publications 66, 89, 107, 108, 133) (INRA, Senior scientist at UMR SAS). He is agro-hydrologist, with competences on environmental observatory management (Head of ORE Agrhys) and agro-hydrological modelling (TNT2, ETNA, COMFORT, AICHA...). His interests span temperate and tropical (Africa, India) conditions. He has developed collaboration with Indian partners since 2002, and stayed in India through IRD deputation in 2002-2005 and since 2014. He published about 50 papers (WOS, IF 17, ResearcherID: C-3090-2011), and he is Associate Editor of Hydrological Sciences Journal (Journal of the AIHS). He has a successful experience in managing ambitious trans-disciplinary projects involving stakeholders, e.g. the **ANR ACASSYA** (2009-2013; Co-PI with C Gascuel, 22 peer review papers, 1 book, high societal impact as it was used by stakeholders as a basis for developing territorial plans in response to the "green algae" crisis in Brittany). He is the Co-PI (with Pr M Sekhar) of the **CEFIPRA AICHA project (2013-2016).** He will dedicate 60% of his time (28 months) to the ATCHA project.
Partner 1: UMR SAS (INRA-Agrocampus Ouest) team has acknowledged experience in integrated modelling of agricultural watersheds, especially nutrient cycling and scenario assessment (**P Durand, C Gascuel and O Fovet**) and will host the activities of **C Aubron (UMR Selmet, agrarian system diagnosis)**.
The net budget of UMR SAS (223.11k€) includes i) Salary of Research Engineer for crop modeling (24 months, **89.928k€,** see description below) and stipend for 3 master students (**10.182k€**) on nutrient cycling and agrarian system diagnostic ii) Equipment (**5k€,** computers for the Engineer and the students) iii) **28k€** for 14 France-India travels (2k€ each) iv) **70k€** of external service (IISc, for workshop logistics and field work, see below) and v) **20k€** of other external expenses including consumables, chemical analysis, and publication fees.

Partner 2: UMR AGIR (AGroecology, Innovations, teRritories is a 80-permanent multidisciplinary research unit (bio-technicians and social sciences) from INRA and three high education schools on agriculture and agronomy from Toulouse. Its scientific objective is to produce knowledge, models and devices to design and support technical and organizational innovations within a sustainable management of regional agricultural and environmental resources. The unit has a strong expertise on innovative systems at the field level (cropping and livestock), on scenario approaches at watershed or regional levels (particularly to manage water resources), on methodologies (e.g. modelling, participative approaches, multicriteria analysis) and onanalysing actors functioning (e.g. lock-in, actors networks). AGIR led several ANR projects (TATA-BOX MicMac Design, O2LA, INTERRA, APPEAU) and 7 PSDR projects (For and About Regional development), was greatly involved in European projects (SEAMLESS , CanToGether)and is co-leader of two specific R&D projects (UMT: mixt unit of research and development) on sunflower and water.

Jacques-Eric Bergez (refs 21, 22, 23, 24, 25), senior scientist, accreditation to supervise research (ASR), INRA AGIR. Main interest is systemic agronomy and modelling. Main research topic is the description and modelling of farmers' practices in order to develop innovative crop management systems. He is the leader of the INRA AGIR research unit (80 permanent persons). He coodinates (2013-2017) the ANR TATA BOX project aiming at developing a methology to help local actors to perform an agroecological transition of their territories. He coordinated (2007-2012) a research and development network on the development of tools and methodology for managing irrigation water resources. He coordinated (2008-2012) a R&D project to develop a regional foresight on cash crops. He is the author of more than sixty research papers and managed six theses. Other members of UMR AGIR include Delphine **Burger-Leenhardt** (INRA), Gael **Plumecoq** (INRA), Julie **Constantin** (INRA) Eric **Justes** (INRA), and Magali **Willaume** (ENSAT); AGIR will host the activities of **UR MIAT**: Hélène **Raynal** (INRA) and Eric **Casellas** (INRA) computer science engineers, RECORD platform.
The net budget of UMR AGIR (246.123k€) includes i) Salary of one Research Engineer for design & assessment (24 months, **90.827k€**), one Study Engineer for developing the coupled model in the RECORD platform (24 months, **76.507k€**) and stipend for 2 master students (**6.788k€**) on scenario modelling and participatory process ii) Equipment (**5k€**), computers for the Engineers iii) **47k€** for 18 France-India travels (2k€ each) and long stay in India for the Research Engineer iv) **5k€** of internal billing for cloud computation and v) **15k€** of other external expenses including consumables and publication fees.

Partner 3: TSE-R (http://www.tse-fr.eu/umr-tse-r?lang=en) is the second French research department in economics in terms of permanent researchers and scientific publications. Its research topics include environmental and resource economics, and in particular empirical and theoretical analysis of water use and management, and deign of public (environmental) policies. TSE-R has built strong links with French and international research teams through a variety of interdisciplinary projects on water issues, biodiversity conservation and environmental impacts of land use change and agricultural practices.
Dr. Alban Thomas (refs 131, 133) is a senior researcher in agricultural and environmental economics with the French Institute for Agricultural Research (INRA) and Toulouse School of Economics (TSE), and he is the head of the Social Science Division at INRA. His research topics include the empirical analysis of environmental impacts from agriculture, the evaluation of environmental policies, water use and tariff design, and the adoption of innovative agricultural systems. He has coordinated several scientific expertises on water and the environment for ministries and international institutions (World Bank, Inter-American Development Bank, Economic Research Forum). He is coordinating since 2014 the interdisciplinary Inra-Cirad ten-year programme GloFoodS on transitions towards global food security. Other scientist involved at TSE-R are **Arnaud Reynaud** (DR INRA natural resource economist with a strong specialization in water economics) ; **Stefan Ambec** (PR Toulouse School of Economics, impacts of environmental policies) and **Stéphane Couture** (CR INRA), natural resource economics, design and implementation of bioeconomic decision models for farm and natural resource management and **Stéphane Cézéra** (IE2) computer science.
The net budget of TSE-R (26.40 k€) includes i) 6 month stipend for a master student (around **3,4k€**), ii) travel costs (**12k€**) including local travels for field work, attending annual project meetings and one conference, and international travels from France to India, iii) **10k€** of other external expenses including books, documentation and software.

Partner 4: University of Rennes 2 is the more important center of research and high education in letters, languages, humanities and social sciences of the West of the France. It integrates the LETG lab (UMR 6554 CNRS, 170 members). LETG research activities fit in the fields of geography and environment. Its research topics are the study of interactions between nature and society at different scales on areas characterized with important environmental and societal problematics. A specific research topic is developed on the study of the interactions between the land use and land cover dynamics at different scales and the climate change. For this purpose, remote sensing data represents an important expertise of the LETG Rennes COSTEL which is involved in numerous international interdisciplinary projects in the framework of the global change (agricultural landscape monitoring, deforestation in tropical regions, urban spread…).
Dr. Samuel Corgne (refs 26, 27, 28, 42, 43) is professor of Geography at the University of Rennes 2 and member of the UMR LETG 6554 CNRS (LETG Rennes COSTEL). His research topics focus on the study of the

land use dynamics on agricultural areas in interaction with environmental problematics (water quality, soil erosion, biodiversity…). The identification, characterization and modelling of the land use and land cover changes with remote sensing data at high spatial resolution on agricultural landscapes constitute his main research activities. He is involved in numerous research program of Spatial Agencies (CNES, ESA, DLR, JAXA…) to evaluate new optical and SAR sensors at high spatial resolution for the land use monitoring. **Pr Laurence Hubert-Moy** (Geographer, remote sensing) will be involved in the project.

The net budget of the University of Rennes 2 (**55.526k€)** includes i) Salary of Study Engineer for the constitution of a Geographical Information System on the study area (4 months, **12.625k€**, see description below) and stipend for 2 master students (**6.788k€**) on optical and radar data processing ii) Equipment (**3k€**, computers and software for the Engineer) iii) **12k€** for 6 France-India travels (2k€ each) iv) **17k€** of other external expenses including consumables, research valorization (conference and publication fees).

Partner 5: The UMR Geosciences Environnement Toulouse (http://www.get.obs-mip.fr/) is part of the Observatoire Midi-Pyrénées and gathers more than 160 permanent staff in Earth Sciences and Environment

Dr J. Riotte (refs 12, 101, 123, 129, 130) is geochemist at the French Institute for Research and Development (IRD) since 2003, specialist of the dynamics of weathering processes and biogeochemical cycles in tropical systems, from the soil-plant to the watershed scales, through the use of natural tracers such as major and trace elements or Sr, Si and U-Th isotopes. J. Riotte is the French chairman of the **International Joint Laboratory "Indo-French Cell for Water Sciences"** (LMI CEFIRSE / IJL IFCWS), set up in 2001 and located at the Indian Institute of Science (Bangalore). Associating 3 Indian Institutions (IISc, NIO, IITM) and 5 French Institutions (IRD, INRA, CNRS, Univ. of Toulouse and UPMC), it involves the equivalent of 30 full time equivalents of researchers, of which 7 French scientists on deputation in India, and 28 PhD students. Scientific activities are pursued around four research themes: (1) Adaptation of pristine & agro- systems to global changes, (2) Continuum ocean-continent-atmosphere: Hydrological cycle & climate variability, (3) Environmental biotechnology and bioremediation, (4) Urban catchments & water systems. Since 2014, the Cell has been highly productive, and has published about 80 articles, many of high impact, due to the excellence of the people and teams involved. J. Riotte is also responsible for the **Environmental Observatory "Small Tropical Experimental Watershed**" (http://bvet.obs-mip.fr). The Environmental Observatory, of which the Berambadi watershed belongs to, provides the international scientific community with unique decennial time series of climatic, hydrological and geochemical variables. More specifically, the SO-BVET aims at (a) determining the fluxes of water, of inorganic and organic matter present in solution (major anions and cations, carbon) and in suspension (particulate organic carbon); (b) proposing budgets of chemical weathering and physical erosion; and (c) evaluating the impact of agriculture upon the above parameters. Its strengths are (1) multiscale approach of nested watersheds, from small experimental watersheds (SEW) to river basin and (2) multidisciplinary approach, currently involving hydrology, geochemistry, soil science, agronomy, remote sensing and ecology.

UMR GET will host the activities **of D. Serça, C. Delon (Laboratoire d'aérologie, OMP)** who are specialists of measurement and modeling of nitrogen gaseous emissions, and **S. Mangiarotti (CESBIO, OMP)** who is a specialist of Environmental modeling.

The net budget of GET, 56.75k€ includes i) stipend for 2 master students (**6,75k€,** 6 months each), ii) travel costs, mainly international travels from France to India for setting up the monitoring for GHG and solute budgets of C and N, local travel for field trips, one conference (**10k€**), iii), consumables such as rhizon samplers, chromatography columns, flasks for field experiments (**20k€**), chemical analyses (**15k€**), iv) small equipment (computer, pH-conductivity probes) (**5k€**).

Partner 6: UMR EMMAH (INRA-UAPV), (http://www6.paca.inra.fr/emmah_eng/) is a multidisciplinary research unit which scientific objective is to develop knowledge and tools for analysing and predicting the impacts of global changes (climate, land cover, agricultural practices) on water ressources and agricultural production at the territory scale. Strong expertise in soil and crop modelling, measurement systems, remote sensing and methods for combining models and observations has been developped for describing landscapes evolution and interactions between surface processes and groundwater behaviour.

Samuel Buis (refs 44, 150, 151, 164, 166) is "Responsable Scientifique" of EMMAH for ATCHA. **He will lead the Work-Package 1**. He is a Research Engineer in applied mathematics since 11 years at INRA. His research focus on the development and application of mathematical methods for modelling, e.g. model inversion, model evaluation, uncertainty and sensitivity analysis ... He has extensively worked on crop model inversion for retrieving soil properties and on the development of mathematical tools for the STICS crop model. He is assistant coordinator of the STICS Project team.
UMR EMMAH will host the activities of **P. Lagacherie (URM LISAH),** soil scientist and expert in DSM technics, leader of task 1.2 ; and some of the **STICS** team members implied in task 2.1 : **N. Beaudoin (UR AgroImpact- INRA)**, coordinator of the STICS Project Team**, D. Ripoche (US AgroClim - INRA**), computer science engineer responsible for the development of the STICS model.
The net budget of EMMAH (74.20k€) includes i) stipend for 3 master students for task 1.2 (**10.2k€**) ii) Equipment (**5k€** computers and software licence for the students) iii) **39k€** for international travels from France to India for attending annual project meetings, delivering annual STICS training in India, funding long stay in India for the Crop Modelling Research Engineer and two international conferences iv) **20k€** of other external expenses including consumables for STICS trainings (USB keys, STICS books, printings, ...), conference and publication fees.

Partner 7: IFP, French Institute of Pondicherry, India: (http://www.ifpindia.org/) is an interdisciplinary research unit, based in Pondicherry (South India) since 1955 under the umbrella of French Ministry of Foreign affairs. It has developed extensive networks with institutions of excellence in India and local partnership in the field of Social Sciences, Ecology, Indian Classical Studies and Geomatics.
Dr. A Richard-Ferroudji (refs 57, 128, 163) is "Responsable Scientifique" of IFP for ATCHA. **She will lead the Task 3.3**. She holds an engineering diploma in water management and a Ph.D. in Sociology. She worked for 11 years at IRTSEA (ex-Cemagref), a French research institute for environmental and agricultural engineering where she contributed to the development of social sciences approaches in interdisciplinary issues, especially with regards to the nexus of water and agriculture. She was involved in several interdisciplinary projects dealing with integrated water management, including designing and the implementing a participatory process involving farmers. IFP team includes Dr. Venkatasubramanian, socio-economist, who has long experience in qualitative and quantitative surveys in rural India.
The net budget of IFP (34.16k€) includes i) 6 month stipend for a master student (**3,36k€**) ii) subcontract (**5k€**) for translator for the field work, for editing documents (Kanada/English) and transcription of audio recording of the participatory workshop and interviews iii) travel costs (**15k€**) including local travels for field work for permanent team (3 weeks per year), trainee (3 months), and translator (6 months)), attending annual project meetings, and one conference, and international travels from France to India, iv) **5k€** Internal billing for using IFP car for the field work in rural areas and guest room for the master student v) **5.8k€** of other external expenses includes one computer, one portable hard disk, one recorder for interviews and workshops, conference and publication fees.

Implication of Indian partners

The project will build on the **Indo-French partnership** initiated during the CEFIPRA project: **IISc** Bangalore/LMI CEFIRSE (Hydrology, hydrogeology, remote sensing - Pr M Sekhar, Pr MSM Mohan Kumar) and **ATREE**- Ashoka Trust for Research in Ecology and the Environment (Social sciences – V Srinivasan, S Badiger). It will be expanded to the consortium gathered by the Karnataka Watershed Department under the Sujala III project. The partnership with these institutions will allow the current proposal to have a **direct impact on capacity building of Indian institutions and dissemination of scientific results for extension services to stakeholders.**

IIsc (Indian Institute of Science) is the premier institute for advanced scientific and technological research and education in India. A strong collaboration has been developed since 2001 between IISc and the proposing French team through the **IJL CEFIRSE** (see above).
Pr M Sekhar (refs 12, 101, 123, 129, 130) interests span Hydrology, hydrogeology, nutrient transport and

remote sensing. He is member of IJL CEFIRSE and **co-PI of the CEFIPRA AICHA project with L Ruiz** and partner in **the Sujala-III project**, in charge of agro-hydological monitoring. He is responsible for the monitoring of Berambadi watershed (**5 project assistants**) and 2 micro-watershed in the Sujala-III project. He is guiding **5 five IISc PhD students**, whose work is based on this observatory. **Pr MS Mohan Kumar,** Hydrologist, specialist of groundwater management issues in India and co-chairman of IJL CEFIRSE is also involved.
In the project, in addition to active participation in research activities, IISc will be in charge of the organization of the 4 workshops, field surveys and of the logistic of field work for the different researchers and student visits (**70k€** of external services).

ATREE (Ashoka Trust for Research in Ecology and the Environment) is a research institution based in Bangalore, India. It has acknowledged experience in the areas of biodiversity conservation and sustainable development. It is one of the few institutions in India promoting interdisciplinary approaches integrating research with policy and action in addressing key environmental problems. ATREE is a key partner of the Indo-French cell of water science **IJL CEFIRSE** since 2010, and coordinated the extensive surveys of agricultural practices and farmer's vulnerability in the Berambadi watershed during the CEFIPRA AICHA project.
Dr Veena Srinivasan (refs 148, 153, 154, 155) is socio-hydrologist. She has a strong experience in studying the bi-directional feedback in human-water systems and comparative studies of socio-hydrologic systems, from local to regional to global scales. Her involvement in the participatory workshops will be crucial for bridging the gaps between natural scientists, social scientists and stakeholders. Other scientists involved in the project are **Dr Srinivas Badiger,** socio-hydrologist (Land, Water and Livelihoods Programme) and member of the previous CEFIPRA AICHA project is also involved.
There is no budget required for this partner; expenses linked with surveys will be taken care of by IFP and costs linked with involvement in participatory workshops by IISc.

WDD (Karnataka Watershed Development Departement) is a state government body created in 2001 to federate the different Departments (Agriculture, Forests, Livestock, etc.) involved in watershed management (http://watershed.kar.nic.in/) in the objective to create a multidisciplinary team to achieve the watershed objectives. It is charge of formulating policies, planning, organizing, co-ordinating the activities and implementing several projects including the Sujala-III project (World Bank).
Main scientific partners in Sujala-III are National Bureau of Soil Sciences and Land Use Plannnig (NBSS&LUP), Indian Institute of Science,(IISC), Bangalore, University of Horticultural Sciences (UHS) in Bagalkot; University of Agricultural Sciences (UAS) in Dharwad, Raichur and Bangalore; Karnataka State Remote Sensing Applications Centre (KSRSAC), Bangalore Karnataka State Natural Resource Disaster Monitoring Cell (KSNDMC), Bangalore. Agricultural extension services organisations are Raitha Samparka Kendra (RSKs) and Krishi Vignana Kendra (KVKs). Staholders are District and Taluk level Watershed Teams and Watershed Committees, and Community Institutions such as, Farmer Groups Producers Groups, HOPCOMS (cooperatives), NGOs and Local Self Government Institutions like Gram Panchayaths and Zilla Panchayaths.
Details of Sujala-III project can be found at: http://watershed.kar.nic.in/SujalaIII_Doc.htm, including location of the 14 micro watersheds and the characterization and monitoring carried out by the project partners.
There is no budget required for this partner; All expenses linked with the monitoring of the 14 experimental watersheds are taken care of by Sujala III project. About **10 PhD students** from the four Agricultural Universities are involved in field monitoring and analyses in Sujala-III and their scholarship is provided by their university; Costs related to the participation of the Sujala-III members in training sessions on metrology, data analysis and modelling and in participatory workshops will be taken care of by IISc.

Short description of non-permanent staff hired by the project

IE land use land cover (4 months) / Geographer with competence in Geomatic, Remote Sensing and environmental problematics; The Engineer will hired during the first months of the project. His t will include i) integrating all the spatialized information useful for the project (land use, hydrology, climate, etc.) in a WEB

GIS (Geographical Information System). The objective of his first task is to provide for the other partners of the project geographical information easily available (with metadata, homogenous coordinate systems…). Second, the engineer will be involved in the remote sensing data processing for land use and land cover mapping. He will participate to pre-processing, classification and analysis of the satellite images acquired on the study area. Here also, all productions (classifications, plots delineations,…) will have to be clearly formatted and integrated in the GIS "ATCHA".
Skills required : Good knowledge of GIS, remote sensing, management data of using Python, ability to work in team and with numerous disciplines, English (fluent)

IR crop modelling (24 months) / Agronomy, statistics, crop modelling
The engineer will be hired for the first 2 years of the project and will lead task 2.1 on the STICS model calibration for new species. He/She will perform the following activities: 1) Create a database including published data, experimental field data collected on the Berambadi and Sujala-III watersheds, and unpublished data from partners of Agricultural Universities 2) Develop a methodology to calibrate a large range of species in collaboration with members of the STICS team 3) Calibrate new species and mathematical optimization with existing tools such as OptimiSTICS and evaluate the simulations 4) Contribute to build a network between Indian crop modeler and experimentalists.
Skills required: Agronomist, crop modeler with strong interest and ability in statistics. Ability to work in network with Indian students and researchers. English (fluent)

IE Integrated Model (24 months) /Computer science, interest in agriculture and environment
The software engineer will perform the following activities during the first 2 years of the project: 1) gather all the software components produced by the different WP (models and data), test and adapt them in order to be plugged onto the RECORD platform, 2) participate to the integration process in order to build the model and test it 3) participate to the design and the development of the information system required by the project, 4) participate to the scenario simulations. The process will consist of the following steps: becoming aware of the scientific problematic, the needs and the constraints of the project, implementing the software development required by the adaptation of the different models and their coupling, carrying out the software tests, conducting the deployment of collaborative tools (in particular for software work and the information system that will help in the management of the big amounts of data that are required and will be produced by the scenario simulation work), building software documentation,.
Skills required: good knowledge of algorithmic, C++ language, R software, management of data using databases such as Postgresql, ability to work as part of a team, English (fluent).

IR "assessment and design" (24 months) / systemic agronomy
The engineer will be hired in the end of the second year of the project. He will focus on the scenario construction (stories, media tools …) and outputs/feedback analysis between stakeholders and scientists. He/she will perform the following activities 1) Organisation of the two last annual workshops (logistic, contact with stakeholders), 2) Facilitation of the workshops (design and assessment of scenarios with stakeholders), 3) Analysis and synthesis of stakeholders outputs and 4) Interaction with the RECORD team to transform scenario storylines into model inputs and to analyse and represent model outputs
Skills required: Agronomist, good knowledge in systemic agronomy (farming practices and constraints), capacity of conceptualisation, knowledge of facilitation techniques or facilitation capacities, ability to work as part of a team, GIS and R user, English (fluent).

3. Project impact, development, strategy of results protection and exploitation (2 à 3 pages)

The proposal will contribute to the **challenge 1 (Défi 1) " Efficient ressource management and adaptation to climate change**" of the ANR's work programme 2016, **axis 6: "Integrated approaches for sustainable development of territories".** This axis specifically calls for building "methods to accompany territorial projects with the help of modeling and scenarios". The focus on South Indian agriculture is in pace with the priority given to "South countries, vulnerable zones with little adaptation capacity". By addressing the interactions and feedback at stake in socio-agrosystems, and with a strong involvement of extension service institutions and stakeholders, the project will contribute to accompany the adaptation of these vulnerable systems in the context global changes. The project will also contribute to **"axe 1": fundamental knowledge in relation with the challenge**, by bridging knowledge gaps on water, carbon and nitrogen cycles in tropical agro-systems. The project falls primarily within the objectives of **Orientation 2 (Evaluation and management of climate and environmental risks**) and secondarily Orientation 3 (**sustainable management of natural resources**) of the National Research Strategy (SNR).

The present proposal is clearly a **"Collaborative Research Project (PRC)"** as he will foster the development of a strong and well-structured French trans-disciplinary community on Integrated Assessment issues. **The proposal has a strong potential in terms of academic production** (peer review articles and conferences), as all the WP will produce innovative results either methodological or by bridging knowledge gaps. In addition, the trans-disciplinary objectives are expected to lead to generic collaborative papers, both on methodologies (Platform for integrated modelling, scenario building and assessment…) and on generic process driving agricultural systems vulnerabilities. **These generic results are expected to be relevant in a large range of vulnerable situations, in France and worldwide**.

All data and metadata produced during the course of the project will in open access, except for data concerning personal privacy (such as nominative survey data). Data will be made available through the project website and through dedicated web services. The geoportal developed for the Cefipra project (http://geowww.agrocampus-ouest.fr/portails/?portail=aicha) will be used and developed for sharing spatial data. Data will also be available through web portals at ORE BVET (http://bvet.obs-mip.fr/fr) and SOERE RBV (http://portailrbv.sedoo.fr/).

As India is not among the countries involved in the 2016 call of ANR, PRCI was not an option. If water is clearly a priority for the Indo-French and Indo-European partnerships, until now Indo-French calls have been focused on development of technologies for urban water supply and treatment. We believe that the socio-economic and environmental issues related to the sustainability of agricultural water resources (representing 92 of total water use) should deserve at least as much interest. **The success of our ANR project would be an opportunity to foster the interest of Indo-French collaborations** on those aspects. Although the Indian institutions cannot be funded by ANR under the current proposal (except through exchange visits of scientists and students, and service delivery for farmer surveys) their implication is secured by the fact that they are already involved in the collaboration mostly through Indian funding and they have expressed an urge for a support in capacity building from the French teams involved in ATCHA (crop modelling, participatory approach, social science).

The socio-economic impact is potentially huge: **the agricultural system under scrutiny concerns several millions of farmer in peninsular India**, and the current agrarian crisis has a tremendous impact in terms of food security, resource management, energy consumption. Awareness among the Indian population, linked with the traumatism caused by the publicity given to the growing rate of farmer suicides, has fostered an urge from the policy makers to implement quick and efficient solutions. However, programs of public subsidies for agriculture (fertilizers and pesticides, free electricity for pumping, new technologies…) elaborated through top-down approaches, are poorly efficient and often counterproductive, as farmer strategies are not taken into account. For example, we observed that the large subsidies given to promote drip irrigation led to increase in irrigated surfaces and shift to crops with higher water requirements (banana), worsening the watershed water balance, and likely to increase soil salinity issues. **By promoting a better dialogue between scientists, policy makers, extension services and farmers, our project is likely to improve significantly this situation in Karnataka, and serve as a generic example**. In addition with the direct collaboration with stakeholders during the course of the project, a national workshop involving scientists and policy makers will be organized in the last year to disseminate our results. Funding for this workshop should be secured through existing Indo-French mechanisms (CEFIPRA and Indo French Network for Water Sciences). In addition, MOOCs will be developed for training students, scientists and extension service agent in environmental monitoring, Digital Soil Mapping and crop modelling.

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Annexe : letter of support from Watershed Development Department, Sujala-III project.

GOVERNMENT OF KARNATAKA

No: : WDD/ED/KWDP-II/IISc-service/2013-14

Project Director & Commissioner
Watershed Development Department,
7th Floor, K.H.B. Complex, K. G. Road,
Cauvery Bhavan, Bangalore-560 009
Dated: 23.03.2016

To,

Dr. Laurent Ruiz,
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Sub : Collaboration with IISc on crop modeling –reg.

Ref: e-mail from Laurent Ruiz Dated:14.03.2016.

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With reference to the above cited subject, we appreciate your initiative to develop appropriate crop models for Karnataka based on LRI database generated under SUJALA-III Project. Since the core objective of SUJALA-III Project is to provide farm specific options/advisories based on LRI data base on conservation, crop yield and ground water management, the initiative is very appropriate at this juncture.

The four packages planned to be taken up under this collaborative research proposal namely Modeling land use and land cover change using multi satellite high resolution data, Digital soil mapping for spatial modeling, calibration of the STICS crop model for sufficient variety of crops under tropical conditions and modeling nutrient cycling in irrigated agro-systems by using the LRI database generated through the SUJALA-III Partners. This will bring out very valuable thematic outputs/models for the benefit of the farmers in the project districts of Karnataka.

The Watershed Development Department is keen to collaborate with the proposed ATCHA project for calibration of validating, particularly of the crop model STICS and for co-building scenarios of farmers adoption to climate change. Further this active collaboration with IISc and Indo French Cell for Water Science, under IISc will form the nucleus for the establishment of Centre of Excellence on crop modeling later in one of the partners institutes.

With best wishes,

Project Director & Commissioner,
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