AICHA

Adaptation of Irrigated Agriculture to climate CHAnge

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IFCPAR/CEFIPRA 4700_W1
february 2013-february 2017
DST-INRA
Cefipra meeting 15th May 2017 REIMS

2010 : DST-INRA targeted call on Water and Agriculture

AICHA project accepted in 2012, started in february 2013

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UMR SAS Sol Agro et hydrosystèmes Spatialisation, Rennes
UMR LERNA Toulouse School of Economics, Toulouse
UMR AGIR Agrosystèmes, agricultures, Gestion des ressources, Innovations & Ruralités, Toulouse
UMR EMMAH Environnement Méditerranéen et Modélisation des Agro-Hydrosystèmes, Avignon
UR RECORD, modelling platform, Toulouse

Indo-French Cell for Water Sciences (IFCWS) Joint International Laboratory
IISc / Institut de Recherche pour le Développement (IRD))

Ashoka Trust for Research in Ecology and the Environment (ATREE), Bangalore, India

UMR COSTEL
Climat et occupation du sol par télédétection, CNRS-Université de Rennes 2

UMR GET
Géosciences Environnement Toulouse (Université de Toulouse, CNRS, IRD)

WATER and AGRICULTURE

Anthropogenic forcing on water and pollutant cycles

Both in India and France :

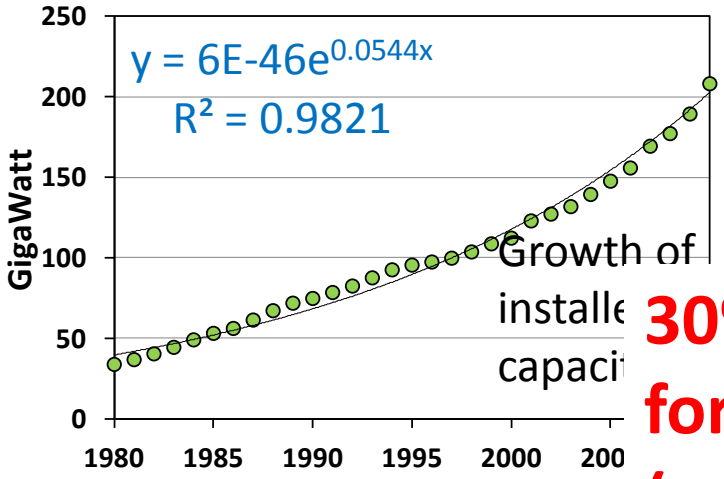
- **Developement of agriculture (*green revolution*)**
- **Increase in food production to achieve self-sufficiency**

Through:

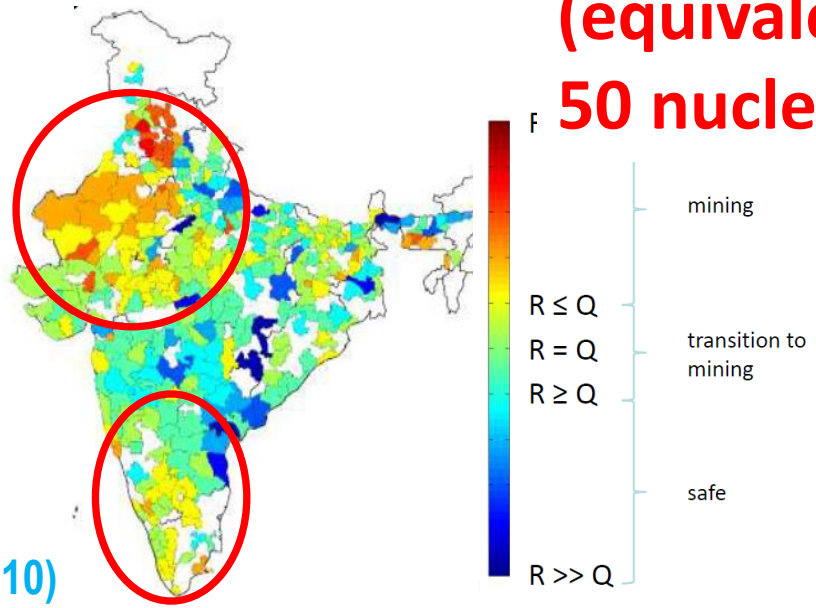
- **Genetics:** Improved potential of crops and animals
- **Increased inputs** to reach that potential
  (e.g. pesticides, fertilisers, mechanisation**, irrigation**)

INDIAN CONTEXT: Agricultural groundwater use linkage with electricity supply (Water – Food – Energy nexus)

Strong growth of electricity consumption

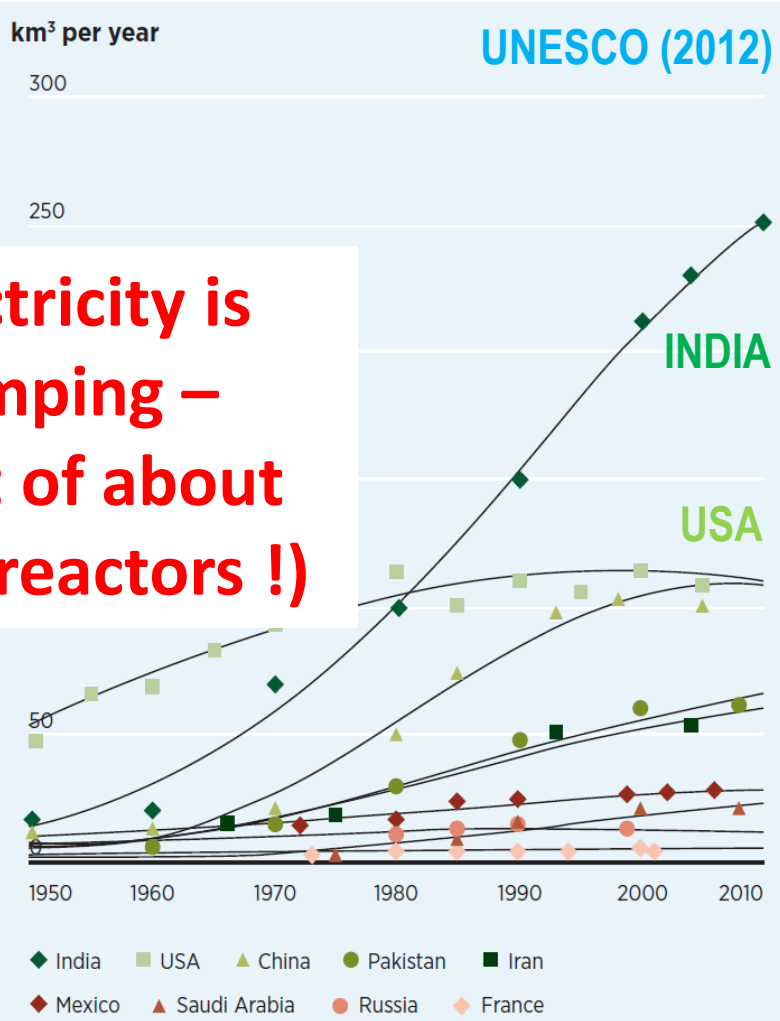


30% of electricity is for GW pumping – (equivalent of about 50 nuclear reactors !)



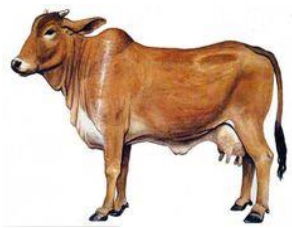
Lall (2010)

Groundwater abstraction trends in selected countries (in cubic kilometres per year)



Indian Agriculture until 19th century = **mostly rainfed agriculture**
+ few open wells + traditional tank system

Agriculture = food-producing for self-consmption strongly integrated with breeding



Herds of local breed cattle = lateral transfert of fertility from marginal land/pastures/forest towards cultivated land

SCA : Céréale/Légumineuse
SCB : Arachide
SCC : Riz irrigué
Parcelles défrichées dans les années 60

Main crops :
Cereals, pulses – some peanut

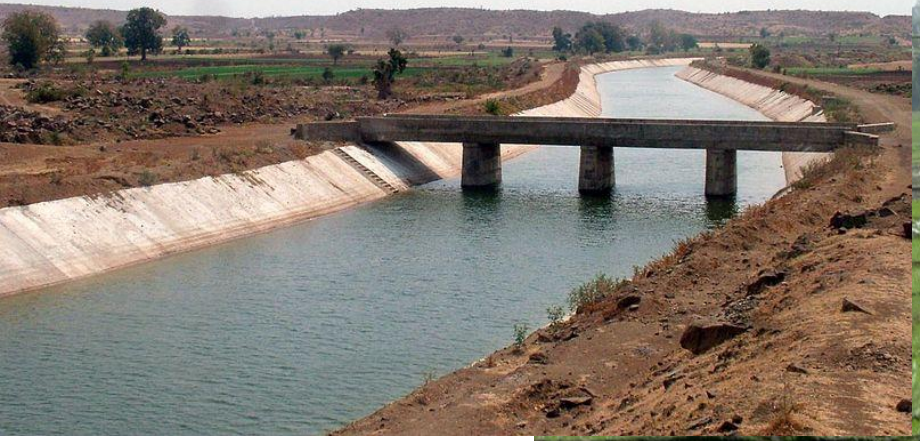
1% of the surface irrigated with tanks

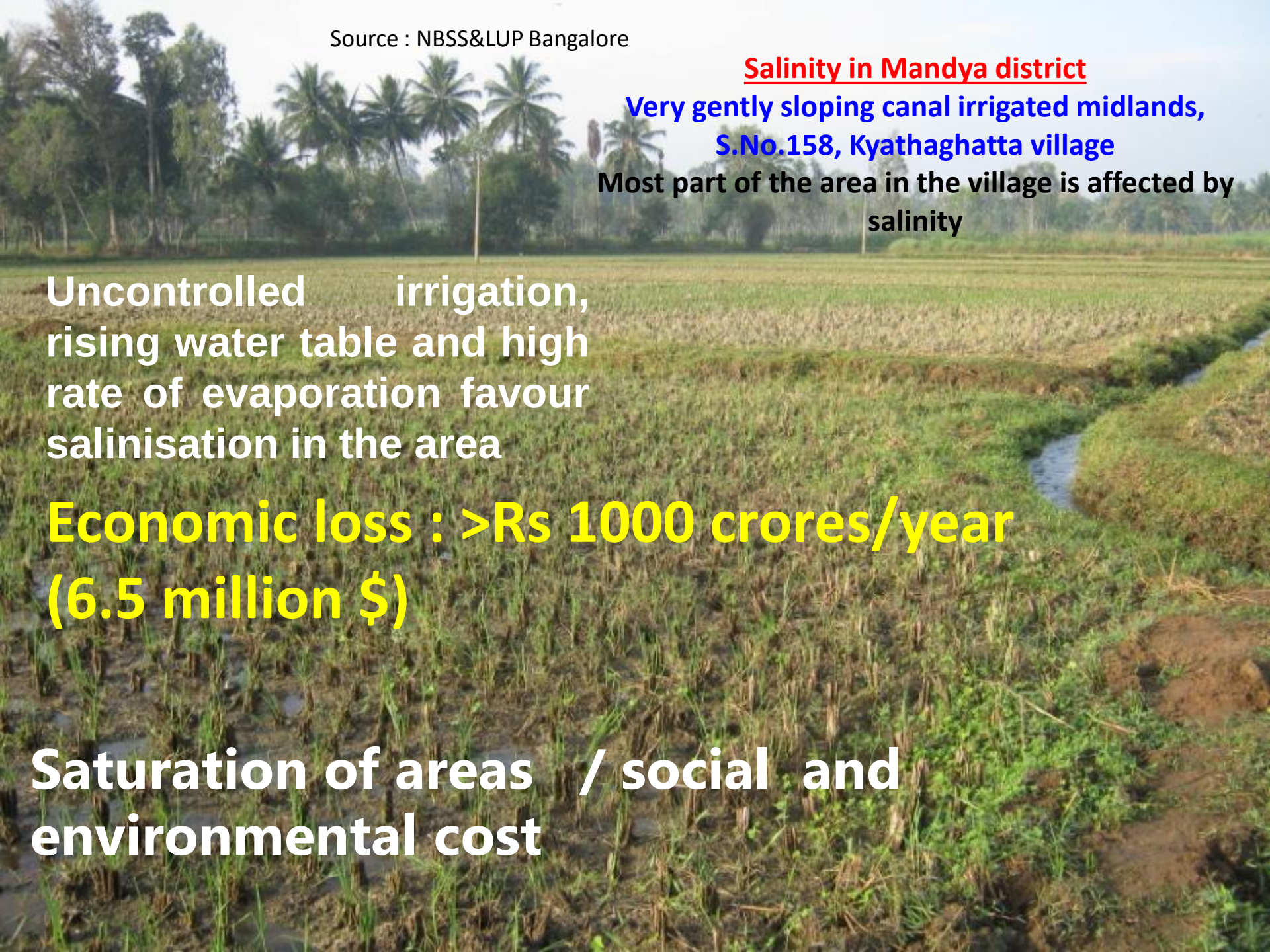
Zone 1
Zone 2
Zone 3

Village en bas de pente
Friche non cultivée
Forêt
Puits ouvert
Tank avec de l'eau toute l'année

1830s until 1980s = from colonial time to **green revolution**
Development of Major irrigation (from rivers coming from mountains = himalayas, western ghats…)

In this case = more crop per drop =
looking for optimal use of available water





Source : NBSS&LUP Bangalore

Salinity in Mandya district

Very gently sloping canal irrigated midlands, S.No.158, Kyathaghatta village

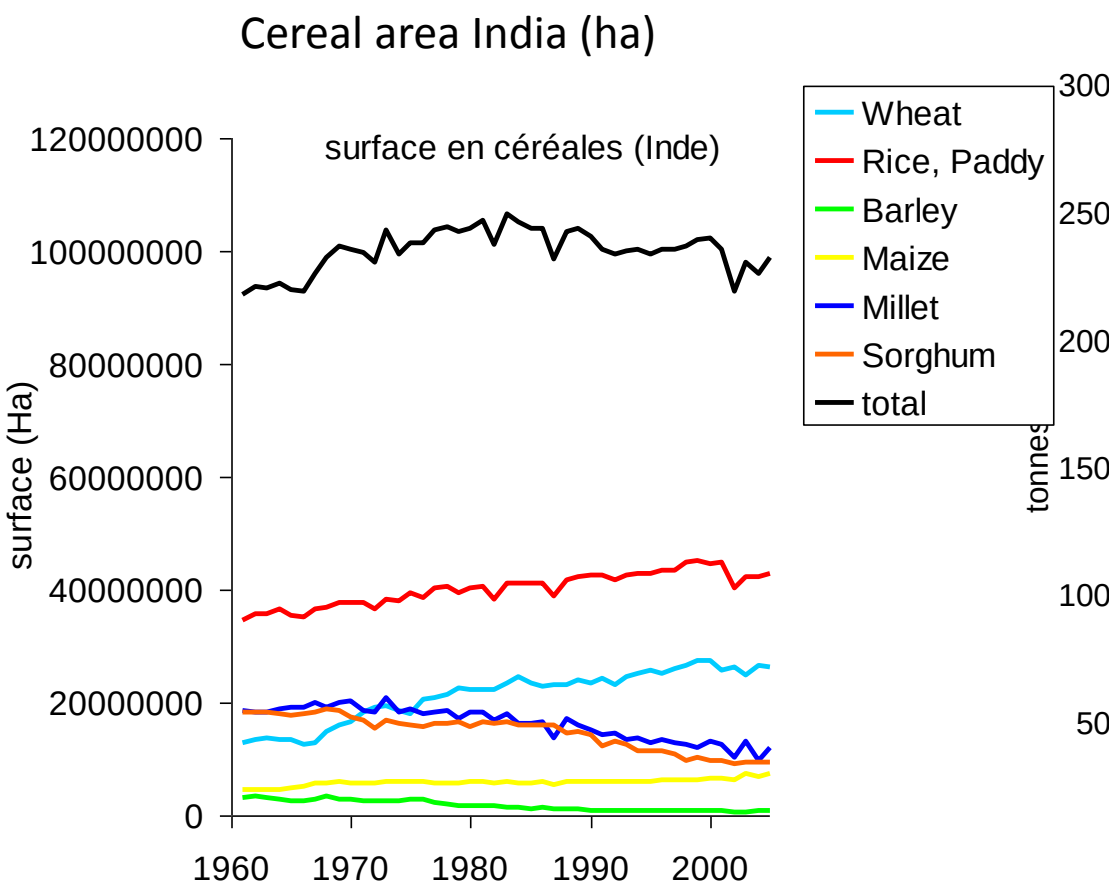
Most part of the area in the village is affected by salinity

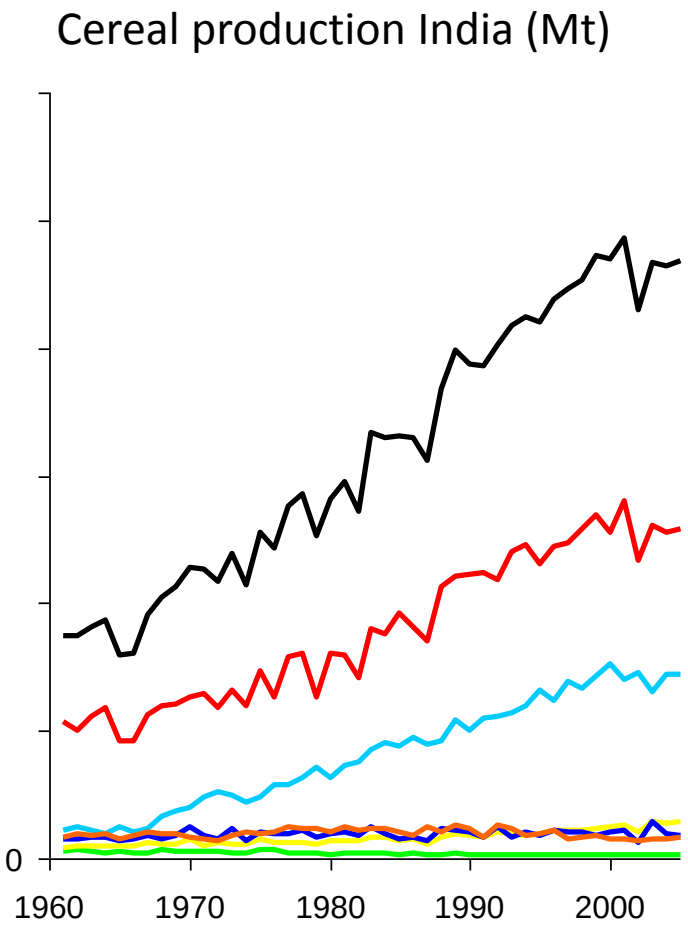
Uncontrolled irrigation, rising water table and high rate of evaporation favour salinisation in the area

Economic loss : >Rs 1000 crores/year (6.5 million $)

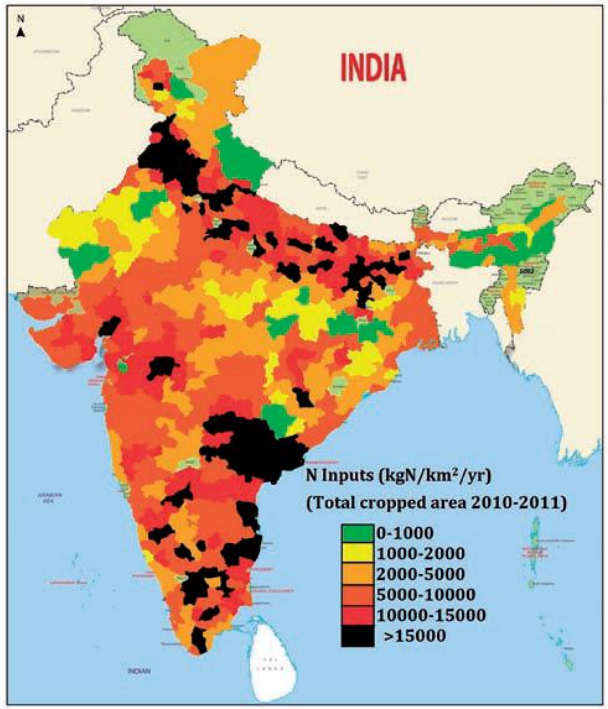
Saturation of areas / social and environmental cost

1970 - 1990: green revolution
based on few improved crops

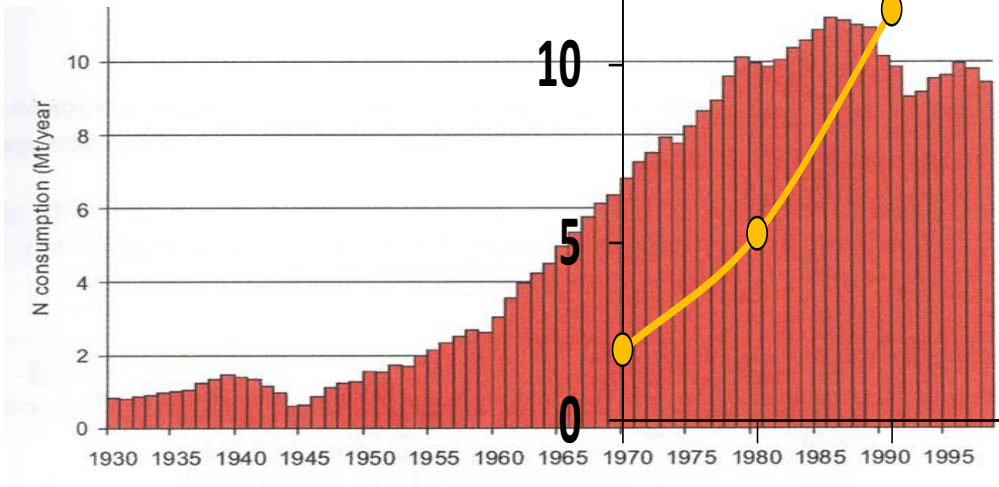




GREEN REVOLUTION = GENETICS + FERTILIZERS + PESTICIDES ~~+ TRACTORS~~ + IRRIGATION

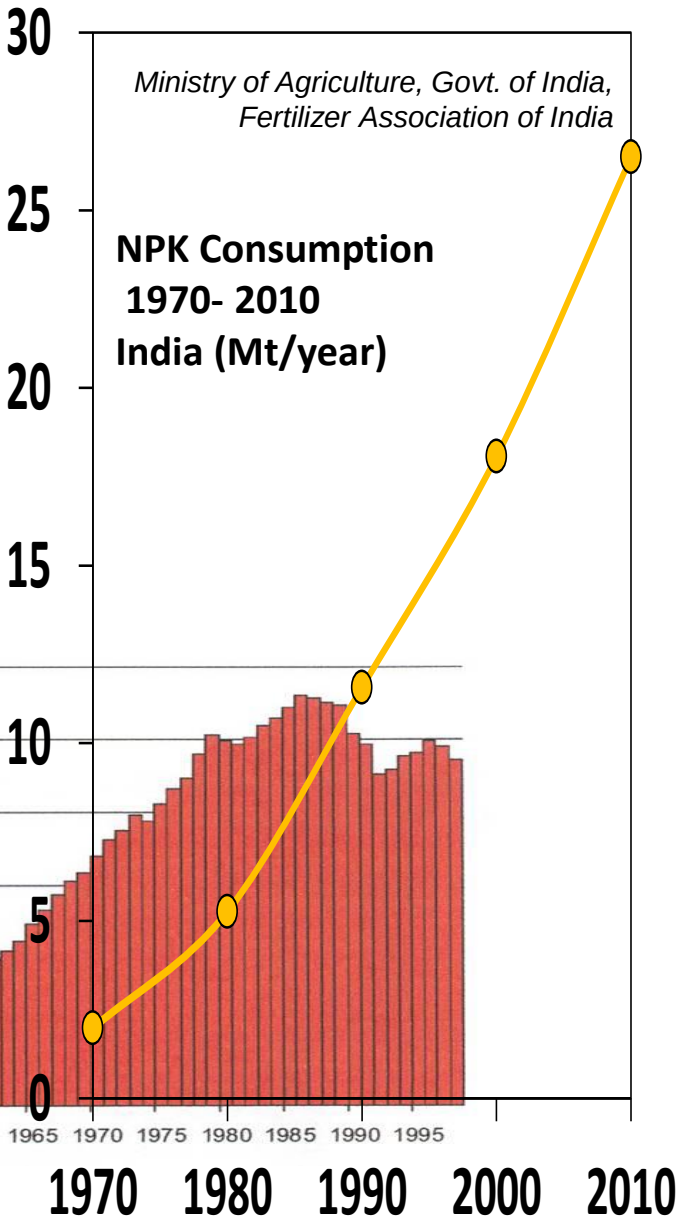


NPK Consumption EUROPE (15 countries)
1930-1999 (Mt/year)



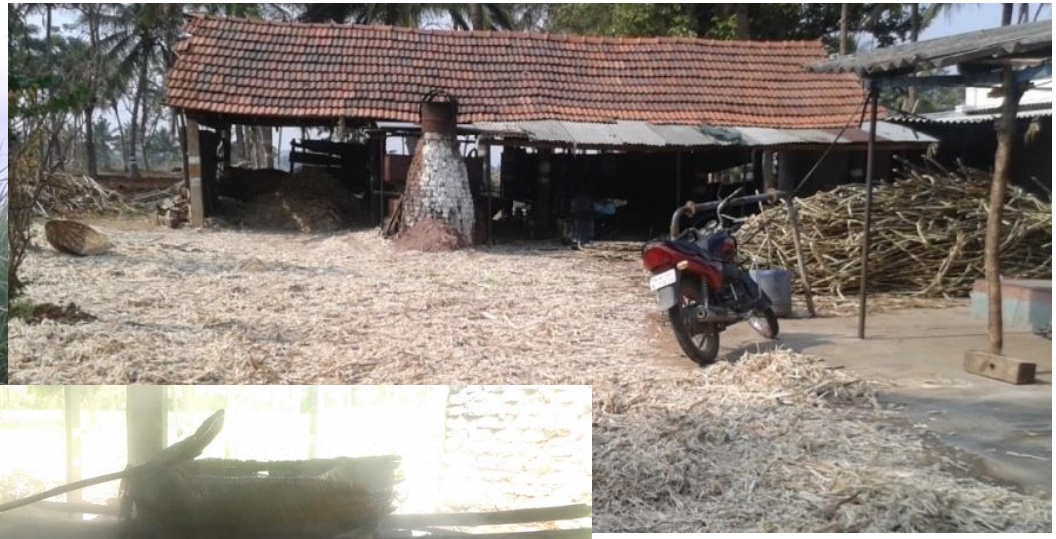
Ministry of Agriculture, Govt. of India,
Fertilizer Association of India

NPK Consumption
1970- 2010
India (Mt/year)



1970-1990 In « rainfed areas » : beginning of open well irrigation (mostly in valleys)

Availability of fertilizer + irrigation = **Sugar cane** …
Only big farmers can invest in Jaggery plants



1980s :

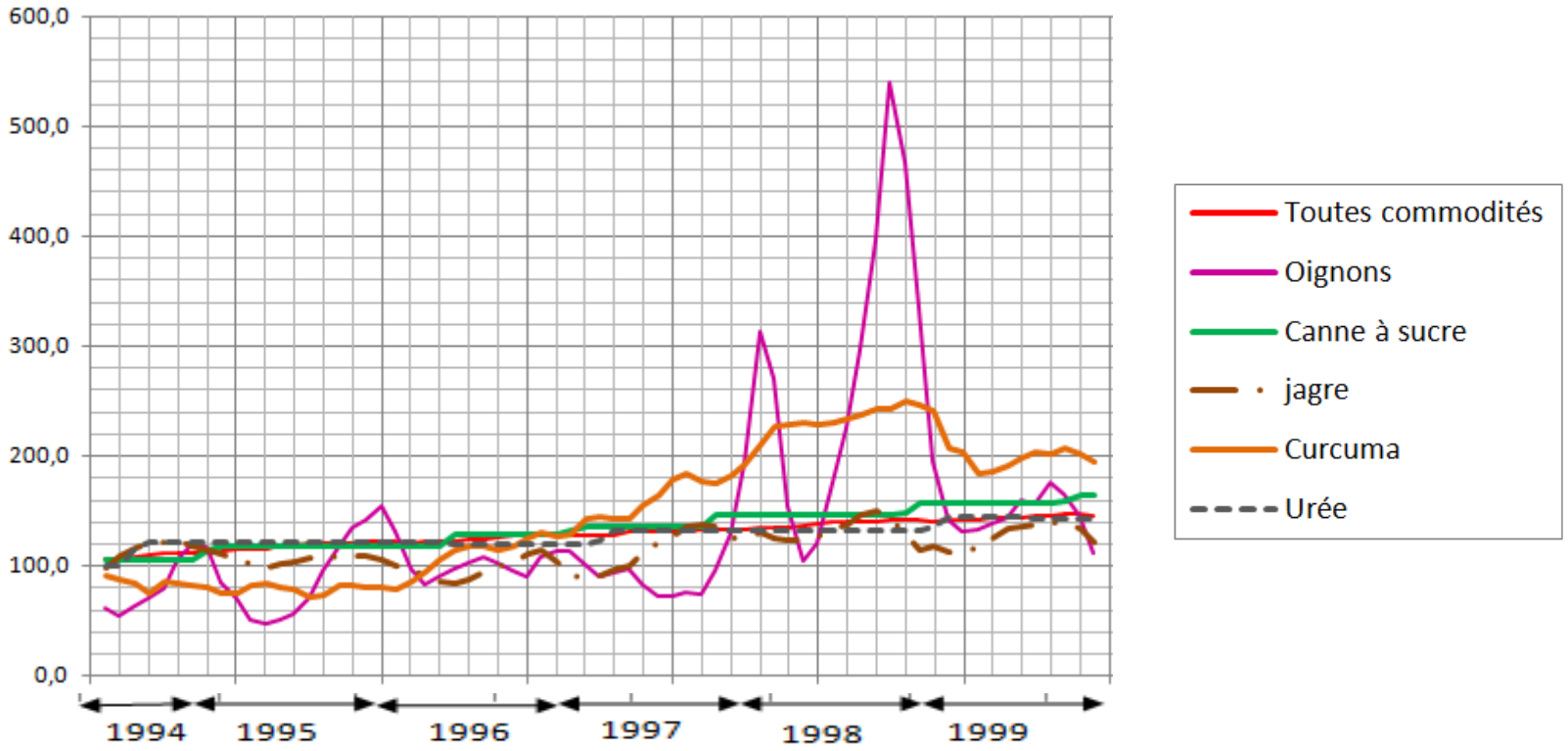
Technology of submersible pump Become affordable : Tubewells = Minor irrigation

PUMP REVOLUTION!

(Molle, Shah et al. 2003)

Incentives for irrigation

- ✓ Sugar cane factories, developpement of crop marketing
- ✓ Free electricity for irrigation (1992 in Karnataka) but limited hours/day
- ✓ Affordable borewells with submersible pumps
- ✓Good prices for irrigated crops



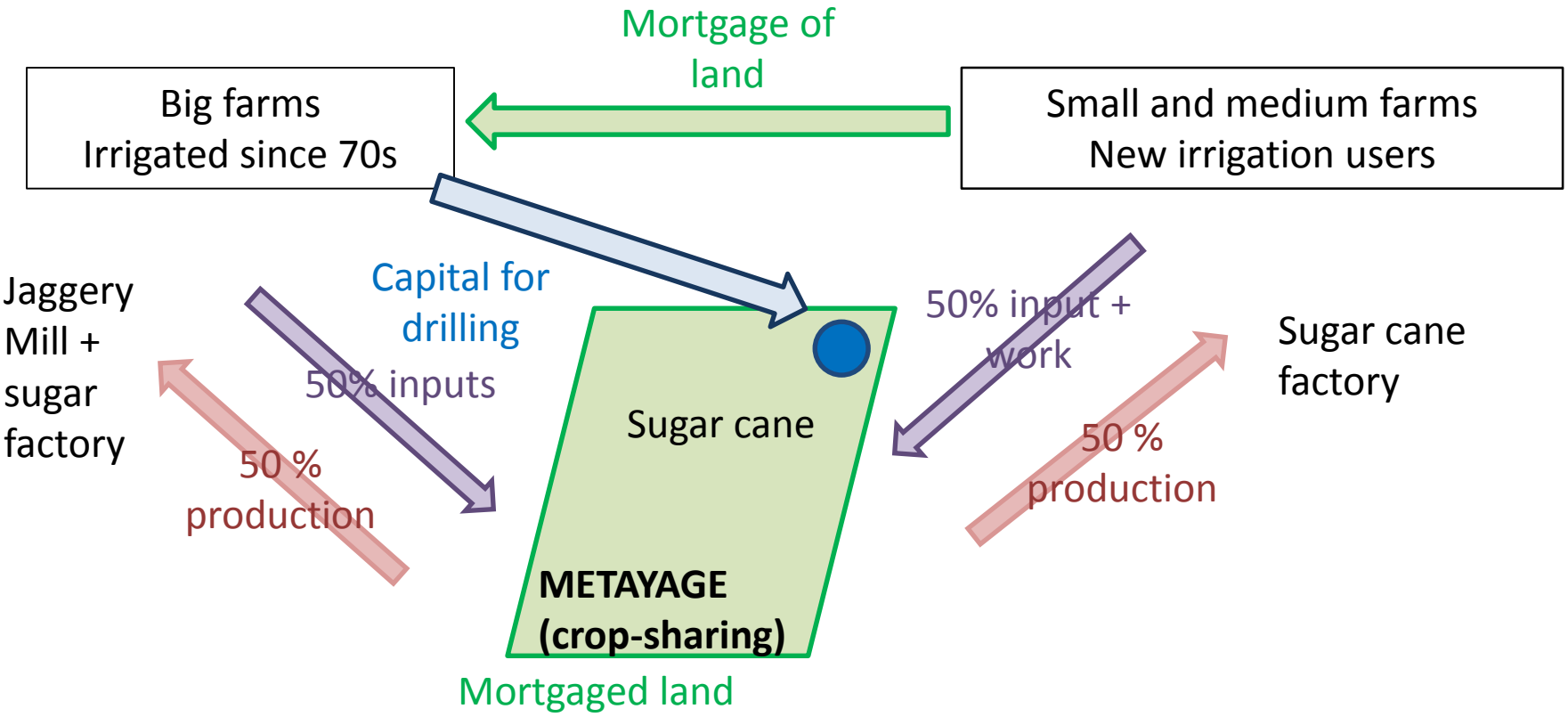
Evolution of monthly wholesale price index (base 100 = 1993 -1994)

Source: Ministry of Commerce and Industry – Government of India

Mechanism for access to irrigation

- ✓ Mobilisation of land and livestock
- ✓ mortgage

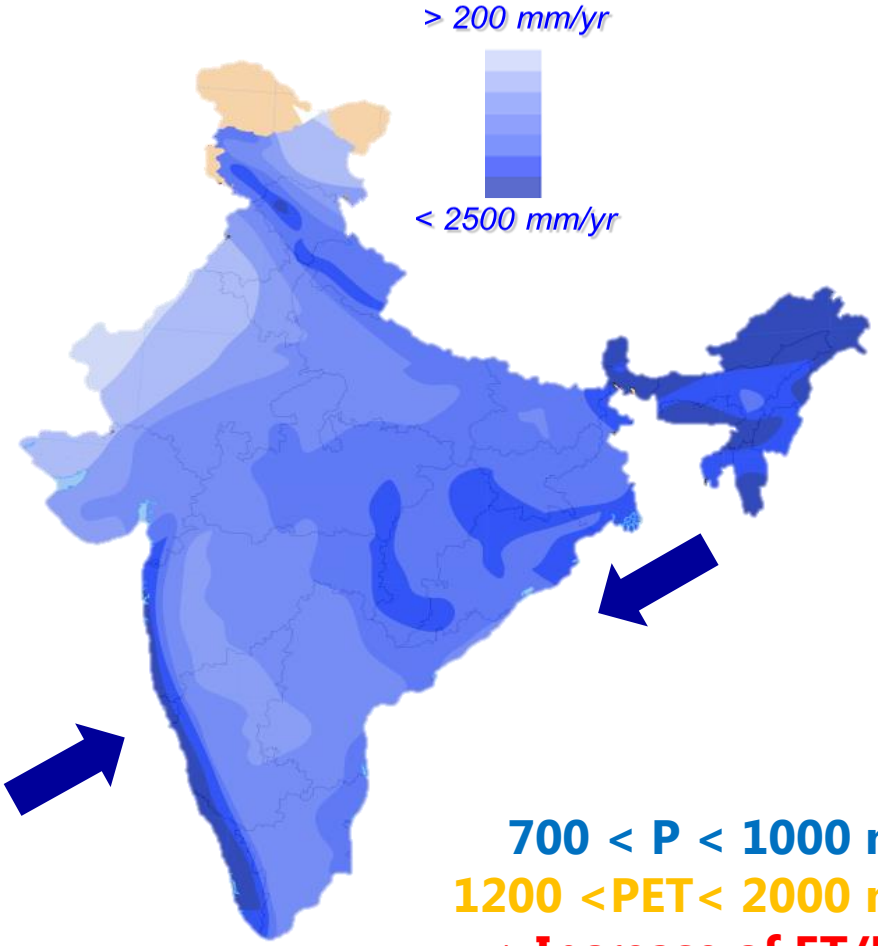
Mécanisme of mortgage

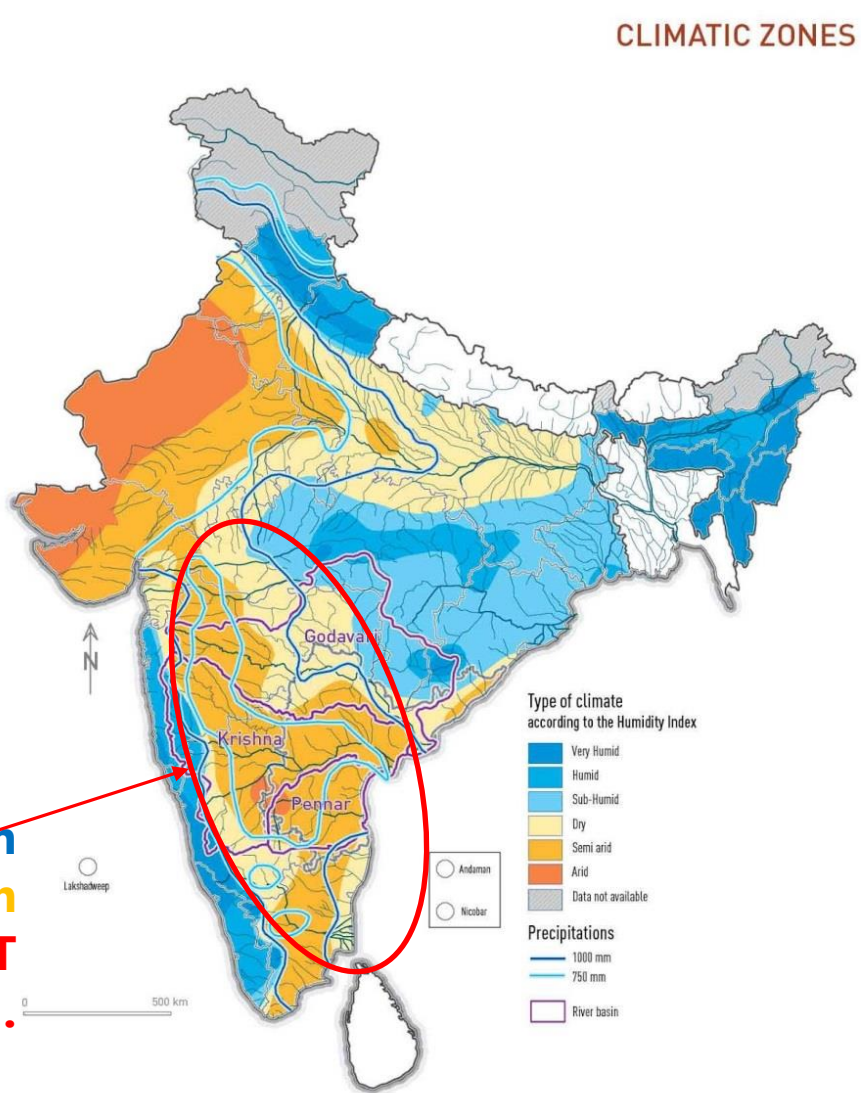


Development of irrigation linked in India with history and specificity of water resources

- Heterogeneous rainfall distribution *(space & time)*

http://water-atlas.blogspot.in/p/chapter-1-andhra-pradesh-in-india.html





700 < P < 1000 mm

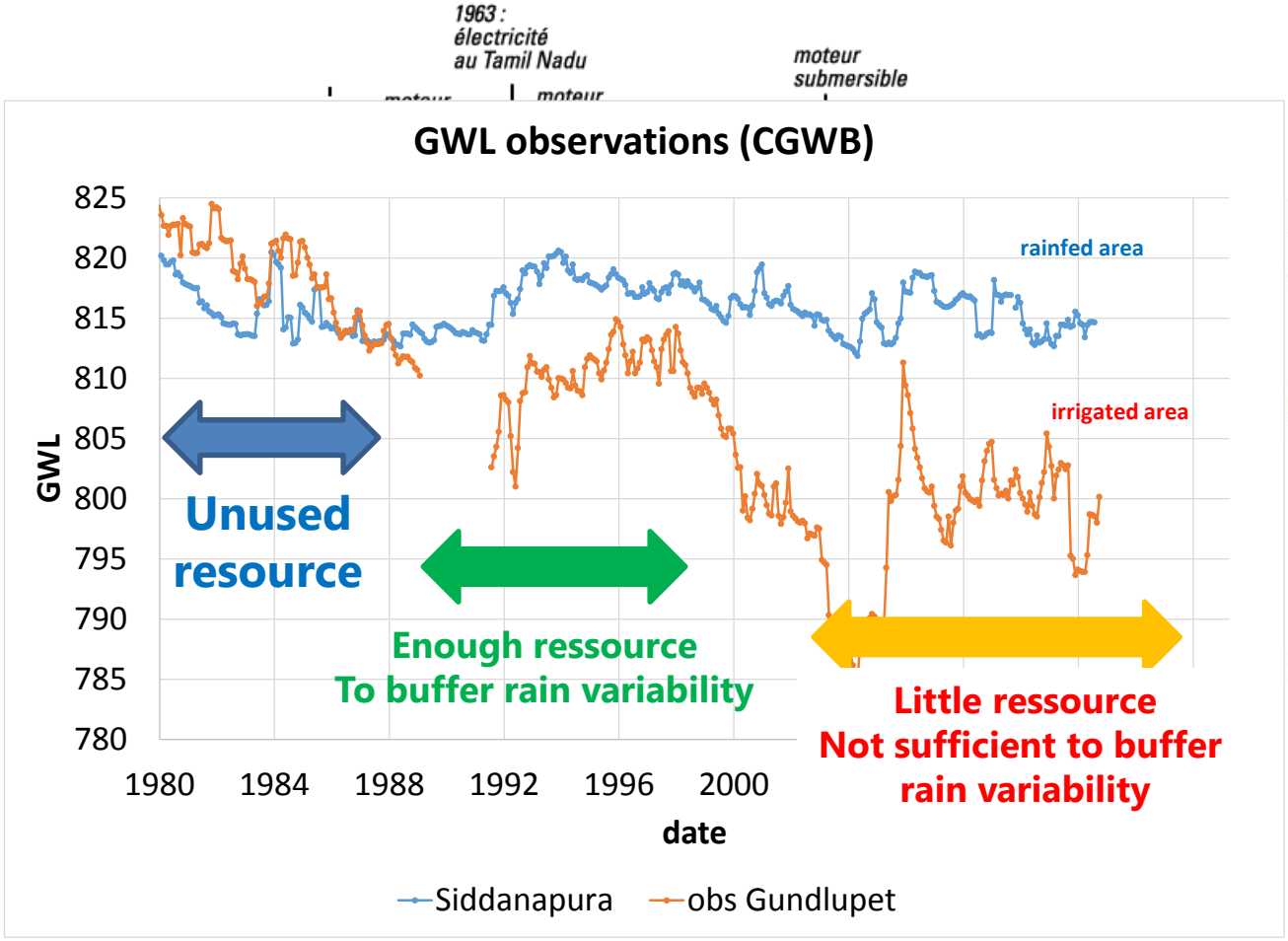
1200 <PET< 2000 mm

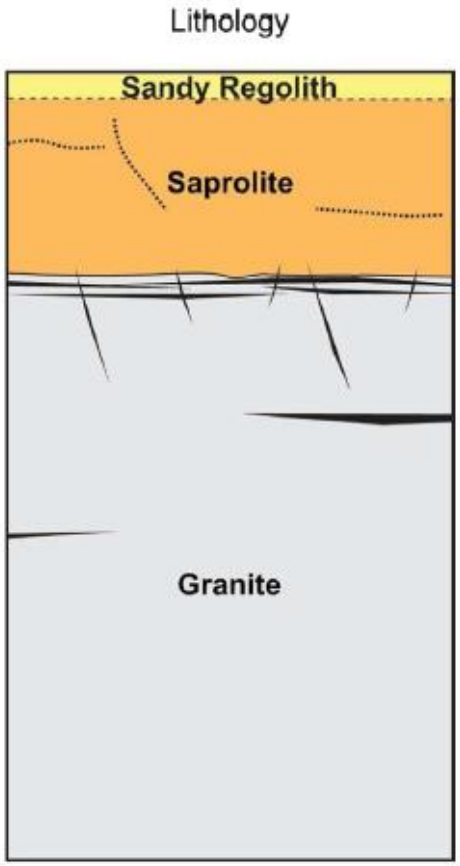
⇒ Increase of ET/PET

can lead to very negative water balance…

2000 to present: Groundwater resource depletion

Perception of groundwater depletion by farmers





Boisson et al, 2015

Olivia Aubriot. L'eau souterraine en Inde du sud. Un savoir réservé aux nouveaux maîtres de l'eau?. Construire les savoirs dans l'action. Apprentissages et enjeux sociaux en Asie du Sud, Edition de l'EHESS, pp.26, 2011, collection Purusartha 29

Adaptation of techniques

From furrow irrigation …

To spriklers…

Then drip irrigation

Adaptation of crops

Décline of sugar cane,
Increase of turmeric with associated crop (garlic, onion, chilly)

Horticulture

Banana

More capital intensive…
many small irrigation users can't follow…

… reduce irrigated area
Some back to rainfed farming
(or loose mortaged land -> landless)

Diversity of Farms In Gundlupet Taluk

present

SP1 : Très grands propriétaires irrigants - Lingayats (+Brahmanes)
8 à 20 ha – 1 VL
Tracteurs
Zones 1 et 2

SP2: Exploitations capitalistes Kéralaises
4 à 10 ha
Zones 1 et 2

SP3: Moyennes à grosses exploitations irriguées - lingayats
2 À 6 ha – 0 – 2 VL – (tracteur)
Zones 1 et 2

SP4: Petites exploitations irriguées – toutes castes
0,4 à 2 ha – 1 - 2 VL
Zones 1 et 2

SP5 : Exploitations pluviales moyennes – toutes castes
1 à 3 ha – 2 - 3 VL - Bœufs
Zones 1 et 2

SP6: Exploitations pluviales petites & moyennes–toutes castes
0,8 à 1,6 ha – 2 - 3 VL
Zones 1 et 2 et 3

SP7: Exploitations pluviales très petites– toutes castes
0,2 à 0,8 ha – 0 - 3 VL – (ovins)
Zones 1 et 2 et 3

SP8: Sans terres – toutes castes
0 ha – 0 - 2 VL – (ovins)

Big irrigated farms

SP1=about 10 households

SP3 =about 500 households

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Small irrigated farms

SP4 = about 1000 households

Diversity of Farms In Gundlupet Taluk

SP1 : Très grands propriétaires irrigants - Lingayats (+Brahmanes)
8 à 20 ha – 1 VL
Tracteurs
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0,2 à 0,8 ha – 0 - 3 VL – (ovins)
Zones 1 et 2 et 3

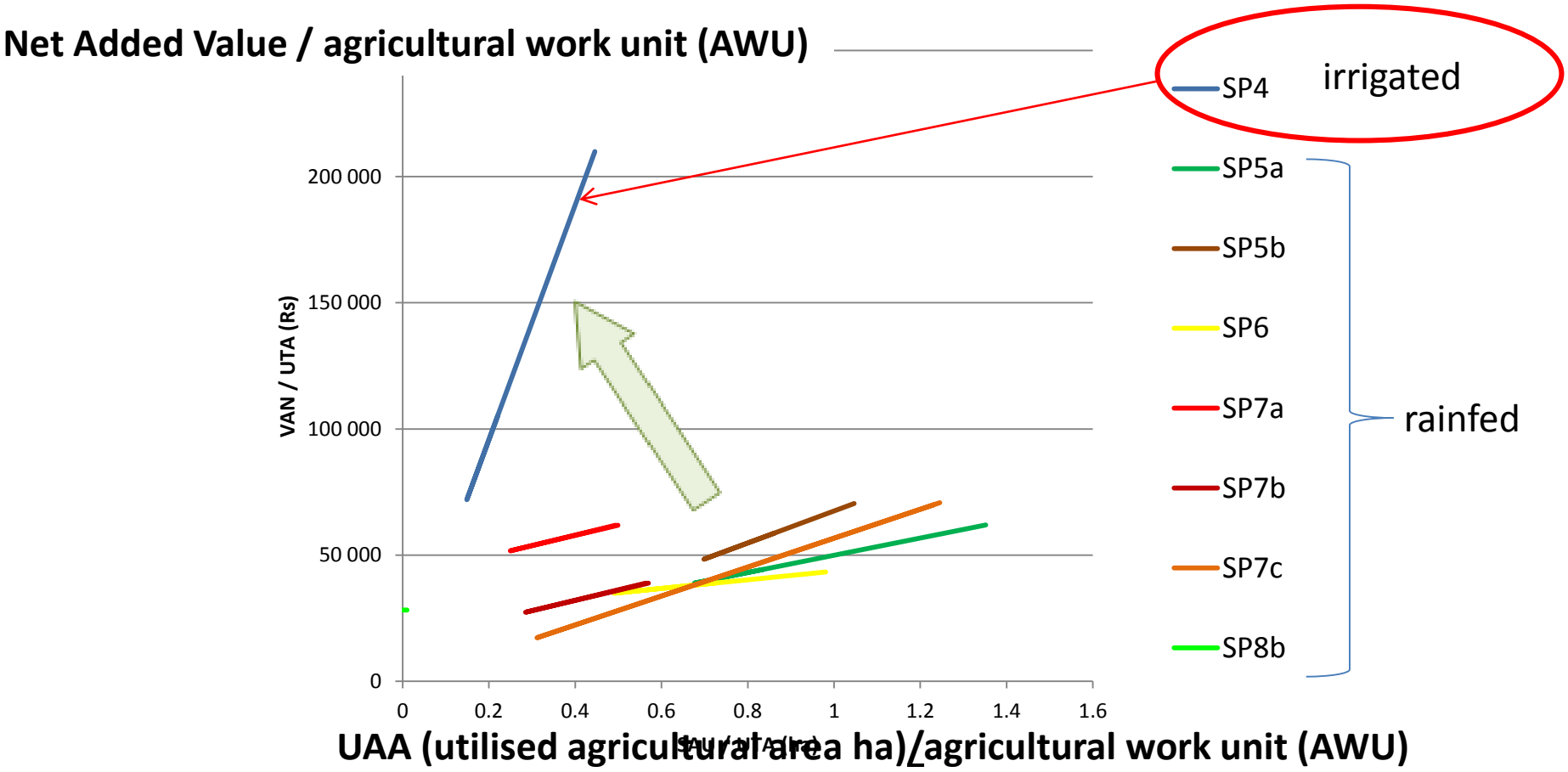
SP8: Sans terres – toutes castes
0 ha – 0 - 2 VL – (ovins)

Medium and Small rainfed farms and landless farmers

= several 1000s of households

Economic assessment (Berambadi region)

irrigation seems to be the only way to increase work productivity in small farms.... (Master report Chloe Fischer 2016)



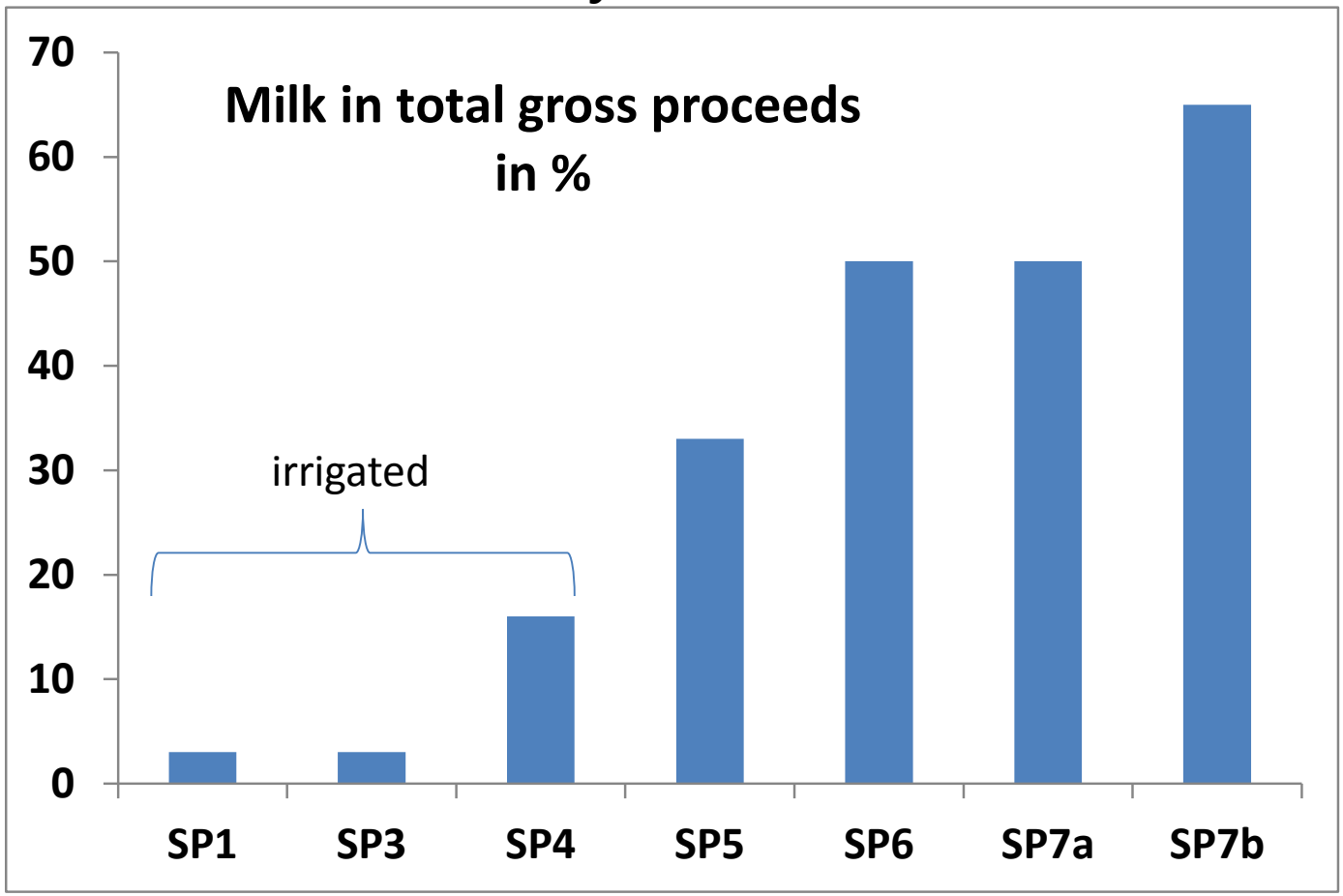
White Revolution

Milk Collection in every village (cooperatives)

Production = irrigation users, rainfed and landless farmers

Milk is essential for rainfed farms

(and for many landless farmers…)



…. But limited by forage availability

Objectives of the AICHA project :

assessing the
sustainability and possible adaptation
of current and alternative
agricultural systems

Can we increase the crop productivity, farmers incomes without further depleting groundwater levels?

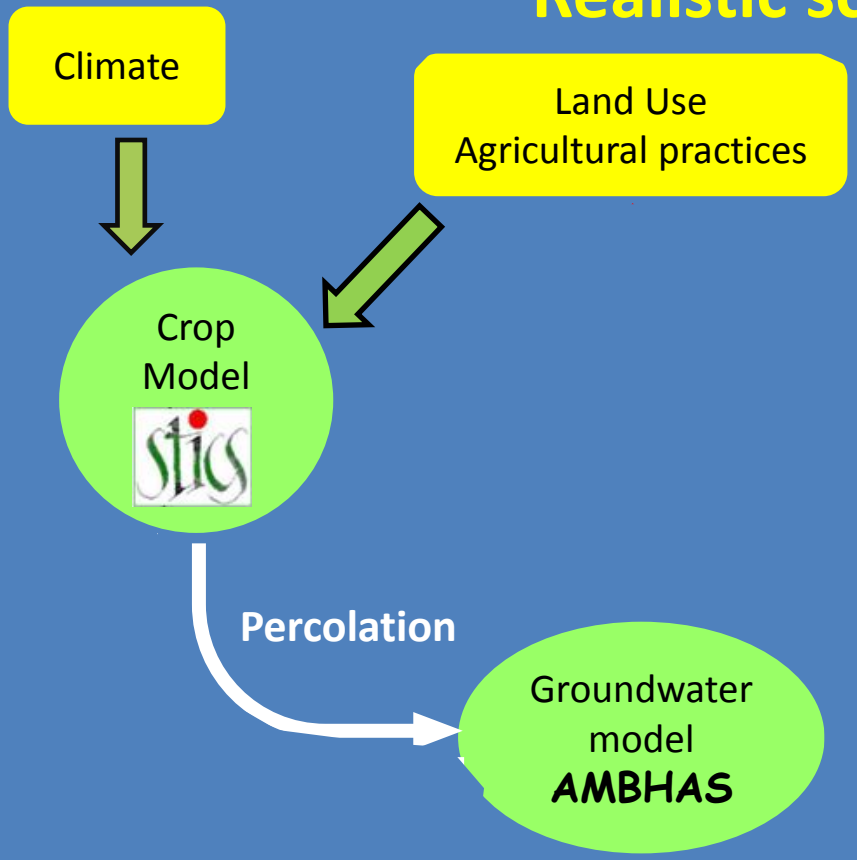
Methods:

- **integrated models**
- **realistic scenarios**

assessing current and alternative agricultural systems for sustainability

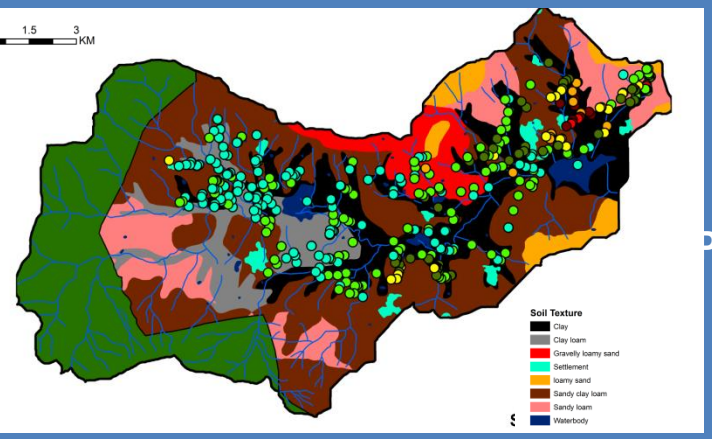
Realistic scenarios ????

Inputs

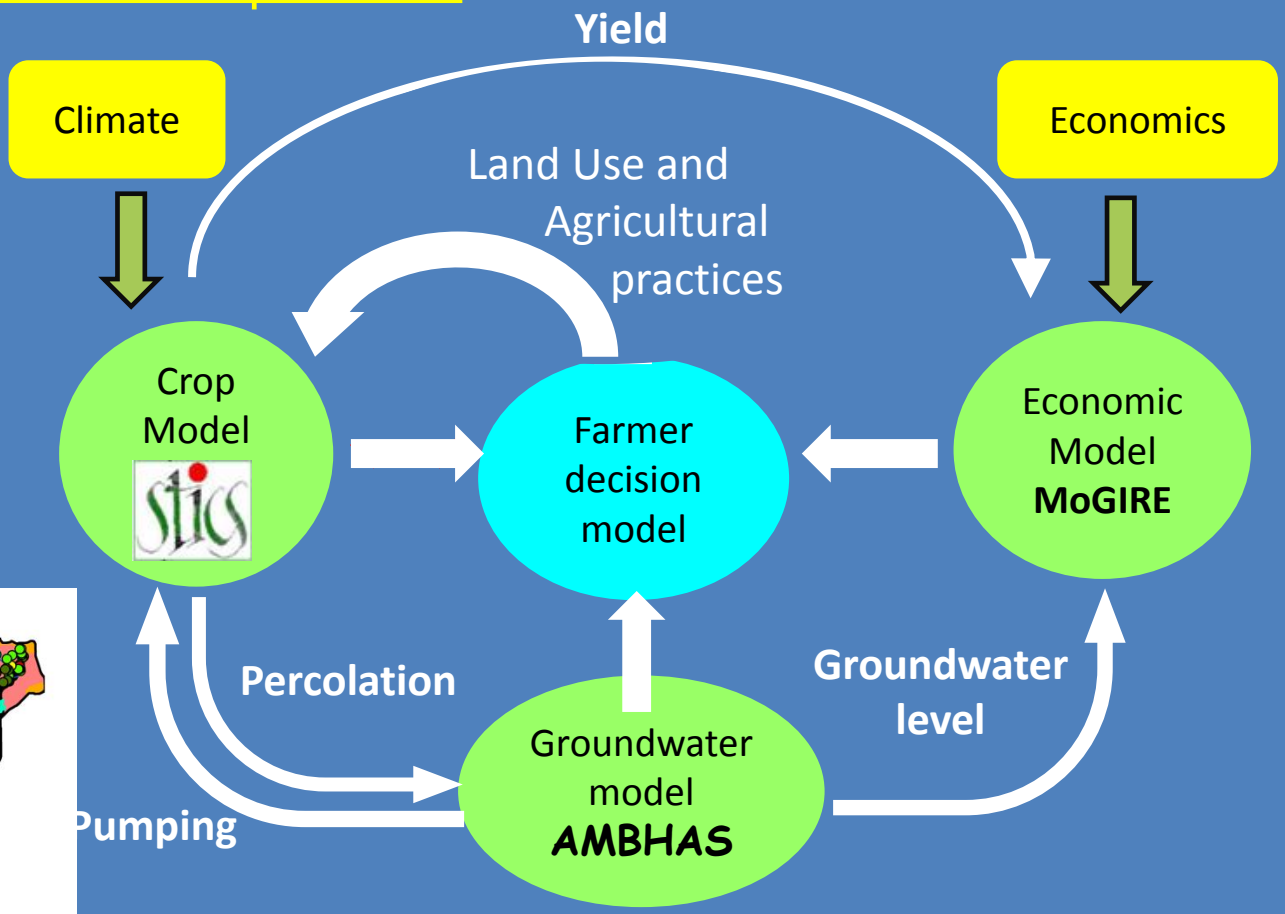


assessing current and alternative agricultural systems for sustainability and possible adaptations

Inputs



Impact of spatial distribution of practices => Distributed model



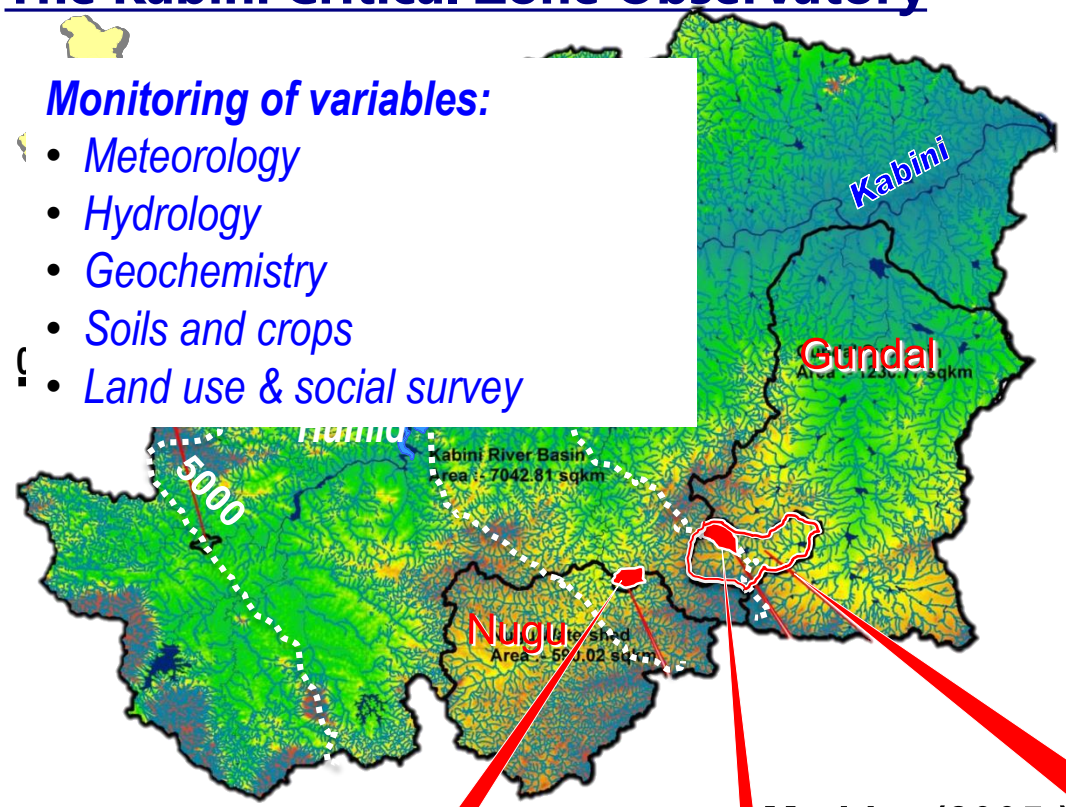
CHALENGES :
Calibrating and validating the model
Before using it for scenarios evaluation

Collection of adequate spatial database for process understanding and modelling

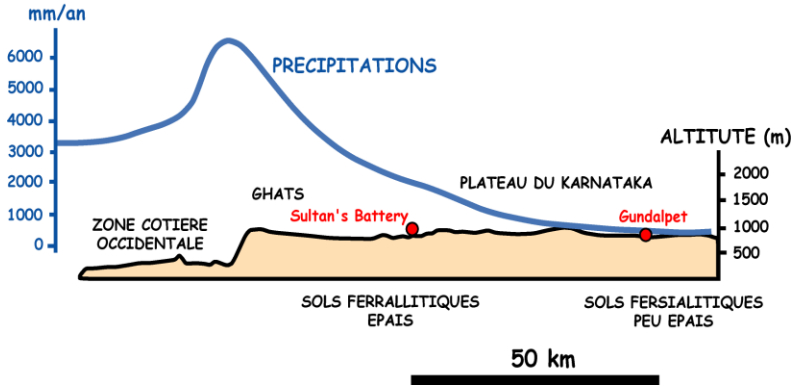
The Kabini Critical Zone Observatory

Monitoring of variables:

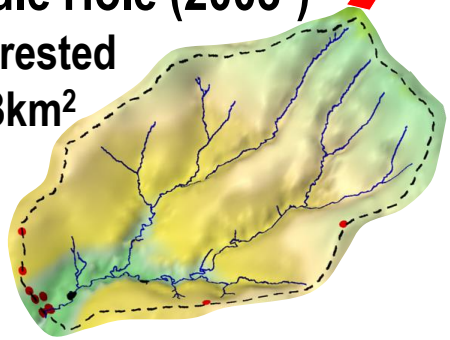
- *Meteorology*
- *Hydrology*
- *Geochemistry*
- *Soils and crops*
- *Land use & social survey*



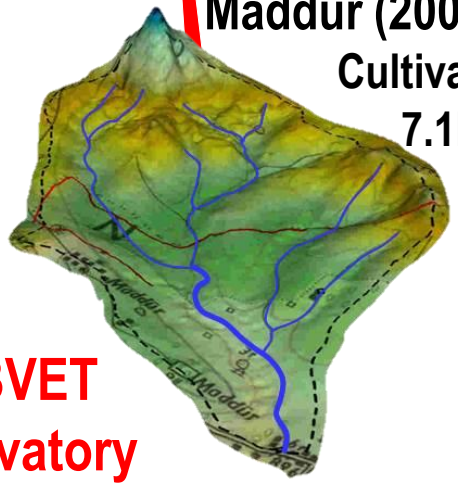
Strong climatic gradient



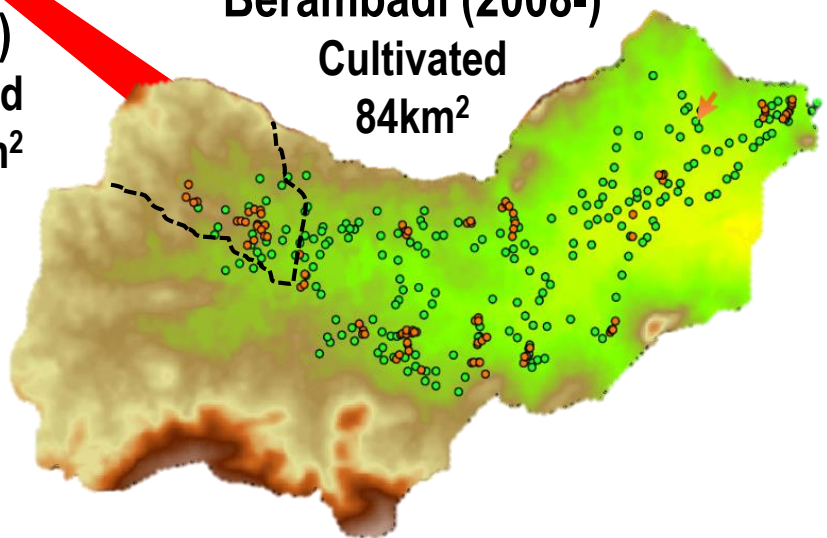
Mule Hole (2003-)
Forested
4.3km²



Maddur (2005-)
Cultivated
7.1km²



Berambadi (2008-)
Cultivated
84km²

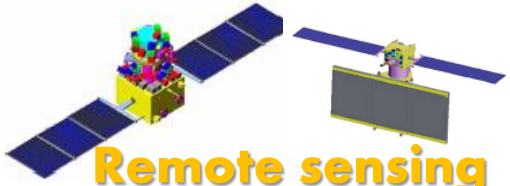


BVET

Environmental Observatory

Data collection

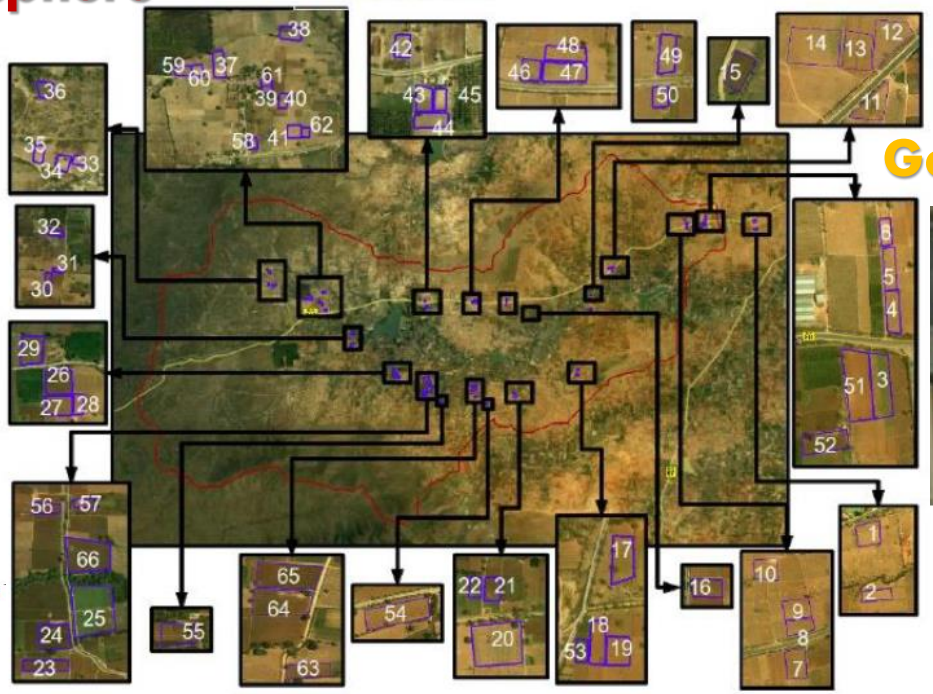
ENVIRONMENTAL MONITORING



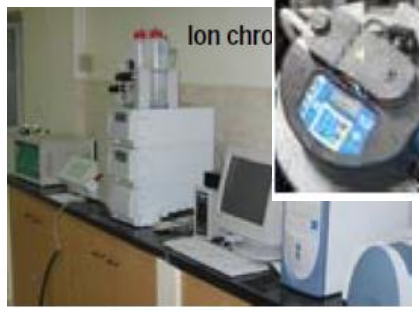
Remote sensing

Hydrology

Atmosphere



Geochemistry



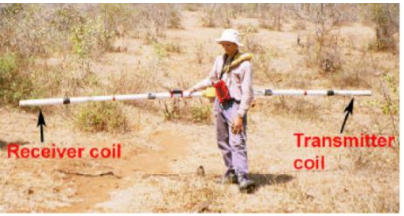
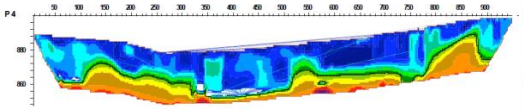
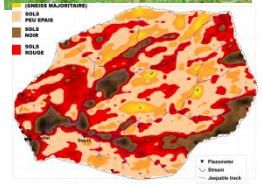


Figure 9 : Geonics EM31 conductivity meter

Geophysics





Soil

Socio economic Surveys

Crops

Monitoring of hydrological & crop variables in the WS

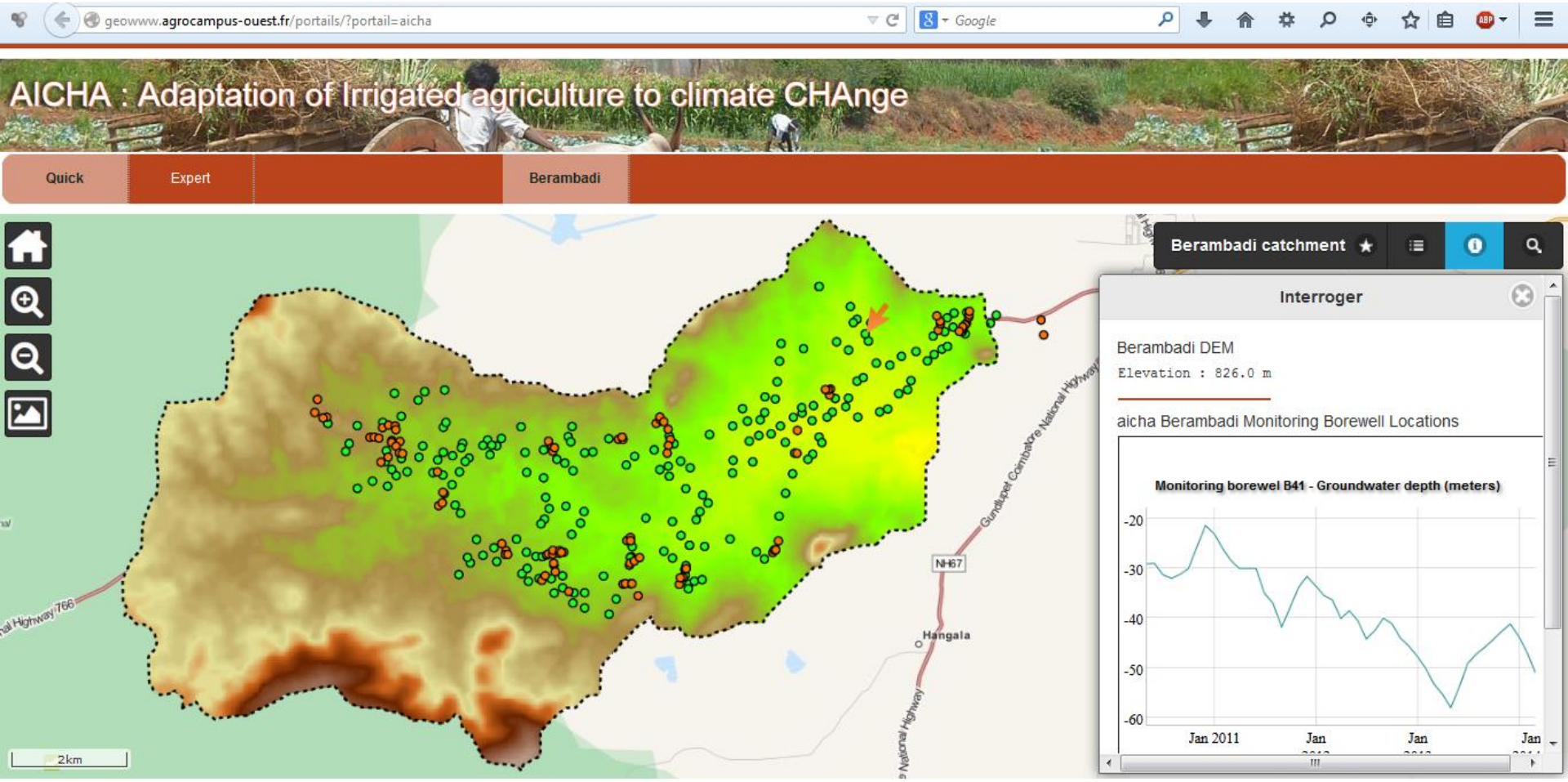
Variable	Sampling frequency
Climatic parameters	15 minute through two weather stations
Runoff	Hourly & daily; specific storms at one location
Surface soil moisture	Once in 10 days at 60 plots; At two locations half hourly
Profile soil moisture	Once in 10 days at 60 plots; At two locations 15 minute sampling gauges
Groundwater levels	200 BWs at 10 day to 1 month
Groundwater chemistry	Seasonal at selected points
Soil parameters	Several locations one/two times for soil analyses
Crop growth parameters	10 day sampling of crop variables (e.g. LAI) in 60 plots
Remote Sensing	25+ images of microwave satellite (RADARSAT-2) for soil moisture, LAI retrieval and soil hydraulic property (SHP) estimation; few images of optical remote sensing (IRS LISS IV) for LULC

Socio economic Survey and agricultural practices

2013 : 100 household surveys in 4 villages, 120 plots with agricultural practices 2011-2013

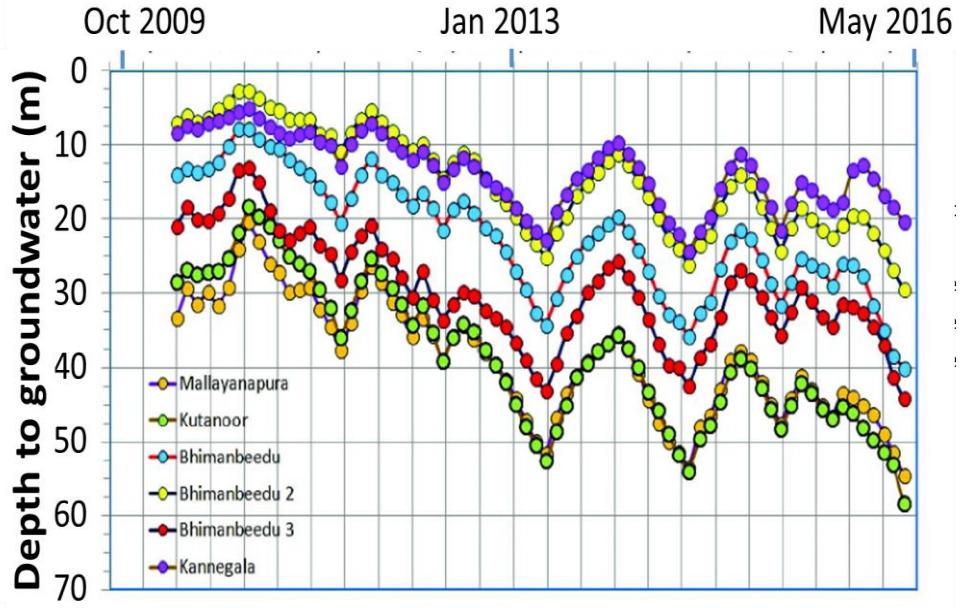
2014 *: 684 household surveys (out of a total of 5461 in the watershed)*

Web portal AICHA to share spatial and time-series databases

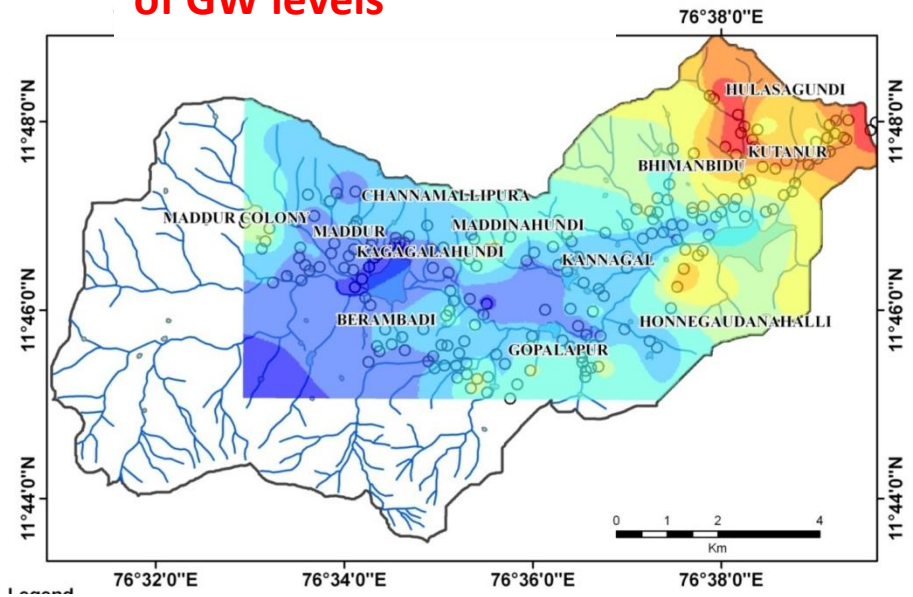


RESULTS : Hydrology

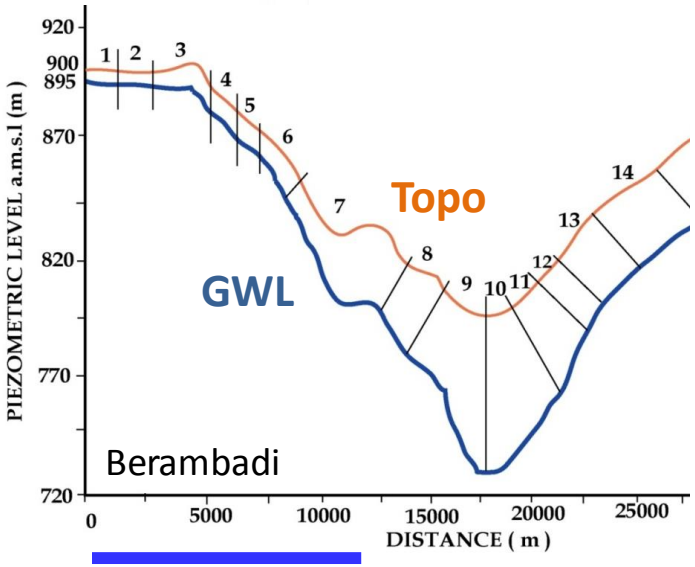
groundwater levels recorded monthly on 200 bore wells since 2010



Large spatial variability of GW levels



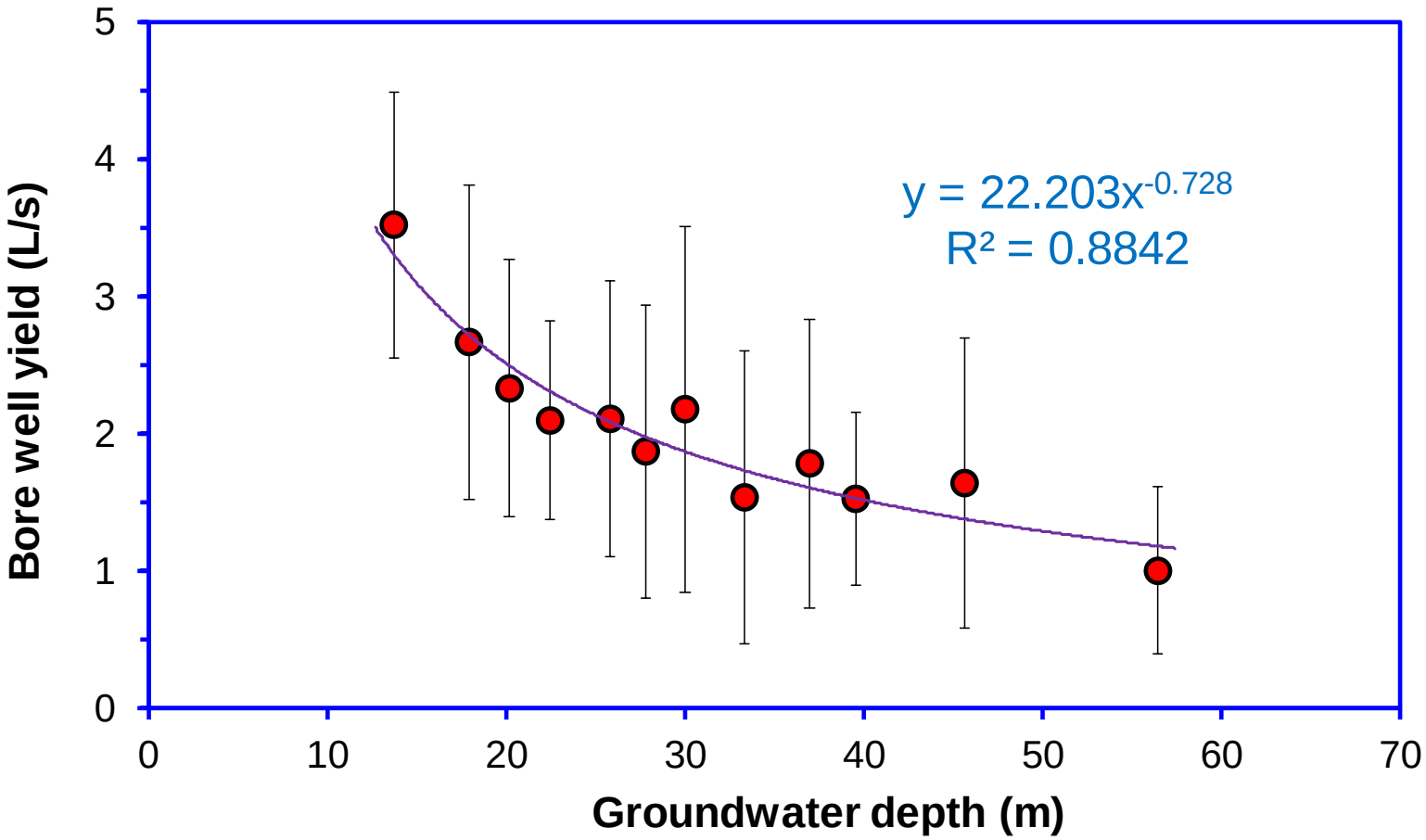
Increase of the hydraulic gradient,
Disconnection between GW and rivers,
turned into ephemeral streams



Sreelash et al, 2013
Ruiz et al 2015

RESULTS : Hydrology

Feed-back of groundwater level on well productivity
(measurements on 120 farmer wells)

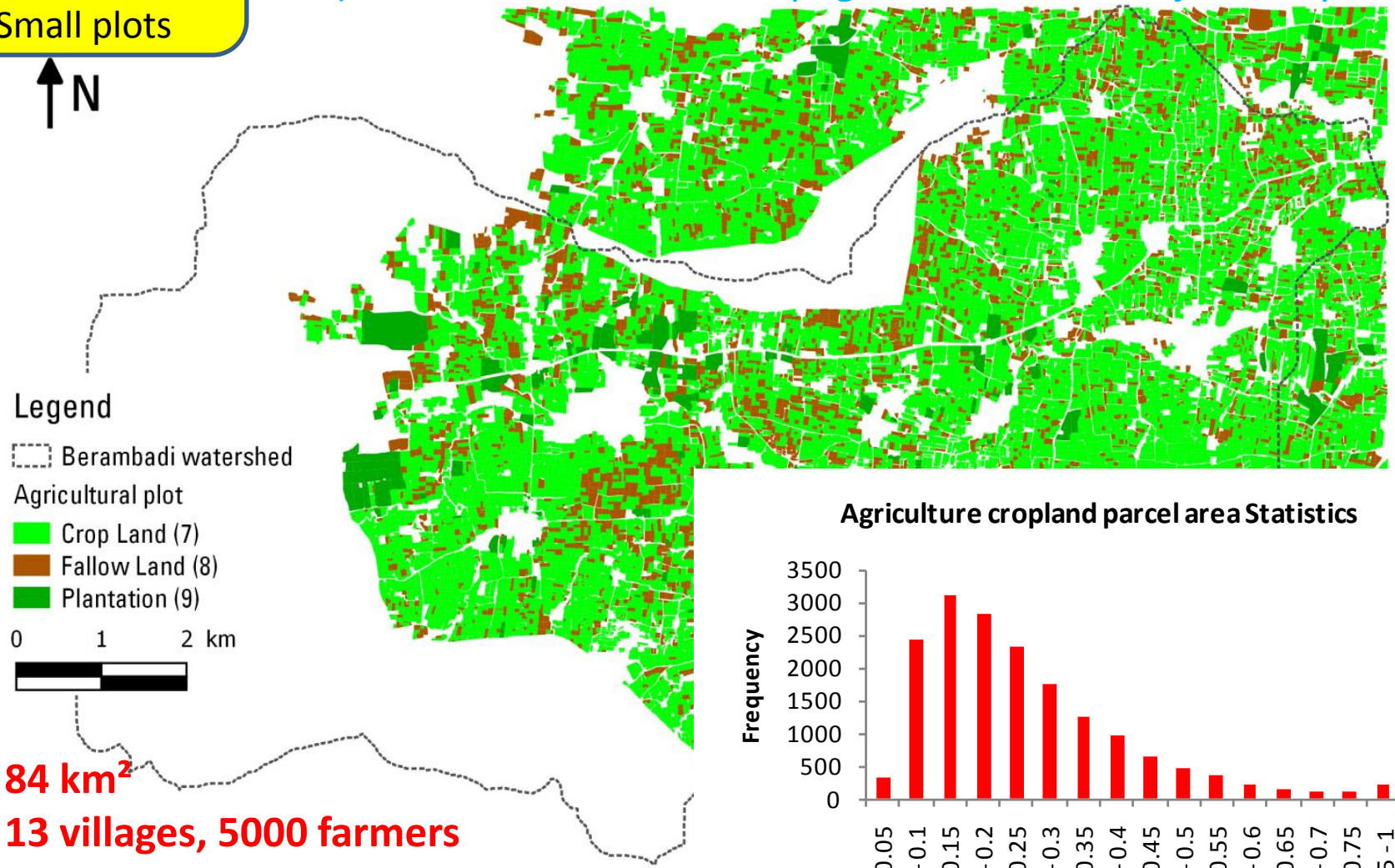


Ruiz et al 2015

CHALENGES :
Large crop diversity
Small plots

Map of plot boundaries

(Mael Ameline, Julie Campagna, Amit Sharma june-July 2014)



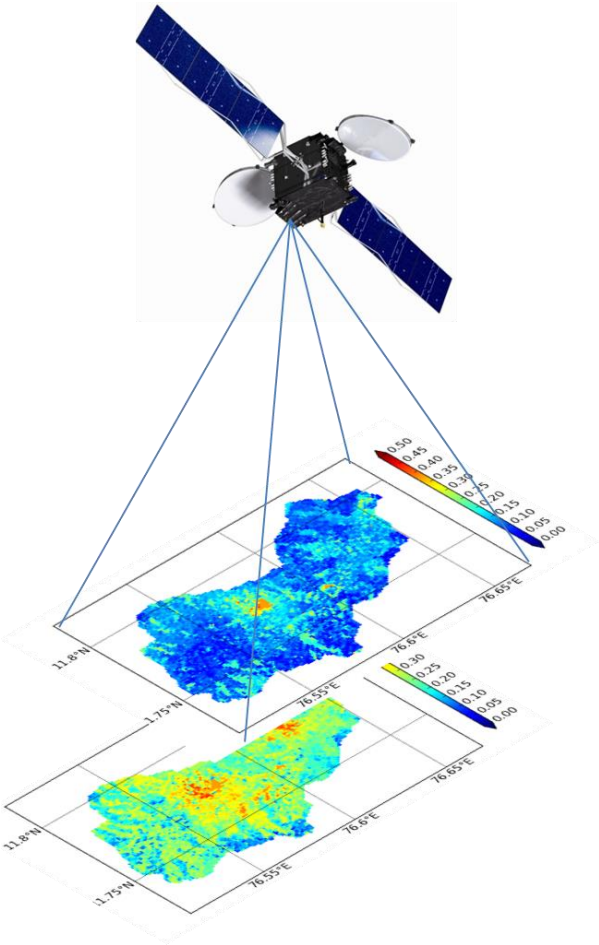
84 km²

13 villages, 5000 farmers

16 800 plots Average size 0.2 ha …

Methodological developments

Multisatellite remote sensing for:



- Estimation of **soil moisture** from Radar satellites (Tomer et al. 2015)

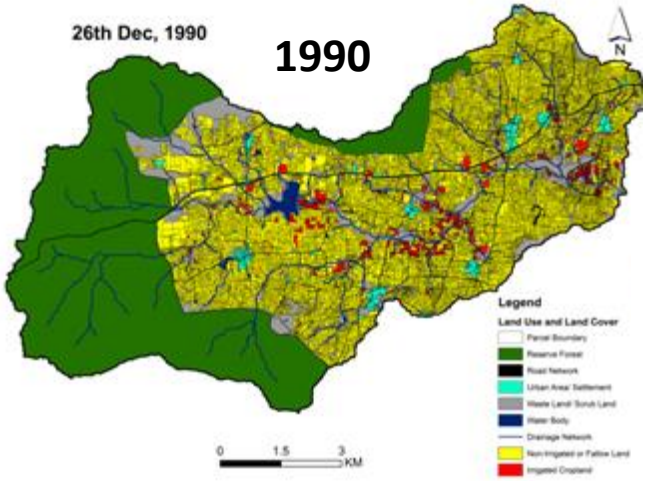
- **Evapotranspiration** (Eswar et al., 2016)

- Estimation of **soil properties** by model inversion (Sreelash et al., 2012; 2013 and 2017)

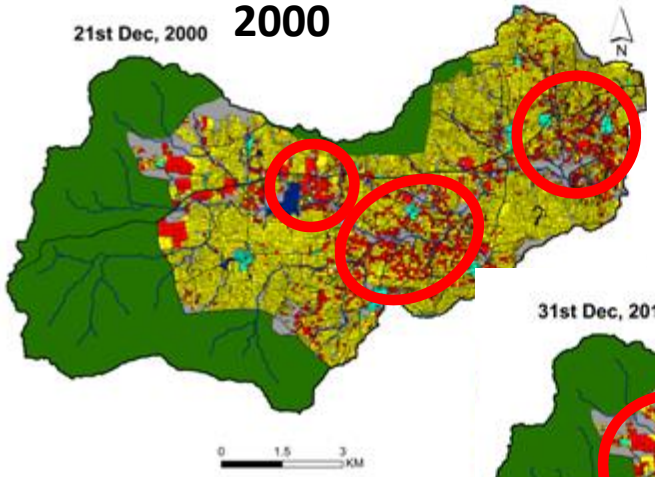
Methodological developments

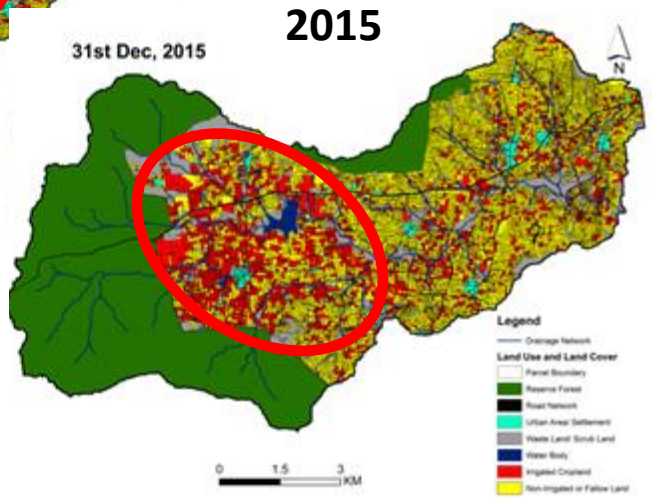
Optical remote sensing for high spatial resolution of LULC

Sharma et al. in prep

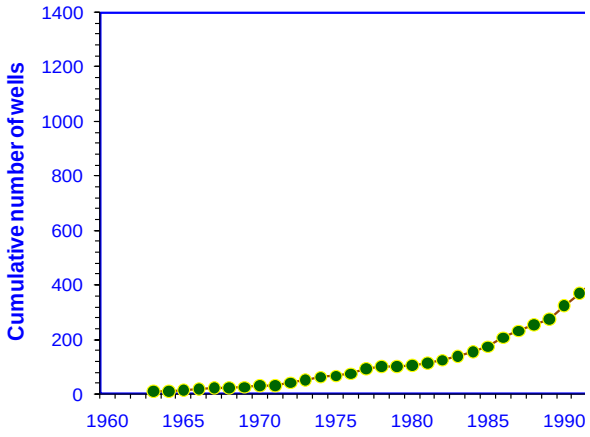


Development of irrigation in rabi season



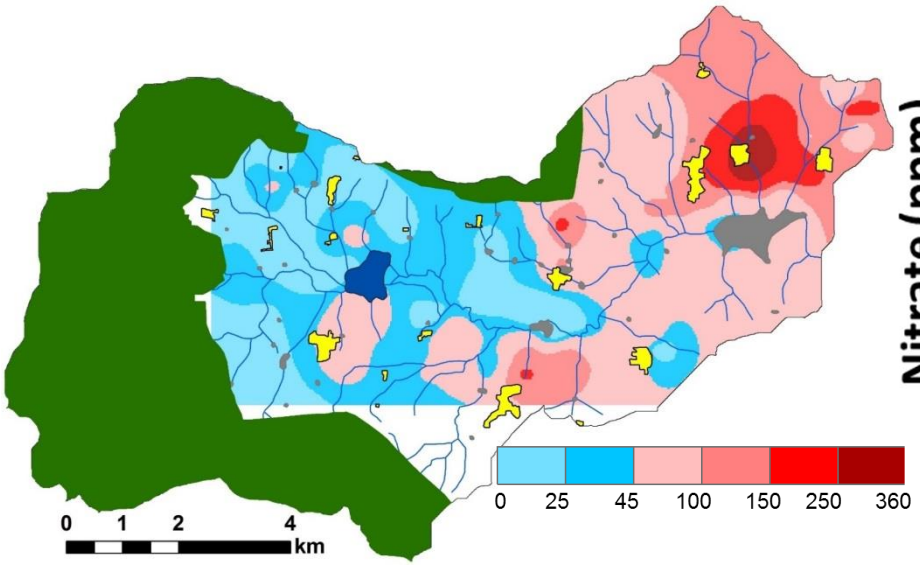


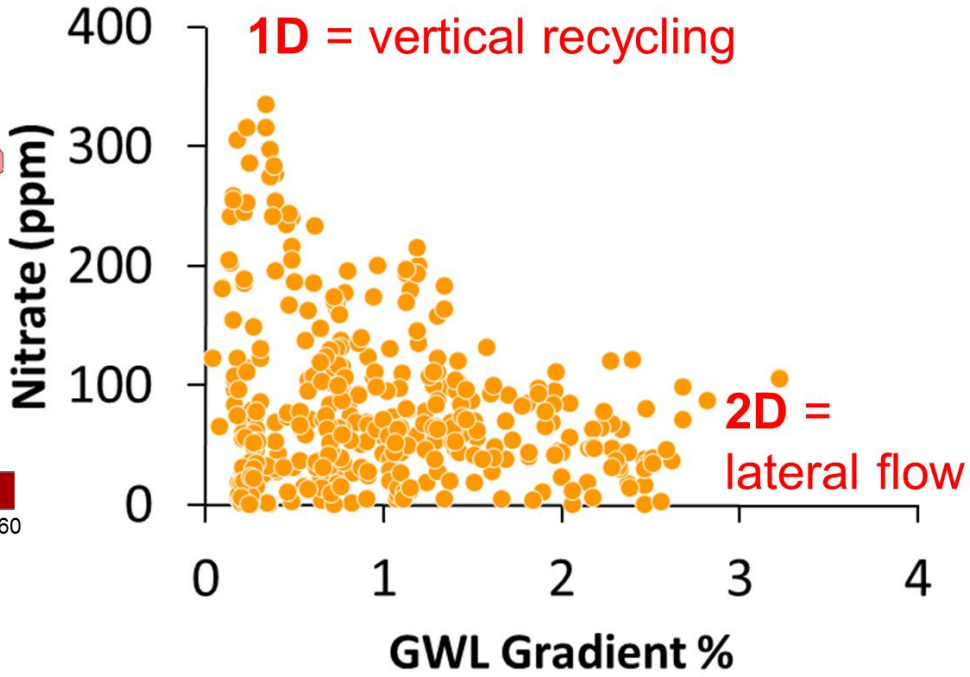
Nb of Borewells



Spatial variability of NO_3 with Groundwater resource at Watershed Scale

(Buvaneshwari et al. 2016)





- Variations of 2-3 orders of magnitude in NO_3
- Hotspots of NO_3 up to 360ppm in groundwater-depleted areas
- Low and moderate NO_3 at shallow groundwater level
- Spatial variation more significant than temporal one

= high hydraulic gradients, inducing larger renewal rates, are buffering NO_3 concentration in groundwater.

- **N by irrigation = "hidden" N input of 200 kg N/ha/year in hotspot areas**

Diversity of farming systems - Typology

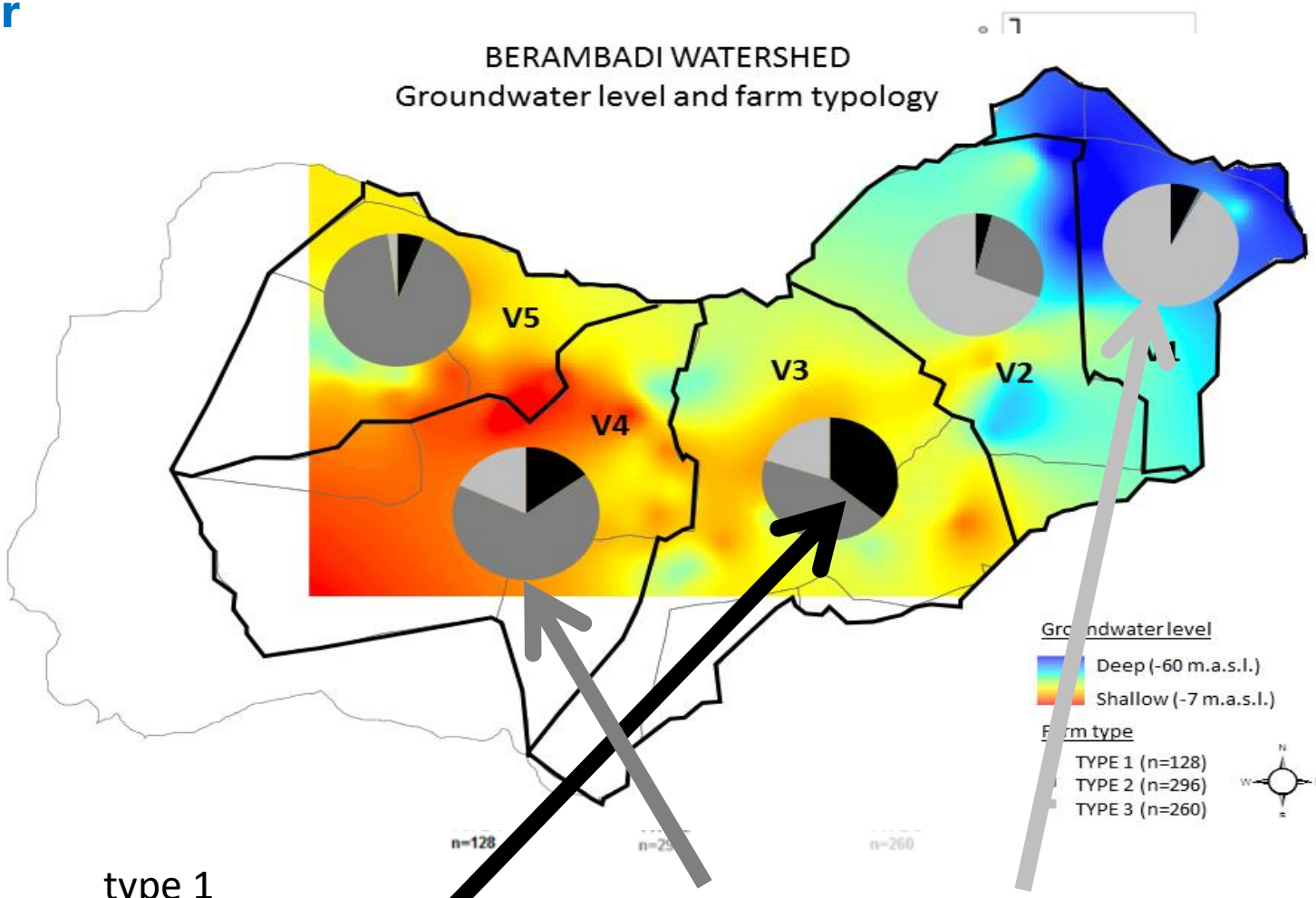
Robert et al., 2017 *Farmer survey on 684 households (out of 5461)*

3 main types of farming systems determined by farm size and access to groundwater

50 qualitative and quantitative variables

Multiple Correspondence Analysis (MCA)

Agglomerative Hierarchical Clustering (AHC) based on the 12 first components of the MCA



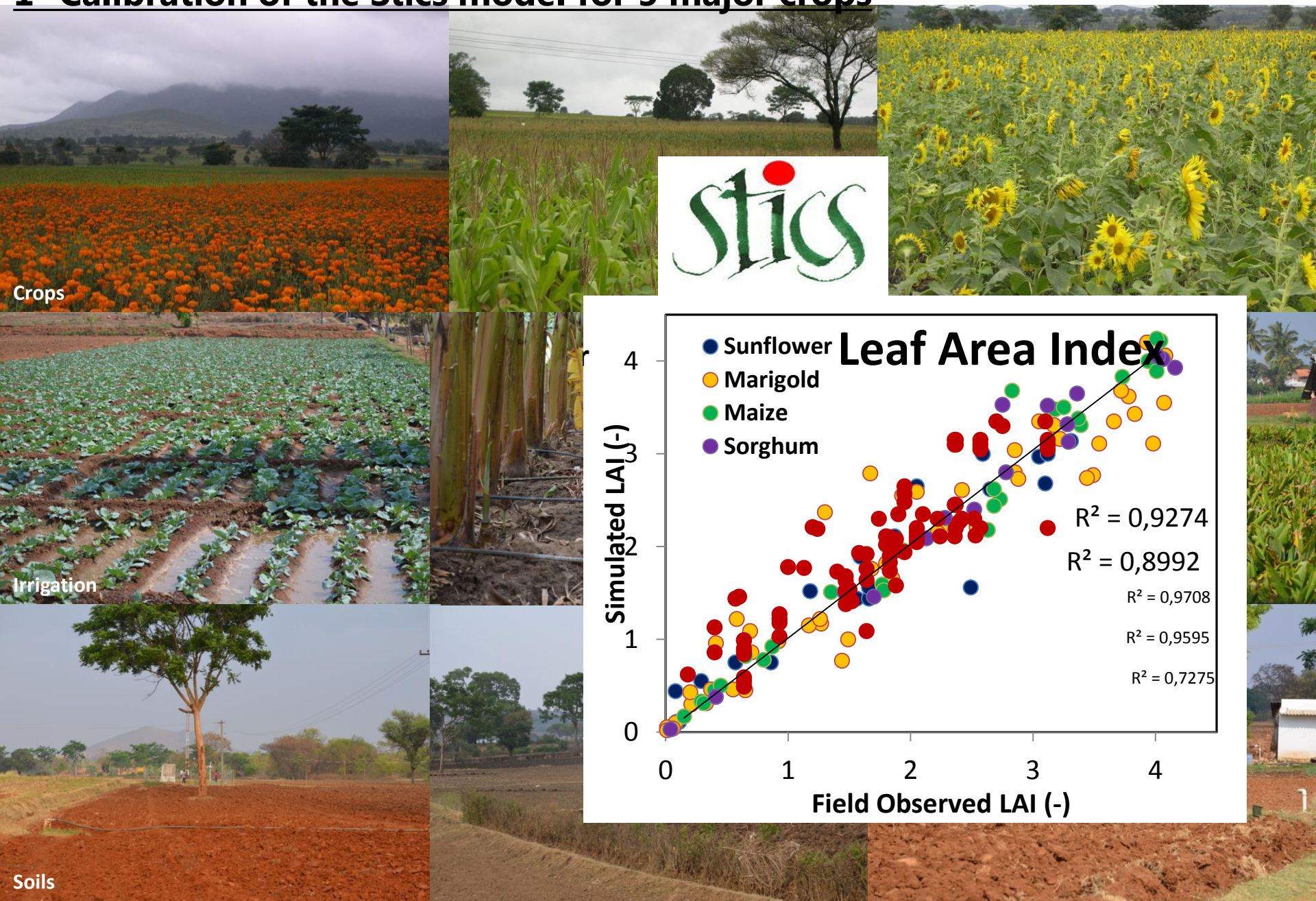
type 1
large diversified and productivist farms

type 2
small and marginal rainfed farms

Type 3
small irrigable marketing farms

Modelling the major compartments of the system

1- Calibration of the Stics model for 5 major crops



WAY FORWARD: **Development of a crop modelling community**

40 participants

ICAR-NBSS & LUP

INRA, Toulouse, Avignon

UAS Bangalore

UAS, Raichur

UHS Bagalkot

UAS Dharwad

WDD Bangalore

NRSC, ISRO, Hyderabad

SAC, ISRO, Ahmedabad

IARI, New Delhi

Modelling the major compartments of the system

Decision model (Robert et al., 2016a)

Generic sequential decision-making framework:

3 levels of decision / adaptation

1) STRATEGIC decision stage: yearly / farm / LT effect

Decision: investment in irrigation system

Adaptation: yearly reviews investment in irrigation equipment

2) TACTIC decision stage : seasonally / farm / MT effect

Decision: select crops and allocation

Adaptation: update cropping system

Economic Model (Robert et al., submitted)

3) OPERATIONAL decision stage : daily / plot / ST effect

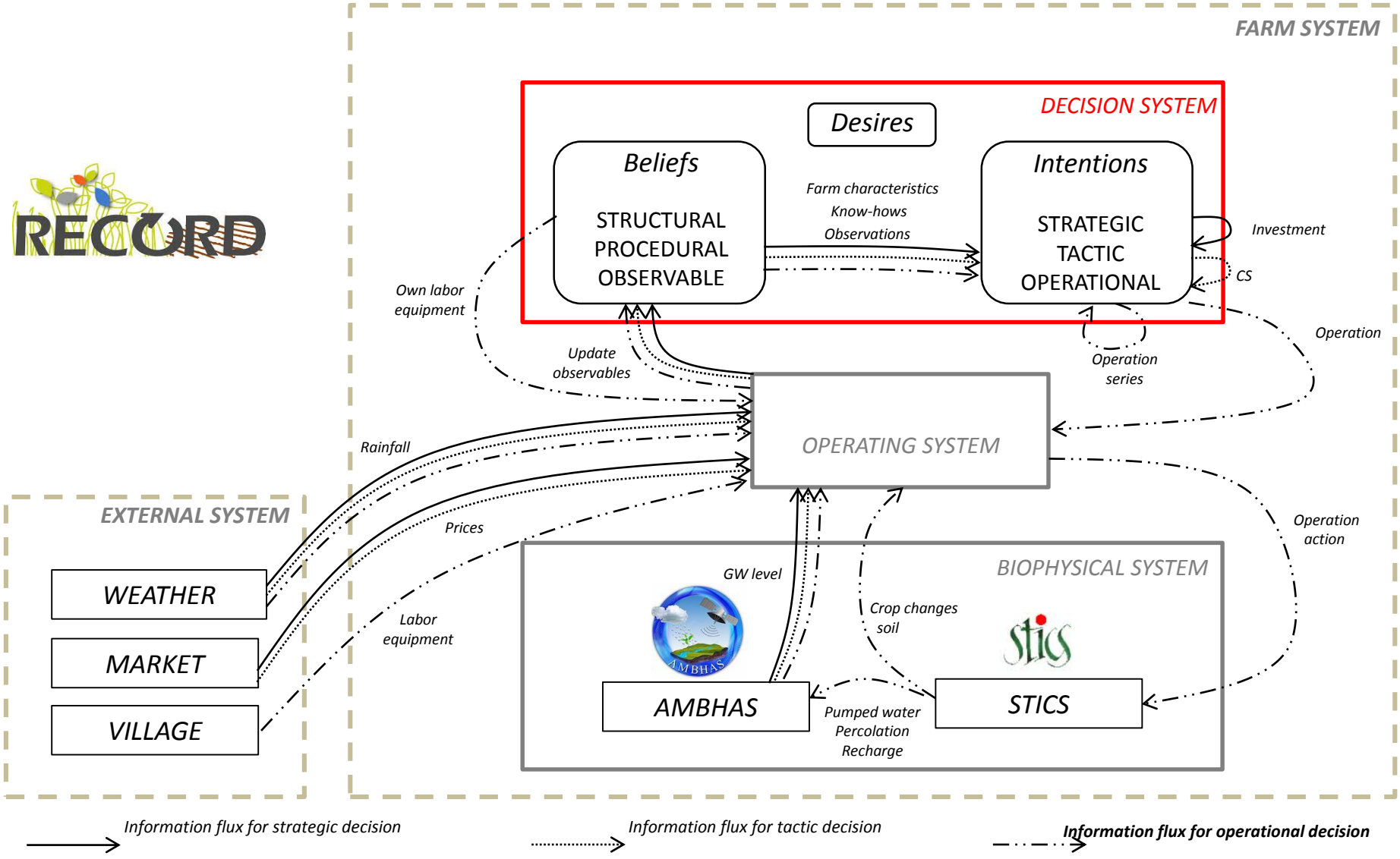
Decision: crop operations

Adaptation: new plan if can't sow or bad germination

Management Model (Robert et al., 2016b)

NAMASTE model (Robert et al., 2016c)

Integrated model developed under RECORD platform



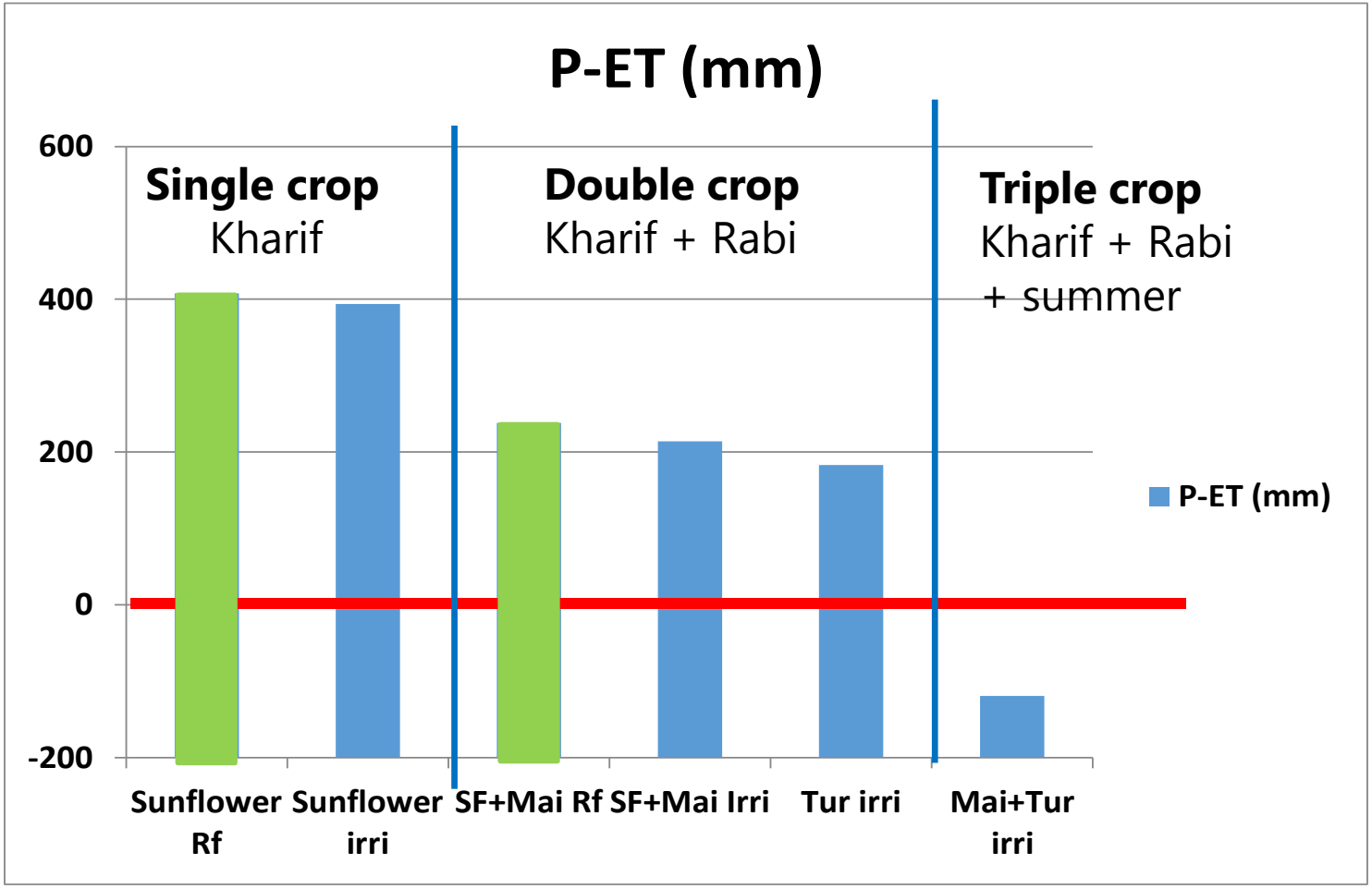
Scenario testing

Plot scale scenarios :

1 - Importance of cropping patterns on water balance

Rainfed

Irrigated

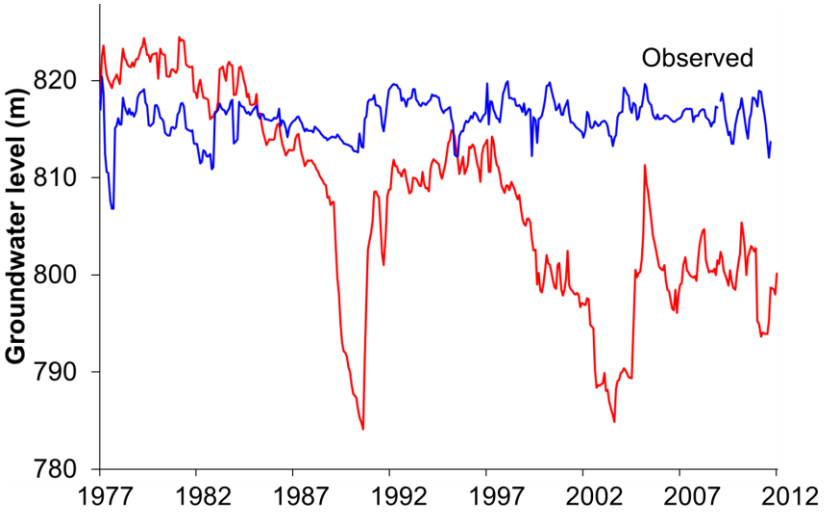


Scenario testing

Plot scale scenarios :

1- Importance of cropping patterns on water balance

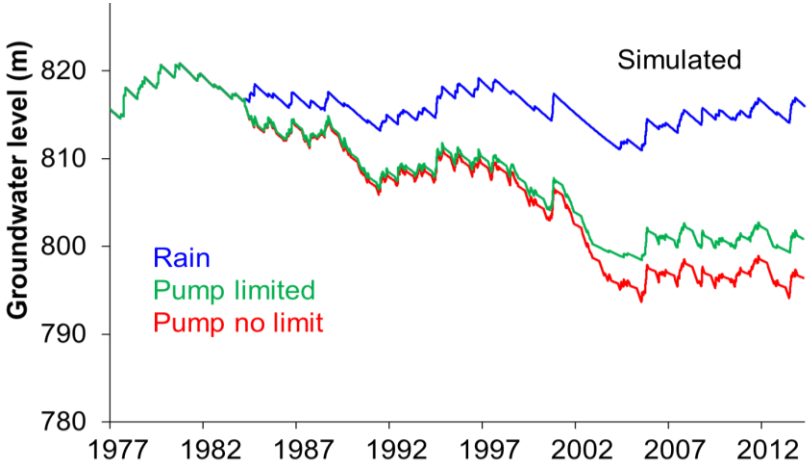
2- importance of accounting for groundwater feedbacks on irrigation capacity.



Rainfed area

Irrigated area

Rainfall is not the cause of GWL decline

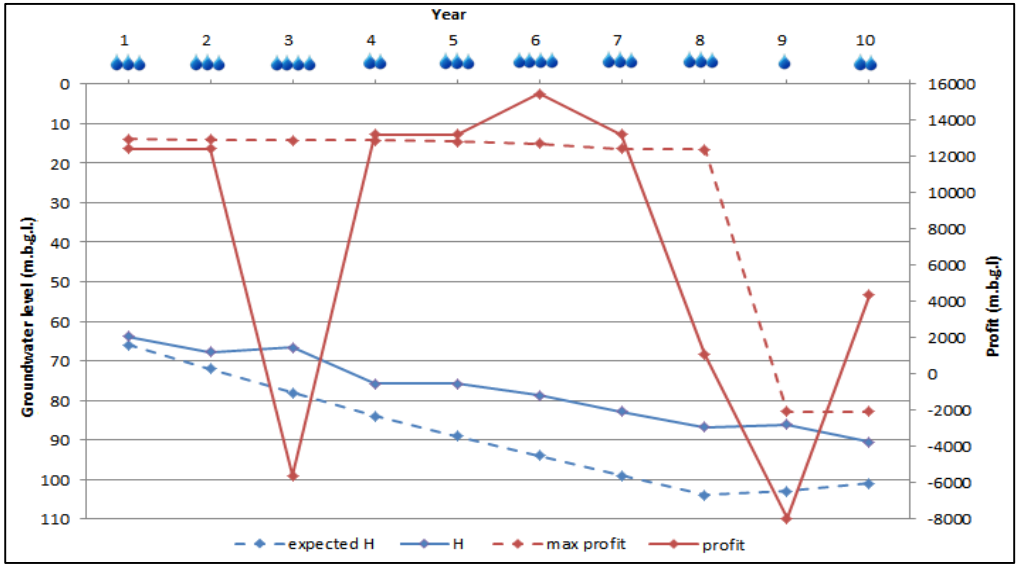


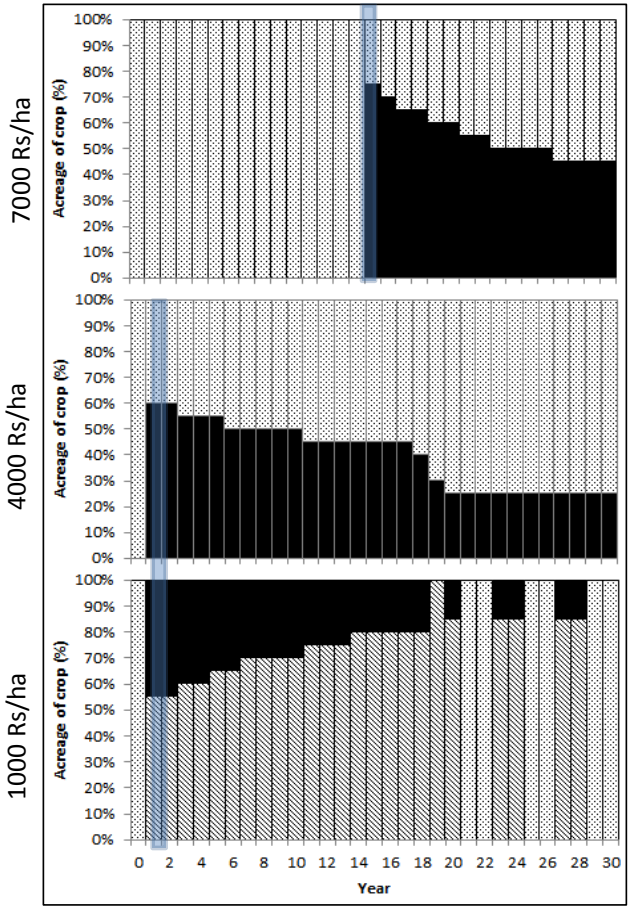
Simulated effect of GW feedback

Scenario testing

Farm scale scenarios

- **increasing the cost of irrigation** => stabilization of groundwater resource but strong detrimental effect on many vulnerable small or medium farms (bankruptcy or return to rainfed agriculture).
- **adjusting temporal distribution of irrigation** (through differential allocation of electricity across seasons): preserve ground water balance while improving and stabilizing crop yields and profit.





CEFIPRA AICHA project achievements

- **Scientific production :**
  - **14 publications** in SCI journals (and few more to come)
  - **4 PhD thesis** (1 French – 3 Indians)
  - **2 MSc Thesis** (1 French – 1 Indians)

- innovative methodologies
- model development
- knowledge on the processes and drivers governing the interaction between anthropogenic activities and the environment

- **Emergence of a unique trans-disciplinary bilateral consortium on sustainability assessment of agricultural systems**

=> ATCHA project, funded by ANR (740 k€, 2017-2020 ; PI Laurent RUIZ)

Accompanying
The adaptation of irrigated agriculture to climate
CHAnge

4 years 2017-2020

Objective:
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.

Build on

- the knowledge gained through the ending project **AICHA** (2013-2016) on the processes and drivers governing groundwater sustainability and farmer adaptation
- The connection established with the project **SUJALA-III** (2014-2019, World Bank).

ATCHA Partnership

French (14)

UMR SAS Rennes / UMR SELMET
UMR AGIR Toulouse / UR MIAT RECORD
UMR EMMAH Avignon / UMR LISAH / UR AGROCLIM/ UR AgroImpact
UMR TSE-R Toulouse
UMR GET Toulouse / UMR CESBIO / UMR LA
UR2 UMR LETG-COSTEL Rennes

Indo-French (2)

IFP Pondicherry
Indo-French Cell for water Sciences (LMI CEFIRSE)

Indian (3+)

Indian Institute of Science
ATREE
Watershed Development Department + Sujala-III partners
ICAR-NBSS&LUP, UAS Bangalore, UAS, Raichur, UAS Dharwad, UHS Bagalkot, KSNDMC, KSRSAC

Agronomy
cropping systems
crop modelling

hydrology

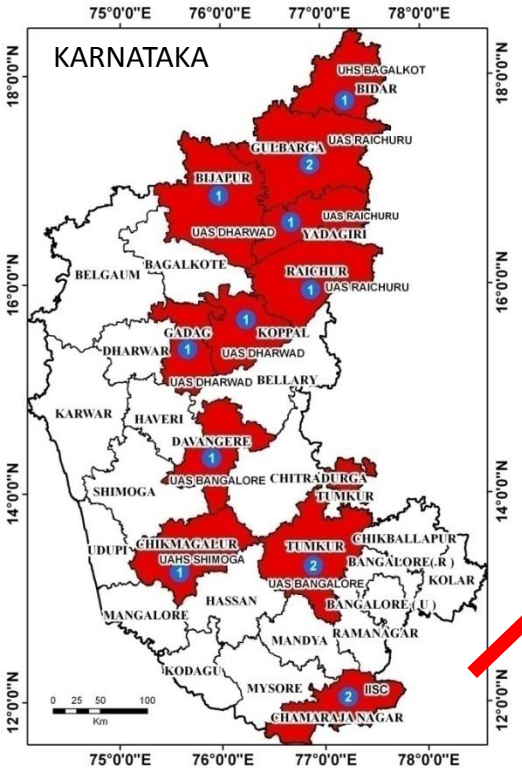
Remote sensing

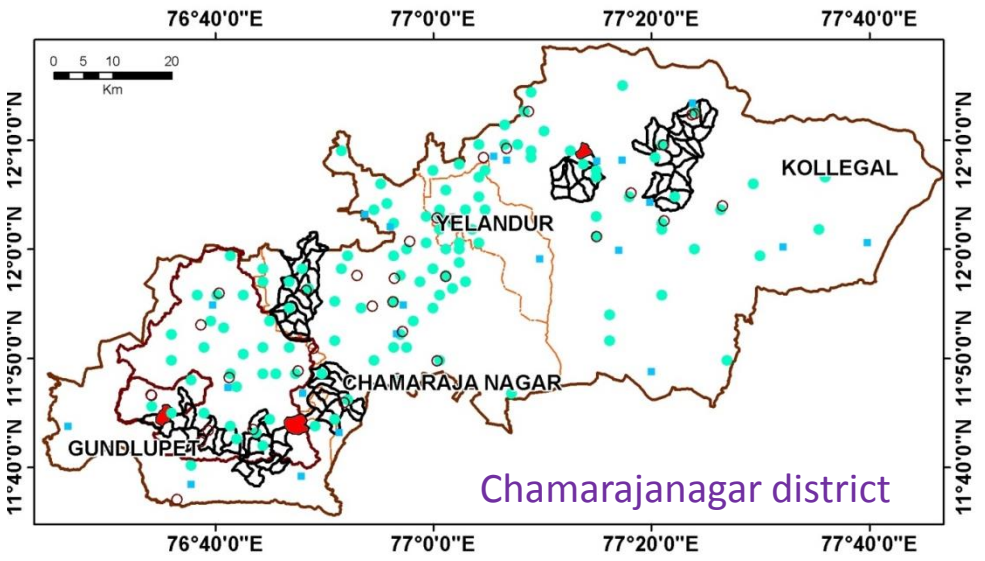
Soil Science

Social Sciences

Economy
Sociology

Test model genericity = Link with **Sujala III Project** 2014-2019





Karnataka Watershed Department

Partners:

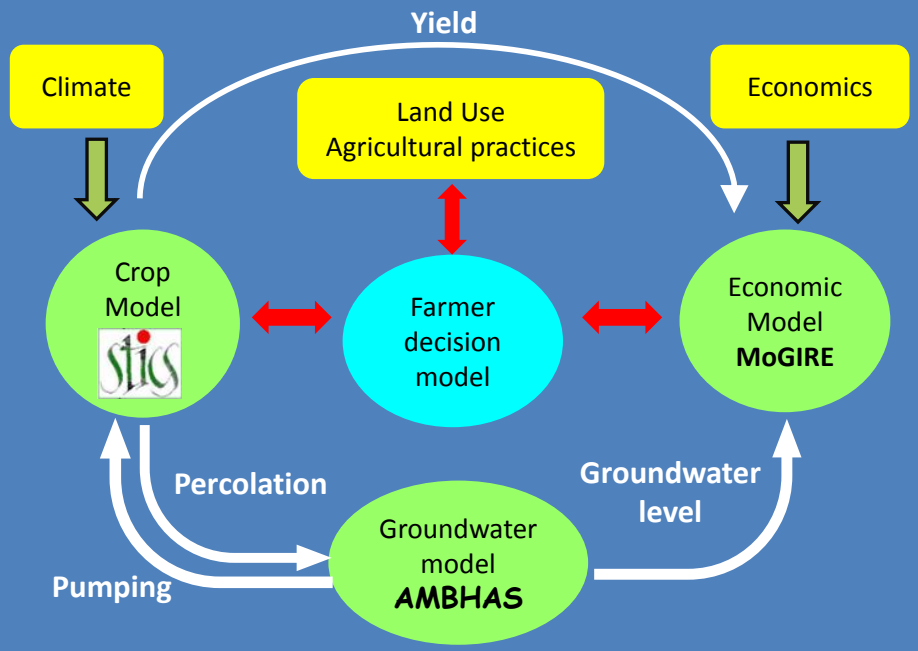
- National Bureau of Soil Survey and Land Use Planning (NBSSLUP),
- Indian Institute of Science (IISc.), Bangalore
- University of Agricultural Sciences, Bangalore,
- University of Agricultural Sciences, Dharwad
- University of Agricultural Sciences, Raichur
- University of Horticultural Sciences, Bagalkot
- Karnataka State Remote Sensing Applications Centre (KSRSAC), Bangalore

➢**World Bank** funded project for Intensive hydrological research in **14 micro-watersheds in 7 districts of Karnataka**

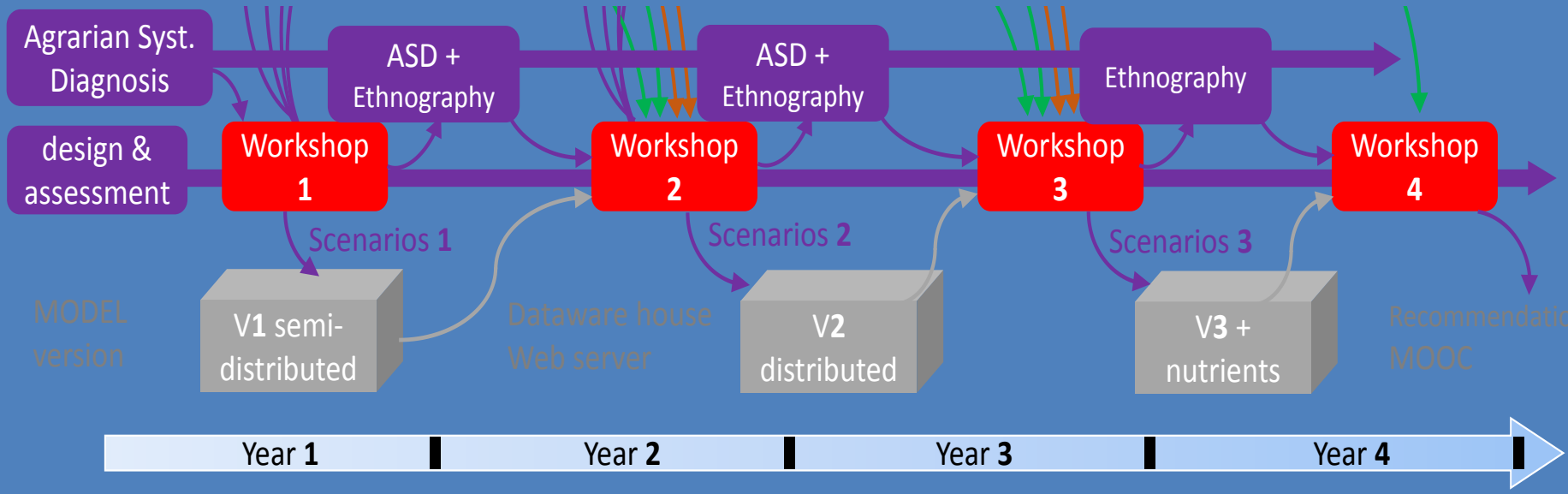
Barambadi as a model : IISc (M Sekhar) in charge of 3 micro-watersheds

Implement yearly workshops with stakeholders to design and assess scenarios

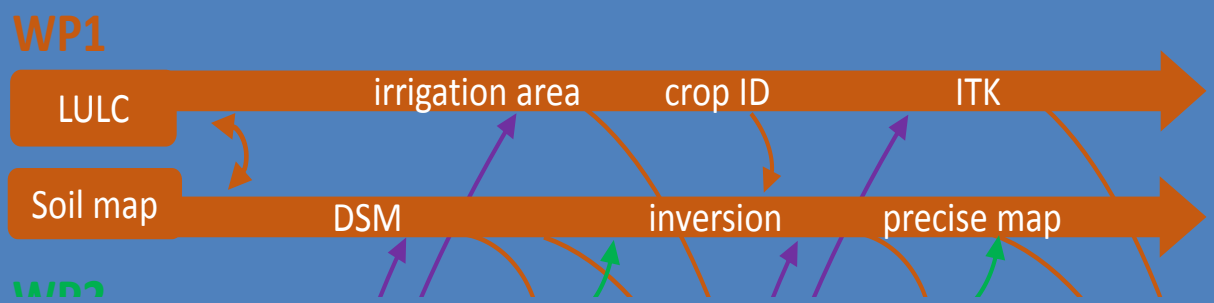
Use the model for co-building scenarios with Stakeholders



Partnership:
(socio Economy)
UAS

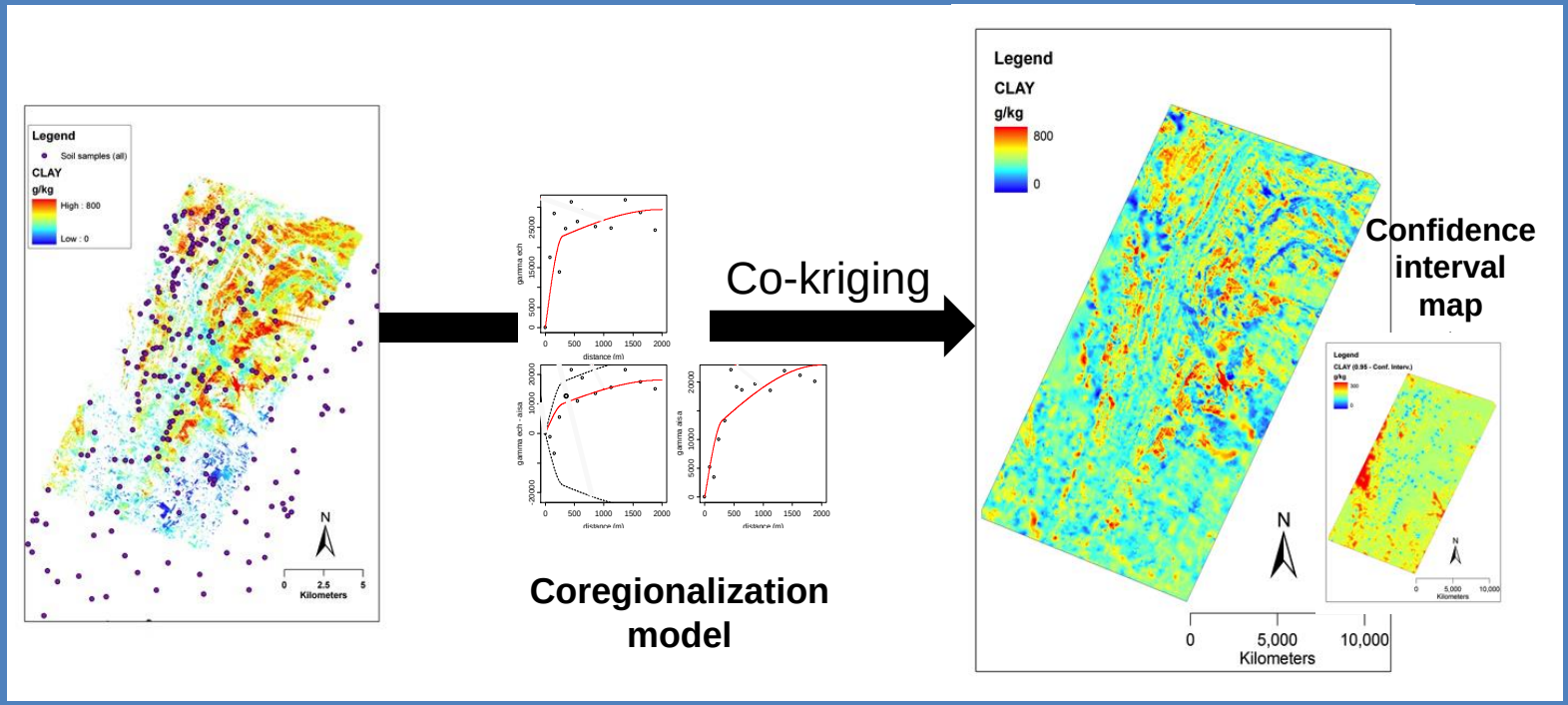


Make the model more realistic



Partnership:
ICAR-NBSS&LUP

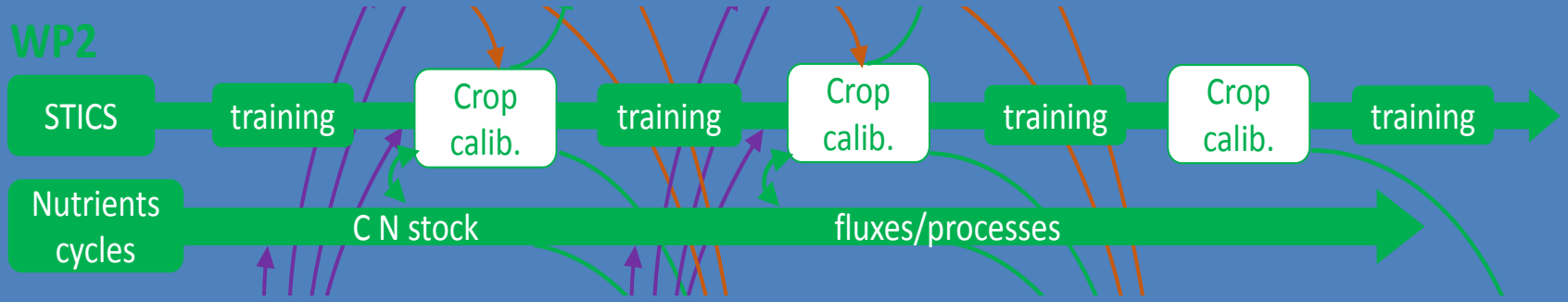
Digital Soil Mapping

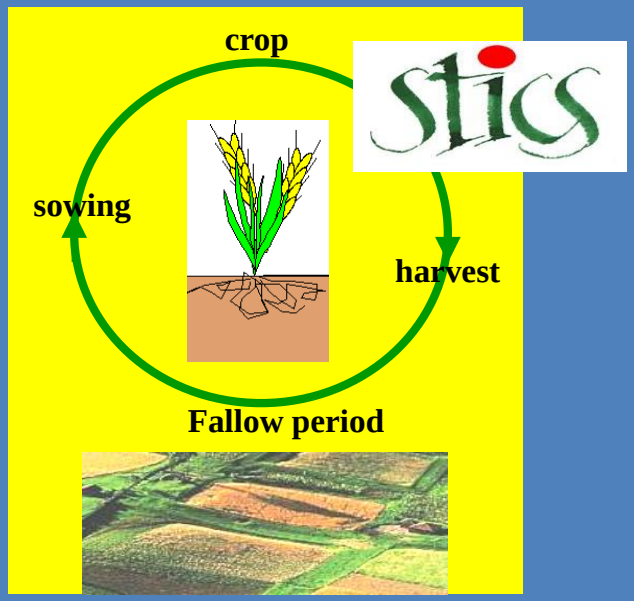


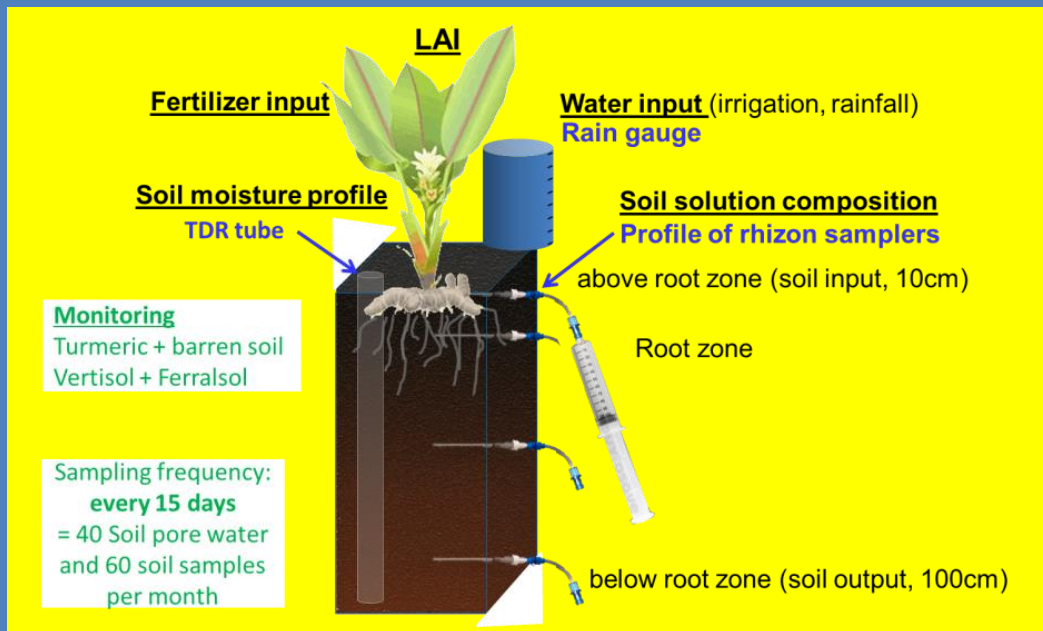
Make the model more realistic

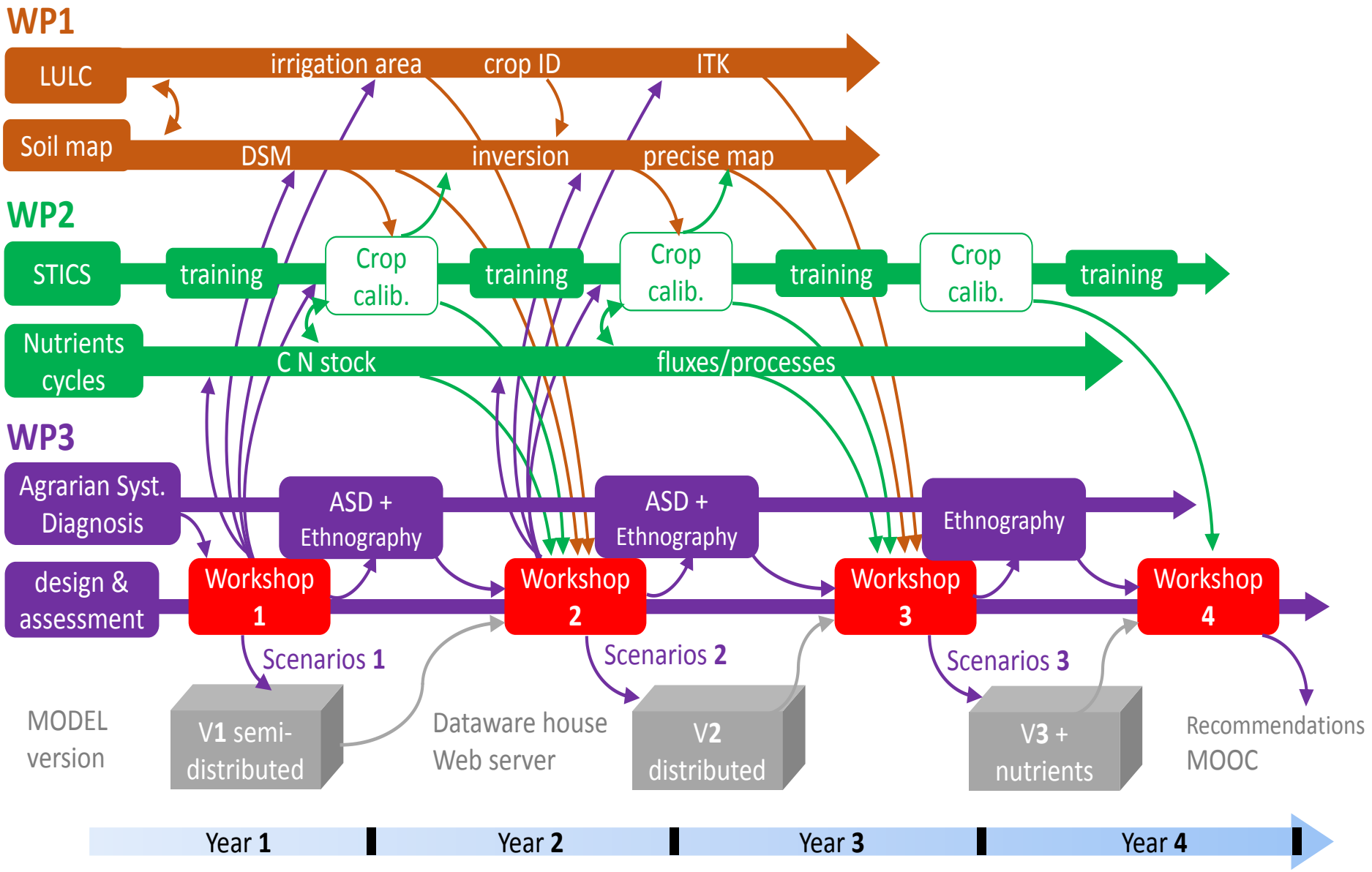
Partnership:
Agronomy/geochemistry
UAS

Crop modelling and nutrient cycling








WP1
LULC
irrigation area
crop ID
ITK
Soil map
DSM
inversion
precise map
WP2
STICS
training
Crop calib.
training
Crop calib.
training
Crop calib.
training
Nutrients cycles
C N stock
fluxes/processes
WP3
Agrarian Syst. Diagnosis
ASD + Ethnography
ASD + Ethnography
Ethnography
design & assessment
Workshop 1
Workshop 2
Workshop 3
Workshop 4
Scenarios 1
Scenarios 2
Scenarios 3
MODEL version
V1 semi-distributed
Dataware house Web server
V2 distributed
V3 + nutrients
Recommendations MOOC
Year 1
Year 2
Year 3
Year 4

Thank you

Thanks to:

IISc, IFCWS Bangalore:	Pr M Sekhar, Pr MS Mohan Kumar, Sat Kumar Tomer, Amit Kumar Sharma, Buvana Sriramulu, Subash Yeggina, Deepti Upadhyaya, Eswar Rajasekar, Sanjeeva Murthy, Giriraj P R, Arun, Venkatesh.
IRD, GET, IFCWS:	Jean Riotte, Laurent Ruiz, Maud Bonzi
ATREE:	Shrinivas Badiger, Iswar Patil, Divya Solomon
INRA AGIR Toulouse:	Delphine Burger-Leenhardt, Jacques Eric Berger, Magali Willaume, Marion Robert
INRA LERNA TSE Toulouse:	Alban Thomas , Stéphan Ambec, Stéphane Cezéra
INRA SAS Rennes:	Patrick Durand, Chantal Gascuel, Laurent Ruiz , Jordy Salmon Monviola
INRA RECORD Toulouse:	Eric Casellas, Helene Raynal
INRA EMMAH Avignon:	Martine Guerif, Samuel Buis, K Sreelash
CNRS COSTEL Rennes:	Samuel Corgne, Laurence Hubert-Moy , Mael Ameline, Julie Campagna, Fanny Gautier, Justine Boulent