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GCRF Global Challenges Research Fund

Future DAMS
Design and Assessment of water-energy-food-environment Mega-Systems

Agent-based Modelling for Exploring Decentralised Water Management

Reflections on the Process and Experience

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UK Data Service Agent-based Modelling Training Series: Guest Seminar

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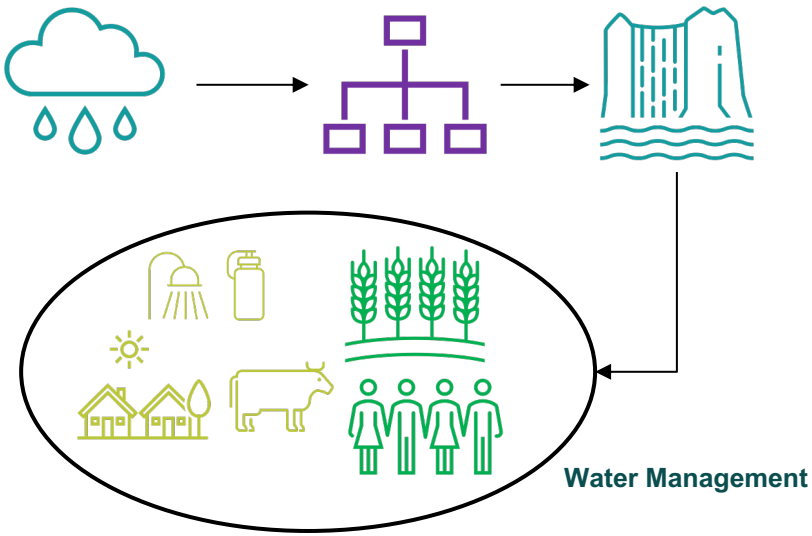
Decentralised Water Management – Background

- Huge investments in large-scale centralised irrigation systems in the 1950s and 60s
- Systems failed or underperformed due to improper planning, poor maintenance and overlooking local needs and traditions



Bali Rice Terrace

- Irrigation management reforms in the 1970s
- Further push for decentralisation of water management in the 1990s Integrated Water Resources Management (IWRM) paradigm

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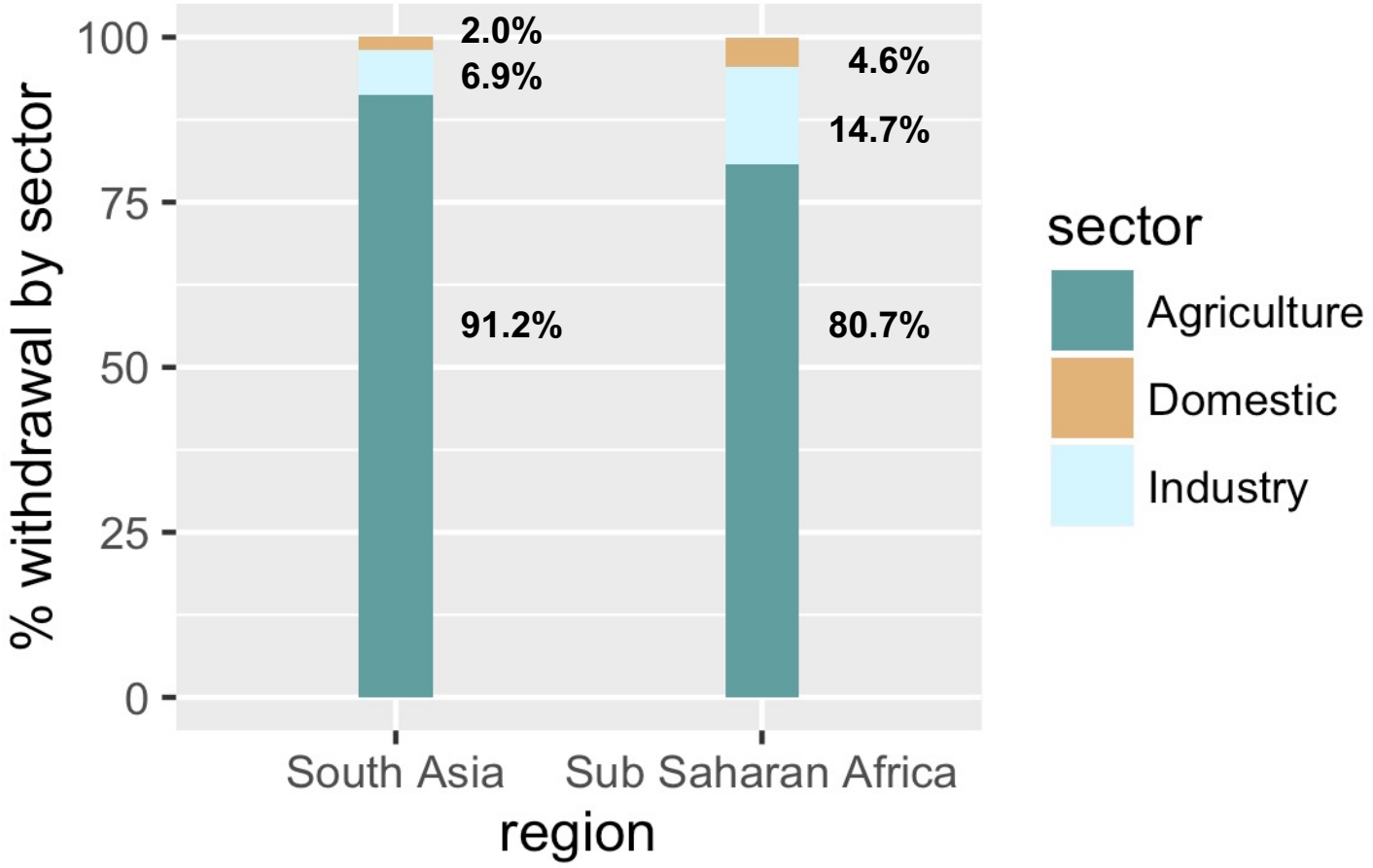
Decentralised Water Management – Sub-Saharan Africa (SSA)



Source: world bank, share of freshwater withdrawals by sector in 2014
https://blogs.worldbank.org/opendata/chart-globally-70-freshwater-used-agriculture

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Decentralised Water Management – Nuances in SSA

- Rainfed farming (traditional systems) and Irrigation farming
- Irrigation can be through farmer-led schemes or sponsored schemes
- Farmer-led Irrigation (FLI) schemes: Smallholder farmers (small farms) organised in groups
- Sponsored schemes: State entities or donors initiate large-scale irrigation projects and handover to scheme-level groups
- **Water User Associations (WUAs)**: Responsible for water management within schemes

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Water User Associations (WUAs)

WUAs are semi-formal or informal institutions

Semi-formal WUAs have institutional mandates:

- Allocate water to users
- Operation & Maintenance of irrigation system
- Collect fees and fines

Generally **small scale** with few hundred members

WUAs often struggle to fulfil mandates

- Expectation: irrigation performance -> agricultural productivity -> cost recovery -> user participation
- Disruptions: limited finances, management & technical expertise; inadequate inputs & market provisions; conflicting water uses

Farmers directing water within their plots. Images shared by and belong to Prof. Eric Ofosu Antwi *https://rcees.uenr.edu.gh/profile-dr-antwi-ofosu-eric/*

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Need to improve WUAs: Our Research

- Significant failures of irrigation schemes, but ongoing efforts to expand irrigation and introduce WUAs in sub-Saharan Africa
- Hence need to understand how WUAs work and explore management options to improve outcomes
- Real-world experiments are expensive and time-consuming; computer simulations provide a tractable alternative
- Question #1: How does participatory irrigation management through WUAs work?
- Question #2: Which management option is better for improving the economic productivity of water users and WUA?

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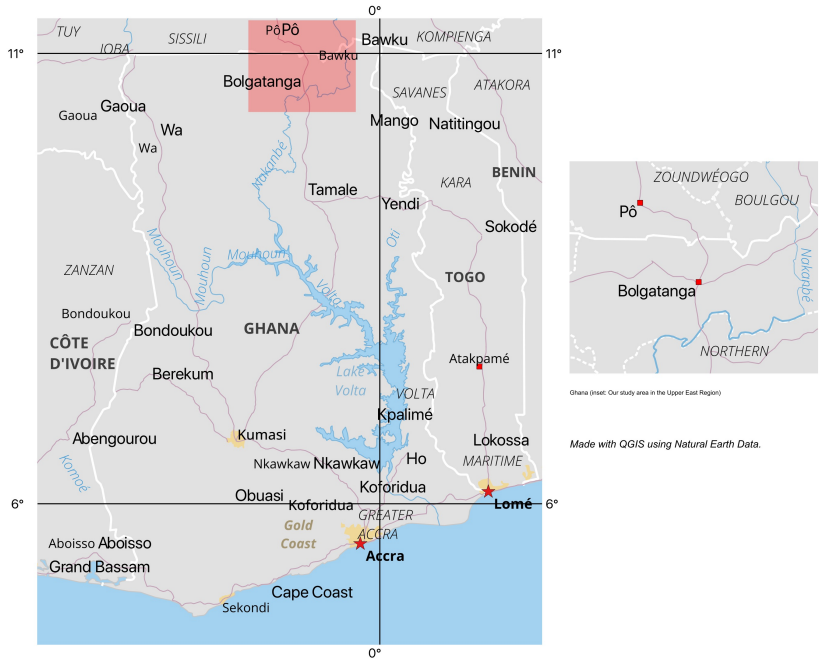
Evidence on the Ground: Irrigation Schemes in Ghana

- Field data to define the scope of simulation and choose an appropriate modelling technique
- Interviews with WUA members and representatives, extension officers and researchers



Ghana (inset: Our study area in the Upper East Region)

Made with QGIS using Natural Earth Data.

Water not exclusive to Farmers – Pastoralists & Households also use water

Water not exclusive to WUA members

Varying views on who can be WUA members and pay for water

Conflicts between water uses

No standard WUA template

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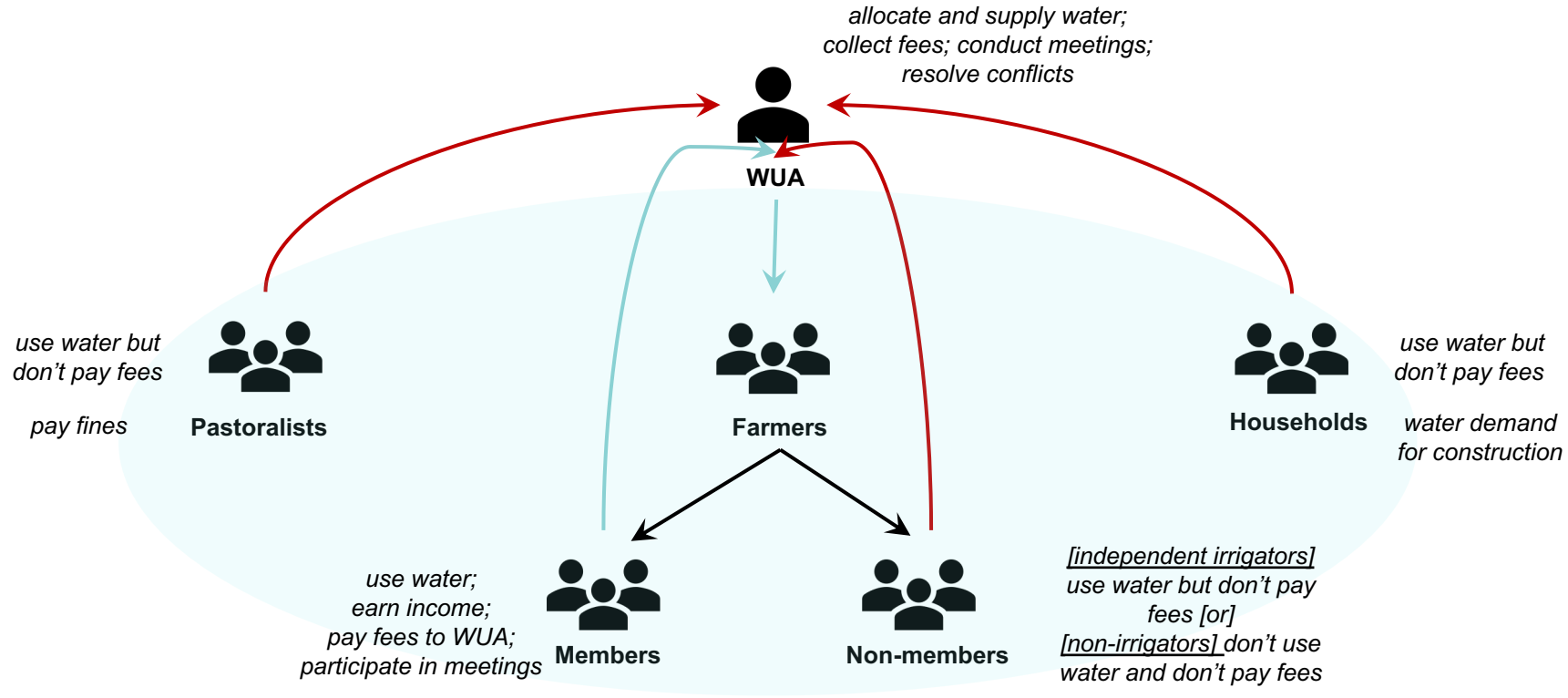
Narrative of Decentralised Water Management through WUAs



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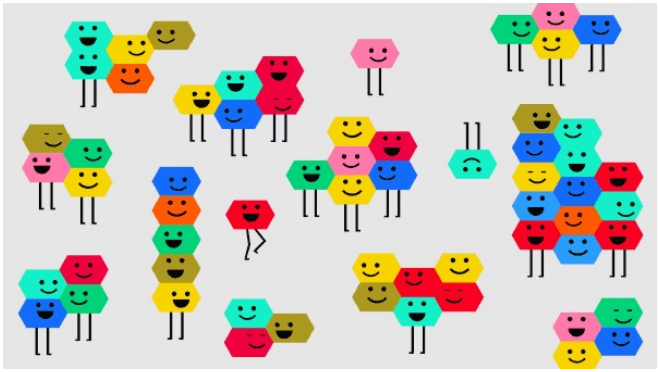
Which Computer Simulation Technique?

- Irrigation scheme as a **socio-ecological system** shaped by the effects of the interactions between human actions, infrastructure, and ecology
- Different types of actors within the system with different objectives and needs for a shared resource – **common-pool resource problem**
- The system has multiple potential causes for failures in terms of exploitation and scarcity of resources, but lacks (partial) **causal explanation**
- **Flexible modelling approach** needed to work with reasonable theoretical assumptions where limited individual-level data is available
- Generate **meaningful counterfactuals**



Agent-based Modelling

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Introducing the WATERING Agent-based Model

- **WATER** user associations at the **I**nterface of **N**exus **G**overnance
- A tool to explore and plan community-level water management:
  - understand and explain the combined influence of WUA policies and community participation on water use and incomes in an irrigation scheme
- Agents are **farmers**, **pastoralists**, **households** and **WUA**
- The environment is a **simulated irrigation scheme**; built infrastructure (comprising of a reservoir and canal network)
- Social environment: neighbouring water users influence each other

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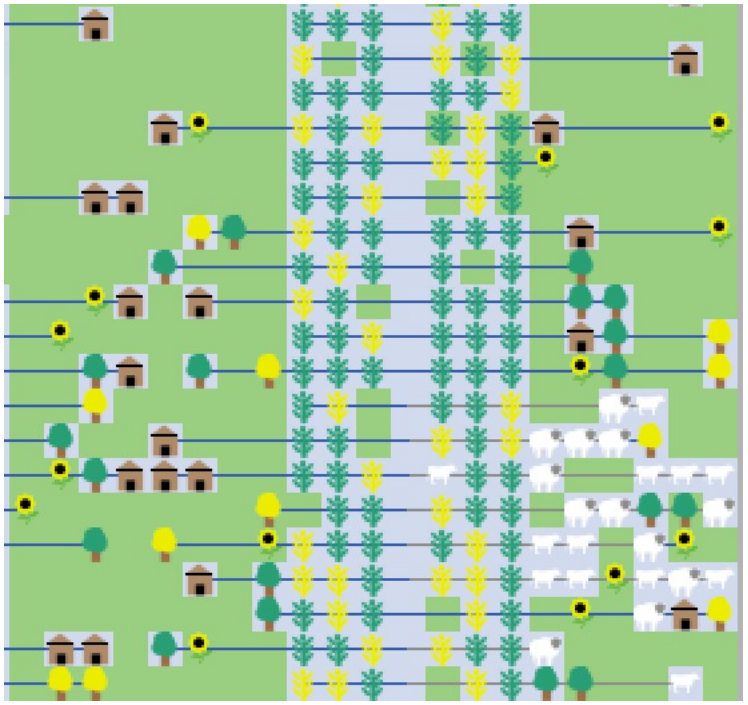
WATERING: A Simplified Irrigation System Simulation

- Implemented in NetLogo
- Empirically informed stylistic model
- Only surface irrigation and gravity flow
- Single WUA within irrigation scheme
- Each farmer cultivates one plot
- Water users don't switch economic activity
- Only one crop per season per plot
- Each tick is one calendar month



WATERING world view

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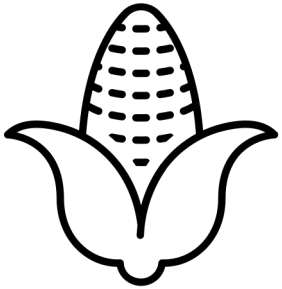
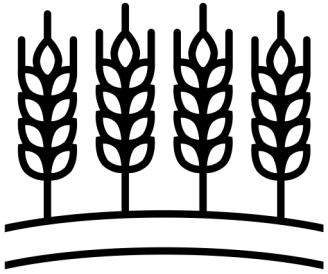
WATERING: Crop Water Demand

- Commonly grown dry season, wet season and multi-season crops are modelled
- One crop per season and up to two crops per year – e.g., one wet season and one dry season crop; two cycles of a multi-season crop
- Crop growth occurs in four stages – initial, development, mid-season, and late season
- Duration of each crop (and crop stages) set via the NetLogo Interface
- Blaney-Criddle method used to *estimate* crop water demand in each growth stage; water supplied through rainfall or irrigation or both
- WUA membership affects which crop(s) farmers grow





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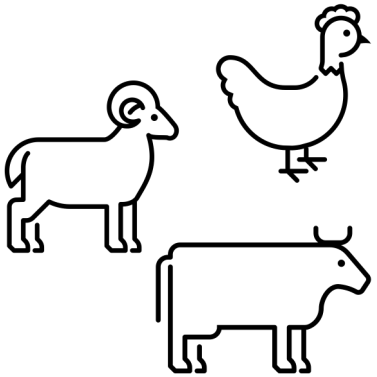
WATERING: Livestock and Household Water Demand

- Pastoralists have large numbers of cattle, goats, poultry; Crop farmers have fewer animals
- Water demand for livestock calculated based on number, livestock type, and average demand by type
- Household water demand calculated based on household size and average water demand per person; random use of water for construction
- Water consumption of pastoralists and households is unregulated
- Potential conflicts between water users



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WATERING: WUA Management Policies

Options	Values	Meaning
Membership	Exclusive	Only scheme farmers can be WUA members
	Inclusive	Scheme farmers, Pastoralists and Households can be WUA members
Water allocation	Upstream downstream divide	Upstream users get water first followed by downstream users
	Equity	Water is divided equally across the scheme
Strictness	Enforce	Full restriction on water use beyond quota
	Incentivise	Limited restriction on water use beyond quota
	Relaxed	No restriction on water use beyond quota

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WATERING: WUA Agent Actions

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Each year, WUA estimates annual water demand by month based on the cropping patterns of farmers

Each month, WUA allocates water to members (proportional to their demand) based on the amount of water available in the scheme

WUA collects fees from members

WUA collects fines from water users, e.g., when livestock destroy crops

WUA uses its income for Operation & Maintenance, e.g., to repair canals

WUA loans money to members affected by income loss

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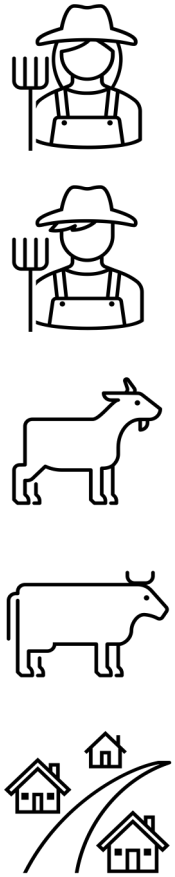
WATERING: Water User Categories

- Types of water users: Farmers, Pastoralists & Households
- Categories of farmers: Scheme farmers, Independent irrigators & Non-irrigators
- WUA members: Scheme farmers only (exclusive WUA membership) or Scheme farmers, Pastoralists and Households (inclusive WUA membership)
- Scheme farmers constitute the majority of water users
- One of three economic states each year: Active, Inactive *(pause economic activity)* or Obsolete *(cease economic activity)*



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WATERING: Water Users' Reactive Behaviour Stance

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Every month, each water user:

- Adopts a reactive behavioural stance (cp or ncp)
- Calculates a utility to cooperate (U_i) with WUA's quotas based on:
  - their own behavioural stance (cp or ncp)
  - the behavioural stance of their neighbours
  - WUA's strictness (enforce, incentivise or relaxed)
- Calculate actual reduction in water demand based on U_i

Reduction in water demand has a proportionate effect on water users:

- less water results in reduced crop yields and lower income
- less water for livestock results in poor health or death

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WATERING Simulations: Input settings

Model Settings	Options	Values
WUA water allocation	2	Upstream-downstream divide Equity
WUA strictness	3	Enforce Incentivise Relaxed
WUA Membership	2	Exclusive to scheme farmers Inclusive of all member water users
Livestock damage?	2	TRUE: Livestock damage canal and crops FALSE: Livestock don't cause any damage
Irrigation events	NA	No. of irrigation events each month: 30 Duration of each irrigation event: 6 Discharge rate: 8 m3/s Irrigation allocation: 60% of water at source Scheme efficiency: 0.6

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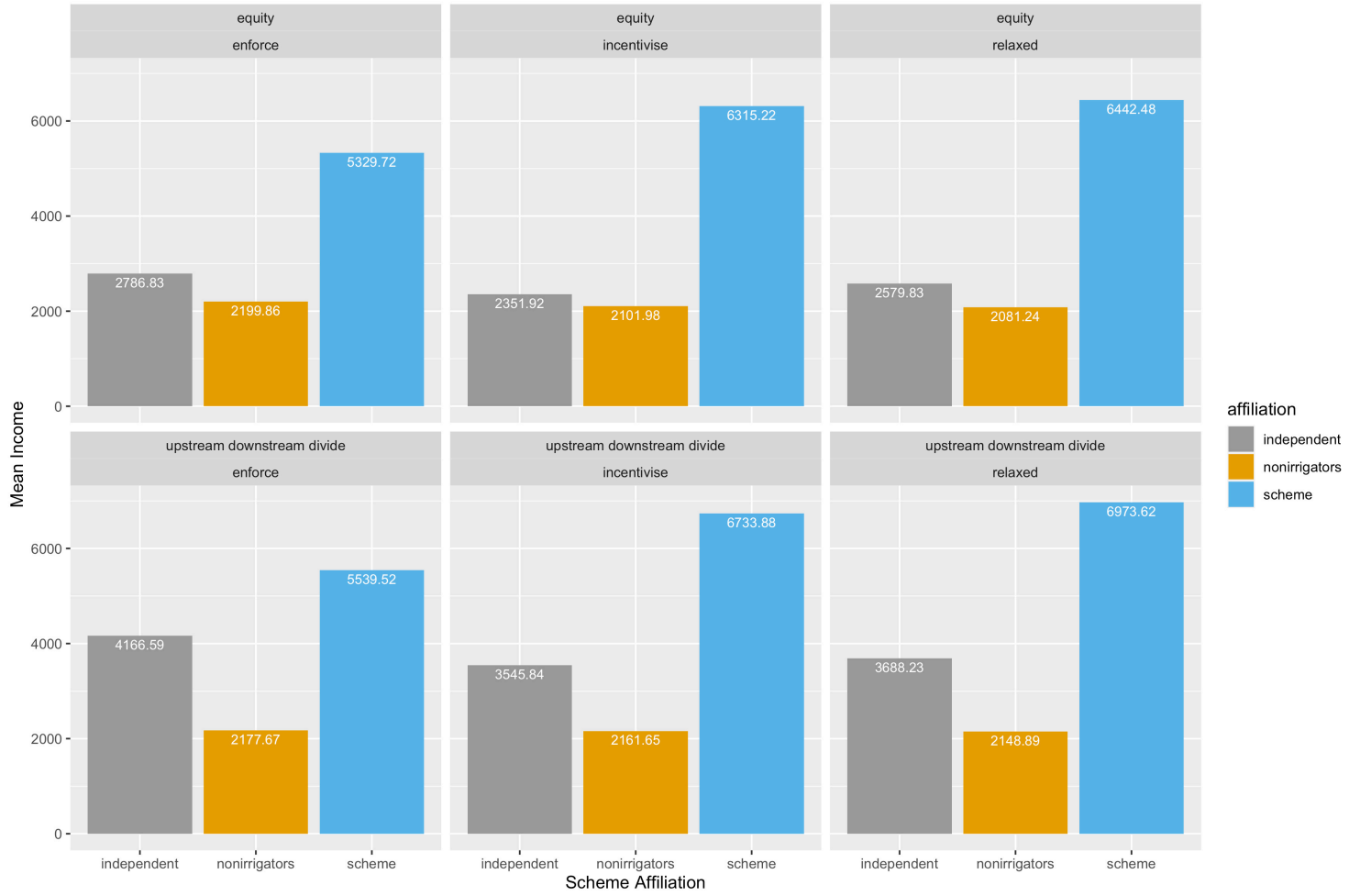
Summary:
- Scheme farmers earn more than independent irrigators and non-irrigators (expected)
- Non-irrigators earn the least (expected)
- Farmers earn more with an upstream-downstream water sharing arrangement (also expected)
- Scheme farmers earn more when WUA is relaxed; (conversely) Independent irrigators earn more if WUA is strict – unexpected!



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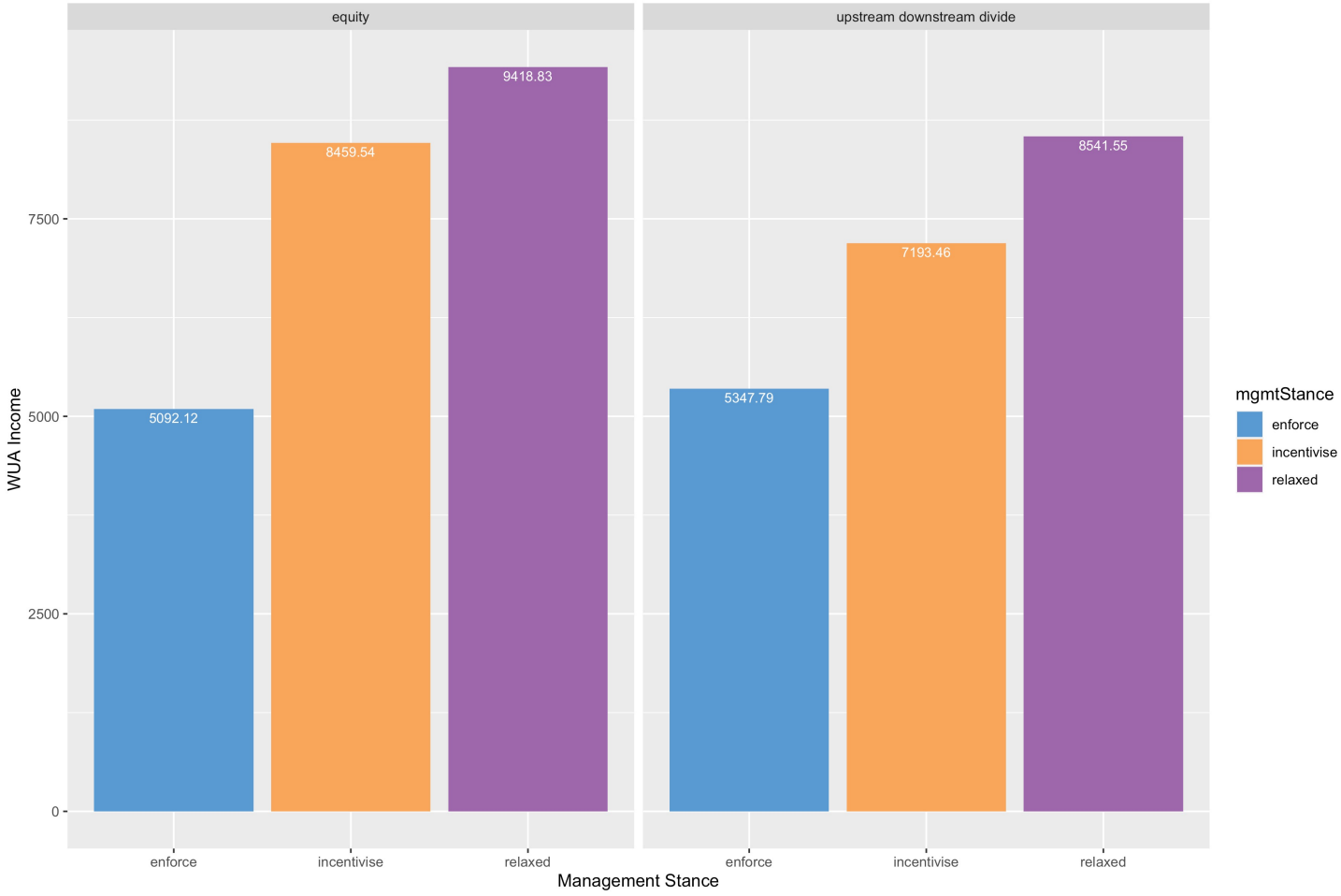
Summary:

- Trend is reversed for WUA income based on water sharing – WUA earns more under an equity arrangement, because more users make marginal profit compared to fewer users making greater profit (in the upstream-downstream scheme)
- It is also in WUA's interest to be more relaxed with its water allocations (avoid strict rationing) to improve income
- With strict rationing, adopting an upstream-downstream water sharing policy might favour WUA income



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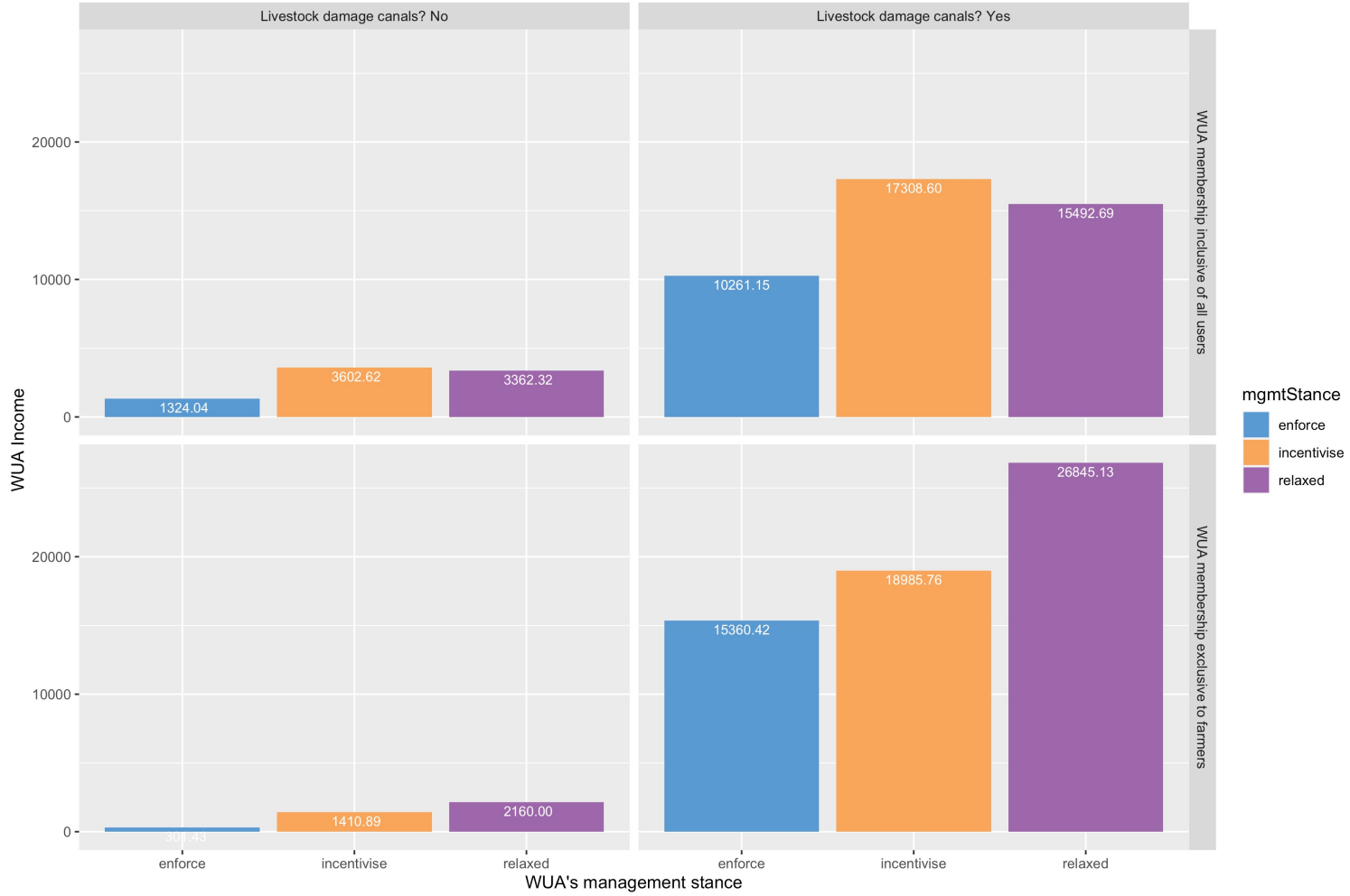
Summary:

- WUA has more income if livestock damage canals; counter-intuitive result; stems from assumption that WUA recovers fines from pastoralists if livestock damage canals
- If livestock damage canals and WUA membership is exclusive to farmers, WUA has more income due to fewer and lower payouts to support members
- If livestock don't damage canals, WUA has more income if membership is inclusive of all water users



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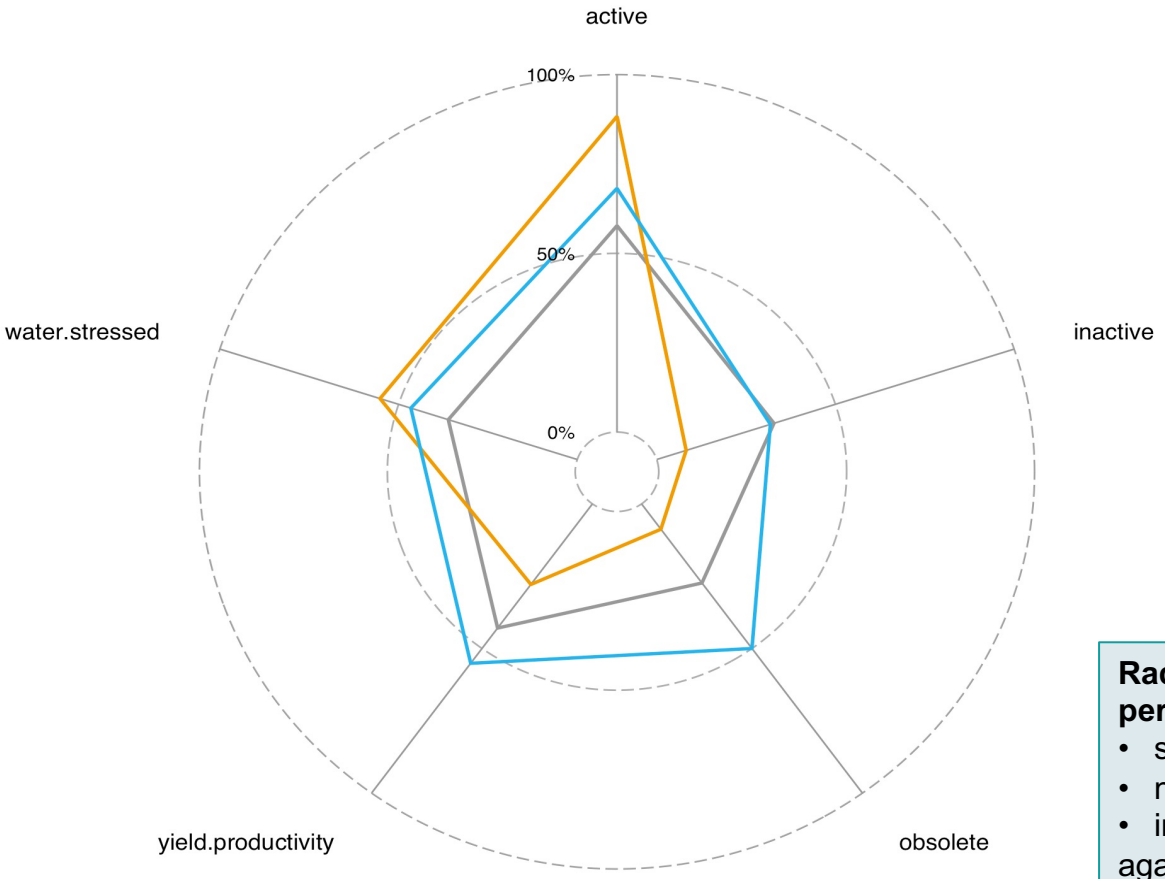
Summary:
- Even if their income is low, non-irrigators remain more economically active than scheme farmers and independent irrigators as they have no water use costs
- Scheme farmers are more water stressed than independent irrigators
- Scheme farmers have the highest yield productivity (crops harvested per unit of water consumed) compared to independent irrigators and non-irrigators



Radar chart showing the performance of:
- scheme farmers (blue)
- non-irrigators (orange)
- independent irrigators (grey)

against different measures

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Revisiting our Research Questions

How does participatory irrigation management through WUAs work? Which management option is better for improving the economic productivity of water users and WUA?

- Being relaxed about water users exceeding their quotas improves the income of scheme farmers (**when** WUA is aware of unregulated water use but is not able to control it)
- Equity water allocation boosts WUA income (**because** more members make enough profits to pay WUA fees), whereas upstream-downstream divide boosts the income of scheme farmers (**because** they are located mostly upstream)
- Exclusive membership (to scheme farmers) works better (**when** livestock damage canals), otherwise inclusive membership is better

Results depends on multiple factors and circumstances!

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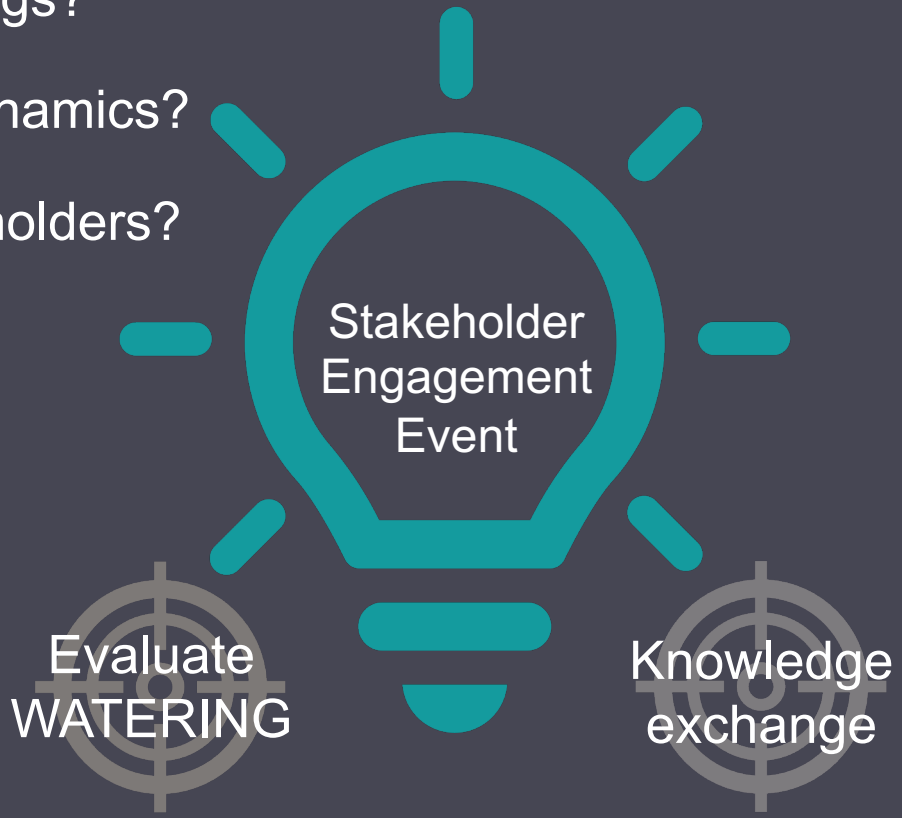
What Next?

- Is WATERING doing the right things?
- Is it missing key elements and dynamics?
- Will the model be useful to stakeholders?
- Sparse or no WUA level data!
- So, how can we know?



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WATERING Systems Mapping Session

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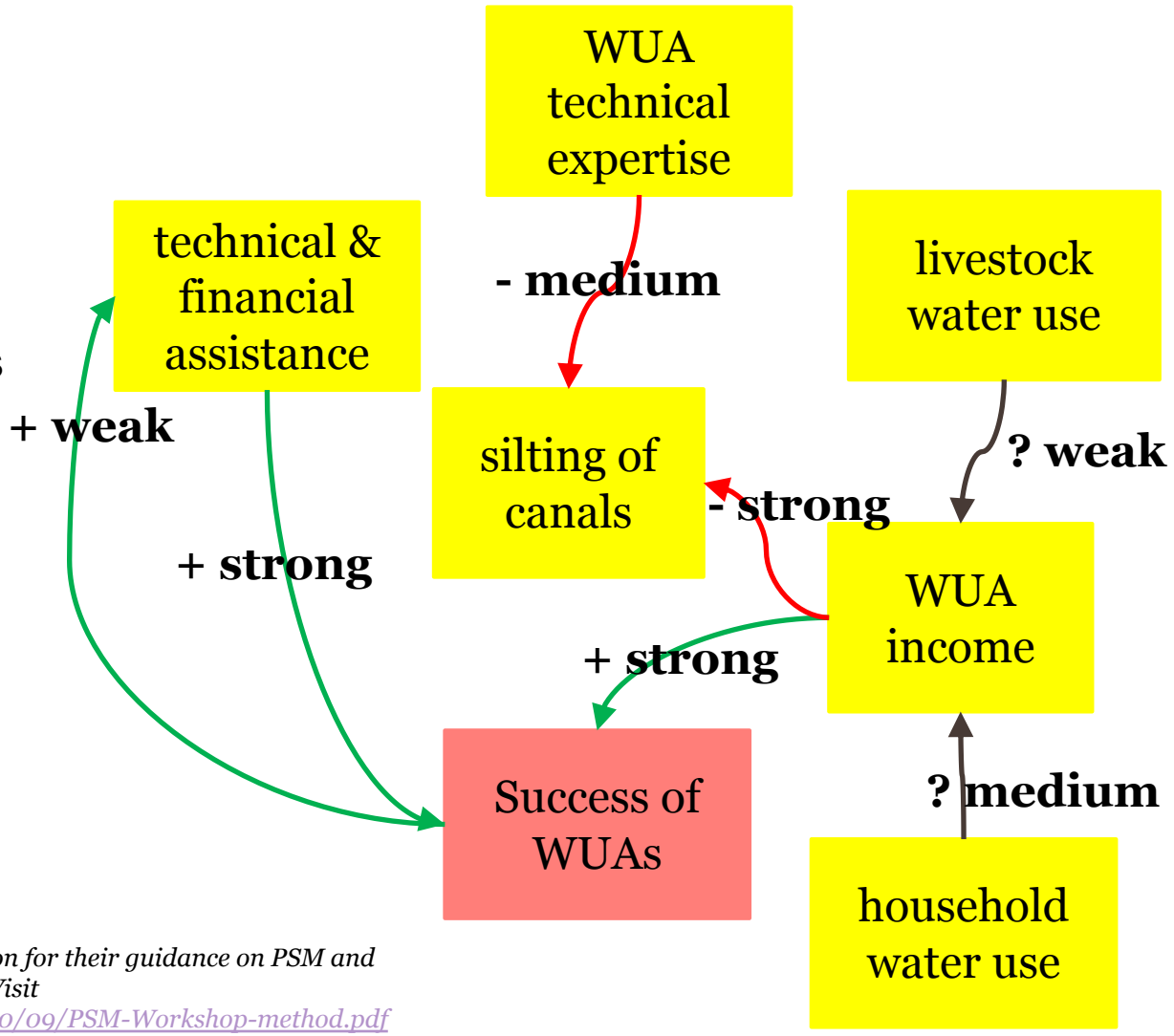
Collaborative participatory activity to:

- Identify key factors
- Identify key connections between factors
- Clarify the nature of connections
- Consolidate understanding



Thanks to Dr Alex Penn & Dr Peter Barbrook-Johnson for their guidance on PSM and Prof Nigel Gilbert for the PRSM tool and guidance. Visit
https://www.cecan.ac.uk/wp-content/uploads/2020/09/PSM-Workshop-method.pdf
https://prsm.uk/

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WATERING Flowcharts Session

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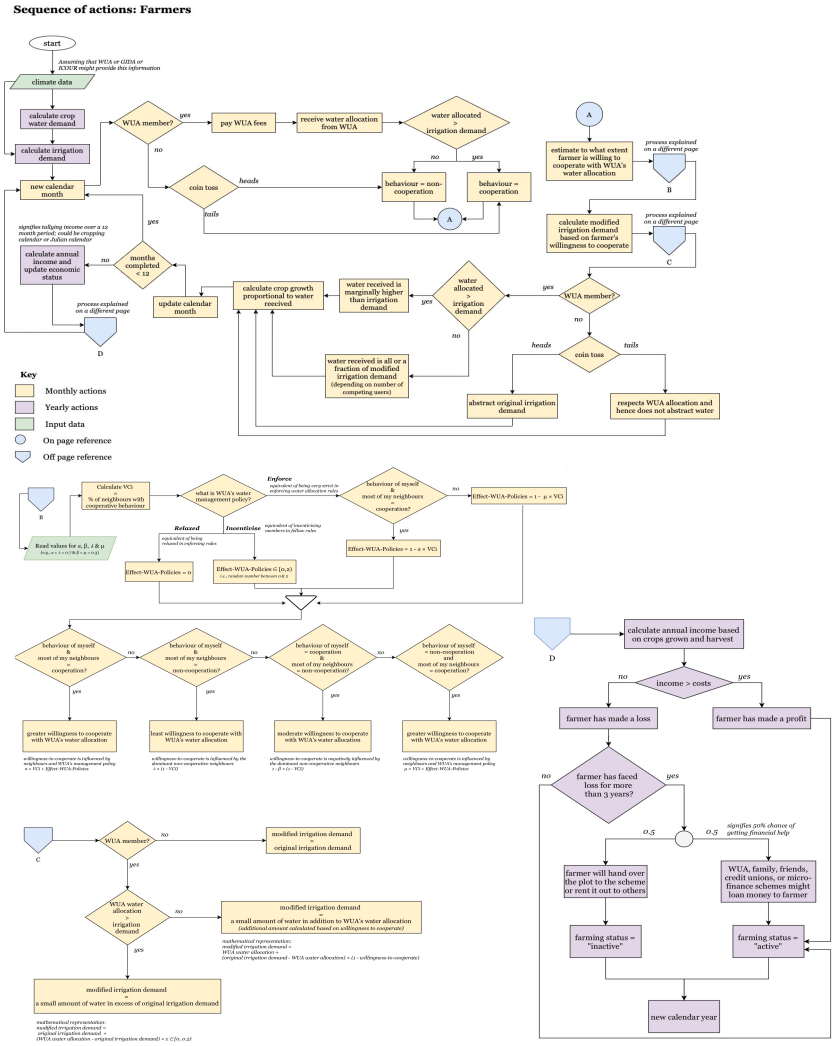
Collaborative participatory activity to review the sequence of:

- Four flowcharts; each describing a sequence of actions performed by specific actors
- Objective: To assess
  - Logic of actions
  - Ownership of actions
  - Preconditions for actions
  - Nature of actions
  - Type of actions
  - Timing of actions



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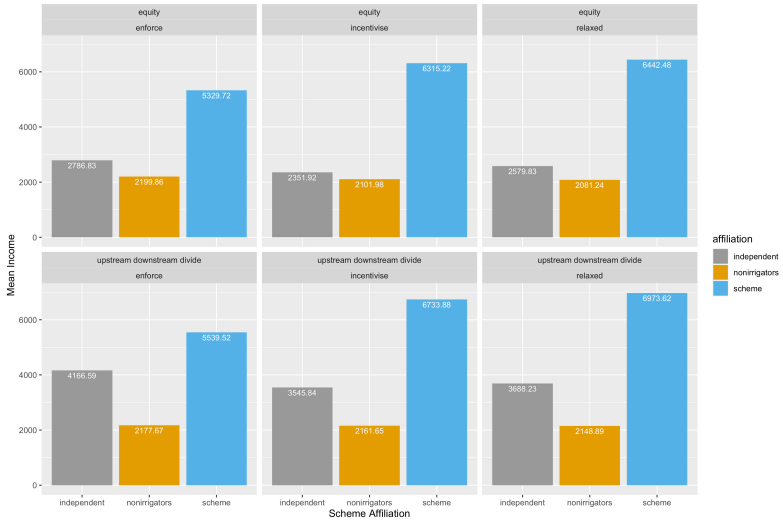
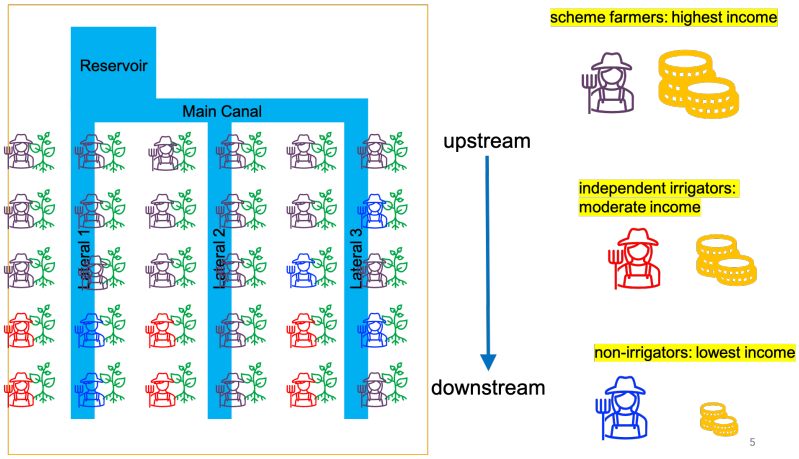
WATERING Stories Session

Story #1: *Our WATERING model simulates an irrigation scheme that has a reservoir, main canal and several side channels. The plots are on either side of the channels. Each plot is farmed by a farmer. There are three types of farmers:*
Scheme farmers (in purple) are WUA members, they pay water fees and WUA fees. Most of them are at the upstream end.
Non-irrigators (in blue) rely on rain for crop growth. They are not WUA members. They do not pay WUA fees or water fees.
Independent Irrigators (in red) are farmers who are not WUA members. They do not pay WUA fees or water fees, but still use water from the scheme. We call this unregulated water use.

Result: *Upstream users get water first, followed by downstream users. We find that Scheme farmers have the highest income, followed by Independent irrigators. Non- irrigators have the lowest income because they only cultivate during rainy season.*
Do you see this in your irrigation scheme?





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WATERING: Overview of Stakeholder Assessment

Model aligned with experience or expectations	○ WUA allocates water depending on supply and demand; collects fee and fines; performs O&M and loans money to members (experienced) ○ Water users tend to cooperate or not cooperate with WUA's water allocation; unregulated water use is prevalent (experienced) ○ Pastoralists and households should be allowed to become WUA members (expectation)
Model diverged from *(or partially aligned with)* experience or expectations	○ Area cultivated would be determined based on water available, so water shortages are unusual (experienced) ○ WUA strictness will increase cooperation with quotas (expectation) ○ Pastoralists and households becoming WUA members will boost its income (expectation; model aligned partially)
Further dimensions to consider	○ Regular WUA meetings enables members to cooperate more/better with WUA policies (experienced) ○ Success of WUA members would encourage others to join WUA (expectation)

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WATERING: Promoting open research practices and reusability

- Reusable modules in software development
- ≃ **Reusable Building Blocks (RBBs)** for agent-based models**:** Sub-models of behaviours or processes useful in multiple contexts *(upcoming session in iEMSs 2022)*
- A reusable model to simulate water flow in an irrigation system https://doi.org/10.5281/zenodo.6323633
- A reusable model to simulate water flow and crop growth in an irrigation system https://doi.org/10.5281/zenodo.6323653

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Taking stock

What I hoped to achieve in this session:

- Share the experience and reflections from developing an agent-based model of decentralised water management in SSA:
  - Based on real-world data
  - For potential real-world application
  - Co-developed and assessed by stakeholders and citizens
  - Developed in iterative fashion
- Developing agent-based model components to promote openness, transparency and reusability

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- **Dr Timothy Foster** (University of Manchester, UK)
- **Dr Nathan Forsythe** (Newcastle University, UK)

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Thank You

Comments, questions, feedback, interested in using WATERING? Please get in touch:

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