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Agent-based modelling of agricultural water abstraction in response to climate change and policies: In East Anglia, UK

Swinscoe, T.H.A., Knoeri, C., Fleskens, L., and Barrett, J.,
Earth and Environment,
University of Leeds,
Leeds LS2 9JT,
UK
Email: {gy10ths; C.Knoeri; L.Fleskens; J.R.Barrett}@leeds.ac.uk

***Abstract*—Freshwater is a vital natural resource for multiple sectors. However, freshwater available for abstraction in the UK and in particular agricultural irrigation in East Anglia is becoming increasingly variable and uncertain due to climate and policy changes, and increase in demand. We present an Agent-Based Model (ABM) that has the capability to capture the complexity of this system as individual abstractors interact, learn and adapt to internal and external changes. The purpose of this model is to understand under which policy and climate change scenarios sustainable water resource management emerges from decisions and interactions of water abstraction licence holders. This poster will present the conceptual model and preliminary results.**

I. Introduction

FRESHWATER is a vital natural resource for supplying drinking water for the public, cooling processes for industries, hydropower for energy companies, and irrigation for agriculture. However, freshwater available for abstraction in the UK and in particular East Anglia is becoming increasingly variable and uncertain due to climate change and increase in demand.

Agricultural crop producers use their irrigation licence to meet crop water demands which vary depending on a range of climate and farm variables. Climate and policy changes greatly influence abstractor's short and long term options (e.g. crop type grown, water availability, irrigation practice, long term infrastructure investments). Under the existing licensing system agricultural licence holders have few options or incentives to manage water efficiently. Water licence trading is difficult to administer, time consuming and rarely occurs, nor have farmers access to other abstractors' unused licensed water as permitted abstractions are not currently linked to water availability. Therefore two new licensing options have been proposed by the Department for Environment, Food and Rural Affairs (Defra) [1] which both aim to address these issues, Current System Plus (CSP) and Water Shares (WS). CSP would be a refinement of the current system, addressing the issues mentioned above, by pre-approving temporary low risk trades. WS would be a greater change where each licence holder has a share in the available water resource, rather than a set amount. This option would permit pre-approval of short term trades and a greater range of trades compared to CSP and the existing licensing system.

As climate and policy changes influence abstractor's short and long term options, these variables clearly influence their short and long term decision making (e.g. crop type, irrigation practice, licence trading, and local interaction with neighbouring abstractors and with the environment). Individual abstractors' behaviours affect water availability at the farm, local, and system level as abstractors adapt to climate change and policies. We have developed an ABM to capture the complexity of this system under various scenarios, and to analyse under which conditions a sustainable water resource management system emerges.

The following research questions are addressed:

- What patterns of water resource management emerge on the system level based on local interactions, adaptations and behaviours of farmers?
- What policies lead to a sustainable water resource management system?

II. Study Area

Agricultural crop production in East Anglia is the largest anywhere within the UK, despite the low percentage of the agricultural workforce used in the region (1.42%). In 2010, 1,381,000 hectares (13,810 km^2) were used for agricultural production in East Anglia, mainly for wheat (36%), other cereals (10%), and oilseed rape (10%) [2]. Water abstraction is already a major input in the crop production process in East Anglia, with 3,670 spray irrigation licences in 2012 (71 % of all licences in the region) [3]. These licences will increasingly need to be relied on as precipitation becomes ever more variable and uncertain due to climate change as demand for water in different sectors increases. East Anglia is already the driest region in the UK, with average annual rainfall between 560 and 720 mm (1971 to 2000) [4].

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III. Method

Agent-Based Modelling (ABM) is being used for its capability to capture the complexity of this system as individual abstractors interact, learn and adapt to internal and external changes. It has been widely applied for land use change [5]-[7], water management [8], [9], and some irrigation studies [10]-[12]. This research addresses these three aspects together as they are crucially interlinked through farmers' behaviour.

Recently, empirical based ABM has gained importance in order to simulate more realistic decision making and behaviour under future scenarios [13], [14]. As systemic patterns of water resource management are not available to assess new licensing policies, it is necessary to know what sort of patterns emerge, based on robust (empirically based) local interactions and behaviours. Therefore, a survey was conducted to identify agricultural abstractor's short and long term behaviour under a range of water availability scenarios within the central area of East Anglia, UK. The survey was based on the Theory of Planned Behaviour (TPB) [15]. The purpose of this survey was to understand how agricultural abstractors behave and interact under different water availability scenarios.

IV. Model Description

Here we present the conceptual ABM based on the Overview, Design concept and Details (ODD) protocol [16].

1. Purpose

The purpose of this model is to understand under which policy and climate change scenarios sustainable water resource management emerges from decisions and interactions of water abstraction licence holders.

2. Entities, state variables, and scales

The main agents are represented as agricultural abstraction licence holders (i.e. farmers). They are characterised by state variables, referring to their different short and long term behavioural strategies and attributes. Farmers' state variables include a range of behavioural variables derived from TPB (i.e. attitude, subjective norm, and perceived behavioural control), and other agent attribute variables such as farm characteristics and social demographics.

The agents environment is represented as a grid based spatially discrete landscape, which closely resembles that of the central Anglian region, UK. The exact farm boundaries are not represented due to reasons of confidentiality. The spatial extent of the model is defined by the spatial extent of the hydrological catchment of the central Anglian region, each cell representing 1ha. These landscape entities will be represented by cells, which are characterised by including elevation and run-off. Links between grid cells form a hydrological network of the model catchment.

Agents and grid cells are updated to record the change in state variables on a weekly timescale. One time step therefore represents one week (52 time steps represents a year) and simulations are run for 35 years to match the climate change projections used [17]. A range of scenarios will be simulated including; climate change induced water scarcity and surplus, particular licensing policies including CSP and WS, and increased demand from other sectors.

3. Process overview and scheduling

Simulations start with all abstraction licence holder entities located on the landscape corresponding to their natural geographic network location. Pseudo-code below illustrates the main procedure and the possible water surplus and shortage decisions available depending on their agent behavioural strategy.

Abstraction licence holders have two decision periods; short term in season decisions (week 1 to 52) and long term strategic decisions (week 52). Abstractors decide every time step to 'seed', 'irrigate', and then 'harvest'. These are short term in season decisions. In week 52, abstractors make long term strategic decisions depending on whether they have experienced a water shortage or surplus for the majority of the season, or over consecutive seasons depending on their behavioural strategy. At the end of each time step, abstraction licence holder and grid cell state variables will be updated to record changes which may have occurred the previous time step (changes may occur depending on agent entities state variables, particularly behavioural strategies).

The in season shortage decisions include the following options; use maximum abstraction licence, to spread water evenly between all crops or to irrigate their most valuable crops, restrict application (i.e. deficit irrigation), or buy more water to meet crop requirements. In the case of an in season water surplus farmers can decide between; selling surplus water to maximise profits, use their abstraction licence to meet crop water requirements and leave the remainder of their licence unused, or abstract surplus water for storage.

Options of the end of season strategic decisions in case of repeated shortage are; grow the same crops but over a smaller area, grow less water intensive crops, increase storage capacity, increase application efficiency, buy more water for the duration of the growing season, apply for a larger abstraction licence, or change nothing. If repeated surplus is experienced in previous seasons farmers could; grow the same crops but over a larger area, grow more water intensive crops, sell surplus water for the duration of the growing season, or change nothing.

```
for every week
  set_climate (adjust temperature and precipitation)
  set_policy (adjust policy variables e.g. water trading)
  for all abstractors [
    seed (depending on climate and behavioural strategy)
    irrigate [
      if shortage [do-in-season-shortage-decisions]
      if surplus [do-in-season-surplus-decisions]
    ]
    harvest (depending on crop and behavioural strategy)
    if week 52  [
      if seasonal shortage [do-strategic-shortage decisions]
      if seasonal surplus [do-strategic-surplus decisions]
    ]
  ]
end
```

V. Conclusion

This conceptual ABM aims to simulate what patterns of water resource management emerge on the system level based on local interactions, adaptations and behaviours, and what policies lead to a sustainable water resource management system. Therefore, this empirically based ABM could provide important answers to the increasing water variability and uncertainty in the agricultural sector. This poster will present the conceptual model and preliminary results.

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