MODELLING THE COMBINED SOCIO-TECHNICAL SYSTEM TO SUPPORT AN ADAPTIVE APPROACH FOR INTEGRATED WATER RESOURCES MANAGEMENT.

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Water systems evolve through time, changing constantly due to physical pressures or as a result of how we manage them. Changing socio-economic conditions drastically increase the uncertainty associated with such changes, particularly with regards to the outcome of water resources management decisions. There is an increasing need for such uncertainties to be recognised and addressed by more adaptive approaches to Integrated Water Resources Management. Adaptive approaches mainly include feedback loops within the decision process, which can only be modelled by conducting “modelling experiments” of the interactions between the socio-economic and the hydrological parameters of the water system. In order to enable such modelling experiments, a conceptual model was created, representing the complete socio-technical water system and identifying the decision points that link the socio-economic and hydrological parameters. These parameters were modelled separately by using modelling tools for social simulation and integrated water resources planning. The decision points form the communication ports between the different modelling tools. In this paper, the design process of the underlying conceptual model is presented and explained. The conceptual model is hierarchically divided into three levels: socio-economic processes of water users, their interactions with the water system and finally the imposed pressures on the complete socio-technical water system. The focus of this work is in the interpretation of the socio-economic processes that drive changes in the urban water system. The conceptual model is operationalized through agent based modelling interacting with water management tools and a proof of concept case is presented and discussed in view of its potential usefulness in the context of a more adaptive approach towards integrated water resources management.

Keywords: integrated modelling, agent based modelling, social simulation, adaptive management, integrated water resources management

INTRODUCTION

The water resources system consists of different elements of two distinct environments: (a) the natural environment which includes physical, chemical, and biological characteristics and (b) the social environment which includes social, political, economic, and technological
dimensions (White et al. [21]). The high diversity of the elements of the water resources system and the interrelations between them, increase the uncertainty regarding the response of the system to anthropogenic and environmental change.

The urban water resources system is mostly affected by pressures relevant to water supply, waste water production and drainage. These pressures are mainly linked to water demand, urban structure and development. Nevertheless, urban structure and development is beyond the scope of this research. However the expansion of urban areas imposes additional pressure to the urban water resources system by increasing demand of water and related infrastructure (Rozos et al. [19]).

An adaptive approach of Integrated Water Resources Management (IWRM) is proposed as a means for progressing IWRM to the next level through recognising uncertainty (Gregory et al. [9]), taking into account learning outcomes (Pahl-Wöstl et al. [17]), including feedback loops within the decision process which change management decisions accordingly (Stankey et al. [20]). The aim of this paper is to propose a conceptual model for supporting the adaptive approach of IWRM and to present “modelling experiments” of the interactions between the socio-economic and the hydrological parameters of the water system.

CONCEPTUAL MODEL

One main driver of the aforementioned pressures is domestic water demand which is widely affected from the social characteristics and the attitudes of households towards water resources and environment overall (Beal et al. [3], Fontdecaba et al. [5], Harlan et al. [10], Mondejar-Jimenez et al. [16], Randolph et al. [18], Willis et al. [24]).

Several domestic water end use studies have identified that household water demand is affected by numerous social and psychological factors, which include: residents’ age, income level, family size, education level, house characteristics (size, age, type of water consuming appliances) as well as other factors relevant to the residents’ environmental behaviour (Arbués et al. [1], Barrett [2], Beal et al. [3], Campbell et al. [4], Fontdecaba et al. [5], Harlan et al. [10], Jones et al. [11], Mondejar-Jimenez et al. [16], Randolph et al. [18], Willis et al. [22] [23]). The following paragraphs present selected findings of an extended literature review regarding the effect of several social characteristics in water conservation attitudes and overall environmental behaviour.

Age is positively correlated with water conservation attitudes, leading people to present a more environmental conscious attitude as they age (Campbell et al. [4], Gilg et al. [6]). Income is regarded to have a positive elasticity on water demand (Ardues et al. [1], Beal et al. [3], Harlan et al. [10]) mainly due to lifestyle, house type, size and overall affluence (Ardues et al. [1], Campbell et al. [4]). However, Willis et al. [22] identified that high income households are more likely to invest in leakage repairs and water efficient appliances thus increasing their water conservation attitude and consequently lowering their water demand. Educational level is positively correlated to water conservation attitudes as well (Campbell et al. [4], Gilg et al. [6]). Family size is positively correlated with water
demand, associating households including children with an increased use of washing machines and showers (Beal et al. [3]). Both Campbell et al. [4] and Willis et al. [24] identified that families, even though big in size, tend to consume less water per person, probably because they have higher environmental awareness and water conservation attitudes.

Environmental behaviour has been identified to increase with higher education, income level and specific environmental campaigns (Gregory et al. [8], Jones et al. [11]). Gilg et al. [6] came to the conclusion that people with a strong environmental behaviour tend to conserve more water. In addition committed environmentalists are in general older with small sized families, a high education level and own their house. On the other hand, non-environmentalists are in general younger, with large sized families that mainly rent their house and have both low income and low educational level.

The following figure presents a conceptual model of the combined socio-technical urban water resources system that shapes domestic urban water demand behaviour (Figure 1). The conceptual model is hierarchically divided into three levels. The first level consists of socio-economic processes of water users, represented by the tree below water use behaviour. The second level includes their interactions with the water system, represented by the links between water use behaviour and state of water resources. The final level is formed by the imposed pressures of the other two levels to the water resources system, water abstractions, wastewater production and drainage. The socio-economic and environmental parameters, included in the conceptual model, are proposed to be modelled separately using state-of-the-art modelling tools.

![Conceptual model of the combined socio-technical urban water resources system](image)

**Figure 1.** Conceptual model of the combined socio-technical urban water resources system, human-environment interactions and tools for modelling the different parameters of the combined socio-technical urban water resources system (black: social simulation, red: urban water management models, purple: econometric models, blue: environmental models)
CONCEPT EVALUATION

The main focus of this work is in the interpretation of the socio-economic processes that drive changes in the urban water system. In the following paragraphs, a proof of concept case is presented in the form of a modelling experiment that investigates the urban water demand behaviour of a population. Agent based modelling was selected for simulating the population, as it was identified, in an earlier publication of the authors (Koutiva et al. [12]), as an appropriate tool in terms of addressing the socio-economic element of the water system and supporting the adaptive approach of integrated water resources management. The agent based model of urban water demand behaviour is implemented using NetLogo, which is an agent based simulation platform and programming language.

The purpose and objective of the modelling experiment is to investigate the decision of a population to change water demand based on social, economic and environmental characteristics. The model comprises of households characterised by age, income, educational level, family size, environmental behaviour and domestic water demand and the environment characterised by water availability. Each household is assigned randomly an age representing the average age of the head of the household (middle or senior). Random sampling from a normal distribution is used to assign to households, domestic water demand, income level (low, medium, high), educational level (low, medium, high), family size (small, medium, large) and environmental behaviour (non-environmentalist, occasional environmentalist, mainstream environmentalist and committed environmentalists) which is also linked to the other social characteristics of the household. It is assumed that, for the purposes of this modelling experiment, all households dwell in houses with the same housing characteristics that affect water demand. Water pricing is used for calculating domestic water cost for each household and remains constant for the purposes of this modelling experiment. The time step of the model is annual. Every year of the simulation, the households, based on their social characteristics, the type of the year and the water cost, choose to change or maintain their domestic demand and the percentage of this change. Figure 2 presents the decision process of the agent based model.

The environment is characterised by a water availability indicator regarding the year type (wet or dry) provided by a water resources planning tool through an I/O process. This information is available only to those households that demonstrate a medium to high environmental behaviour. The connection between the water resources planning tool and NetLogo was achieved using Matlab (Figure 3).
The next figure (Figure 4) presents an example of the percentage of water demand change for a 10 year period for six socio-economic groups of the experimental population (households of middle-aged and seniors with high, medium and low income levels). The percentage of water demand change follows at certain time steps the evolution of the water availability index. However, other parameters, such as the individual’s social characteristics affect water demand behaviour.

**DISCUSSION**

Understanding the dynamics of human group processes is difficult as they are complex, nonlinear, path dependent and self-organizing (Macy et al. [14]). Furthermore, human –
environment interactions can be better analysed by assessing the attitudes and behaviours of both individuals and society (Kurz [13]). It is, therefore, important to understand the social (further to the personal) dimension of water demand behaviour since it is shaped not only by their individual characteristics but also by the housing market, fashion, entertainment and lifestyle (Harlan et al. [10]).

A modelling experiment was created for evaluating a conceptual model of the combined socio-technical urban water resources system. The socio-economic processes behind water use decisions were simulated by assigning socio-economic characteristics to households and then modelling the interactions between the users and the water system. The interplay between personal and social dimensions of water use decisions was then mapped, through the model, onto changes in domestic water demand. The results are promising and suggest that using agent based modelling to simulate domestic water demand provides a powerful interface between the social and the physical domains, allowing investigations of the impact of the physical system (e.g. water availability) to attitudes and vice versa. This interface could greatly enhance the ability of current Decision Support Systems (DSS) for water resources management to handle complex (more often than not socio-technical) scenarios explicitly and potentially improve their function as stakeholder communication and consultation tools (Makropoulos et al. [15]).

CONCLUSIONS

An adaptive approach towards integrated water resources management can be supported by including feedback loops within the decision process, which can be modelled by conducting “modelling experiments” of the interactions between the socio-economic and the hydrological parameters of the water system. This research proposed a conceptual model for assessing these interactions and developed a modelling experiment to evaluate the proposed conceptual model. The results suggest that it is indeed possible to link social simulation and water resources management tools leading to a more consistent and inclusive conceptualisation of the behaviour of the complete socio-technical water resources system and, it is suggested, ultimately to more flexible and adaptive decision making.

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REFERENCES


