7 Conclusion

This research intends to demonstrate the utility of modelling for assessing assumptions made regarding social phenomenon. The case selected involves using Multi Agent Systems in social simulations to represent and analyse the water demand forecasts developed by the Environment Agency using scenarios.

The conclusion of the study has been discussed with the Environment Agency, which concurs with the method and results developed in the previous chapters. In order to generate the arguments for this discussion, the research followed logical steps, each presenting challenges or technical findings.

Chapter 2 presents the point of view that demand management is useful to tackle the challenges of maintaining sufficient headroom. But demand management is not necessary. It can be overlooked, as it is only considered as part of a range of options to keep sufficient water supply.

This chapter provides several examples of how countries have been using and researching water demand management. These countries often are in a different position to the UK, or so people think. Rainfall and therefore water resources in the UK are not as high as one might think. Despite spells of floods, one can likely remember the drought warnings, and dry summers experienced in the UK (in recent years, 1995 and 1977 stand out). Some regions are hit more than others. With the issue of sustainable communities arising, the management of scarce resources such as water appears more and more in the media. As it has been advertised, the population density in South East England linked with low precipitation makes it a region relatively dryer than Spain, and than some African countries.

This justifies the interest in understanding water use and its components. It is currently too costly, or simply not possible to increase water supply. In order to help achieve a balance between supply and demand for water, government and institutions turn towards the study of water demand and water demand management (amongst other aspects). This equilibrium (or more likely inequality) is sought for the current situation, as well as the next 10 or 20 years.

Simultaneously with this growing interest, advances in electronics and computing have led to the development and diffusion of new processing tools and modelling techniques, one of them being computer simulations. An analysis of the system involved showed that it had characteristics that made it unsuitable for commonly used statistical tools.

There are phenomena in the sample, such as the presence of positive kurtosis and multiple interactions amongst households with subjective beliefs. The observations gained from the phenomena also display the property of what has been defined as Self Organised Criticality. This consequence of these phenomena and properties is the presence of complexity, which restricts the potential tools to tackle the representation of this system.

Chapter 3 proposes Multi Agent Systems as a solution to these difficulties. It provides details of the nature of Multi Agent Systems, and explains why they are an appropriate tool for modelling such phenomena as presented in the previous chapter. This chapter then describes modelling processes and the different ways they can be used.

Starting with the problems related to the representation of a range of social phenomena, the chapter also presents the different techniques that can be used. These can be mainly separated into qualitative and quantitative approaches. Presenting the bases of Multi Agent Systems introduces an approach that does not need to be restricted to this dichotomy. Also providing a few thoughts on integrated assessment and advantages and constraints of stakeholder participation, this chapter ends with the details of the necessary tools used in the modelling, with a focus on SDML.

Chapter 4 presents details of the scenarios devised by the Environment Agency as an example to demonstrate the suitability of Multi Agent Systems. The chapter begins with the introduction and analysis of the scenarios developed by the Environment Agency, and what particular assumptions they include. From these are devised principles, model assumptions and algorithms, which are then detailed. While the representation of innovation and innovation diffusion is treated separately, overall model details and important assumptions follow, addressing more general characteristics of the model. The various outputs and inputs to the model that result from these choices are then explicitly listed. First the components of the model are described, according to the characteristics and properties of the Agents, the Environment, the Interactions, and the Organisation. The model structure and sequence provides at the end of the chapter the global vision to tie the components together.

Chapter 5 contains the simulation results and the sensitivity analysis of these results. Following the presentation of the theoretical model, this chapter focuses on the model itself and the results of the simulation runs. Introducing the specific details and values that are integrated into every scenario, simulations corresponding to a scenario are presented. The analysis of results for every one of them demonstrates that the characteristics which invalidated the use of common techniques are still present. It also shows that every scenario yields a different output, and different evolution of water demand. This chapter also includes specific analysis of different variables of the model (the grid structure, the agent density, the vision range, the memory), and the study of the diffusion of innovation. The latter is found to be linked with some characteristics of the network's structure, and the overall impact of the previous properties or values can be considered as significant but moderate in this case, since only the combination of extreme cases would result in important differences in the outputs of simulations.

Chapter 6 concludes with a discussion on the findings regarding different aspects of scenarios and the Environment Agency's view of this research. The outputs of every scenario are analysed, comparing the evolution of water demand in the scenarios, but not the absolute levels. Scenario A, provincial enterprise, shows a reduction of 33% in global demand, with a slow decrease from 2007. Scenario B, world markets, remains the highest at all times with a marked decrease of about 20% in total over the period. This scenario remains the one displaying the highest volatility in the evolution of global water demand. Scenario C, global sustainability, shows a reduction of about 50% in water demand, consistent with the presence of innovative clean technologies. Scenario D, local stewardship, presents a decrease of about 38% in global demand but it seems that towards the end of the simulation, even scenario A shows a lower demand, which seem to confirm that the major component of the reduction in this model remains the technological change. This analysis points to the impacts of the assumptions upon the overall result of the simulation and demonstrates that the differences in these assumptions generate significantly different outputs.

Concluding remarks help understand the extent of the analysis, and its limits. There are characteristics of the model that do not cover all situations. An example is given with the miscellaneous component. The nature of the modelling and the nature of the miscellaneous uses are not compatible, but this is an issue only if one expects absolute results from this model. The fact that the population is static is another significant and immediate limit of the model. This is an aspect that the research could focus on in the near future.

An overview follows of the discussion that took place with the Environment Agency. They have shown a lot of interest in this research, when the results have been presented. They confirmed that their understanding and use of scenarios have been correctly interpreted, and that the scope of this type of modelling would be suitable, and could be considered, for their next set of strategic forecasts.

Ultimately, the results obtained allow concluding that the scenarios devised by the Environment Agency are consistent, and that the behaviour they exhibit seems reasonable at a global level.

In the eventuality of further development of this particular model for scientific purposes there are aspects of the model that could be addressed. It would be difficult to include the miscellaneous use, as this is a conceptual issue, at least with this type of modelling. But other parts of the model could be improved with additional research. Computational limitations can be tackled in at least two ways: first with a "natural" improvement of computer hardware and processing power; and second optimising the code or its compilation (including changing to a different language altogether). There are probably multiple ways to undertake the latter, and the processing power freed by such modifications could help either multiply the runs, or increase the level of detail taken into account.

The limits of the model's focus have been set at the beginning of this thesis, and it is unclear whether these can be removed. For example, including explicit financial aspects would require a much more complex model, and an enormous amount of information would need to be collected. But despite the difficulty, this might be one of the most immediate challenges to tackle. The current situation is that on average 75% of the households in England and Wales are charged a flat fee for their water use. This is changing with more and more companies amending their policies, and imposing a metered supply to households, according to specific criteria (new homes and change of occupancy being the most frequent).

On the other hand, there are some changes that could improve the details of the model without this type of burden. This is the case, for example, of family structure. One could decide to include the details of occupancy of households, as well as the characteristics of the occupants. This involves additional challenges regarding time in the model as the agents representing the people would age. It would therefore be necessary to include birth rates and death rates as part of the population management module or rules.

Increasing the number of appliances taken into account will be possible as they develop and become a part of the regular reports from water companies. This involves appliances and devices that were previously classified as miscellaneous uses, such as water softeners, or the use of rainwater harvesting systems (for example water butts) for external uses. Water softeners have a negligible impact on a household demand, and are more of an issue for the companies that are trying to assess what the minimum demand is. But rainwater harvesting systems are becoming more common, and with an increased metering penetration, some households start looking for substitutions for the public water supply. Such systems, when fitted, can replace up to 30% of all water used. This is significant and needs to be included in the reflection on the next development stages.

Another improvement would be to include not only characteristics of appliances for a household, but number of rooms. There is a statistically significant effect of the number of bathrooms upon the water demand for a household. A Multi Agent System, probably in cooperation with specific qualitative analyses, would be an ideal tool to try and address the reasons for this effect.

Finally, as an investigation of the structure of the model was undertaken, one could wonder whether a totally different form of communication between agents could be used. Based on a grid, the communication of agents depends on their location and their vision range, as well as on the algorithms used to represent the communication process. The impact of characteristics of the grid such as its size, shape, or dimensions needs to be examined in detail, to avoid building a model whose structure could have more influence on the result than the values of the variables and parameters used.

A solution to avoid the issue of location on a grid is to discard the concept, and use other means to link agents together. A possibility is to use tags. Tags are observable markers that can be attached to an agent, and can represent a wide variety of characteristics, such as cultural or personal traits. They are flexible, and according to the definition provided in Edmonds and Hales (2003), the tag approach could also be used to match endorsements. According to the authors, tags are "*identifiable markings or cues attached to agents that can be observed by other agents (…)* [that] *can also evolve or change in the same way that behaviours can evolve and change*". Moreover, the use of tags does not compromise with the benefits already presented of a multi agent approach, as they still allow the modelling process to be independent from potentially inadequate theories.

The comparison of the results obtained from models using the two approaches would be of interest. To start with there should be an investigation of whether the two models can validate each other. From that point, the influence of structural differences could be displayed. Both modelling techniques show equal promises, and comparing them with the current system is quite a challenge.