6 Discussion

6.1 Introduction

This final chapter presents some conclusions and remarks related to this work, as well as expectations both from the model and from the Environment Agency.

The first part addresses issues of validation and targets of the model. It is followed by remarks on assumptions or limitations of that model. Then the Environment Agency's own aims with the generation of the scenarios, and views upon this work are presented. Finally, the question of validation and consistency of scenarios is answered.

6.2 Aspects of scenarios

6.2.1 The conclusions of scenarios: figures of water demand

The scenarios and their associated assumptions were expected to result in multiple but typical water demand patterns. A representation of these patterns can be used in order to assess the differences specific assumptions and components bring to the values and changes in water demand from the agents.

As developed in section 5.2.2, individual runs for every scenario show significant differences. The complete set of runs for one scenario therefore creates an actual envelope for possible paths and / or values for the corresponding water demand. Due to the limitations of the method employed, mostly practical regarding processing power and timescale, the envelope is practical, and not theoretical. In theory it is possible that all scenarios actually have equal and very large envelopes. This would greatly reduce the information contained in the description of such an envelope.

In order to describe the evolution of water demand in different simulations, the indicator used and displayed in graphs is the average of water demand across the various runs with one particular set of parameters. Another relevant indicator could have been the median value. The graph below shows the average and median values for four different sets of parameters.

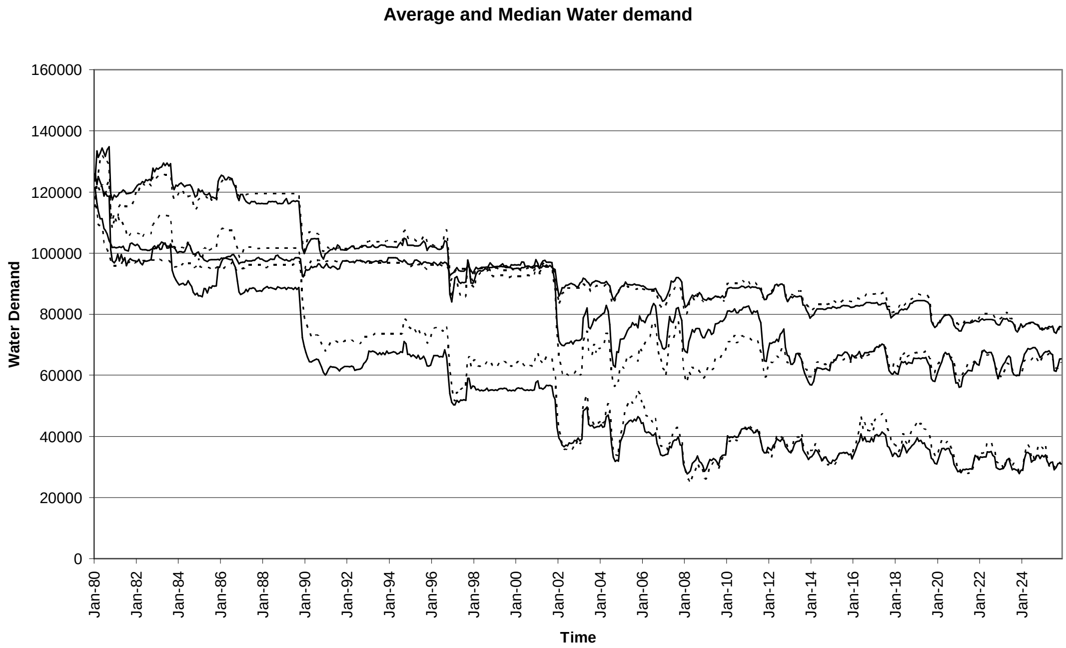

Figure 60: Average and Median Water Demand

Although there are differences, they are minimal when the simulation does not feature extreme values. Therefore in the absence of salient negative aspects of any of these two measures, the average is used, due to ease of computation.

The graph below represents averages of 10 runs for every scenario.

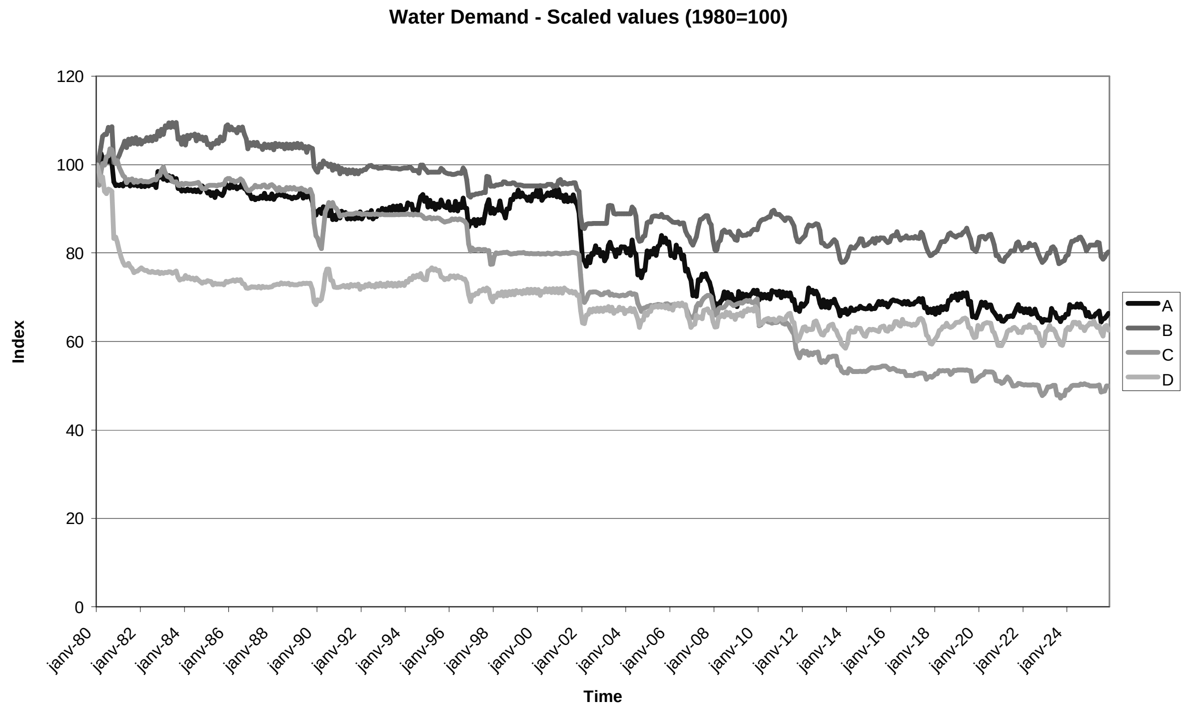

Figure 61: Results for each scenario – Scaled values

While one might argue that this is not representative enough to draw any conclusions on statistical grounds, the characteristics of scenarios seem clear enough.

Scenario A, provincial enterprise, shows a reduction of 33% in global demand. This decrease is partly explained by the sharp drops in 2001 and 2007, while during the other periods, the decrease seems much slower, although present.

Scenario B, world markets, remains the highest at all times. The decrease is also marked and reaches about 20% in total over the period. While the 2001 sharp drop is visible, the effects of other climatic changes are not long term ones, apart maybe from the one in October 1989. 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. This is consistent with the assumptions made regarding the commitment of institutions to research and development of innovative clean technologies. The decrease is steady, with sharper drops in 1997, 2001, and 2010-2012. It is worth noticing that the 1990 decrease has only been observed in the short term. This could indicate that while such a policy could work, the current technological progress alone might not suffice to achieve the expected decrease in water consumption.

Scenario D, local stewardship, also presents a decrease of about 38% in global demand. Nevertheless, most of this decrease (equivalent to a 25% drop) is between 1980 and 1982, with only a further 13% from 1982 to 2025. The 2001 drop equates to roughly a quarter of this reduction, and scenarios A and D reach the same level. Towards the end of the simulation, it seems that even scenario A results in lower demand than scenario D. These results seem to confirm that the major component of the reduction in this model remains the technological change. Scenario D is comparable to scenario C in its initial assumptions, but the regionalisation it considers removes the emphasis scenario C made on innovation.

6.2.2 The different ranges of figures inter scenarios

If one intends to draw conclusions at the aggregate level for specific scenarios, it is necessary to make sure of their validity. One of the conditions for validation of statistical results is that the sensitivity of these results is such that they cannot be mistaken for a standard error or somehow unrelated variations.

One might have assumed that the changes within scenarios could have provided some useful insight on the different influences and their combination. The situation is not so. By comparing the standard deviation intra-scenarios with the standard deviation inter-scenarios, it is unclear whether this model can be used as a tool for answering this question.

Based on averages of runs, the dispersion for every scenario is calculated via the inter quartile range. Results are as follows:

Scenario	Inter quartile range
A	29025
B	22426
C	40618
D	11908

Table 25: Dispersion per set of scenario simulations

It is visible from Figure 61 displayed above that scenarios A and B present similar patterns, despite differences in the levels of demand obtained. The statistics confirm this parallel. The confidence interval and standard deviation, while providing results in line with the inter quartile range, are not provided because as expressed earlier, the underlying distribution could have undefined moments.

Scenarios C and D are opposite, with C being the most variable, while D is the most stable. This high variability of scenario C partly describes the fact that it is the scenario achieving better savings, while the steadiness of scenario D is confirmed once again here.

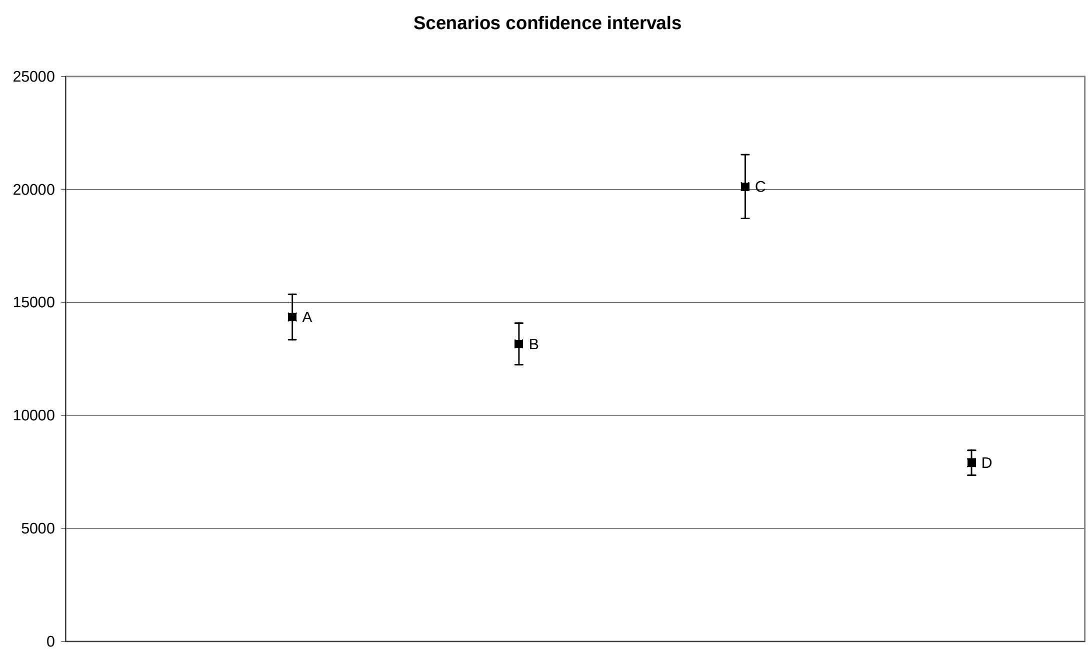

Figure 62: Scenario confidence intervals

6.3 Remarks

6.3.1 The miscellaneous component and its elements

Section 5.2 describes the reason why the nature of the object and the nature of the tool sometimes do not match and cause a flaw in the representation. It is not common when a tool points out the exact nature of the modelling problem and a clear expression of the tool's own limitations. It is a rare occasion where the tools actually help pointing out the difference in knowledge regarding the various components that can be identified as generating water use.

All common uses of water are accounted for by a microcomponent analysis. A household penetration of a few per cent is generally sufficient for the appliance to be included in the list to be considered. Water softeners and the appearance of "total showers" provide a recent example of such flexibility. As it is based on observation, mainly through surveys undertaken by regulators or undertakers, it picks up unlisted appliances as soon as they take a significant part of water use.

Miscellaneous uses include unidentified appliances, as well as already identified appliances that are linked with uncommon uses. For example, home based medical equipment resulting in a significant use of water is qualified as "miscellaneous". Similarly, as "miscellaneous" is the categorisation of unknown use from the supplier's point of view, it includes uses that are not authorised for the customer. An undeclared hairdressing activity in the house would significantly increase tap water use. The supplier, assuming a standard pattern of use, would estimate a reasonable use according to the social and physical characteristics of the household. The fact that they would be incorrect generates a discrepancy between the estimate and reality. This in turn causes the miscellaneous use component to increase.

A typical example of a common appliance filling an unusual function is provided in Jenking (1973) following the 1967-72 metering programme. The 400 properties were checked for leaks and other water supply issues before the demand became monitored. A specific house showed a large increase in water use overnight, resulting in technical teams looking for leaks. When they could not find any, the investigation started focusing on legitimate uses of water. They then discovered "the bath full of water, the cold tap and the overflow running merrily and a number of trout swimming around the bath with apparent contentment.” (Herrington 1996, p.237)

Hence, the nature of miscellaneous use makes it not only difficult to specify, but also difficult to represent as a generic component whose characteristics evolve with time.

A solution has been to distinguish amongst the miscellaneous uses and categorise them further according to the way this evolution takes place, resulting in three equal elements.

The first remains constant per capita.

The second remains constant per household.

The third varies at the same proportional rate as the total of the identified components.

The combination of these elements results in an implementation of the following type:

$$\text{Miscellaneous} = N \times [f1\ (Pcc) + f2\ (H) + f3\ (d(IMC)/d(t))]$$

where

H = number of households considered,

Pcc = average Per Capita Consumption in the sample considered

IMC = Identified Micro Components

t = time

Despite what might seem a convenient way to represent miscellaneous use, it is not included in the model described in this research. It is obvious that the formula above only provides clues concerning what miscellaneous use actually is, and what an estimate of it could be, based on related indexes. This is a statistical approach, whose field of application is too restricted to be used in this work, as expressed in chapter 2.

6.3.2 The static population

The agents in the model are situated, and their behaviour is defined according to rules set by the modeller / user. An important difference between the assumptions made by the Environment Agency and its implementation in this Multi Agent System is the static population.

Not only does it not evolve with time, it also does not move around on the grid. While the grid is not a geographic representation, one could observe that there is evolution even within the individuals' social "sphere".

There are practical reasons for this situation. The most immediate is one of coding difficulties. This covers several aspects. First, as every agent has a memory, via endorsements, of its environment, the calculations and computer memory space would have been much greater[20]. Second, the algorithm itself of how this evolution takes place would have to be devised, and to be as representative as possible, would require the inclusion of many more variables or assumptions, such as financial, familial or employment status. The scope of the research needed to be constrained by the goals set. Implementation difficulties are not an issue that should force a choice of model, assumptions or techniques. In the present case, one objective has clearly been set as interpreting and validating the model results.

As the model grows, and as the number of parameters and variables increase, the possibility to isolate, or identify phenomena and components of their causes reduces.

By implementing what some could consider to be more detailed behaviours for a society, Multi Agent Systems lose one of the very assets that resulted in their selection for the current model: the possibility to relate every rule to an observable and justifiable behaviour (if possible objective) for actual human societies.

The validation of behaviours and representation of models has been targeted for all components of the Multi Agent System. Including more (but uncertain) details and / or components would go against this aim.

[20] For information, in the final version of the model, simulations took several days, and results were stored in hundreds-of-megabytes-files.

In addition, the population projections themselves are fluctuating every year, as the changes in every census demonstrate. This further reduces the possibility to validate any result obtained from a simulation.

The Environment Agency used a very simple growth assumption in the scenarios, a linear increase of the population. This was the aggregation of data available from the companies' water resources plans, mostly using linear trends for simplicity.

6.4 Use and limitations of scenarios

Used with scenarios, MAS can be a powerful tool. This research demonstrates that pre-existing scenarios can be assessed with ABSS. Due to the nature of MAS, the main interest is in applications that are related to social phenomena. The variety of entities that one needs to consider, together with the potential complexity that might result are difficulties many modelling tools cannot overcome, unlike MAS.

The use of MAS with scenarios presents advantages:

- MAS will help fin possible conflicts within the scenario.

By implementing scenarios using a Multi Agent System, one has a possibility, with tools such as SDML, to use these as a way to detect whether all assumptions are consistent with each other. This can be either in the process of writing the formal model itself, or thanks to automatic verification procedures that might be built in the tool used.

- MAS will help assess drivers, influence and sensitivity

As a Multi Agent System needs to make explicit the status and role of agents (or stakeholders), as well as the processes involved in the model, all observed results can be tracked back to which element(s) is (are) responsible for a particular behaviour.

There are other challenges with Multi Agent Systems.

- computational issues, possibly a trade off between quantity and quality of information

Depending on the software one uses to build a model, and the available processing power, there is a possibility that the resulting model could so slow to run that it would not be practical. In order to keep simulation speed reasonable, it might be necessary to use fewer agents, or a simplified representation, with less rules. Ongoing improvements in computing technology will certainly help in overcoming this hurdle.

- MAS helps directing questions

Where an agent or a behaviour to represent in not immediately obvious, MAS help in focusing on what information is required: what is the nature of the agent, or what are its relations with the others / its environment, how does it perceive its environment, and in which way does it react to it, considering its aims, etc. Rather than describing a system as a whole, a multi agent based model requires a clear understanding of the elements of the system, and how they interact together. It is frequently while trying to provide this information that the lack of knowledge results in critical assumptions, or further, more focused, research.

As a consequence, Multi Agent Systems are currently an interesting prospect, already used in many fields. Evidently there is potential for expansion, as likely successes will get researcher's attention.

With the development of Multi Agent Systems, their use in representing scenarios is likely to become more widespread. Because of (or thanks to) the capability of MAS to deal with multiple levels of detail, from micro to macro components of a model, more research might be undertaken regarding the basic principles models of artificial societies are built upon.

Cognition, evaluation, subjectivity are some of many abstract concepts that are going to be investigated. Many alternative ways of implementing these will emerge, some certainly being better than others. They will all provide a better understanding, and a more accurate representation of basic processes.

One can consider that scenarios use a top down approach because they cannot manage otherwise.

Scenario forecasts will benefit from these improvements. Scenarios are currently imagined, or considered as the consequences of specific phenomena for a given set of relatively high level assumptions. In the current example, the main drivers are described as social values and governance structure. The corresponding scenarios require that experts translate this global situation into what would be equivalent beliefs for agents at a micro level.

By improving the representation of agents and their basic processes, it will become possible to devise scenarios via a bottom up rather than the current top down approach. The consistency of assumptions both at micro and macro level will become easier to compare and put to the test.

6.5 The future of Environment Agency scenarios

The second part of the discussion with Rob Westcott addressed the links between this research and the Environment Agency's own vision of scenarios.

The scenarios were generated in order to "*test how likely a set of objectives may succeed in different political, social, technological, environmental climates but they cannot readily predict the level of success under a specific set of circumstances, e.g. current perceptions, prejudice, infrastructure, governance, attitudes, etc. This would need a new scenario each time."*

Well aware of limitations of their approach, they wanted to "*allow time to adapt, scenarios' effects were delayed to 2010 generally".*

When asked to comment on this research, and whether they had particular expectations from these simulations, they replied they would look for *"an indication of more likely/less likely responses to a set of assumptions."* They are adamant that they do not want these simulations to investigate the likeliness of any specific scenario since, as they put it, "*No probability could be attached to Agency's scenarios."*

They envisage that this type of research and simulations could become useful to the industry, the regulators, or more globally institutions, fulfilling different aims: first at a generalised strategy / overview level, assessing complete sets of assumptions, consistency of hypothesis, or estimation of consequences; but also at a more detailed level, to "*test very specific responses to a single initiative.*"

Enquiring as to whether the scenario assumptions could be validated or invalidated by such simulations, the answer became more pragmatic. Their opinion was that neither was possible, "*as no one scenario will apply.*"

Nevertheless, discussing further, they agreed with the potential of simulations as a means to evaluate individual, specific relationships and assumptions regarding the consequences of policies or regulations, provided they are represented properly. The simplicity and accuracy of modelling that should be reached before this is possible is however an issue, and they are aware of this challenge, as it is according to them *"Impossible to validate whether an outcome is a consequence of competing traits, a coincidence or whether the "scale" issue is the cause."*

By "scale" they mean the size and complexity of the system, rather than only the size of a grid, or number of agents, and it is difficult to disagree with this, given the current state of knowledge.

Globally, the Environment Agency could appreciate the potential of social simulations and Multi Agent Systems. The emphasis on processes and the virtual indifference to geographical scale (but not its complexity) led them to consider this method when devising their next project addressing water demand forecasting issues. In particular its relevance was accepted for appraising the potential impacts of policies affecting behavioural changes.

6.6 Last words on scenarios

The subject of the modelling is the scenarios presented by the Environment Agency. The implementation of these scenarios has been undertaken as scrupulously as possible, and results have been analysed.

This research is not trying to assess which scenario is the best according to some targets, be they environmental or political or other. All scenarios have been modelled with equal care and method so the validation is not trying to assess which one has been implemented best.

The validity of a model depends on what the aim of the model itself is. This aim provides guidelines on whether the abstract model and its representation are consistent with the issue addressed. Therefore consistency has been leading the progress of this work. In chapter one and two, water demand and different modelling methods have been presented. The selection of tools such as Multi Agent Systems and object oriented social simulations was the result of their strength and the fact that they are appropriate for dealing with the issues raised.

It is not easy to find criteria that can be used for the assessment of a model that is representing social phenomenon. In hard sciences, where equations can be used to accurately represent the system observed, one way to judge a model, is to rely on its capacity to reproduce specific observed results, or to infer from its results, obtaining validation of the model via realisation of its prediction(s). A typical example for such a validation is the analysis of the trajectory of planets, and the discovery of Neptune at the location and time where the theory developed predicted there would be a planet.

The ease of proof and absence of ambiguity in this case are not valid for all sciences, especially not social sciences. Due to the doubtful representation of cognition and reflection, amongst other processes, the phenomena themselves that result from these are very difficult to take as an absolute benchmark for the model.

This is why the assessment is not going to be focusing on the results (although they can certainly be part of it), but mostly on the processes involved in the modelling. In the end, it all comes down to an evaluation of the representation as an example of best practice.

As expressed in chapter 3, Edmonds (2000) suggested that models should be judged according to process criteria for the modelling steps. The following list presents a selection of these:

1. Abstraction: is it specified?
2. Design: is it clear how the design relates to the abstraction?
3. Inference: is the inference of outcomes sound?
4. Analysis: is the analysis clear?

5. Interpretation: is the interpretation justified and relevant?
6. Application: are the conclusions in terms of the target systems justified?

The following paragraphs will argue that these criteria have been fulfilled.

The abstraction has been specified in chapters 4 and 5, demonstrating the structure and algorithms later implemented in the formal model. The limits of the phenomenon covered are also described, explaining earlier why some aspects such as the financial situation of a household are not taken into account.

The reasons for the design are provided in chapter 3, where the modelling principles used are presented, and as explained, the consistency testing of the scenarios devised by the Environment Agency, used with necessary stages of reverse engineering, help insure the link between the abstraction and its implementation.

In the previous chapter, the outputs of the model are presented according to the set of assumptions used. While these are benchmarks for the analysis, the stability results themselves are investigated when specific parameter values or phenomenon are put under scrutiny.

The analysis then undertaken assessing the differences between simulations of scenarios and how well they match the description of the scenarios from the Environment Agency is presented.

The interpretation of the results from this research is provided, from a quantitative point of view by statistical tests, as well as qualitatively via an interview with Rob Westcott.

In the end, the conclusion is that it is not unreasonable to consider the scenarios as distinct, plausible and consistent. Nevertheless, the quantitative aspects have not been, for reasons already provided, validated via the simulations in the current model.

6.7 Conclusion

Section 6.2 presented the different aspects of the results, first for each scenario individually, then comparing them. Figures of water demand were characteristic for each scenario, with the apparent confirmation that technological change is the most important parameter to explain decreasing water demand. The analysis of confidence intervals confirms the similarities between A and B, as well as the differences between C and D.

Section 6.3 emphasizes the fact that the model does not include all the characteristics presented in the original scenarios. A steady population and the absence of the miscellaneous component due to the inadequacy of such a catch-all concept in an agent based system could be the main reasons for not obtaining results closer to the Agency's.

Section 6.5 explained that discussion with the Environment Agency showed they appreciated the potential of social simulations and Multi Agent Systems. The emphasis on processes and the virtual indifference to geographical scale (but not its complexity) led them to consider this method when devising their next project addressing water demand forecasting issues. In particular its relevance was accepted for appraising the potential impacts of policies affecting behavioural changes

Section 6.6 provides an answer to the question whether the scenarios described by the Environment Agency are consistent and can be validated. The simulations undertaken during the course of this research seem to corroborate if not the absolute figures, at least the global trends considered by the Environment Agency.