CHAPTER 4

Scenarios of Water Demand Forecast

Olivier Barthélémy

Abstract

The Environment Agency developed forecast scenarios in order to assess future water demand in England and Wales. A model based on a Multi Agent System is used to implement these scenarios, putting them (and the model itself) to the test of statistical properties observed in actual data.

The model is constructed by attempting to capture evidence-based phenomena. Agents represent households and are located on a regular toroidal grid. Agents have a limited vision which allows them to gather information which is then evaluated subjectively according to the agent's values through endorsements. A policy agent is present, and its impact upon the specific scenario is represented by the timing and nature of innovations.

The evolution of an agent's actions will depend on its information, its memory, and how it assesses both the information itself and its origin.

The data generated is analysed using non-parametric statistics in order to confirm that, just like observed data; it is unlikely to have an underlying normal distribution. The results confirm this assumption as well as distinct patterns for every scenario.

4.1 Water demand management and Policy

4.1.1 Current research

In developed countries, a lot of effort is now turned towards the management of water (Butler, Memon, 2005). The concern is that the water demand has been increasing, while the available quantity of water is limited. As water supply must meet that demand it is the whole water system that is endangered. The increasing interest in demand side management is due to its relative low cost and flexibility. For example, the largest reservoir in

England, Kielder, has been built in accordance to forecasts of rising water demand that did not realise. Since there is a sequence in the system, from demand to supply, succeeding in understanding and eventually influencing demand is being active. The water companies are trying to forecast the demand in order not to remain reactive, being able to plan for their own development.

In the existing literature, two different approaches are used to deal with water demand management: a qualitative one (used in surveys or interviews), and a quantitative one, mainly based on econometric studies.

Part of the qualitative approaches, recent research projects (for example Water cycle in New Developments[1], or preliminary work from Lancaster University) are investigating the reasons for which people use water. Their aim is to improve the understanding of why it was used in such a way, and is therefore addressing the issue of the perception of water by its users. The researchers use interviews with customers from a specific water company to obtain the information required.

The data accumulated is valuable and informative, but comparisons between different households are rarely possible, as they have different beliefs that cannot be measured (literally) against one another.

Surveys generally have two aims. While the first one is trying to understand the consumption structure and patterns, the second is more focused on trying to devise and evaluate policies related to water demand. In the late 80s, several studies were undertaken in the UK, for many of which the issue of metering was central. The SODCON is a comprehensive survey launched in 1991 of domestic water consumption in the East Anglian region. Its goals were to provide notably an explanation of the factors that determine unmeasured demand, details of the patterns of water consumption, estimates of demand responses to various tariffs structures, and detailed cost of metering. The descriptive statistical analysis provided an important database of information and constituted a starting point for an analysis on a household level.

Tate (1990) published an in-depth review of water demand management in Canada for four water use sectors: municipal, industrial, agricultural, and non-withdrawal uses. This review gives a global idea of water demand management, dealing with implementation techniques and evaluation criteria of the result.

Econometrics is the main type of quantitative model of water demand management. This consists in linking “external” data to a particular water demand (average, highest, etc.). Most of these are weather effects.

Herrington (1996) investigates which climate variables seem to be more closely related to water demand, and the quantitative responsiveness of the latter to climatic changes. Unfortunately, the UK led studies seem to have statistical problems, from suspected multicolinearity to the inadequacy of the methods used (e.g. non-stationarity in Smith, Turton *et al.,* 1978). Still the conclusion from every study is that sunshine seems to be the least useful variable (although it is as well the least tried), whereas both rainfall and temperature are often significant.

Also, Mayer (1975) showed that the results of several econometric models were highly specific to the period they were computed. This issue probably relies on the

[1] Cf. http://www.wand.uk.net/

fact that no behaviour or interaction itself is taken into account by an econometrics model.

Herrington reached the same conclusion, noting that the best estimations for the period from 1960 to 1980 "gave poor results for that part of the 1980s decade where the absence of supply restrictions allowed the exercise to take place". The conclusion was even stronger, noting that "in general, the better the original forecasting, the worse the prediction" (ibid., p.78).

The distinction made in the literature is based on the fact that that while most of the necessary analysis of the consumer behaviour is qualitative, relying mostly on in depth interviews, when it comes to water consumption, most of the existing studies are empirical and quantitative.

These approaches are only dealing with some aspects of the problem. The current issue is not single faceted though, and that is why each of these methods can only bring a partial view of it. Hence the point to demonstrate here is that a water demand management based on understanding the social influences is a viable and complementary approach.

4.1.2 Regulation

In England and Wales, since their privatisation in 1989, 22 water companies are regulated by the Office of Water Services (economic regulator), the Environment Agency (environmental regulator), and the Drinking Water Inspectorate (drinking water quality regulator). Water companies must ensure that the balance between water supply and water demand is not negative, either now or in the future. Anticipating the evolution of water demand is hence compulsory, and companies should be able to infer possible future patterns of water consumption in the presence of climate change.

This is one of the reasons for generating forecasts. The Environment Agency developed forecasts regarding the evolution of water demand as part of its strategy. These forecasts are based on scenarios, and are developed in "A scenario approach to water demand forecasting" (Environment Agency, 2001), in which every scenario represents a set of assumptions that is regarded as plausible. These assumptions lead to a forecast of water demand levels and their evolution up to 2020 via a consistent reflection.

Recognising that the difference between scenarios is based on differences in household behaviour can be understood as a necessity for including qualitative components into any model of the problem. One could attempt to use purely qualitative methods to assess the scenarios, but this would prevent any quantitative results from being obtained (and therefore quantitative techniques for testing the results of the research).

Multi Agent Systems (MAS) have no underlying theory other than the one the modeller chooses to use, and therefore have (in general) no intrinsic limitations on their expressive power. Multi Agent Systems provide a tool to successfully implement the representation and analysis of the scenarios used by the Environment Agency for future projections.

4.1.3 Statistical properties

It is commonly assumed that the behaviour of a system can be foreseen. But as complexity generates non-straightforward behaviour (Edmonds, 2000), if a system is recognised as complex, this assumption cannot hold. Pavard and Dugdale (2000) define a complex system as "a system for which it is difficult, if not impossible to restrict its description to a limited number of parameters or characterising variables without losing its essential global functional properties." The properties of such complex systems are: non-determinism, limited functional decomposability, distributed nature of information and representation, emergence, and self-organisation.

Natural and social systems generate data characterised by the presence of occasional and unpredictable events.

The characterisation of an event in the case of social systems can be done through the changes that occur within. The time series or cross sections analysis of a specific indicator will reveal changes from two situations, referenced by the stage, or object studied, or location (commonly shown for the number of references in a paper, the values of stocks in finance, the number of links pointing to or originating from a web page web links, or town size distribution).

For example, in the case of modelling water demand, one can consider water consumption as a random variable, and treat these data via some statistical method in order to know more about the eventual underlying distribution. Statistical software can apply a test like the Kolmogorov-Smirnov to a set of data, and assess whether the sample observed could have come from a set with a particular (known) distribution. This includes a test for normality. When putting actual water consumption data to this test, the results are non-ambiguous. The probability that it is part of a normal sample is very close to zero.

Figure 4.1 displays two distributions. The bar chart is the actual distribution of observed relative changes in a simulation run, while the curve represents the theoreti-

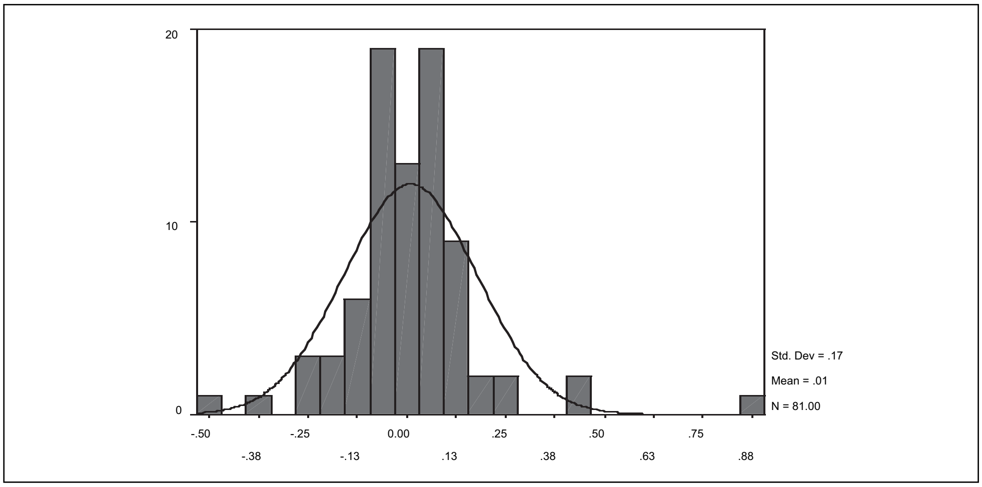

Figure 4.1. Comparison of distributions for a given sample

cal distribution for such values should the sample be normally distributed. The standard deviation and mean used to generate the theoretical distribution are taken from the sample of observed data [1].

Tests tend to confirm the assumption that this sample does not suit a normal pattern. The property showed, a relatively fat tail and thin peak, is known as leptokurtosis. This means that there is in the sample an excess of data values near the mean, and far from it.

Instead of normal distributions, even with time-dependent mean and variance considered by economists, physicists like Per Bak (1997) used the power law devised by Pareto in 1893. If the data observed suit this kind of distribution, the consequences are important. The probability density function of the Pareto distribution has two parameters, a as the "peakedness" parameter, in the interval (0,2], and β as the "skewness" parameter, in the interval [-1,1]. The issue is that these parameters have critical values. When a is equal to 2, the characteristic function of the paretian distribution reduces to that of the normal distribution. But for $\alpha < 2$, there is no finite variance for the distribution, and for a less or equal to 1, there is no finite mean.

Moss (2002) has investigated some different means of generating such a distribution. Three explanations are: a normal distribution with predictable time varying parameters, a stable Pareto distribution with infinite variance generated by self organised critical social process, or a non stable distribution generated by a self organised critical social process.

Because the model self-organises around the critical state and remains around that state thereby to produce power law distributed data of extreme events, this phenomenon was called self-organised criticality [2]. Some necessary conditions in which self-organised criticality (SOC) emerges were summarised by Jensen (1998), including interactions among model components being a dominant feature of the model dynamics.

The social embeddedness is coined in Granovetter (1985) and defined by Edmonds (1999), as "the extent to which modelling the behaviour of an agent requires the inclusion of other agents as individuals rather than an undifferentiated whole". It means that formally, it is more relevant to model an agent as a part of the total system of agents and their interactions as opposed to modelling it as a single agent that is interacting with an essentially unitary environment.

4.2 An Example of Multi Agent Model

The Environment Agency's scenarios developed are based upon 4 assumptions: human choice and actions shape the future; the future cannot be foreseen, but exploring it can inform present decisions; there are many possible futures; scenarios development involves rational analysis and subjective judgement. Principles for the model are categorised according to the governance and social values used in the scenario. The

[1] While a standard limitation of the KS test, this results in overestimating the chances that the underlying distribution is found to be normal.

[2] Because the model self-organises into the critical state and remain in that state thereby to produce power law distributed data of extreme events.

role of the regulator as well as the important assumption on household water supply is also addressed, as they are reasons for tackling the representation this way.

4.2.1 Representation of main drivers

The representation of the social values of households has implications regarding the way they see and judge that environment. The argument here is that someone caring about community will put a greater emphasis on the community as a driver of his own behaviour. Selecting the appropriate weights of influence in the already existing model can then represent this indicator. The endorsements can be ranked, from an individualistic (self-centred) point of view, to a more citizen (globally influenced) one. They can therefore be used to represent the concern and influence of a particular agent (Barthélémy, Moss et al. 2002). There is a link here between the fact that an agent is community oriented, and its major influences are in the "community" around him, his neighbourhood. What is called community in the Environment Agency approach is actually referred as "neighbourhood" within the model as the immediate social environment of the agent. As it is expressed in their description, community also seems to have the meaning of "citizenship", or behaviour in line with the idea of not wasting limited resources.

While social values can be represented through a simple choice of different ranking and / or values of the endorsements themselves, this is not possible for the governance structure. Consequently, unlike the first part of the influences, this classification of the scenarios will be done using the detailed approach. For a given state of social values, the governance structure will be identified (and the scenario defined) by the range of available appliances, their associated values (ownership, frequency, volume, replacement rate), and the presence or not of technological regulations.

The representation of the technological regulator is simple. Since the regulations are enforced in the scenarios, there is no need for a dynamic adaptive regulation, i.e. the presence in the model of an agent that would evaluate the situation and eventually decide for the need of intervention. Like the emergence of new appliances, which was already implemented, it is present as a constraint upon the appliances. Since the scenarios describe accurately when regulation happens, the influence on the model is that from a given date onwards, some devices are made available or unavailable for the households.

The data used for climatic conditions is partly simulated. It is originally based on the recording from the meteorological station in Lancing, West Sussex. The actual data goes from 1980 to 1997. The data for the following period has been generated during the course of the Climate Change: Demand for Water (CCDeW) project by Downing, Butterfield et al. (2003) and Edmonds, Barthélémy *et al.* (2002). It is based upon the UK Climate Impacts Programme (UKCIP) Medium High assumption of climate change. This was developed in 2002, and corresponds to the outputs of the UKCIP02 project (Hulme, Jenkins and al., 2002).

4.2.2 Inputs and Outputs

The model is supposed to represent an artificial society, providing some insight into patterns of behaviour for water demand within a group of agents. It is also the opportunity to try using multi agents systems, in order to reach the structural flexibility that is necessary for testing climate change scenarios.

The model is shaped by the relevant characteristics of the target system.

Agents are on a grid. The situation of agents within the model must resemble the situation in the real world. Using a grid to locate them could be seen as a twofold mechanism. The grid could represent either a social system, or a geographical situation. A grid also introduces the concept of population density, and distance. Agents can be placed at random, or in a given location if necessary.

There is a policy agent, which is by design a public broadcaster. Every agent can access the information it contains. The reason for implementing such an agent is that there needs to be a representation for the public voice, the advice given on national media. It is something households are sensitive to, although with some nuances. It seems from experience that the households are reacting not to the media, or the government, but to the legitimacy of the message. During the drought in 1995, households reduced their water consumption when exhorted. But when it became known that the appropriate procedures were not followed, some quickly shifted back to their normal behaviour, till the same exhortation was repeated, this time with the insurance that it was a legitimate call.

There are various kinds of policy agents, as described earlier. The Policy Agent is an important source of information and guidance. Only one is currently implemented, because it is the chosen level of details, and also since it is not one of the main issues for the model. Moreover, there is a significant difficulty in faithfully representing various kinds of policy agents, and a lack of information about their behaviours. Nevertheless, several policy agents could be implemented if needed, provided appropriate help from the stakeholders.

The policy agent reacts to droughts. The only concern for the policy agent is the current status of the water stocks in the system. It only reacts to scientific evidence. This evidence is the soil moisture deficit, which is the quantity of water contained in the ground.

The weakest definition of a drought ultimately comes to the lack of moisture in the soil. Throughout this work we will refer to drought as hydrological droughts, which happen when surface and subsurface water supplies are below normal, (by opposition to meteorological[4], agricultural[5], or socio-economic[6] droughts). The reason for this choice is that the hydrological drought precedes the socio-economic one, and that it is the one upon which the water companies have some influence. Indeed, not only climate factors have an impact upon it, but also landscape and land use. Hence the presence of new dams can have a significant impact upon it. Consequently, the soil moisture deficit can be considered as an appropriate indicator of the surface and subsurface water supplies. This indicator has been analysed, and is commonly used.

More formally, in the presence of a drought for the second (or more) consecutive month, the Policy agent will broadcast a message based on the average frequency of

[4] A meteorological drought is a measure of departure of precipitation from normal. Due to climatic differences what is considered a drought in one location may not be a drought in another location.

[5] An agricultural drought refers to a situation when the amount of moisture in the soil no longer meets the needs of a particular crop.

[6] A socio-economic drought refers to the situation that occurs when physical water shortage begins to affect people.

use and volume per use for a given appliance. In that case, the Policy Agent generates a factor equivalent to the square root of the current proportion of soil moisture that it applies to the frequency of use and the volume per use, in order to broadcast a recommendation with these new values.

One can see that with this implementation, when the drought increases, the recommendations of the Policy Agent increase as well.

Every household is defined by its set of Ownership, Frequency and Volume, which defines an output to the model. Some economics indicators are not used, such as the income of the household. Nevertheless, a household is defined by its location and by its endowments and its use of water. Taken globally, rate of ownership can be translated into effective ownership for a given household via probabilities, or it could be imposed to fit a situation, for example to the extent of imposing clusters of households that would possess (or not) some specific appliance. The associated frequency of use, and volume per use are also informed by real data provided by stakeholders.

Ultimately, the output of the model will be a demand for water, computed in multiplying for every household the ownership (then a binary value) by the effective frequency of use, by the volume per use, and summed up for all the agents.

Every agent has endorsements. The method to generate this subjective value is taken from Cohen (1985). The different endorsements are ranked in classes of importance, the higher the class, the higher its contribution to the total value of the endorsement.

Every agent has a limited memory, which restricts the choices for actions. Every month, the household eventually forgets some of the actions it has been doing. Its only choice remains between the actions that are remembered and the actions that are presently observed. The memory is associated in the model with a probability to remember the past actions. This probability is decreasing as time goes, and is positively linked with the importance of the corresponding action. In other words, a household will always forget the past actions, but it will forget less quickly (or remember more) those that were important at the time.

Every household is amenable to suggestion by the water authority to different extents. Real life observation demonstrates that some people show more citizenship, while some others are more exclusively self-centred (i.e. selfish). They actually value (or endorse) a signal differently depending on its source. This particularity is implemented here with the help of the endorsements. An agent would rate in a specific order the actions suggested by the policy agent, the neighbour's observation, or its own actions. This represents the general influence of the household. The model allows the user to select the proportion of agents (on average) that would have a specific main influence. I.e. the population can be purposely divided into for example 35% of households mainly influenced by their immediate neighbours, 55% influenced mainly by their own actions, and the rest influenced by global messages from the policy agent.

Every household has public and private activities. With respect to water consumption, some appliances are generally used in such a way that they will or will not be visible by the neighbours. Sprinkling a lawn is most likely to be observable, and not only during the act, but also as long as the traces induced remain (wet pavement, wet grass). The same applies for washing and drying clothes, for example, amongst other uses. Hence, the user can choose the activities that will be visible by the others (or public activities), and those which will not (or private activities).

Every household can evaluate its asymmetrical relationship with its neighbours. Neighbours are endorsed, i.e. households will have a subjective point of view upon every one of them. As it is subjective it is not symmetrical since for example a household can be envied by another one, while the opposite is not necessarily true.

Every household's demand is influenced only by its endorsements. In the event of seeking some more accurate, and more detailed data, it would be necessary to implement a direct influence of climatic conditions upon the use of specific appliances. This would require a fine grain of analysis. For example, climatic conditions of a bank holiday Monday in May would become the most important parameters for the demand for water.

Every household decides to use the pattern that it values the most. Using a simple principle of rationality means that when an agent has to make a decision, and in the absence of constraint, it will select the decision that has the highest value in his mind. The value can be the returns expected from that decision, or in the case of behaviour, the behaviour it rates the highest. In order to express subjective values for an agent, it is useful to turn towards the fields that have already tried to analyse and present a solution to his problem. The consistency principle is presented in "Social Psychology" by Brown (1965). It refers to the fact that social studies show that we tend to feel closer to what is like us, and we tend to like what seem closer to us. In Brown's words, "it seems to be a general law of human thought that we expect people we like and respect to associate themselves or disagree with ideas we like and respect and to dissociate themselves or disagree with ideas from which we dissociate ourselves." This logic in attitudes and beliefs is labelled cognitive consistency.

Agents rate every appliance. Emerging technologies are subjectively rated on the basis of what information is communicated about them. They are eventually made available from a given point in time, from which it is entering the knowledge of the household. Although some studies on the diffusion of innovation may suggest that some agents know before others that a product is becoming available, it can be argued that the small group we are dealing with here has a global perception of the available appliances.

Agents can adopt new products. There are two possibilities for a household to take the decision of changing a given appliance. The first case is if the already owned older substitute fails, and the second is the probabilistic representation that on average, a household will renew its appliances every 5 years. The adoption process is then triggered according to these 2 possibilities.

Soil moisture deficit is computed through the modified Thornthwaite algorithm. Soil moisture deficit is a good indicator for water stocks, since it takes into account the evaporation, through the mean temp, sunshine time and precipitation. It is commonly and internationally used for that purpose (Thornwaite and Mather, 1955). It is computing the Potential Evapotranspiration, or PET. PET is a measure of the ability of the atmosphere to remove water from the surface through the processes of evaporation and transpiration assuming no control on water supply.

Appliances can break according to some probability. The breaking of an appliance or risk of failure is used in manufacturing processes studies to define Mean Time Between Failures (MTBF), a useful indicator for repairable items. In the industrial sector, reliability data have been gathered and are available, like the values of the observed failure rates. This failure rate is generally forecast using a weibull probability density function.

Every agent can see its neighbours, according to two basic rules. First, they must share a coordinate, and second, they must be within a range of vision on that axis that is determined by the user. The fact that they must be on the same row or column has no real-world justification. Nevertheless, there is a lack of knowledge on the social distances and neighbouring that prevents us from using an already validated technique in that case. The range of vision is then representing the fact that the neighbours from a given agent have to be within "sight" of that agent, and therefore provides that horizon.

Every household is influenced by the neighbours, by itself, and by the global broadcast. Every household knows that it exists, that its neighbours exist, and that a greater entity exists (the Policy Agent, representing for example the Government, or manager of the system). It has beliefs that make it more or less sensitive to each of these entities. It can be seen as the importance of selfishness, the influenceability, and the citizenship that they integrate.

Figure 4.2 represents the structure of the model, separated by main agent and influences. Temperature, rainfall and sunshine hours per day are inputs for the agent representing the ground. The policy agent observes the result. Simultaneously, the households are defined through their activity, frequency and volume, and can observe each other. The policy agent also has an influence on the households, while the latter process all the information and influences they have in order to generate individual and global aggregate demand for water.

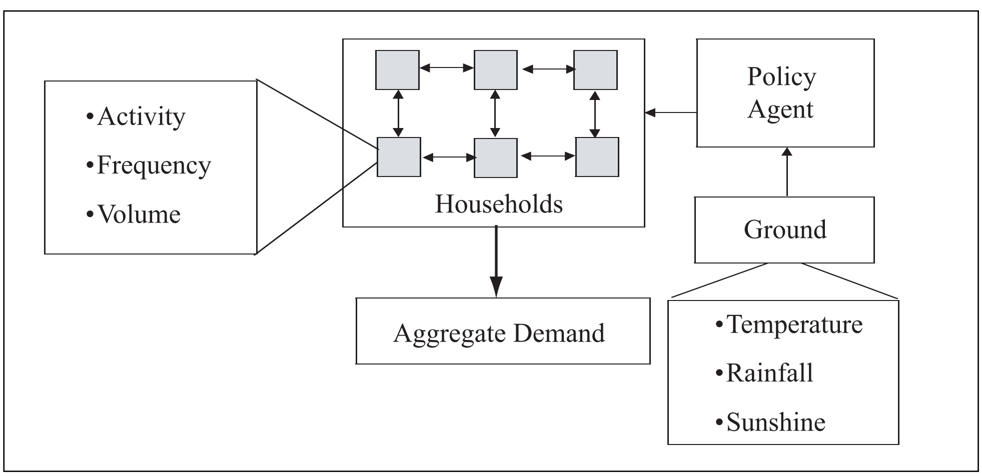

Figure 4.2. Model Structure

4.3 Simulation results

4.3.1 Scenario A: Provincial Enterprise

A few graphs are provided to help with the representation of the simulation results. When representing scenario outputs, each line represents a different run of the water demand simulation. The time, in months elapsed or in month / year format, is on the X axis and the water demand levels are on the Y axis is. When useful, the monthly average over all runs is also present and is indicated by a thicker line. The graph shows a generally decreasing trend.

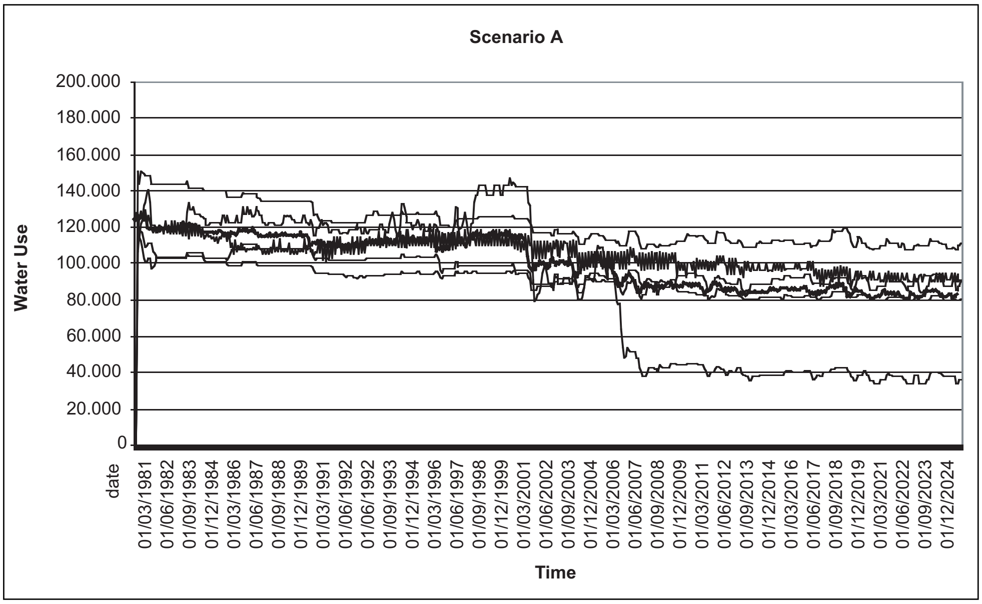

Figure 4.3. Scenario A

There are two noticeable series displayed. The first one is the one with extreme behaviours. In the same simulation, the variations are such that although it does not start as the highest or lowest water use, increases in 1998 and decreases in 2001 and 2006 are having an important effect on the demand levels. Although the first large peak seems to be the obvious consequence of the drought starting in August 2001, the increase starting in 1998 does not seem to have an environmental cause.

The second drop, in 2006, is not justified by the climate either. One can observe that other simulation runs are not affected this way.

The other eye-catching pattern is the frequent micro fluctuations of the data from the second topmost series from 2004. Although the general shape of the water demand is not extreme, it is clear that there is an element of instability that is not present in other runs.

The use of statistical software allows a different analysis, investigating the underlying distribution of these data. As indicated earlier, the presence of defined second moments is a critical factor for using statistical techniques upon datasets. It is now interesting to check whether the generated data also has this property.

A kurtosis value is computed for every data set. The Kurtosis value is a measure of the extent to which observations cluster around a central point, a measure of the peakedness of a probability distribution. Positive kurtosis indicates that the observations cluster more and have longer tails than those in the normal distribution (this property is leptokurtosis) and negative kurtosis indicates the observations cluster less and have shorter tails.

Statistical analysis demonstrates that the probability that any of these differences are normally distributed is nil.

4.3.2 Scenario B: World Markets

In the representation of scenario B (Figure 4.4), there does not seem to be any extreme run. All have slightly decreasing trends, and seem to follow roughly the same pattern.

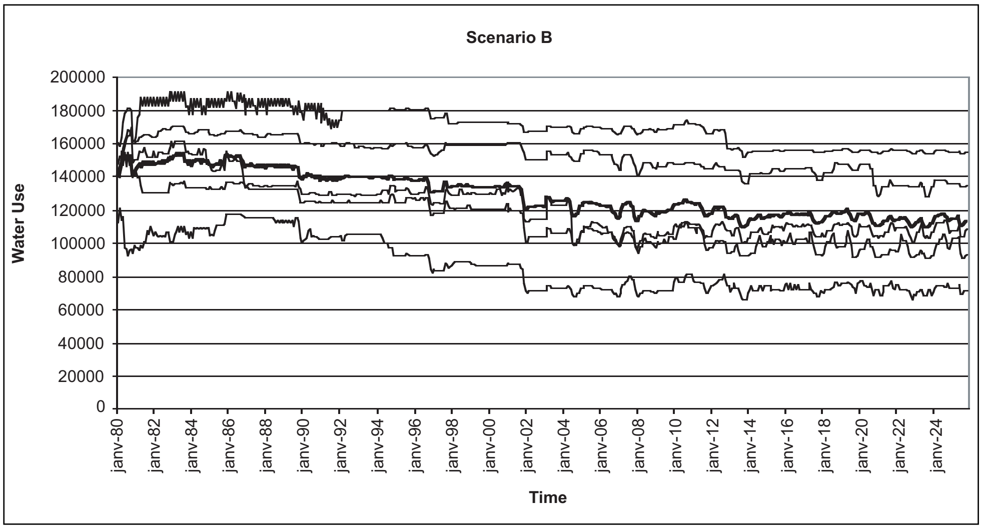

Figure 4.4. Scenario B

The highest run shows an interesting instability up to 1991. The cycle of households copying each other is broken by the appearance of power showers. The introduction of power showers and their adoption provide new recommendations to households, who discard their showers, and the system is then harmonised. This demonstrates that the high frequency variability observed could be due to a flaw in the processes.

Descriptive statistics shows a lack of stability amongst various runs of a specific set of simulation. The variance as well as the standard deviation is high, denoting the large differences in values from one series to another. The negative kurtosis expresses a distribution with tails shorter than they would be if it were normally distributed.

As before, the Kolmogorov-Smirnov 2-tailed asymptotic significance confirms a probability of 0 for the assumption of normality to hold for relative changes in the runs.

4.3.3 Scenario C: Global Sustainability

While the patterns of the different runs in Figure 4.5 look similar, there are interesting differences. The water demand does not always seem to change in a (roughly) similar manner. Some reactions to drought are unmistakable, but the 2010 changes in the highest run cannot be explained by climatic conditions. The simultaneous introduction of three new technologies seems to be the reason for such changes.

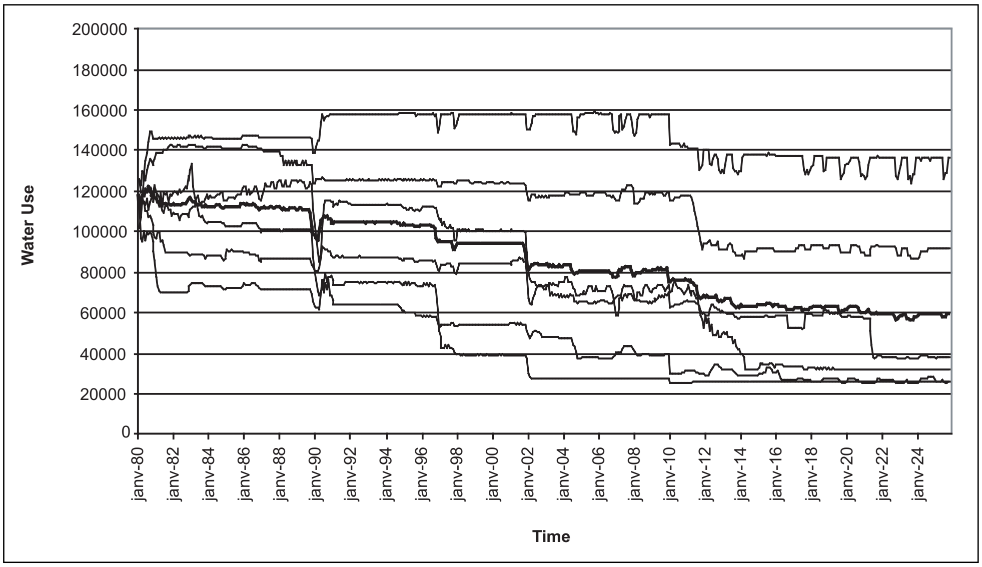

Figure 4.5. Scenario C

One can notice that from 2014 onwards, there is a grouping of some runs, even more visible after 2022. The 2010 drought does not seem to have a significant impact upon the second topmost series, while the 2011 drop in consumption of this series is the biggest and fastest of all.

Descriptive statistics show the same negative kurtosis as for the previous scenarios, with shorter tails, also allowing the rejection of the normality assumption. Moreover, differences in mean and standard deviation also hint at the differences of consumption levels amongst the runs.

The use of the Kolmogorov-Smirnov test on relative changes confirms the fact that the relative changes are not normal either, with all probabilities of the sample of origin being normally distributed equal to zero.

4.3.4 Scenario D: Local Stewardship

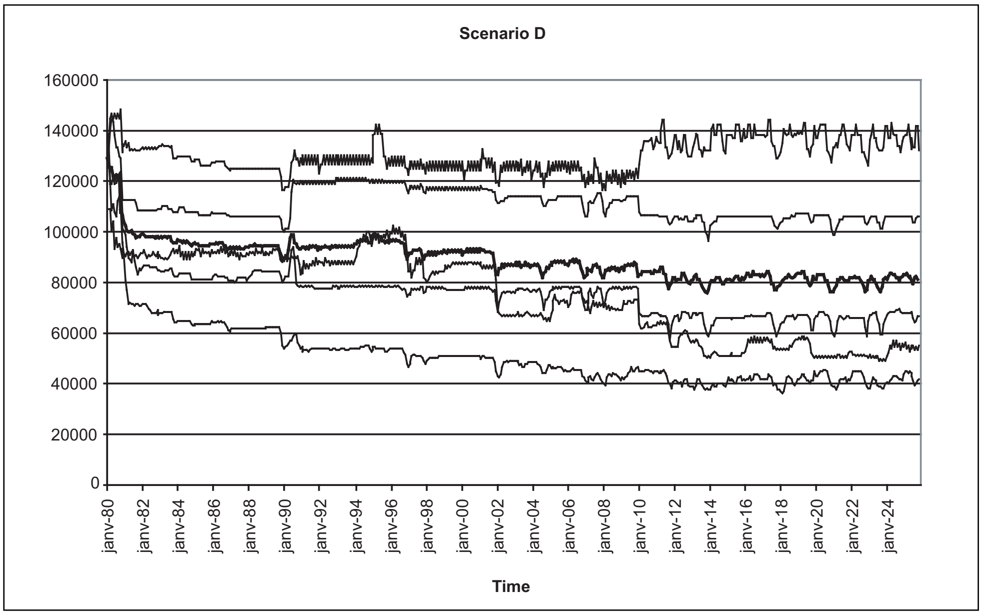

Figure 4.6. Scenario D

The noticeable increase in water use in the end of 1990 (see Figure 4.6), following a decrease a few months earlier can be explained by the events taking place then in the model. Towards the end of 1989, there are three consecutive months of relative drought, and the policy agent broadcasts its recommendations, which results in a decrease in water use. In 1990, the availability of power showers on the market is becoming clear, as their high volume per use translates into an upwards demand for all runs.

For the first time in assessing the scenarios, three of the runs have a positive Kurtosis. This indicates that the observations cluster more and have longer tails than those in the normal distribution. The runs affected are the lowest one, the second lowest one till 2002, which then becomes third lowest, and the second to the highest.

4.4 Conclusion

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.

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, the envelope is practical, and not theoretical. In theory it is possible (though fairly unlikely) that all scenarios actually have equal and very large envelopes. This would greatly reduce the information contained in the description of such an envelope.

Averaging 10 simulation runs for every scenario seem to display individual characteristics clearly.

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 seem 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 on 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.

Based on averages of runs, the dispersion for every scenario is calculated via the inter quartile range. The results are shown in Table 4.1.

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

Table 4.1. Dispersion per set of scenario simulations

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.

Figures of water demand are characteristic for each scenario, with the apparent confirmation that technological change is the most important parameter to explain decreasing water demand. A steady population and the absence of the miscellaneous component due to the inadequacy of such a "catch-all" concept into an agent based system are the main reasons for not comparing simulation results with absolute values obtained by the Environment Agency. Nevertheless results suggest that the model itself could be verified (Barthélémy, 2006). In addition, the analysis of outputs from innovation diffusion process (for example), matches observations and generally accepted theories, which could imply that parts of the model could also be validated.

As proposed by Edmonds and Moss (2005), this research suggests that in cases where complexity is present, the use of multi agent models and descriptive methods has benefits over other modelling techniques which rely on simplifications earlier in the modelling process.

References

1 Bak, P., (1997), *How nature works: the science of self-organized criticality,* Oxford University Press.

2 Barthélémy, O., (2006), Untangling Scenario Components with Agent Based Modelling: an Example of Social Simulations of Water Demand Forecasts, Ph.D. Thesis, Centre for Policy Modelling, Manchester Metropolitan University.

3 Barthélémy, O., S. Moss, et al., (2001), Policy Modelling with ABSS: The case of Water Demand Management, CPM Report 02-92.

4 Butler, D., Memon, F. A., (2005), *Water Demand Management*, IWA Publishing, London

5 Brown, R. W., (1965), *Social psychology*, New York, Free Press.

6 Cohen, P. R., (1985), *Heuristic reasoning about uncertainty: an artificial intelligence approach,* London, Pitman.

7 Downing, T. E., R. E. Butterfield, and al., (2003), *Climate Change and the Demand for Water,* Oxford, Stockholm Environment Institute Oxford Office.

8 Edmonds, B., (1999), "Capturing social embeddedness: A constructivist approach.", *Adaptive Behavior* 7(3-4): 323-347.

9 Edmonds, B., (2000), "Complexity and Scientific Modelling", *Foundations of Science,* 5: 379-390.

10 Edmonds, B., Moss, S., (2005), From KISS to KIDS – an 'anti-simplistic' modelling approach. In P. Davidsson et al. (Eds.): Multi Agent Based Simulation 2004. Springer, Lecture Notes in Artificial Intelligence, 3415:130–144.

11 Edmonds, B., O. Barthélémy, et al., (2002), Domestic Water Demand and Social Influence - an agent based modelling approach, CPM report 02-103.

12 Environment Agency, (2001), *A scenario approach to water demand forecasting,* National Water Demand Management Centre, Worthing.

13 Granovetter, M., (1985), "Economic-Action and Social-Structure - The Problem of Embeddedness", *American Journal Of Sociology,* 91(3): 481-510.

14 Herrington, P., (1996), *Climate change and the demand for water,* HMSO. London.

15 Hulme, M., G. J. Jenkins, et al., (2002), *Climate change scenarios for the 21st century for the UK (UKCIP02) - technical report*.

16 Jensen, H. J., (1998), *Self-organized criticality: emergent complex behavior in physical and biological systems*, Cambridge University Press.

17 Mayer, T., (1975), "Selecting Economic Hypotheses by Goodness of Fit", *The Economic Journal*, 85(340): pp. 877-883.

18 Moss, S., (2002), *Policy Analysis from First Principles,* Proceedings of the National Academy of Sciences of the United States of America 99, 7267-7274.

19 Pavard, B., and J. Dugdale, (2000), "The contribution of complexity theory to the study of socio-technical systems", *New England Complex Systems Institute electronic journal*, 335: 8.

20 Smith, R. J., P. Turton, and al., (1978), *The impact of social and economic factors on consumption from public water supplies,* Reading, Central Water Planning Unit.

21 Tate, D. M., and Canada Inland Waters Directorate, (1990), *Water demand management in Canada: a state-of-the-art review,* Ottawa, Environment Canada.

22 Thornthwaite, C. W., and R. Mather John, (1955), *The water balance,* Centerton, N.J., Laboratory of Climatology.